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The Management of Cognitive Resources

Allan MacLean

1986

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A thesis submitted for the degree of Doctor of Philosophy in  
the University of Durham

Department of Psychology  
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## ABSTRACT

### The Management of Cognitive Resources

Allan MacLean

It is argued that an understanding of complex cognitive performance can best be achieved by considering both processing and representational cognitive resources. In any given task, control processes are important for configuring such resources appropriately and passing information between them. A computer controlled alphabet counting task which allows storage and processing requirements to be independently manipulated is used to gain a better understanding of the organisation and utilisation of resources by providing access to the microstructure of performance.

Three main directions are explored. The first establishes baseline conditions for varying parameters of the task. Most notably, it demonstrates that resources are typically set up for the expected task difficulty prior to the task commencing, rather than as a consequence of immediate task demands. The second theme explores individual differences in carrying out one of the more complex conditions of the task, and shows that subgroups of subjects can be isolated who exhibit distinct patterns of performance. Moreover, in a task of this complexity, gross predictors of individual differences, such as IQ, do not relate to overall performance in any simple way, although they can be understood within each subgroup. The third group of experiments explore sensitivity to stressors external to the immediate task. Two 'environmental stressors' (alcohol and noise) and one 'cognitive stressor' (an additional concurrent memory load) are examined. Reliable differential effects are observed on the storage and processing phases of the task within individual subjects, but variations in the precise pattern of effects between subjects result in group data being potentially misleading.

Finally, the requirements for an appropriate framework which can capture the most important aspects of resource management are considered, and a framework incorporating components of contemporary models of working memory is presented.

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Lastly, I would like to give a special mention to Fiona, not so much for helping the completion of this work (quite the opposite in fact!), but for making it all worthwhile nonetheless.

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I declare that the work in this thesis is my own and has not been submitted for any other degree.

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## CHAPTER 1

### INTRODUCTION

#### 1.1 PROCESSING AND STORAGE

The concepts of processing and storage have been central in cognitive psychology from the very inception of the discipline. However emphasis is typically placed on one or the other in most theoretical accounts. This is in part a side effect of the tendency for laboratory studies to investigate only a very small subset of the psychological domain using particular techniques. Depending on the precise nature of the problems being tackled either storage or processing language often seems more appropriate for describing it. To make a very crude distinction, reaction time studies are often concerned with the time course of mental processes, whereas memory studies (using errors as the major dependent variable) rely heavily on the concept of storage, talking about the store being searched, capacity limitations and the like.

However, in everyday tasks more complex than those typically studied in the psychology laboratory the roles of storage and processing often seem much more distinct, each having its role within the overall framework of the task requirements. There are many situations where input from the outside world has to be stored temporarily and processed internally into another form



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before it can be properly interpreted. For example, in learning morse code, sequences of dots and dashes have to be held in memory and translated into meaningful units. These units may be individual letters for the novice or whole words or even phrases for the expert (eg Bryan and Harter 1899). A similar translation problem is likely to be faced by people who are competent but non-fluent in a second language. A sequence of words in one language may be held in memory and translated into the other language before comprehension can take place. Contemporary psychology has remarkably little to say to assist us in understanding what is going on these situations which involve complex performance. The next section outlines some relevant approaches to the problem.

### 1.2 APPROACHES TO COMPLEX PERFORMANCE

Much psychological research attempts to understand complex performance by looking at hypothesised individual components in isolation. This section outlines research from a number of directions which highlights the danger of this approach.

#### 1.2.1 Reading

Normal reading embodies a complex interplay between storage and processing requirements: syntactic and semantic aspects of the text have to be processed; some form of the results of this processing has to be stored to allow integration. The fact that the combination of storage and processing is important for normal reading can be illustrated by a number of recent studies (eg Daneman and Carpenter (1980, 1983); Daneman, Carpenter and Just

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(1982)). It has been shown that neither simple processing (Jackson and McLelland 1979) nor simple memory span (Hunt, Frost and Lunneborg 1973; Daneman and Carpenter 1980) correlate with reading ability. However Daneman and Carpenter (1980) showed that a test with both processing and storage demands did correlate with reading comprehension. This 'reading span' test involved reading a number of sentences and remembering the final word in each sentence until the entire sequence of sentences had been presented. Working memory span was defined as the number of sentences which a subject could process in this way, and still recall the final words in the correct order. Daneman and Carpenter interpret these results as indicating a competition for processing and storage resources in a limited capacity working memory system. However, this interpretation is probably a little over simplistic. For example Klapp, Marshburn and Lester (1983) have shown that a simple processing task embedded in a span memory task does not interfere with the retention of the memory string. The data are therefore not inconsistent with the view that the ability to manage multiple resources required for a complex task is the crucial factor. The most important point to note is that simple measures whether of storage or processing in isolation are not sufficient to understand the more complex behaviour that corresponds to reading. Other studies in different areas bear this out, emphasising the importance of 'control processes' (eg Rabbitt 1979) or a 'timesharing ability' (eg Damos and Wickens (1980); Damos and Smist (1983); Ackerman, Schneider and Wickens (1984)). However, these studies tend to

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focus on showing the existence of a timesharing ability and do not systematically investigate how it relates to underlying storage and processing requirements. The above would suggest that to understand complex performance we should not consider storage or processing resources, or indeed resource management, in isolation, but need to show how all of these inter-relate.

### 1.2.2 Mental Arithmetic

Mental arithmetic is another domain in which there are distinct requirements to hold information internally and carry out internal transformations on that information. In particular, multi-digit mental arithmetic where carrying is involved requires relatively sophisticated management of intermediate results. If anything, mental arithmetic would appear to be a more tractable domain than reading to explore the components of complex performance since it is often carried out in a series of simple well defined steps. Despite this, very little work has been done looking at multi-digit mental arithmetic (see Svenson, 1985). An important exception is the work of Hitch (1978). In a series of studies he showed that a considerable amount of the patterns of errors observed when subjects carry out mental additions could be explained by a model which assumes decay in working memory storage (Baddeley and Hitch 1974) as a function of the number of intervening events between the time the item was encoded and the time at which it had to be recalled for output or subsequent processing. An important reason for the success of Hitch's investigation of mental arithmetic was the fact that he commenced the studies with a task analysis of mental addition in terms of

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the processing and storage requirements within the working memory framework (Baddeley and Hitch 1974). Further, before commencing his major studies, he investigated the range of strategies which might be expected in carrying out the task. It was only by taking account of such strategy differences that he was able to obtain comprehensible results. Such variations in strategy become particularly important as tasks become more complex and are a major reason many psychologists shy away from directly investigating complex behaviour. In addition to reflecting the way in which storage and processing abilities are used, such strategies almost certainly reflect an ability which involves managing the resources involved in carrying out the task of mental arithmetic, much as appears to be the case with reading.

### 1.2.3 Individual Differences and Intelligence

Variations in strategy as mentioned in the previous section go hand in hand with individual differences. For example Hitch (1978) found that a number of different strategies for ordering the components of the mental arithmetic task were used by his subjects. However, the vast majority of individual subjects tended to opt for a consistent order in which to carry out the task. A few opted for different strategies depending on the characteristics of the particular numbers to be added - for example whether carrying would be required. Individual differences are therefore apparent in the way people tackle such tasks.

One of the commonest means of measuring individual differences is

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by means of intelligence tests. Although a vast psychological literature exists on intelligence and individual differences, most of it is based on tests which have fairly high reliability, but little validity. They therefore give no insight into the nature of the underlying cognitive structure. One of the few attempts to remedy this situation and gain an understanding of intelligence in terms of information processing has been performed by Hunt and his colleagues (eg Hunt, Frost and Lunneborg (1973); Hunt, Lunneborg and Lewis (1975); Hunt (1978, 1980); MacLeod, Hunt and Mathews 1978). They have focused primarily on verbal intelligence, and have attempted to identify information processing components which underlie performance on psychometric intelligence tests by looking at the relationship between the test scores obtained and batteries of information processing tests. Again, simple measures of memory span or processing do not correlate highly with scores of intelligence. Rather, Hunt (eg Hunt 1980) believes that variation in the strategies on which people can call and the attentional resources which they have available are the major determinants of intelligence within a normal population. Again, an ability to manage the resources available seems to be important in determining the overall patterns of performance observed.

Another approach worthy of a brief mention is that of Sternberg (eg 1977a, 1977b, 1980, 1983). He has also attempted to identify underlying information processing components of intelligence. His approach relies on a technique of presenting reasoning problems to subjects in such a way that they initially receive

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partial information about the problem, and then the remaining information required to solve it. By manipulating the dividing line between these phases of the problem Sternberg claims to be able to identify components of the solution process which correspond to elemental information processing components. One problem with the approach is that by forcing particular subdivisions of the problem on the subjects they may be coerced into tackling the problem in unnatural ways (eg Grudin 1980). In contrast to Hunt (and indeed the main focus of the present work), Sternberg focuses on components such as 'mapping', 'inference' and 'comparison'. However, his approach is still worthy of note here since it attempts to identify the underlying components of complex performance in a relatively direct way.

### 1.2.4 Divided Attention - Dual Tasks

The area of attention has generated a much larger literature on what might be regarded as complex performance. Here however, we would typically be talking about doing two simple things at once, rather than the components which make up a complex unitary task. For example this may involve selectively listening to messages in one ear while a second message is simultaneously presented to the other ear (eg Broadbent 1958); it may involve having to be ready to respond to a probe task which is secondary to the main task (eg Paap and Ogden 1981; McLeod 1978); or it may require carrying out a motor task such as tracking while simultaneously performing an information processing task (eg Wickens 1976).

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The rationale behind such studies has typically involved arguments over the existence or the source of capacity limitations in information processing. Clearly if such limitations exist they are also likely to be important in complex 'unitary' tasks such as reading or mental arithmetic as well as in complex 'multiple' tasks such as monitoring control panels in nuclear power stations. Such capacity limitation theories tend to divide into two camps. The first assumes a unitary 'attentional capacity' (eg Norman and Bobrow 1975) which defines the upper limit of energy available to carry out any task. This limit may not be fixed - for example Kahneman proposed that 'effort' may change the amount of capacity available. The important point about such a theory is that it assumes that whatever cognitive energy is required to carry out a given task comes out of a common pool. When that pool is exhausted, any further demands will result in insufficient energy being available to carry out the task and so performance will suffer. The second approach assumes that there are a number of independent capacities available. These may be very task specific (eg Allport 1980a, 1980b), or they may be separate, general purpose, resources - some candidates here might be visual resources, auditory resources and motor resources (eg Navon and Gopher 1979). In this case the interference between tasks which is usually observed would only result if the same resource was required for more than one component of the joint tasks. Evidence for such a view comes from cases where minimal interference is observed in dual task performance when there

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appears to be little overlap in the resource requirements of the two tasks (eg McLeod 1978). Unfortunately, although attractive in principal, it is not easy to investigate what resources are being used by a given task (eg Navon 1984). One reason for this difficulty is that when tasks are combined to investigate mutual interference, in the best of the Gestaltist tradition the resulting combination of tasks has emergent properties which were not seen in either of the tasks in isolation (see Duncan 1980). This of course is an age old argument in psychology - a similar criticism (Kulpe 1895) led to Donders' (1868) subtractive method for deriving processing stages falling into disuse for seventy years. As Duncan (1980) points out, these arguments in themselves need not mean that it is pointless to carry out such experiments, but rather alternative explanations based on emergent properties of combined tasks should be considered carefully in conjunction with the simpler explanations.

Not only must changes in processing which may take place when two tasks are combined be considered, but so must changes in processing as a result of practice. Our knowledge of what actually changes with practice is remarkably sparse (eg Rabbitt 1979, 1981). One approach which seems to be becoming more and more popular is that certain processes can be carried out 'automatically' both in perception (eg Schneider and Shiffrin 1977; Shiffrin and Schneider 1984; Hoffman, Nelson and Houck 1983) and in memory (eg Hasher and Zacks 1979). Unfortunately the notion of automaticity still has little to say about what is really changing, being primarily defined in terms of a lack of

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interference between laboratory tasks. Some clues do however exist which might help to explain what happens with practice. For example, Spelke, Hirst and Neisser (1976) trained two subjects to read for comprehension and write down dictated words simultaneously. After considerable practice they were able to perform both tasks together as well as they could separately. Spelke et al conclude that "people's capacity to develop skills in specialised situations is so great that it may never be possible to define limits on cognitive capacity". An alternative explanation might be that such a conclusion is based on considering inappropriate variables. If we consider the initial impact of information theory (Shannon 1948) on psychology, attempts were made to measure the number of items which memory could hold. It soon became clear that 'items' had to be interpreted in a rather flexible way, so that Miller (1956) suggested that memory capacity consisted of seven plus or minus two 'chunks'. Over the years the precise interpretation of this has become problematic. For example, the same material presented to the eye or ear has different consequences for subsequent recall (eg Crowder 1978); different 'support' techniques such as mnemonics have different consequences (eg Roediger 1980a). Similarly, when we are considering processing capacity, the units about which we are talking need to be defined to allow us to consider capacity limitation in any meaningful way. To return to the study of Spelke et al (1976), they showed not only that it was possible to learn to combine the tasks of reading and writing dictation, but also that only a tiny proportion of the words presented were available for later recall. One component of learning therefore

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appears to be minimising processing which is irrelevant for the task at hand. In this sense, we might regard combined tasks after extensive practice as being equivalent to a single task. It is however not clear whether the resources required are simply managed more efficiently, thus reducing irrelevant processing, or whether the resources themselves demand less processing capacity to carry out their role in a well practiced task.

### 1.2.5 Stress and Arousal

Work on stress research has tended to be intimately linked with work on attention for both practical and theoretical reasons. From the practical point of view, there has been tremendous interest in the effects of stressors such as noise, heat, fatigue and alcohol in complex work environments such as aircraft cockpits, military command and control systems and nuclear power stations. The previous section suggests that even ignoring additional variables such as stressors, the way in which people will behave in such environments will not be easy to predict.

In attempting to account for the effects of stressors, the concept of arousal has often been used. The concept originates from attempts in the 1930's to link behavioural performance to variations in psychophysiological activity (see Davies 1983). More recently, this variation has been linked with the concept of attention. One particularly influential approach along such lines was that of Easterbrook (1959). He proposed that increased arousal affected attentional selectivity by changing cue

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utilisation. This accounted for the traditional inverted-U relationship between attention and arousal by assuming that as arousal increases fewer irrelevant cues will be utilised and performance will improve. However, after a certain point only a subset of relevant cues will be used and so performance will deteriorate again. This account can also handle the fact that difficult tasks seem to be more affected by high levels of arousal than easy tasks since they might be expected to involve the use of more cues for adequate performance and so high levels of arousal, restricting the range of cues utilised, would lead to a greater decrement in more difficult tasks. Elegant as this account appears, it has proved of limited value in mapping from the supposed arousing properties of different stressors to resulting performance. The major reason for this is that different stressors which are supposed to increase arousal can have different behavioural consequences. For example, noise and incentive are both traditionally held to increase arousal level. However, it has been shown that these stressors have quite different effects in the pattern of intentional and incidental learning in short term memory tasks (eg Hockey and Hamilton 1970; Davies and Jones 1975).

Such inconsistencies arising from interpretations of results based on the notion of a single dimension of arousal have led to views which regard arousal as having more than one component. Broadbent (1971) suggested that much of the inconsistency observed in the stress literature could be resolved by assuming two arousal mechanisms, one similar to the traditional concept,

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and the second monitoring and compensating for changes in the first. If different stresses affected each of these mechanisms in different ways, conflicting patterns of results could be explained. However, although potentially more comprehensive, it is still not clear just how adequate this theory is - indeed Broadbent himself (1983, p727) admits that 'this theory has not been seriously tested, and is almost certainly wrong in detail'. A still more complex solution has been proposed by Hockey and Hamilton (1983) who review patterns of behavioural change associated with a wide number of stressors and suggest that the most appropriate way to describe them is in terms of the overall pattern observed in the associated shifts in behaviour. Certainly the wide variation in patterns of increment and decrement in performance they show with only five behavioural variables suggests that even a two mechanism view is likely to be inadequate.

Another problem which is likely to cause problems with the interpretation of data from stress experiments is the kind of tasks which have typically been used. The individual tasks tend to be traditional laboratory memory, perception or tracking tasks (see Eysenck 1982), but in many cases differential effects have only been shown in dual task studies where two such tasks have to be performed simultaneously. As discussed earlier, it is often not clear that such combinations of tasks will react in the same way to stressors as the individual tasks would in isolation - there are for example clear indications that emphasis on which task is primary and which is secondary will interact

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with performance measures obtained under the influence of stressors (see Hockey and Hamilton 1983). More importantly, many of these dual task studies have involved incidental learning. It is not clear whether decrements in such learning under stress occur because subjects chose not to process the irrelevant stimuli or because they could not process them (Eysenck 1982). As with consideration of what is involved in carrying out complex tasks earlier, we are again faced with the possibility of the stressor affecting an ability to manage the resources available to the system contrasting with a direct effect on these resources themselves. It therefore not at all clear from such studies what effect we might expect of stressors on the real-life tasks discussed earlier in this chapter.

One series of studies which may address this problem is reported by Hamilton, Hockey and Rejman (1977). They suggested that noise is beneficial for simple tasks involving fast throughput, but detrimental for more complex tasks which tend to rely more on memory. This is obviously similar to the more general Easterbrook hypothesis discussed above, but has the additional claims about the kind of processing involved as well as its complexity.

The most interesting task used by Hamilton, Hockey and Rejman (1977) was what they called a 'closed system thinking' task which involved counting forward through the alphabet from a given starting position and if necessary keeping the resulting letter in memory while similarly processing another letter. The task

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thus involved both storage and processing components in such a way that their relative contributions to the task as a whole could be independently manipulated. This task is particularly noteworthy for two reasons. The task properties map well onto the distinction between processing and memory resources discussed earlier. In addition, it provides a single scenario in which to test the claim that noise tends to speed up rate of processing, but impair tasks which rely heavily on memory factors. Thus the same basic task might be expected to show an improvement in noise when parameters were chosen which emphasised processing speed and minimised storage requirements, and to show a decrement in performance when the memory storage components became crucial. The pattern of data they obtained indeed broadly confirmed this prediction, but it still left some uncertainty as to the source of the performance decrements in the tasks which involved the larger memory loads. For example, did the processing phases of the memory intensive tasks remain faster in noise, or was there a general decrement in overall performance as the task became more complex? Or was it the increased complexity and thus the effect of noise on a resource management ability which was primarily responsible for the decrement in performance with the more complex tasks?

### 1.3 MEASURING COMPLEX PERFORMANCE

#### 1.3.1 The Microstructure of Performance

As indicated in the previous section, when we wish to understand how the components of a complex skill are made up we need some

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way of investigating these components individually, while maintaining their relationship to the complex task under investigation. We know little enough about the microstructure of complex skills in their own right, let alone how they might change under the influence of stressors. However, the previous section suggests that a symbiotic relationship may exist between understanding the effect of stressors such as noise, and understanding the components of complex skills. For example, if we could investigate a potentially complex task such as that of Hamilton et al (1977), discussed in the previous section, in such a way that we could get some independent measure of the individual components involved, we would be in a position to see if noise does indeed have a differential effect on these components even when the overall performance is impaired. Conversely, if stressors can be shown to selectively affect individual components of a complex task, they may provide a useful tool for better understanding the task itself.

In many complex tasks such as reading which were discussed earlier, it is not at all clear how putative components would map directly on to any dimension along which they could be easily measured. However other tasks such as mental arithmetic (see Hitch 1978) and the closed system thinking task used by Hamilton et al (1977) appear to have a fairly well defined sequence to their solution. If this sequence could be tapped at appropriate points, it may well be possible to obtain a much better idea of how the microstructure of such tasks is organised, and what effect concurrent changes in cognitive load as the task becomes

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more difficult, or indeed stressors, have on that microstructure.

Mental arithmetic would appear to be an ideal candidate for such an investigation since complexity can easily be increased by increasing the number of digits in the numbers to be handled, or by manipulating the need for carrying. However, it is less easy to manipulate the processing requirements of mental arithmetic. For example, although some studies suggest that a large addend requires more time to handle than a small one, suggesting that more processing is required (eg Groen and Parkman 1972; Moyer and Landauer 1967), it appears that adults in particular often rely on overlearned associations to combine small numbers (Svenson 1985). This is probably most apparent when we consider the overlearned multiplication tables which used to be a feature of our school system. Moreover, some adults have rather sophisticated and unpredictable strategies for rounding larger numbers to make 'easy' problems and then adjusting the result afterwards to obtain the correct result (see Hitch 1978).

The closed system thinking task used by Hamilton et al (1977) is very similar to mental arithmetic in many ways in terms of the cognitive components which are likely to be involved. It also has much in common with the working memory span task reported by Daneman and Carpenter (1980), discussed earlier, since both tasks intermix bursts of processing, or 'throughput' to use Hamilton et al's (1977) term, with more static memory requirements. The memory load can easily be manipulated by adjusting the number of items which have to be kept in memory before a response can be

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given. As with the Daneman and Carpenter task, we might expect the combination of storage and processing requirements to be reflected in an ability to manage the combined cognitive resources rather than simply to reflect the efficiency of these abilities in isolation.

This task has the advantage that counting through the alphabet is not an overlearned skill in the average person, and so an increase in the distance through the alphabet which has to be counted is more likely to be reflected in a real and predictable increase in the processing requirements. This task would therefore appear to be a useful 'halfway house' between the complex tasks such as reading and mental arithmetic, which previous sections suggested current research techniques do not allow us to explore as comprehensively as we might like, and the simpler laboratory tasks which are relatively well understood, but which do not seem to generalise well to understanding more complex performance. Whether the reason for this lack of generalisation is that the combination of resource requirements causes mutual interference, or whether the combination introduces a new factor of resource management is not immediately obvious.

The next chapter outlines how it might be possible to explore the microstructure of a task such the one of Hamilton et al (1977) involving 'alphabet arithmetic' (henceforth called the 'alphabet transformation task') using computer techniques to measure the subcomponents of the task.

## CHAPTER 2

### THE ALPHABET TRANSFORMATION TASK

#### 2.1 INTRODUCTION

The previous chapter suggested that the Alphabet Transformation task of Hamilton et al (1977) could be adapted to allow the microstructure of performance to be examined in detail. The task involves counting forward through the alphabet by a number of places and for a number of letters before a response is allowed. The two parameters, distance through the alphabet to be counted, and number of letters to be retained in memory can be manipulated to systematically vary the processing and storage requirements. This chapter describes the basic task in more detail and shows how it can be adapted so that its microstructure can be examined. Finally, the basic experimental procedure and design used to measure the performance microstructure in the main studies to be reported later is described.

#### 2.2 THE ALPHABET TRANSFORMATION TASK

##### 2.2.1 Description of Task

The essential properties of the alphabet transformation task are first of all that it requires a number of distinct resources. These are required to carry out three basic task demands - accessing a letter in the overlearned ordered alphabet sequence

## The Alphabet Transformation Task

in long term memory, counting a specified number of places forward in this sequence and maintaining the results of the latter operation in memory while performing the same operations on subsequent items. Secondly, the nature of the task requires that the resources have to be used in a particular sequence, so that efficient use of control processes is required to coordinate them.

There are two components to the alphabet transformation task which can be manipulated. The first of these, Transform Size, ( $t$ ) refers to the number of places through the alphabet which subjects have to count from a specified starting letter in order to reach their required solution. For example, if the starting letter is 'J' and  $t=4$ , (ie the subject is given the problem  $J+4=?$ ), then the subject would have to count four places forward in the alphabet from J, ie KLMN, to reach their target - N in this case. The second independent variable, Memory Load ( $m$ ) is the number of items which subjects have to transform before they are allowed to report the solution. In the previous example, subjects may be able to report the solution as soon as they reach it ( $m=1$ ), or alternatively, they may be required to hold this solution in memory until a number of letters have been similarly processed (eg a problem such as  $JBRM+4=????$ , where the subject is only allowed to report the solution when the entire string of letters has been calculated). In this latter case, the subject must transform four letters ( $m=4$ ) before reporting the result (NFVQ in this case) as a single response. The task not only requires efficient use of transformation and storage resources,

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but also efficient switching between the two as the task becomes more demanding. By combining different levels of  $\underline{t}$  and  $\underline{m}$ , it is thus possible to investigate the interaction between these two variables fairly precisely. Figure 2.1 shows how the task increases in difficulty along both of these dimensions as  $\underline{t}$  and  $\underline{m}$  vary from 1 to 4.

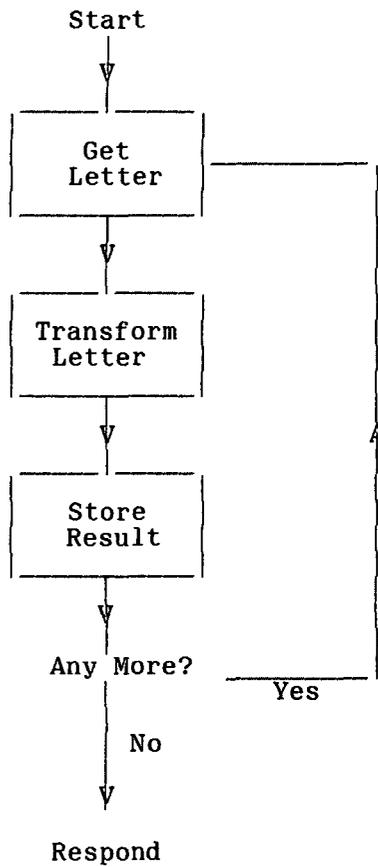
### 2.2.2 Background to Task

As discussed in chapter one, Hamilton, Hockey and Rejman (1977) used a paper and pencil version of this task to look at the effect of noise on performance. They presented subjects with the sixteen tasks defined by the combinations of storage load and transformation shown in fig 2.1 ( $\underline{m}$  and  $\underline{t}$  each varying from 1 to 4). Subjects were presented with a separate sheet of paper for each condition on which were printed columns of single letters, groups of two letters and so on as appropriate, and were told the number of places to transform through the alphabet for each condition. Where groups of two or more letters were presented, subjects were instructed to issue their response as a single unit. Work on each sheet was terminated before all items had been transformed, and the overall time at task was measured. From this the time per letter output was calculated for each work sheet. Hamilton et al (1977) found that increases in the length of the required transform were dealt with more effectively under noise than in quiet, but only when storage load was very low. Tasks involving a high storage load took longer to complete under noise. These results were interpreted as representing the

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		TRANSFORM RULE			
		+1	+2	+3	+4
MEMORY LOAD	1	J → K	J → L	J → M	J → N
	2	JS → KT	-	-	-
	3	JSB → KTC	-	-	-
	4	JSBM → KTCN	-	-	JSBM → NWFQ

**Figure 2.1** Sample tasks with transform size and memory load ranging from 1 to 4.



**Figure 2.2** Simple flow chart of solution stages for the Alphabet Transformation task.

## The Alphabet Transformation Task

resultant effects of different changes in the system characteristics under noise, in particular, increased information transmission, and reduced holding capacity for currently activated items in memory. However, these conclusions had to be inferred from a rather crude single index of the average time required to process each letter derived from the total solution time for a block of similar items.

This paper and pencil version of the task is therefore rather unsatisfactory in a number of respects. There was no check that, despite the instructions, subjects really issued all of their responses as a single unit - with the best will in the world they may still have found that although they had worked out the entire solution, while they were outputting it they forgot the final items and had to go back to work these out again. If the correct solution was finally reached, there was no measure of any error correction procedures which were used to attain that solution. Quite apart from any procedural difficulties of this type, the rather crude nature of the data makes it impossible to answer any questions about the interaction between the underlying component processes as transformation and storage load are manipulated - for example is the impairment shown by Hamilton et al (1977) due to an overall impairment in both transformation speed and storage time in the more difficult conditions, or does the transformation time retain its relative advantage under noise with a much greater increase in storage time swamping it?

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### 2.2.3 Measuring the Microstructure of Performance

Let us consider the psychological resources which are likely to be involved in this task. First of all, let us consider them in terms of stages implied by the structure of the task itself. We can represent these stages in a flow chart (fig 2.2). Note that this flow chart immediately separates out components which relate to potential storage and transformation resources. Our understanding of the psychological processes which make up the task would be considerably enhanced if we could measure the time taken to perform these component steps of the task independently, rather than have to rely on inferences from the total time taken to carry out a number of trials without any clear idea how the solution time was distributed. Ideally what we want to do then is to partition the complete solution time into the discrete stages represented here and get a measure of the time taken by each stage rather than simply an overall time to complete the entire problem.

This goal was achieved by presenting the starting letters individually on a CRT screen under computer control. The subject could indicate that he was ready for the next letter by means of a hand held push button. The transformation time was measured by requiring the subject to transform through the alphabet overtly, and monitoring his speech output. Fig 2.3 shows the relationship between the assumed underlying psychological resources and the flow of control detected by the computer for a transformation of 4 and storage load of 4. The task is split into 5 distinct cycles separated by button presses - the first four are

## The Alphabet Transformation Task

Button Presses	Screen	Principal Mental Operations	Code for Phases
	_	(Signal that trial is available)	
BP1	J	Encode - access LTM at 'J'	E1
	J	Transform J-> KLM <u>N</u>	T1
	J	Store [ <u>N</u> ]: Rehearse	S1
BP2	S	Encode: Access LTM at 'S'	E2
	S	Transform S-> TUV <u>W</u>	T2
	S	Retrieve [ <u>N</u> ]: Update [ <u>NW</u> ]: Rehearse	S2
BP3	B	Encode: Access LTM at B	E3
	B	Transform B-> CDEF <u></u>	T3
	B	Retrieve [ <u>NW</u> ]: Update [ <u>NWF</u> ]: Rehearse	S3
BP4	M	Encode: Access LTM at 'M'	E4
	M	Transform M-> NOP <u>Q</u>	T4
	M	Retrieve [ <u>NWF</u> ]: Update [ <u>NWFQ</u> ]	REC
BP5		Prepare response [ <u>NWFQ</u> ] Output response [ <u>NWFQ</u> ] (Post output phase ignored)	OL OUTPUT
BP6		(Signal to computer for end of trial)	

**Figure 2.3** Principle mental operations underlying each task stage with a memory load of four items and transform distance of four. This produces five cycles, each with three phases.

## The Alphabet Transformation Task

processing cycles and the final one is the response cycle. Each cycle is further subdivided into three phases. The first phase is the time taken to encode the stimulus, access long term memory and prepare to transform. It consists of the time from the subject pressing the button to the detection of speech indicating that he has started transforming (or responding in the case of the final cycle). The second phase is the time to transform to the required letter (or say the response in the final cycle). This is measured by the duration of the subject's speech. The final stage, measured by the time from offset of speech to the next button press, indicates the time required to retrieve and update the store and rehearse the new sequence. (Note that in the final processing cycle (cycle 4 in the above case) we might expect little or no rehearsal since no further transformations are required - only preparation of the final string for recall. This storage phase is therefore likely to be qualitatively different from those in the earlier cycles).

Using this method, it should be possible to access the microstructure of the task and get a much more direct feel of the interaction between manipulative and storage resources in cognition, as well as investigate how these are affected by environmental stressors such as noise.

Although the behavioural subcomponents of the task split up in this way are strictly serial with precisely defined beginning and end points for each, this does not necessarily imply that a strictly serial model of the psychological correlates of that

## The Alphabet Transformation Task

behaviour, such as that proposed by Sternberg (1969), is appropriate. Successive processes may well overlap so that for example some aspect of the storage process may be still going on while the next item is being encoded. A model such as the "cascade" model of McClelland (1979) could thus be equally appropriate. What is assumed however is that the dominant processing going on at any one time is going to be that which corresponds to the current behavioural phase. As such we would expect the temporal profile we obtain to reflect predominantly a combination of the relative difficulty of the current operation, or the perceived vulnerability of the products of the operation to interference by a later phase of the task.

### 2.3 PROCEDURAL DETAILS

The experiments were all run on-line, controlled by an IBM 1130 computer, via a WDV interface, the stimuli being displayed on a Tektronix 603 monitor with P31 phosphor. Broad band noise was presented through Koss PRO-4A headphones by a Grason-Statler 1702 audiometer. The background noise level was set at 45dBA for all conditions to help to mask extraneous noises, and was increased to 95dBA for conditions where noise was used as a stressor. In all cases the verbal protocol of the subject's responses was recorded on a TEAC tape recorder to enable any queries regarding the correctness of the subject's response to be checked later if necessary.

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The subject sits in a soundproof cubicle wearing the headphones with a boom microphone attached, and holding a push-button switch to control the presentation of the stimuli. Before each block of five trials a message appears on the screen reminding the subject of the condition about to be presented. A square subtending an angle of approximately 0.8 degrees appears before each trial to inform the subject that he may start the next trial as soon as he is ready. When the button is pressed, the first letter appears on the screen (subtending an angle of approximately 1.5 degrees). The subject then overtly transforms the required number of letters forward in the alphabet, starting with the letter immediately following the one presented on the screen. For example if 'J' is presented and the required size of transform is four, then the subject would say 'K L M N', the final spoken letter being the one he is required to remember until the end of the trial. His speech is passed on to the computer via an amplifier and purpose built smoother-rectifier which produces an envelope of the original speech waveform. The leading and trailing edges of this envelope are then detected by the computer to determine the duration of the speech by detecting the time for which the signal level is above a preset threshold. As well as using the presence of a signal to record the temporal information for the trial, the signal is fed back to the experimenter in the form of a light which illuminates when a suprathreshold signal is being detected by the computer. This enables the experimenter to ensure that no extraneous noise is being picked up, and also to check that the subject's speech is being detected reliably. The experimenter set up the input level for each subject by adjusting

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the gain of the amplifier so that the VU meter on the amplifier gave a suitable reading, and the feedback from the computer showed that speech was being picked up at appropriate times. In practice it was found that once settings were found for each subject, adjustment was seldom necessary during the rest of the session.

When the subject has correctly transformed the letter presented, he then ensures that he has remembered it and presses the button again as soon as he is ready for the next letter. Subjects were instructed not to request the next letter until they felt they were actually ready to transform it. When the button is pressed again the old letter disappears from the screen to be replaced by a new one in the same position on the screen. He then transforms this and adds the result to the previously remembered item in memory. This cycle is repeated until the required number of letters have been processed. When he is ready to respond after processing the last letter, the subject again presses the button to clear the screen and give his response overtly. When he has finished responding, the subject finally presses the button to signal the end of the trial.

As soon as the trial has finished, control is then passed back to the experimenter who is sitting outside the cubicle and listening to the subject's response. Each subject is presented with a different random set of stimuli for the appropriate condition and a score sheet is prepared in advance of the trial. The experimenter marks the subject's response against the answer

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for the trial given on this score sheet, and by pressing one of two buttons in front of him informs the computer whether the subject was right or wrong. Control is then passed back to the subject - the square appears on the screen to inform him that he can proceed when he is ready. The experimenter control panel thus allows continuous monitoring of the subjects verbalisation to ensure that it is being reliably detected by the computer, as well as indicating when the subject has finished a trial or block to inform the experimenter to mark the previous trial and to ensure that the items on the experimenter's score sheet are synchronised with the stimuli the subject is seeing.

The action of articulating overtly to perform the transformation, and pressing the button to move on to the next task cycle seem to be very compatible with the psychological structure of the task. Subjects learn when to press the button very quickly and the verbal and motor requirements seem to have minimal interference on the main task. Even when not required to transform overtly, subjects report subvocalising the transformation phase of the task anyway. The close similarity between the properties of covert and overt speech in terms of their time course has been confirmed by Landauer (1962) who concludes: "It seems that one does not think words and numbers (and letters) appreciably faster than one can say them aloud, suggesting that the two behaviours may involve much the same central processes." More recently Haber and Haber (1982) have shown a close relationship between the patterns of spoken and silently read material based on its

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articulatory difficulty. It thus appears that there is a close relationship between overt speech and covert speech, or indeed even thinking or reading, which does not necessarily involve subvocalisation. In addition as subjects report subvocalising each step of the transformation when carrying out the alphabet transformation task, requiring overt articulation of this problem solving process should be both natural for the subject and provide data which reasonably reflects the task steps which would be taking place without overt articulation.

### 2.4 EXPERIMENTAL DESIGN

#### 2.4.1 Stimuli

The stimulus letters were chosen so that there were never any vowels in the correct response. The correct response was thus never a pronounceable string, which would have been likely to reduce the memory problem. No letter was ever presented more than once in any trial and 'wrap-round' from the end of the alphabet back to the beginning was never required. In all the experiments, trials were presented in blocks of five correct trials. Each block was preceded by a message to the subject telling him the number of letters to be presented and the size of the transform to perform, either to inform him that a new condition was about to be presented, or to remind him of the condition under which he was being tested. There were a maximum of ten trials available in each block. The block terminated either when the subject had correctly completed five trials or when all ten trials had been used up. This latter occurrence was

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very rare in reasonably practiced subjects. Every subject received a different set of stimuli. Before each session a list of the stimuli to be presented to each subject and the correct responses was prepared by the computer to enable the experimenter to score the subject's performance and ensure that incorrect trials could be replaced immediately.

### 2.4.2 Practice and Training

Subjects were first gently introduced to the task by giving them a few blocks (the precise number varied slightly from experiment to experiment) of single letter cycles with varying transform sizes. The number of letter cycles was then gradually increased as they gained in confidence, up to a maximum of four letters ( $m=4$ ) and maximum transform size of five ( $t=5$ ) in the experiments to be reported here.

### 2.4.3 Errors

There are a number of possible sources of errors within the task structure. These split into two main types. Procedural errors occurred either if the the subject pressed the button for a new letter while still transforming the previous one, or if the button was pressed for a new letter before any transformation had been done on the preceding one - usually due either to the subject pressing the button twice by mistake, or his speech not being detected for some reason. In either case the trial was immediately terminated and the subject was informed of this by a row of three x's appearing on the screen. The experimenter was

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informed of the error by a light illuminating outside the cubicle. When the subject pressed his button to clear the error message, the square indicating that a new trial was available, appeared on the screen. In addition, any trial could be aborted from outside the cubicle by the experimenter if for example the subject coughed, or some extraneous noise which would interfere with timing the component durations was picked up, or if the subject realised in mid trial that he had lost track of the sequence he was trying to remember. Any error of this form was recorded as an abandoned trial. It was also possible of course for the subject to finish the trial but give an incorrect response. This was noted by the experimenter on the log of the subjects performance. If the error occurred as an error in transforming on the part of the subject, the source of the error was noted. If the response was given incorrectly, the actual response given by the subject was noted. No time data was recorded for trials which were not completed, as it would not be directly comparable with temporal data for complete trials because of missing data points, however the temporal patterning of all trials which were completed, correctly or not, was recorded.

### 2.5 TERMINOLOGY

This section summarises the various components of the alphabet transformation task and the way in which the text refers to them.

m - memory load: the number of letters which have to be transformed.

## The Alphabet Transformation Task

t - transform size: the number of letters to be counted after the starting letter to reach the required target.

The precise conditions on any trial will be referred to by the memory load and transform size, for example m=2, t=4 refers to a transform size of 4 and a memory load of 2 (2 letters presented to be transformed). In discussion about particular conditions, when it is not necessary to stress either memory load or transform size independently, the shorthand 'Cnt' will be used, where 'n' refers to the number of letters presented, and 't' refers to the transform size. So the above mentioned trial would be referred to as C24.

Each trial consists of a number of CYCLES, one for each letter presented and a response cycle. Each cycle is subdivided into three PHASES.

For the main cycles these are referred to as:

E - Encoding phase: the time between indicating readiness to transform and starting the transformation.

T - Transform phase: the time taken to articulate the transformation

S - Storage time: the time between finishing transforming and indicating readiness for the next item.

The response phases are referred to as:

REC - Recall time: the storage time of the final main cycle

## The Alphabet Transformation Task

OL - Output Latency: time to begin uttering response after  
indicating readiness to do so.

OUTPUT - Time to utter response.

## CHAPTER 3

### THE MICROSTRUCTURE OF PERFORMANCE - STUDY 1

#### 3.1 STUDY 1

The first experiment was designed to establish a baseline for performance on the alphabet transformation task, and to investigate how the temporal microstructure varied as the memory load ( $\underline{m}$ ) and transformation size ( $\underline{t}$ ) were varied.

##### 3.1.1 Subjects

Nine undergraduates from Durham University served as subjects (7 female and 2 male). Each subject attended for three sessions, each of 1 hour and was paid 90p per hour for participating.

##### 3.1.2 Procedure - Session 1

Session 1 familiarised the subjects with the task and obtained data on the slope of transformation time with only a single letter to transform (ie  $\underline{m}=1$ ). Each subject was given 16 practice trials of C33 (ie  $\underline{m}=3$ ,  $\underline{t}=3$ ), 8 practice trials of C43 ( $\underline{m}=4$ ,  $\underline{t}=3$ ), and 5 trials each of  $\underline{m}=1$ ,  $\underline{t}=1-5$ . Data were then collected for twenty trials of each of the the five conditions defined by  $\underline{m}=1$  and  $\underline{t}= 1, 2, 3, 4 \& 5$ . The experimental trials were presented in blocks of five correct trials for each condition (see full description of procedure in chapter 2). One block of each condition was presented in random order until each of the five

conditions had been presented once. This was repeated four times to collect the twenty trials required.

### 3.1.3 Procedure - Sessions 2 and 3

Sessions two and three investigated the effect of increasing the memory load with varying transformation sizes. Each session started with four practice blocks of five trials with  $\underline{m}=2,3$  or 4 and  $\underline{t}=1,3$  or 5, and continued with three repetitions of the nine blocks defined by the combination of  $\underline{m}=2,3$  and 4 and  $\underline{t}=1,3$  and 5. The nine blocks were presented in a random order within each replication. Thus 30 trials were obtained over the two sessions for each of the nine conditions.

## 3.2 RESULTS

### 3.2.1 Overview - Total Time

Before looking at the microstructure of the data in detail, this section summarises the total time taken to carry out the task for each condition used. These data are shown in figure 3.1.

Analysis of variance (ignoring  $\underline{m}=1$ , since it contained transform sizes not used elsewhere) confirms that there is indeed a main effect of both memory load ( $\underline{m}$ ) and transform size ( $\underline{t}$ ), as well as an interaction between them:  $F(2,16)=291.2, p \ll .0001$ ;  $F(2,16)=187.1, p \ll .0001$  and  $F(4,32)=81.2, p \ll .0001$  respectively. Such effects may of course be primarily due to more letter cycles being required for increasing memory loads, and increasing transform time being a result of increased transform size. The following sections will examine these differences in more detail to see if there are important effects of the storage and

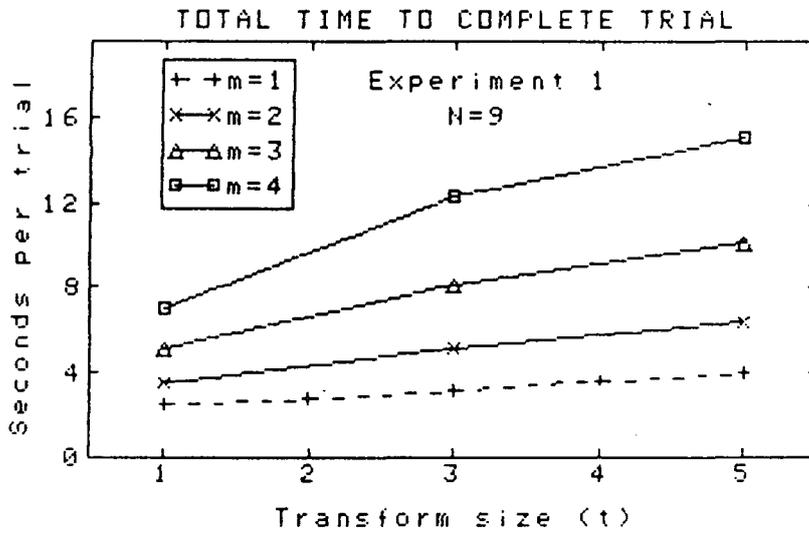


Figure 3.1 Total time taken to complete trials as a function of memory load and transform size.

transformation components remaining when the more trivial aspects are ignored. The next section examines the  $m=1$  condition to establish a baseline for the transformation rate in the absence of any memory load.

### 3.2.2 Single Letter Cycle

The median time for each component of the task was obtained for each condition for each subject, and the mean computed across subjects. Fig 3.2 shows the mean time for the encoding and transformation components under the  $m=1$  condition as a function of the transform size.

It can be seen from the figure that the time taken to transform increases linearly with transform size ( 99.75% of the variance due to increasing  $t$  is accounted for by a linear trend), with a mean slope of 344ms per item. The encoding time - the time to access long term memory and prepare to transform increases slightly with  $t$  ( $F(4,32)=6.89$ ,  $p=.0006$ ). There is a significant linear trend ( $F(1,32)=22.9$ ,  $p<.0001$ ) which accounts for 83% of the variance, and has a slope of 32 msec per item. Thus as the length of the subsequent transformation increases, the latency to commence transforming also increases.

Even this simplest version of the alphabet transformation task with no memory load has a problem solving component attached to it. It would be interesting at this stage to have some idea of how much this aspect of the task is influencing the component durations and how much of the duration is due to the limitations

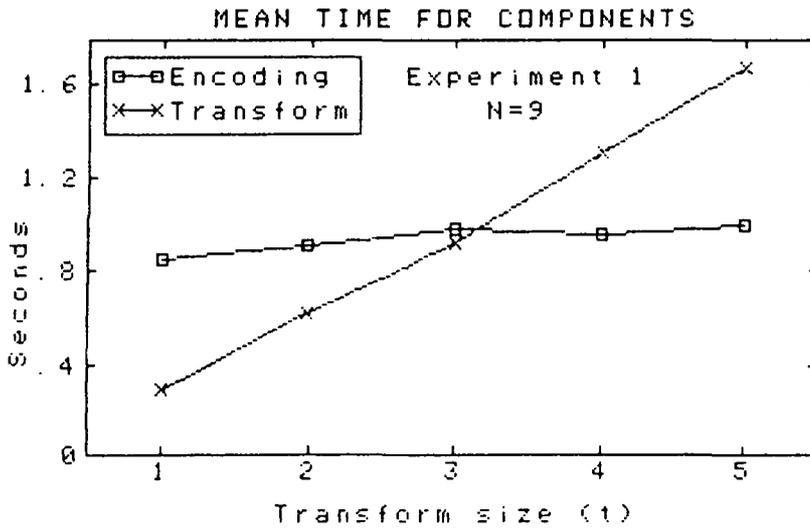


Figure 3.2 Mean time for encoding and transformation components as a function of transformation size for  $m=1$  (no memory load)

## The Microstructure of Performance - Study 1

of the system's ability to prepare to speak and to articulate. A number of studies in the literature pertain to this question. The most relevant ones have been concerned with the latency and duration of articulation either when the utterance to be spoken is or is not known in advance. Eriksen, Pollack & Montague (1970) and Klapp (1971) have shown that when required to speak words of varying syllable length which they know in advance, subjects take 250-400 msec depending on practice and precise experimental conditions, and show no increase in latency due to length of articulation. However, when the item to be spoken is not known in advance, their subjects take from 450-500 msec to begin speaking a single syllable, and show an increase of about 15 msec per syllable in the utterance to be produced. This contrasts with 850 msec for a single letter and 32 msec per additional letter in the current study. Subjects in this study had more prior practice than those in Klapp's (1971) study, so it seems likely that the considerably longer latencies are due to the greater complexity of this task. Although it is always dangerous to compare absolute times across studies, the magnitude of the differences and the greater cognitive load on the subjects tend to indicate that the difference is likely to be real. Sternberg, Monsell, Knoll & Wright (1978) and Monsell & Sternberg (1981) have carried out extensive studies on latency and duration of articulation when the speaker knows in advance what he is going to say. They have been particularly interested in how motor programs which are responsible for speech output are organised and used, especially in relation to the length of the utterance. They show a latency under conditions where the

speaker knows in advance what he is going to say, of about 260 msec plus about 12 msec for each additional 'stress group' (a speech segment associated with one primary stress). This increase in latency with the length of the utterance apparently contrasts with the findings of Eriksen et al (1970) and Klapp (1971), but this is probably due to the fact that Eriksen et al and Klapp used only single words and two digit numbers which are likely to be confounded with regard to the stress group concept of Sternberg et al.

Sternberg et al present duration of articulation data which shows an articulation rate of about 90 msec per syllable. This is comparable to the rate obtained by Landauer (1962) for both overt and implicit speech. This rate is much faster than that obtained in the current study, though there are of course, a variety of crucial differences. The most critical of these is the fact that articulation in this case is essentially part of a problem solving task. It is most unlikely therefore that a motor program for the entire sequence is prepared in advance, or at least if it is, the result of it is not known to the subject without actually going through the articulation phase. The much steeper slope of transformation time would suggest that the item to be spoken is being worked out as the transformation progresses rather than being planned in advance. Finally, Hamilton and Sanford (1978) show that where subvocal articulation occurs as a problem solving aid in a symbolic distance task (using letters of the alphabet), the rate per letter is very similar to that found in the current

## The Microstructure of Performance - Study 1

study, thus lending weight to the argument that the rate of articulation used as a problem solving aid is considerably slower than simple rapid articulation with minimal additional cognitive requirements.

Data in the current study show a remarkably linear relationship between length of utterance and its duration, however Sternberg et al (1978) claim a small quadratic component as well. This component is only statistically significant in one out of the four relevant studies they report, and in general seems to be due almost entirely to the rate of uttering a single word being reduced slightly compared to that of uttering several words. In fact the only study they report in which it is significant is one in which subjects recite ascending digits and for which they report an articulation rate of 58 msec per item. This is obviously much faster than normal speech, and it seems likely that such a rate would only be obtained when the utterance had been rehearsed in advance. Attempts by the present author to obtain samples of spoken single digits for digitisation purposes have shown that it is extremely difficult to get comprehensible samples of a duration of less than 200 msec. This is probably because syllables which appear on word boundaries can be merged together (elided) when a sequence of words is spoken, so the duration of a spoken sequence will be less than the total time to speak each word separately. Indeed this is one of the problems which makes continuous speech recognition by computers so difficult. It is likely that this is responsible for the quadratic component found by Sternberg et al (1978).

On the basis of the data discussed above, there is obviously considerably more involved even in the simplest versions of the alphabet transformation task than the simple response requirements of the task, and it appears that being able to access the microstructure will give us a much richer grasp of the underlying cognitive processes. We will return to a more detailed account of the likely cognitive resources required after looking at data from the more demanding conditions of the task.

### 3.2.3 Multiple Letter Cycles

As before, the median time for each component was obtained for each subject for each of the nine conditions. As there are a different number of task cycles as  $m$  varies, direct comparison of single components is rather complicated. So first of all let us consider the mean value of all similar components in each trial as being representative of the typical time to carry out that part of the task. For example in the  $m=4$  case there are 4 processing cycles. Each one has an encoding time, transformation time and storage time associated with it. We can thus take the mean of these four times to obtain a representative time for each of the three main task phases for each subject for the  $m=4$  conditions, and similarly for the three cycles of the  $m=3$  and two cycles of the  $m=2$  conditions. These data are shown in figure 3.3. A separate analysis of variance was performed for the means of each of these three main phases of the task as well as the the

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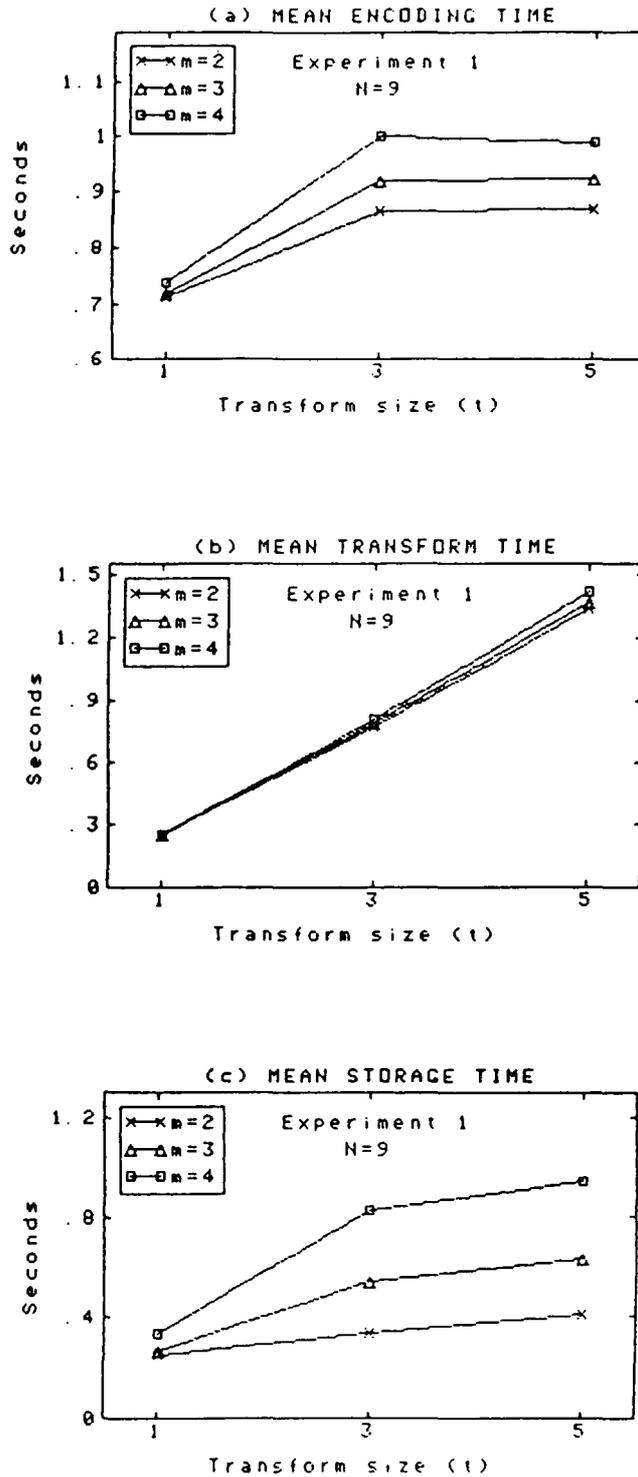


Figure 3.3 (a) Encoding, (b) Transformation and (c) Storage times for  $m=2-4$  as a function of transformation size.

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first cycle on its own and the final response phases. The results are summarised in table 3.1.

	<u>m</u>		<u>t</u>		<u>m x t</u>	
	F(2,16)	p	F(2,16)	p	F(4,32)	p
Encoding	12.1	.0009	41.7	<.0001	5.0	.003
Transform	9.3	.002	185.6	<.0001	6.5	.0009
Storage	34.1	<.0001	38.9	<.0001	14.2	<.0001
E1	9.63	.002	26.7	<.0001	1	-
T1	13.3	.0006	180.8	<.0001	3.4	.019
S1	30.1	<.0001	21.8	<.0001	5.9	.0014
Rec	17.7	.0002	13.8	.0005	2.8	.04
OL	1.5	.26	3.6	.05	1.7	.16
Out dur	88.0	<.0001	4.3	.03	2.3	.08

Table 3.1 Anova results for experiment 1: Memory load (m) by Transform Size (t).

3.2.3.1 Encoding Time

Figure 3.3(a) shows encoding time as a function of transform size. As noted above, each point on the graph is the mean of the four encoding times for m=4, 3 times for m=3 and 2 times for m=2, averaged across the nine subjects. Analysis of variance of this data revealed that encoding time increases as a function of both m ( $F(2,16)=12.14$ ,  $p=.0009$ ) and t ( $F(2,16)=41.65$ ,  $p<.0001$ ). In addition there was a significant interaction between the two variables ( $F(4,32)=5.02$ ,  $p=.003$ ). Note however that the effect as t increases is due entirely to the transition between t=1 and t=3. The jump from t=3 to t=5 causes no further increase in encoding time. However, there is a considerable increase in

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encoding time as  $\underline{m}$  increases, particularly when  $\underline{t}$  is greater than one.

The most striking aspect of the encoding data is what appears to be a qualitative difference between  $\underline{t}=1$  and the larger transform sizes. Such a difference is likely to be a result of different resources being involved in the different situations. It is likely that there will be a strong association between each letter in the alphabet and its immediate successor. If this is the case there will be either a minimal resource requirement in carrying out the  $\underline{t}=1$  tasks, or at least any resources required do not overlap with those required for handling the memory load component of the task.

For the larger transform sizes, an alternative strategy involving explicit counting through the alphabet would appear to be involved. The data suggest that such a strategy does not require increasing resources as the size of the transformation increases since there is no further increase in encoding time as  $\underline{t}$  increases from 3 to 5. However, as there is a consistent increase in time required as the memory load increases, this would suggest that there is an overlap in the resources required by the counting strategy and for remembering earlier responses in the sequence.

### 3.2.3.2 Transformation

Fig 3.3(b) shows the transformation time for  $\underline{m}=2,3,4$  as a function of  $\underline{t}$ . As before the time shown is the mean of the

## The Microstructure of Performance - Study 1

transformation times for all cycles of the task. Analysis of variance revealed that as memory load increases the time spent carrying out the transform also increases ( $F(2,16)=9.29$ ,  $p=.002$ ). As shown before with  $m=1$  there is a linear relationship between the time taken to carry out the transformation phase and the transform size,  $t$  ( $F(2,16)=185.6$ ,  $p\ll.0001$ ). The slopes of average transformation time against  $t$  show a small but highly significant increase ( $F(4,32)=6.48$ ,  $p=.0009$ ) from 273 msec/item for  $m=2$  to 279 for  $m=3$  and 291 msec/item for  $m=4$ . Note that this is slightly less than that of 334ms/item obtained in session one for  $m=1$ , but is still much greater than the articulation durations reported by Sternberg et al (1978) (see previous section). The decrease in time per item is accounted for by the extra practice subjects have had with the task by this stage. (This explanation cannot account for any differences between the conditions in sessions 2 and 3 since the order of blocks was completely randomised). The important point here, however, is the increase in slope with increasing memory load in this phase of the task which is primarily concerned with transformation. There is therefore a strong implication that a smaller share of available resources is available for transformation as the memory load increases. However, the precise interpretation of this increase in slope will depend to some extent on whether it is due to particular cycles of the task, or to an overall slowing of transform speed in the more difficult conditions. We shall consider it again later in the chapter when the data has been examined in more detail.

3.2.3.3 Storage

Fig 3.3(c) shows storage time as a function of transform size. This time, the points on the graph show the means of the medians of one less than the number of processing cycles in each trial, (see the discussion of the task in chapter 2 for a fuller discussion of why this is so). Briefly however, the time between finishing transforming the final letter and indicating readiness to respond is qualitatively different from the corresponding phase earlier in the trial. Active storage is not required here since all that is necessary is to retrieve the items in store and give the response - there will be no more interference from transforming before the end of the trial. Data presented in a later section will emphasise this distinction. The analysis of variance of these data shows that there are massive effects of both transformation size ( $F(2,16)=38.92, p<.0001$ ) and memory load ( $F(2,16)=34.05, p<.0001$ ) on the time spent in this phase of the task. The interaction ( $F(4,32)=14.19, p<.0001$ ) is a result of there being much less increase in the time spent as a function of  $m$  for  $t=1$  compared to the larger transform sizes. As noted with the encoding times,  $t=1$  seems to place a much smaller load on the system (or at least uses different resources), so these trials are able to cope with increases in memory load with minimal trouble. However, in contrast to the encoding times, there is an increase from  $t=3$  to 5, although it is considerably smaller than that from  $t=1$  to 3, especially as  $m$  increases. The main observation to be made at this stage is that when either  $t$  or  $m$  is small then the other has a relatively small effect, but as

soon as both become more difficult there is a much sharper increase in the time required to ensure that the items to be remembered are adequately stored. Thus the more resources the task requires, the more time has to be spent rehearsing the sequence to be remembered to ensure that it will be possible to retrieve it when required.

#### 3.2.4 Within-trial Data

The data discussed so far is based on a single derived figure for each of the major components of the task, irrespective of the number of task cycles from which that component was derived. This section will concentrate on what happens across letter cycles for each of these components. Fig 3.4 shows that at least with some of the components there are substantial changes in duration as the trial progresses.

Because of the different number of cycles associated with changes in memory load, it is not possible to statistically analyse the relationship between memory load and cycle in a particularly meaningful way. Consequently, nine separate analyses of variance were performed for each of the task phases (E, T & S) for each of  $m=2,3$  & 4, with  $t$  and position in the trial (cycle number) as the factors of interest. The results of these analyses are shown in table 3.2. As would be expected from the results already discussed,  $t$  is highly significant in all cases and is therefore not included in the table. The reader is referred to the discussion of the mean durations of each phase in the previous section to understand the effects of variation in memory load.

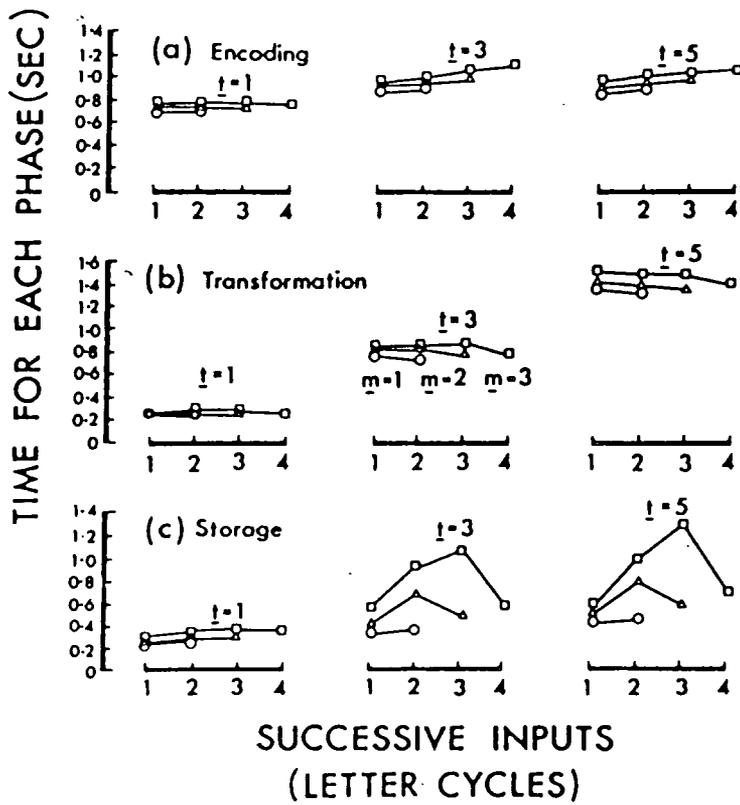


Figure 3.4 Time to carry out each phase of the task as a function of Memory Load, Transform Size and Input Cycle for (a) Encoding time, (b) Transform time and (c) Storage time.

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This, in conjunction with the graphs in fig 3.3 should suffice to allow an initial interpretation of changes in  $\underline{m}$ . The only information thus missing is the interaction between  $\underline{m}$  and cycle and it is not clear at this stage how it could be examined in any case.

		$\underline{m} = 2$			$\underline{m} = 3$			$\underline{m} = 4$		
		df	F	p	df	F	p	df	F	p
Encoding	Cycle	(1,8)	< 1	-	(2,16)	1.1	.36	(3,24)	1.7	.19
	Cyc x $\underline{t}$	(2,16)	2.9	.08	(4,32)	1.5	.23	(6,48)	2.9	.017
Transform	Cycle	(1,8)	10.9	.01	(2,16)	14.3	.0005	(3,24)	6.4	.003
	Cyc x $\underline{t}$	(2,16)	6.2	.01	(4,32)	< 1	-	(6,48)	< 1	-
Storage	Cycle	(1,8)	1.1	.32	(2,16)	12.3	.0008	(3,24)	11.2	.0002
	Cyc x $\underline{t}$	(2,16)	< 1	-	(4,32)	14.7	<.0001	(6,48)	9.2	<.0001

**Table 3.2** Anova results for Cycle x Transform size analysis for the nine subjects in experiment 1. For  $\underline{t}$ , in all cases  $F(2,16) > 14$ ,  $p < .0005$ .

3.2.4.1 Encoding times

Table 3.2 shows that there is no main effect of letter cycle for any  $\underline{m}$ . However, for  $\underline{m}=4$ , the interaction between cycle and transform size is significant. Fig 3.4(a) shows that this is due to the fact that for  $\underline{t}=3$  & 5, as the trial progresses there is a slight increase in encoding time, whereas for  $\underline{t}=1$  there is a slight decrease. Although this interaction is comparatively weak compared to the other effects discussed so far, it again points to the difference between the  $\underline{t}=1$  condition and the larger

transform sizes, in that the  $\underline{t}=1$  condition places little or no load on the system as the trial progresses.

#### 3.2.4.2 Transform time

Table 3.2 shows a consistent effect of letter cycle on transform time for  $\underline{t}=1, 3$  & 5. Fig 3.4(b) shows that this is due to the transform time in the final cycle being consistently lower than the previous cycles in each condition. (The mean decrease is 28 msec for  $\underline{m}=2$ , 52 msec for  $\underline{m}=3$  and 54 msec for  $\underline{m}=4$ ). The size of transform does not appear to affect the size of the decrease, except for  $\underline{m}=2$  where the interaction between  $\underline{t}$  and cycle for  $\underline{m}=2$  is due to the dip being greater for  $\underline{t}=1$  (48 msec) than for  $\underline{t}=5$  (10 msec),

There are several possible reasons for this dip in the final transform time. As the actual memory load on the system is at its maximum during this cycle, it seems unlikely that the effect is due to competition for resources, since a hypotheses of this nature would predict the opposite trend. If however the increasing memory load on the system actually changes the properties of the system, it may be that a process such as transformation is actually speeded up. This would be consistent with notions such as those of Kahneman (1973) which claim that cognitive effort is important in determining the properties of the system. On this analysis, increasing task demands could be argued to increase effort which in turn increases the rate at which the transformation is performed. If this were the case, a more linear decrease in transformation time would be expected,

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unless there is a cusp where difficulty increases dramatically for the increase in load from two to three items.

An alternative argument can be made from the standpoint of preparation. The final cycle contains the last transformation required, and so if preparation to transform has to be kept 'loaded' at all times during the task except when it is no longer needed, then resources may be freed allowing the actual transformation to occur more quickly. In addition, the 'storage' phase which follows this transformation phase is rather different from the previous storage phases in that rehearsal is not required. It may be that preparation for rehearsal is taking place concurrently with the transformation and thus slowing it down in the earlier cycles. This could in fact be at least partly due to the impending need to switch from overt to covert speech once the transformation is completed. Weber, Blagowsky and Mankin (1982) have shown that for lists presented to subjects where they are required to rapidly alternate between mouthed and spoken speech on alternate items, there is a substantial switching time required to complete the sequence. This is less likely in this case for two reasons. Firstly, as pointed out before, the articulation in this case is part of the problem solving strategy, and as such is considerably slower than simple articulation. Secondly, the transition between transformation and rehearsal coincides with the transition between two conceptually different groups of items, and as such the switch is likely to be more strongly marked for reasons other than the simple voicing one.

Although the precise reason for this final decrease in transformation time is not completely clear at the moment, there is certainly evidence that preparation plays some part in determining transform time. Figure 3.4(b) and table 3.1 show that there is a substantial increase in transformation time overall as  $\underline{m}$  increases. Most importantly, this appears to hold even in the earliest parts of the trial, in which case it cannot be solely due to any actual load on the system. The first cycle will be examined more closely shortly.

#### 3.2.4.3 Storage time

As shown in fig 3.4(c) and table 3.2, storage time shows the most striking changes in duration as the trial progresses, but only in the more difficult cases where both  $\underline{m}$  and  $\underline{t}$  are greater than 1. Fig 3.4 shows that in these cases the storage time rises steeply until the penultimate cycle. Thereafter, the characteristic drop in "storage" time on the final cycle in these cases is a reflection of the argument presented earlier which points out that the subject expects no more interruption of the items in store before he has to respond, thus requiring less rehearsal at this final cycle. The initial increase is presumably due to the increasing size of the set which has to be remembered - it would be expected that the larger this set is, the longer will be required to rehearse it. There appear to be other relevant factors as well. The strong interaction between  $\underline{t}$  and cycle (table 3.2) implies a preparation or rehearsal component to the

storage process. The longer the expected duration of the ensuing transformation, the longer rehearsal is required to ensure that the information will still be intact when it is required again. However, as before it would appear that a more general preparation for the expected size of transformation and memory load is involved, since even the first cycle shows evidence of an increase as these factors increase. The next section examines this in more detail.

### 3.2.5 First Cycle Data

There were hints from the within trial data of evidence of effects of both memory load and transform size even on the very first cycle of the trial. In some ways this would be rather surprising since the actual processing required should be identical for all conditions. For encoding, no matter whether there are 2 or 4 letters to remember, and no matter whether the transform size is 1 or 5, the subject has the identical task of encoding the item on the screen, accessing it in long term memory, and preparing to transform it. The duration of the transform time will obviously vary with the size of transform, but there is no storage load yet no matter which condition is being performed. In the storage phase, one and only one item has to be stored for later, no matter what condition is being carried out. In all, we should not be very surprised if there is comparatively little effect of either manipulation on the first cycle.

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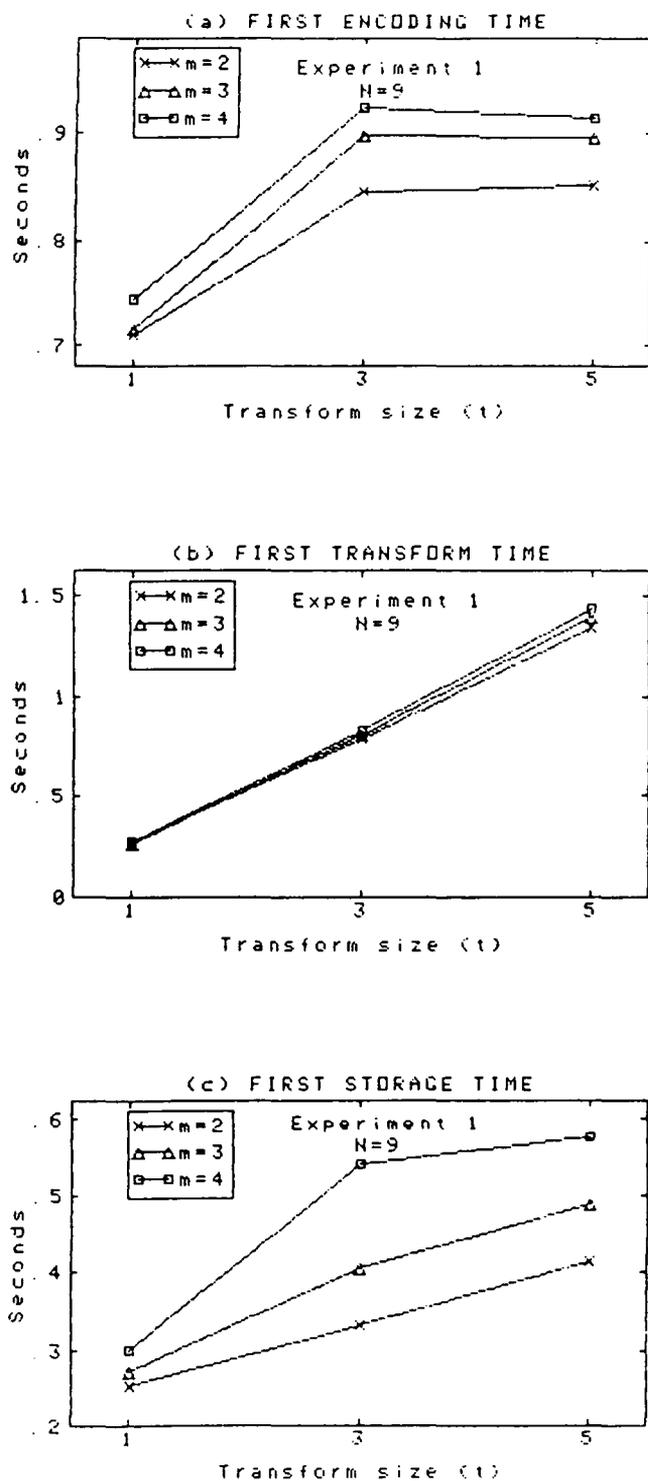


Figure 3.5 Data for the first cycle only of (a) Encoding time; (b) Transformation time and (c) Storage time as a function of memory load and transform size.

The data from the first cycle are presented in figure 3.5. It can be seen that the patterns observed are remarkably similar to those for the means across all cycles (figure 3.3). The analysis of variance (E1, T1 and S1 in table 3.1) confirm the similarity of the patterns. The only discrepancy is that there is no interaction between  $\underline{m}$  and  $\underline{t}$  for the encoding time.

This pattern of data strongly suggests that it is inappropriate to think of the processing involved in carrying out a complex task simply as the sum of the moment to moment requirements of the immediate task demands, but rather it would appear that the system has to be set up in advance in an appropriate configuration of resources for the complete task to be carried out. The temporal pattern observed is therefore a function of that configuration rather than that required for more local immediate processing requirements of a subset of the task.

### 3.2.6 Other Task Components - Response Phase

For completeness, the changes in the response task components as a function of memory load and transform size will now be briefly examined. There are three relevant components to discuss. Response latency is the time from terminating the final response to indicating readiness to respond. (This is in fact the "storage" time of the final letter cycle and was briefly mentioned in the previous section). Output Latency is the time from indicating readiness to respond to initiating the actual response, and Output Duration is the actual time to give the response.

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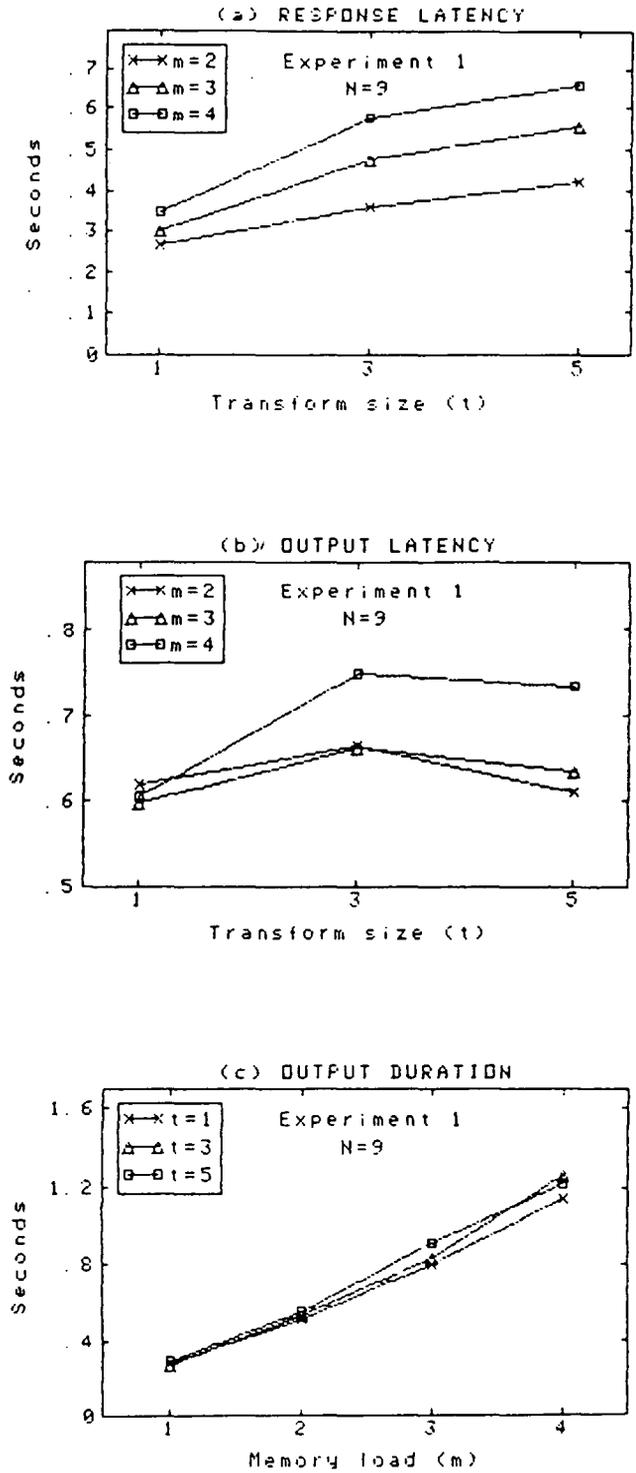


Figure 3.6 The three response phases as function of memory load and transform size: (a) Response Latency, (b) Output Latency and (c) Output Duration.

### 3.2.6.1 Response Latency

Fig 3.6(a) shows response latency, that is the time from finishing transforming the final letter to indicating readiness to respond by pressing the button.

The analysis of this data (Rec in table 3.1) shows a very similar pattern to that of the mean storage phase of the task (fig 3.3(c)), with the latency increasing with both  $\underline{m}$  and  $\underline{t}$ , although again there is less effect of increasing  $\underline{m}$  when  $\underline{t}=1$ , and the increase between  $\underline{t}=3$  and 5 is less pronounced than with the earlier storage phases. This phase is nevertheless much faster than the immediately preceding phase (fig 3.4(c)), as there is no need for the amount of rehearsal required in the immediately preceding storage phase. It seems reasonable to expect a greater number of items to be retrieved to take longer, and the greater the duration of the preceding transformation phase, the more decayed the memory trace is likely to be and thus the longer the retrieval time.

In addition, the overall difficulty of the particular task condition is likely to be influencing the component duration in the same ways as discussed for the main components earlier.

### 3.2.6.2 Output Latency

The output latency is the time from indicating readiness to respond to initiating the response. Table 3.2 (OL) shows that there are minimal effects of the experimental manipulations on this component, with the exception of a weak effect due to  $\underline{t}$ .

The time involved in this component can be seen in fig 3.6(b). As the strength of this effect is considerably less than that of the other data discussed so far, it will be ignored for the present.

### 3.2.6.3 Output Duration

The time to speak the response (Out dur in table 3.1; see also fig 3.6(c)) shows a very weak increase with  $\underline{t}$ , and minimal hint of an interaction between  $\underline{m}$  and  $\underline{t}$ . The effect of  $\underline{m}$  itself is of course largely due to the different number of items which have to be spoken, and shows a mean slope of 339 msec per item, which is considerably slower than the 280 msec/item slope of transform time. This relatively large time per item compared to both transform rate in the current experiment, and the rates of articulation obtained by eg Landauer (1962) suggests that the entire response string was not always instantly available, despite the fact that the subject had already indicated being ready to respond. Another possibility is that the rate of extraction of items from an output buffer is slower when the items do not form a fixed sequence, or possibly that different buffers with different temporal characteristics are involved in the transformation and response phases of the task.

### 3.2.7 Internal Consistency of Data

The discussion so far has concentrated on the effects observed averaging across subjects. The reliability observed indicates that all subjects must show essentially the same patterns of

performance. As a further indication of the reliability of the technique, it would be useful to know how consistent is the microstructure of performance within a single subject. Figure 3.7 shows the microstructure of the first block of trials in session 2, and the final block of trials in session 3 for the C45 condition for two individual subjects. It is clear that within each subject the patterns observed are remarkably stable. However, the two subjects are clearly distinguishable, particularly with regard to the time spent in the storage phase. Subject CW spends 2-3 seconds on storage after each letter, whereas subject SD spends only a fraction of a second in the storage phase. Despite these apparently quite different strategies, the overall results would suggest that the changes in the patterns as a function of memory load and transform size must be very consistent. It would appear that within a single subject, both the duration of components and their patterning is very stable, and between subjects the patterning as a function of memory load and transform size is also very stable. However, figure 3.7 suggests that there are strong individual differences in the way in which subjects allocate time to the different components. A later chapter will examine such differences in more detail.

### 3.2.8 Errors

The final data to be reported here are the distribution of errors across the conditions. Three distinct types of errors were possible. (See chapter 2 for a discussion of the relationship between the task procedure and errors.)

The Microstructure of Performance - Study 1

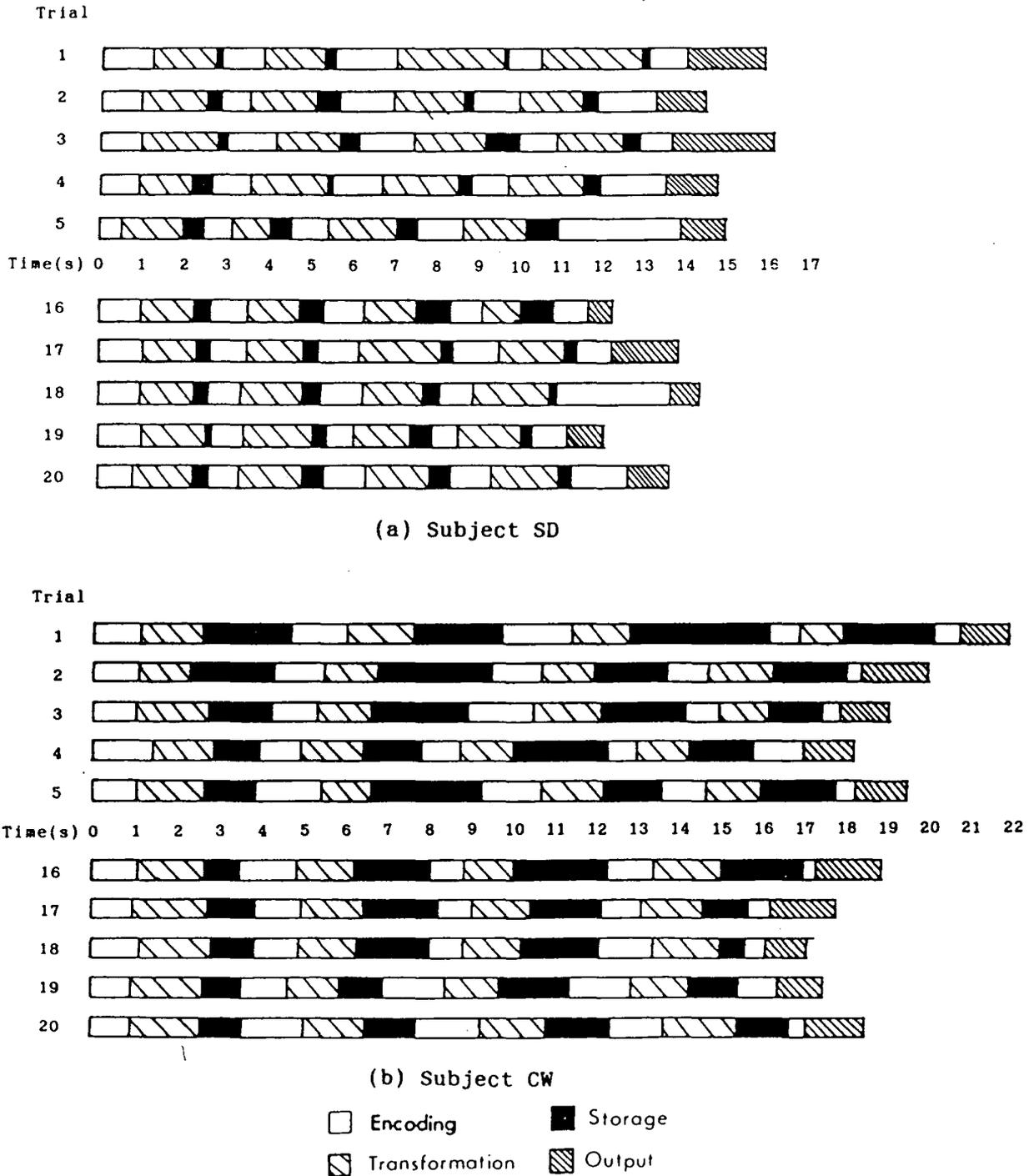


Figure 3.7 The microstructure of the first and last block of individual trials for condition C45 for two subjects. (a) Subject SD. (b) Subject CW.

### 3.2.8.1 Procedural errors

The first are 'procedural' errors, which are expressed as the percentage of trials abandoned before completion, relative to the required number of trials. All trials on which a procedural error occurred were replaced. Fig 3.8(a) shows the relationship between procedural errors and task condition. Analysis of variance confirms that no effect approaches significance - the highest F value is for  $t$  where  $F(2,16)=1.72$ ,  $p=.21$ . So although this type of error is relatively frequent, with a mean of 12%, it does not depend on task difficulty.

### 3.2.5.2 Transformation Errors

The second type of error involves the transformation process - counting forward the wrong number of letters; missing a letter in the sequence etc. This type of error was very infrequent (less than .6% in every condition).

### 3.2.5.3 Recall Errors

The third type of error is a recall error, where either an intrusion occurred in the recall list, or a letter was recalled in the wrong position in the list. These errors are only collated from trials which were completed (ie no procedural error trials are included), and are scored on the basis of the overall number of letters which were to be recalled. Fig 3.8(b) shows that there is a clear relationship between the proportion of errors of this type and condition. The error rate is highly significant as a function of both  $m$  ( $F(2,16)=16.4$ ,  $p=.0001$ ) and  $t$

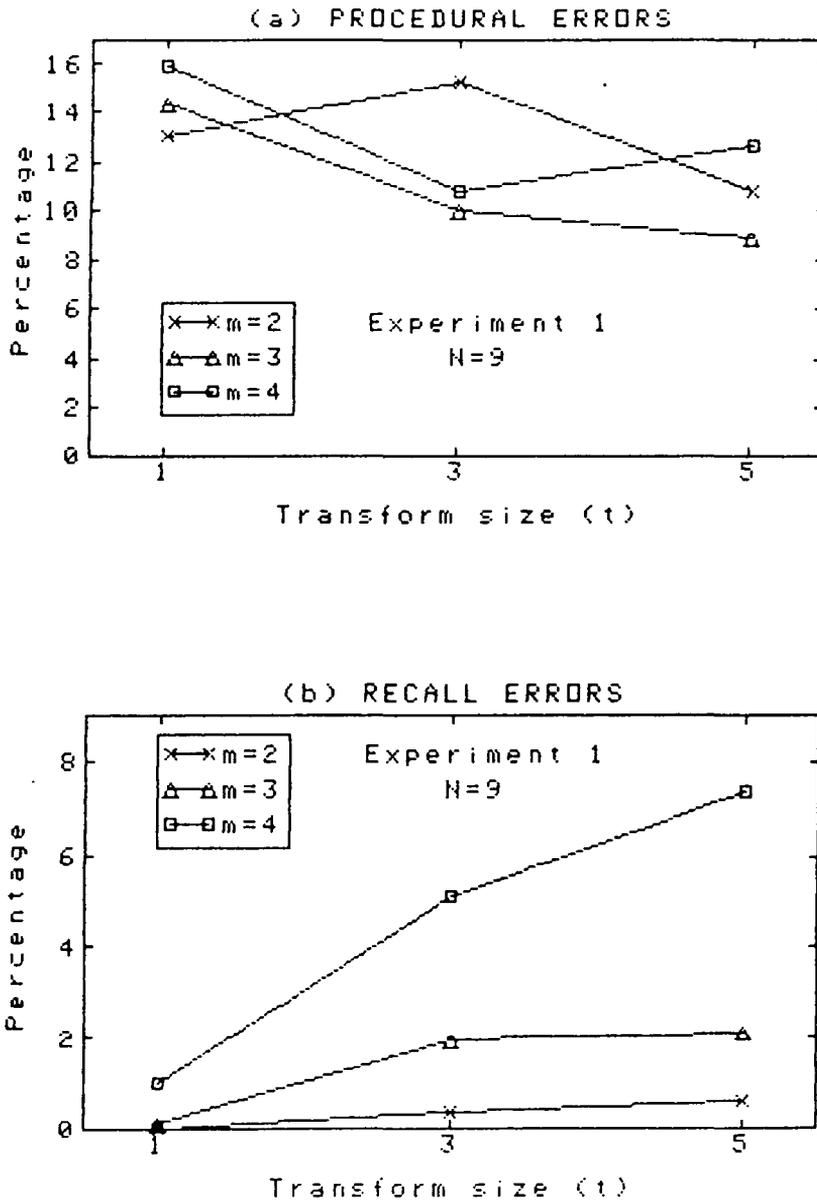


Figure 3.8 Errors as a function of memory load and transform size: (a) Procedural errors expressed as a percentage of the total number of trials required and (b) Recall errors expressed as a percentage of the total number of letters transformed.

## The Microstructure of Performance - Study 1

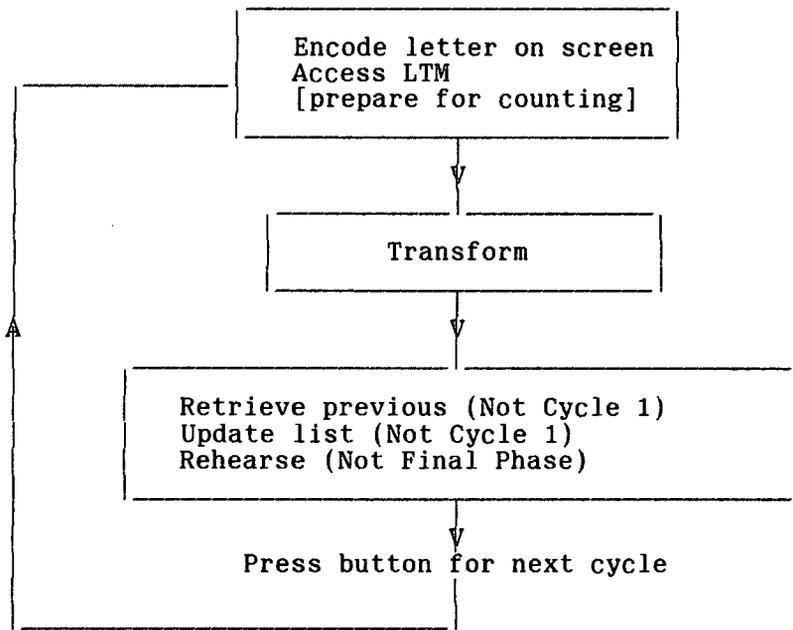
( $F(2,16)=16.2$ ,  $p=.0001$ ) and their interaction ( $F(4,32)=7.7$ ,  $p=.0002$ ). In this case, the more difficult the task, the more errors are likely to be made, even though the task is self-paced. As this mirrors general trends of the time data, there is no hint of any speed accuracy tradeoff affecting the data, and it confirms that the more complex conditions really are more difficult to perform.

### 3.3 SUMMARY OF RESULTS

The preceding sections have discussed the detailed results with particular emphasis on individual task components. This section summarises these results in relation to performance on the task as a whole. First of all let us consider the range of processes likely to be involved in carrying out the task and how we might naively expect them to be affected by the manipulations used. Figure 3.9 shows a schematic of the steps involved in carrying out a cycle of the alphabet transformation task, with the hypothesised underlying cognitive resources for each task phase.

If we take the straightforward view which says that resources will only be directly affected when the immediate task demands require additional processes, we would expect increases in the memory load (both in terms of the dynamic load from cycle to cycle as well the changing load with different conditions) to affect only the storage time. Moreover, we would expect the times for all phases of the early cycles not to vary as m increased since the processing demands at those early stages should be identical.

The Microstructure of Performance - Study 1



**Figure 3.9** Organisation of resources required to carry out task (excluding response phases).

We might expect variations in  $t$  to have some effect on all components. For example, longer encoding times might be expected if more LTM has to be activated to allow the larger transformations, and longer storage times might be expected if more rehearsal is required to sustain the memory trace through the longer transform time that greater transform sizes will inevitably entail. However, we would not expect any increase from cycle to cycle since the transformation demands are identical on each cycle for any given condition. We might expect no interaction between  $m$  and  $t$  (with the possible exception of the storage phase) since the usual argument given for such

interactions is that the the task requires a single resource to be used by more than one activity (eg Navon and Gopher, 1979; Shallice, McLeod and Lewis, 1985). It was argued in the first chapter that processing and storage resources are quite separate cognitive entities. We might therefore expect no interference between them. The data presented earlier clearly belie such a simplistic view of how resources are used to carry out the alphabet transformation task. Three classes of effect are worthy of consideration in helping to clarify the phenomena which must be accounted for.

1. Dynamic Memory Load As the trial progresses, E and S become slower (not for  $t=1$ , and not for the final cycle of S). Conversely, T gets faster, with an especially noticeable dip in the final cycle.
2. Strategy Differences (Resource Configuration) The  $t=1$  condition appears to be qualitatively different from the other two transform sizes. It shows negligible differences between conditions as  $m$  varies, whereas there is a strong effect of  $m$  for the larger transform sizes.
3. Expected Difficulty (Preparation/Maintenance) All phases of the task (except for the response phase) are slower with increasing  $t$  and  $m$ , and the interaction between the two is generally over-additive. This is true for the very first cycle and is not simply a result of increasing load as the trial progresses.

3.3.1 Dynamic Memory Load

Let us first consider the dynamic memory load on the system. As the trial progresses, the number of letters to be carried increases. This is indeed reflected in the storage time as the simple model outlined above suggests. However, there is also a tendency for the encoding time to increase as the trial progresses, and there is a definite decrease in the transformation time. Although variations in  $t$  do not change the load on the system as any trial progresses, there is evidence that they have a substantial effect. In particular the cycle  $x$  transform interaction for storage times is highly significant (table 3.2), and there are hints of interactions with cycle in some of the other phases. This must be a reflection of interference in the system between the overall load and the transformation requirements, suggesting that the two may not be independent. However, this cannot be taken as strong evidence of non-independence between storage and processing requirements since an alternative explanation is that in a limited capacity system, the more resources required for the transformation, the less are available for handling the increasing memory load and the increased difficulty of combining the two is reflected in slower performance. The decrease in transform time in the final cycle suggests a more specific explanation of the type of dependence which may arise out of the combination of a number of resources in a complex task. It may be that the transform time can be speeded up to minimise the delay from one storage phase to the next and so the decay on the stored response trace. Support

for this argument also comes from the increase in storage time as t increases. Increasing use of the rehearsal part of the storage phase may be necessary to ensure a sufficiently strong trace to withstand the duration of the subsequent transformation.

More generally, the most striking effect showing an influence of one component on the other is the effect of memory load on transform time. Figure 3.9 would suggest that transform time should be the purest component since it contains only a single activity which should be strongly related to transform size and have little relationship to memory load. It is indeed the most stable component of all, having a very small variance. However, it shows a very reliable, if relatively small effect of memory load (as well as an interaction with transform size), so that the more difficult the task as a whole becomes, the slower the transform time becomes.

### 3.3.2 Resource Configuration

The interactions between storage and transformation components seen in the previous section suggests that the precise resources required to carry out a complex task must be considered in total rather than individually since a changing load on one component has implications for task phases emphasising the other. However, it is not only important to understand how the resources being used for a given task interact. It is also important to understand what configuration of resources is actually required.

The most obvious example of this comes from considering the greatly reduced times required for  $t=1$ . It was argued earlier that the patterns and level of performance observed in these conditions seem qualitatively different from the larger transform conditions. First, increases in memory load make much less overall difference to the time taken than is the case with larger transformations. Second, as the trial progresses and the memory load builds up, very little additional time is required, even for the storage phase. A plausible explanation for such qualitative differences is that  $t=1$  does not simply place less demand on the resources used (such as those indicated in figure 3.9), but that a different configuration of resources is used for this condition. The most likely area for such a difference is in the way the transform is carried out. In general, there is a strong association between a letter of the alphabet and its immediate successor (eg Hamilton and Sanford, 1978). It may then be unnecessary to actually count through the alphabet (or to prepare to count), it being sufficient simply to access the LTM representation of the letter presented on the screen in the encoding phase, and say its successor in the transform phase. Thus a different strategy could more efficiently cope with the task demands of the  $t=1$  conditions. Most importantly, the lower resource requirement of this strategy removes much of the overheads of simultaneously managing the transform and storage components which are particularly apparent in the storage phases of the more difficult conditions.

### 3.3.3 Resource Preparation and Maintenance

As immediate task demands increase from cycle to cycle there are clear effects on the time taken to carry out each component. This fits in well with the common assumption that resources are recruited as and when required, and so immediate task demands at any point determine the nature and duration of the currently active processes. However, there is evidence in the current study that the overall requirements are also very influential, so that the effect of one component is noticed in phases of the task for which it would not be expected to be relevant. This suggests that the complete configuration of resources required has a pervasive effect on all parts of the task solution. Most importantly, there appears to be an effect of expected difficulty, so that the more difficult the task to be carried out (both in terms of the set of resources required and the expected load on these resources), the longer it will take to carry out all components of the task. The most compelling evidence for this conclusion is the data from the very first task cycle (fig 3.6). In all conditions the pattern of data observed is very similar to that from the later cycles. Despite the fact that the actual task requirements for this cycle are identical irrespective of the expected memory load, there are substantial increases in the time required for each phase of the first cycle as a function of the expected memory load. The system must therefore be allocating resources based on perceived future needs rather than actual current needs. Similarly with increases in transformation, although increased duration would be expected in

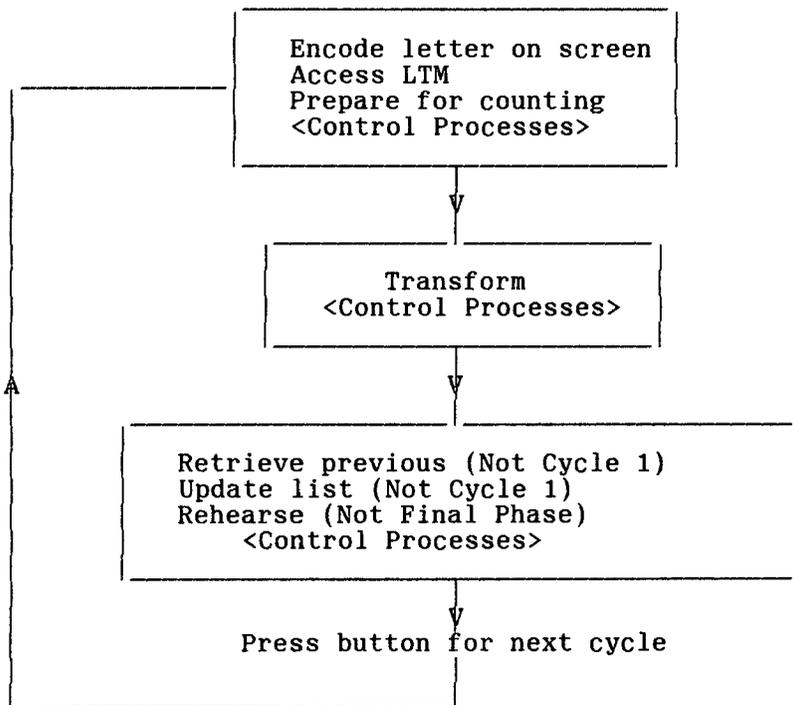
both E and T, there is no reason to suppose on the basis of a model which only takes actual requirements into account that the storage time for the first cycle, where only a single letter has to be stored irrespective of condition, should increase. It should also be borne in mind that as the task is totally self paced, preparation for the expected requirements of the particular condition to be performed can be carried out before the trial commences. The effect of task condition therefore must be due to the state of readiness into which the subject has configured his mental resources to deal with the expected requirements, rather than the the act of preparation itself. In other words, the subject does not take longer in the first cycle as task difficulty increases because he is preparing for the task, but because the state into which the system has already been prepared reduces the efficiency of the immediate performance of the current cycle to increase efficiency of performance of the complete task. As such, an important factor is likely to be the maintenance of the resource state required for task solution. This is most likely also important in the later task cycles, but is less easy to disentangle in them since it is confounded with the more dynamic task requirements. The finding of a pervasive preparation effect runs counter to the implications of much of the literature. It is commonly assumed that resources are recruited as and when required, and that the actual requirements of the system at any time determine the nature and duration of the currently active process.

#### 3.3.4 Executive Control

No consideration has been taken so far of how the resource configuration is arrived at or how it might be monitored once it is set up. An important concept which is gradually emerging in the psychological literature is that of executive control. The need for such a concept has been around for some years - for example in the 'central executive' of the working memory system (Baddeley and Hitch, 1974). However, work which directly addresses the nature and properties of control processes is sadly lacking, as has been lamented by Rabbitt (1979) and Logan (1985) among others. Two forms of executive control are worth considering briefly. One form relates to the construction of a set of appropriately configured resources to carry out the task. Any time overheads due to this would not be expected to be reflected in the current data since the task is self paced, but the previous section suggested that the maintenance of such a set of resources is reflected in the temporal patterns of performance.

The foregoing has so far implicitly assumed that when the appropriate set of resources has been configured, the task can be carried out purely by virtue of that configuration. However, it may be that continuous monitoring of the resources being used is necessary to ensure adequate performance (over and above simply maintaining the resource configuration in a state of readiness). If this 'control processing' is a single resource which monitors both the memory load and transformation aspects of the current task, then some of the interactions between the two components, which seemed rather anomalous earlier can be easily accounted

for. For example, the effects of memory load on transform time would not be due to a direct interaction between transformation and memory resources, but would be due to increased memory load putting greater demands on the control processes which are monitoring the transformation, and so slowing down the whole transformation phase of the task. On this argument, the presence of control processes should be acknowledged in all phases of the task, as shown in figure 3.10. The assumption would be that control processes have some role in all task phases, whether it be to monitor the progress of the currently active process, or to allow a smooth switch from one process to another.



**Figure 3.10** Organisation of resources required to carry out task, including control processes (excluding response phases).

## The Microstructure of Performance - Study 1

The present chapter has discussed the results of the first experiment and has gone some way towards exploring the implications of the data for the way in which mental resources are allocated, and the role of the control processes which manage them. More detailed discussion of the nature of the resources required and their interrelationship will be postponed until a later chapter, where more data will be available to replicate and extend the current findings.

## CHAPTER 4

### THE MICROSTRUCTURE OF PERFORMANCE - STUDY 2

#### 4.1 INTRODUCTION

Experiment 1 looked at the properties of the alphabet transformation task for a sample of university students. It showed us how performance is affected as task difficulty increases, both in terms of memory load and transformation time, and how the level of performance observed seems to be a function of two factors: (1) the actual demands of the task at any instant in time, and (2) the cognitive state which results from the expected task demands. Although the main results were highly reliable and a wide variety of conditions were explored, since only nine subjects were used, all from a university population, it is not clear how generalisable the conclusions are likely to be. Consequently, experiment 2 was designed to look at performance of a larger group of subjects who would be expected to have a different level of ability from the university students and who would be likely to be less homogeneous in ability than a university population.

#### 4.2 STUDY 2

##### 4.2.1 Subjects

Forty one third form pupils aged 15 - 16 from a local secondary

school (12 male and 29 female) took part in this experiment. The subjects attended the Durham Psychology Department for two days in groups of three, taking part in this and another unrelated experiment. In this time each subject attended two sessions which are relevant to the the current chapter, each of about forty five minutes duration at approximately the same time on consecutive days.

#### 4.2.2 Procedure - Session 1

Session one familiarised the subjects with the alphabet transformation task and obtained data on the slope of transformation time with a single letter cycle (i.e.  $m=1$ ; no memory load). Subjects were given six blocks of practice trials with  $m$  varied from one through four and  $t$  of 2,3 or 4. These were then followed by two blocks of five completed trials of each of  $t=1$  through five for  $m=1$  (see chapter two for a full description of the block structure), making ten trials each for each of the transform sizes one to five.

#### 4.2.3 Procedure - Session 2

Session 2 took place on the day following session 1 at approximately the same time of day (late morning). It started with three blocks of practice trials ( $m=2,3$  and 4,  $t=2$  or 4). Subjects then received 12 experimental blocks of five trials each - for  $m=2,3$  and 4 and  $t=2$  and 4, each condition presented twice in random order. It was decided not to use  $t=1$  conditions in this experiment as experiment 1 indicated that a single transformation imposed minimal extra cognitive load as  $m$

increased. Instead,  $\underline{t}=2$  and 4 were chosen, partly in an attempt to fill in the gaps left by experiment 1 and partly because it was felt that the  $\underline{t}=5$  condition may be rather difficult for some of the subjects.

### 4.3 RESULTS

#### 4.3.1 Single Letter Cycle

Similar analyses were carried out as for experiment one. Figure 4.1 shows how the encoding and transformation times vary as a function of the transformation size for  $\underline{m}=1$  (no memory load). The pattern of results is very similar to that obtained in the previous experiment. Note however that the subjects in this case are very much slower. The mean rate of transformation is 450 msec per letter (344 msec in experiment 1). 99.4% of this is accounted for by a linear trend, thus confirming the linear nature of the relationship between transformation size and duration found in experiment 1. The pattern of results for the encoding time is similar to that obtained in experiment 1. There is an increase in encoding time as  $\underline{t}$  increases ( $F(4,160)=5.89$ ,  $p=.0004$ ), but as before it is due entirely to the encoding time for  $\underline{t}=1$  being faster than  $\underline{t}=3,4$  and 5 (all of which are identical) (Scheffe c.r. at  $p=.05$  is .325 sec). Although numerically the encoding time for  $\underline{t}=2$  is intermediate between  $\underline{t}=1$  and  $\underline{t}=3$ , it is not reliably different from either. Again, overall performance is considerably slower than was seen in experiment 1 (1.587 sec against .932 for the overall means collapsed across all five transform sizes).

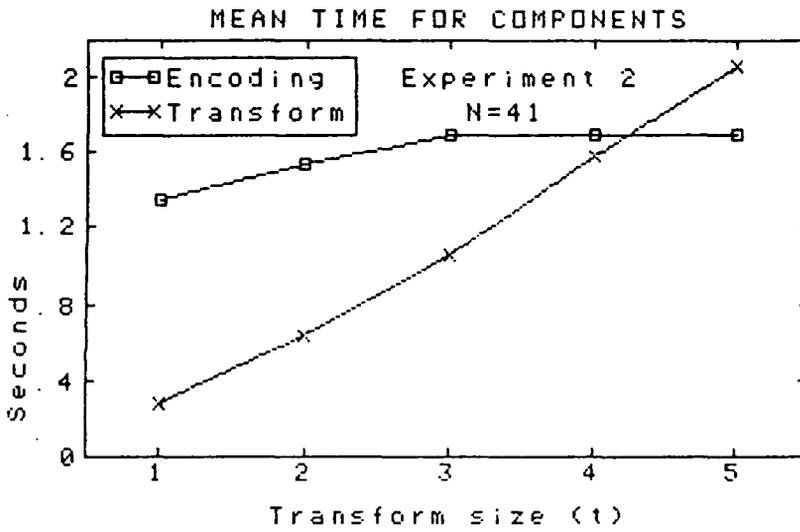


Figure 4.1 Mean time for encoding and transforming components in experiment 2 as a function of transformation size for  $m=1$  (no memory load).

#### 4.3.2 Multiple Letter Cycles

First, let us compare the general level of performance of this group of subjects with the subjects of experiment 1. A cursory glance at figure 4.2 indicates that any hope of interpolating this data with that of experiment 1 is doomed to failure as performance is about 80% slower for this group of subjects, when the total time to solve each problem is considered - even comparing them with the next most difficult condition from experiment 1.

Reference to figure 4.3 indicates that each individual component is slower than was seen in experiment 1. This is clear despite the fact that the conditions performed by each group were different. The differences in performance levels is due to at least two factors - the level of ability of the subjects and the amount of practice they have had with the task. The entire difference is certainly not due to practice differences, as can be seen from comparing the data on the  $m=1$  condition in session 1 where this group was also considerably slower and the amount of practice was approximately the same. The range of times in the two groups as shown in figure 4.2 shows considerably more variability in the subjects in the current experiment, although even the fastest subjects are generally slower than the slowest subjects in experiment 1.

Despite the large differences in the level of performance, we can still examine the extent to which the pattern of changes due to the experimental manipulations is consistent between the two

The Microstructure of Performance - Study 2

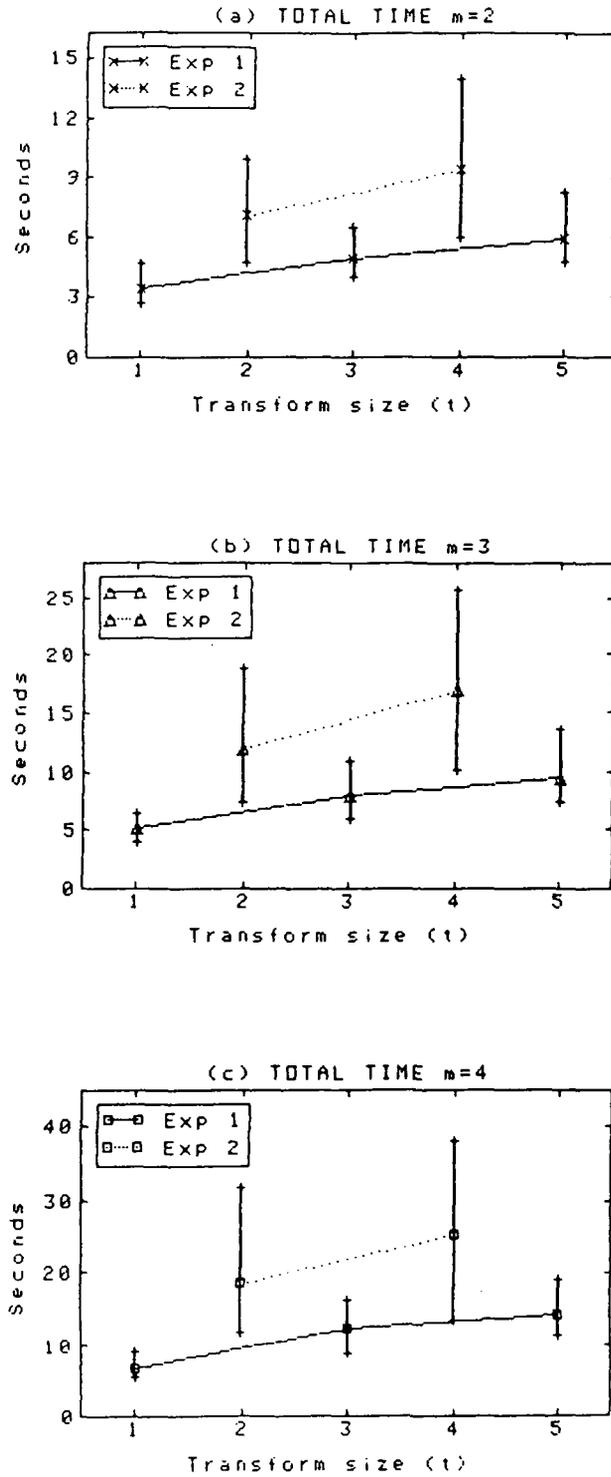


Figure 4.2 Comparison between experiment 1 and experiment 2 of median total time and range of times to complete a trial for each condition. (a)  $m=2$  (b)  $m=3$  (c)  $m=4$ .

The Microstructure of Performance - Study 2

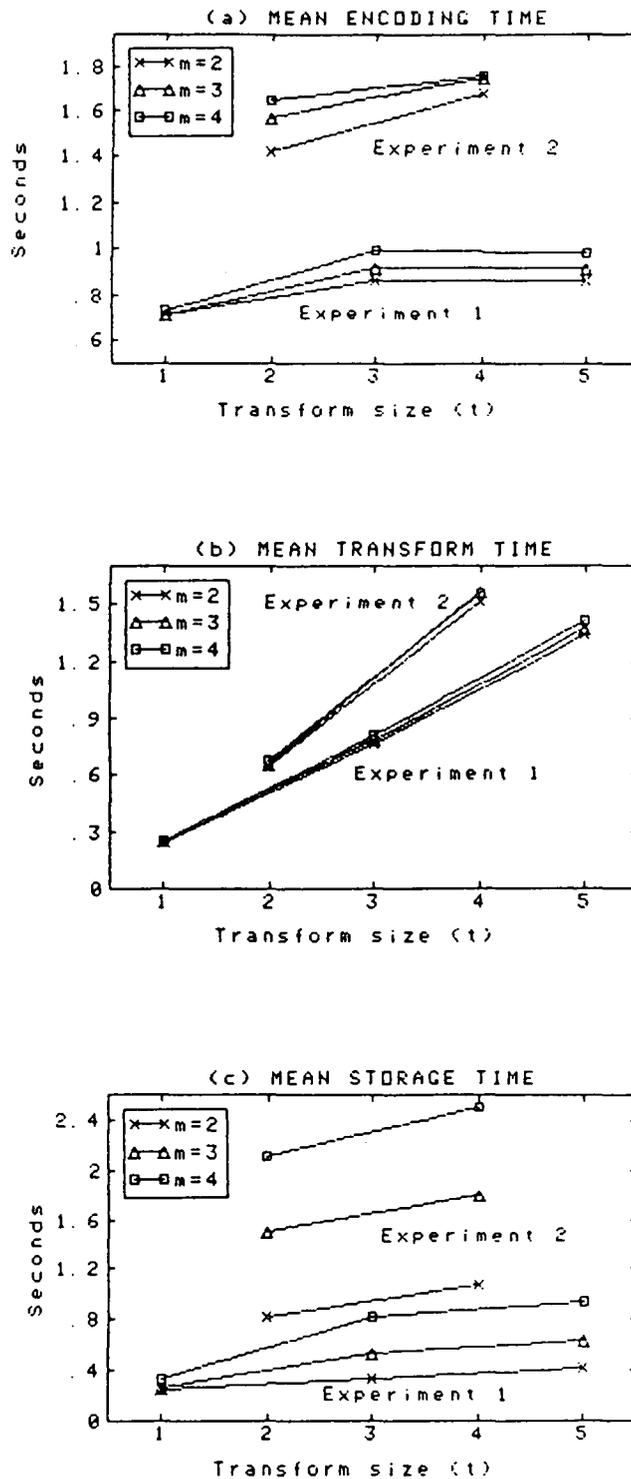


Figure 4.3 Comparison of mean component times in experiments 1 ( $t=1,3,5$ ) and 2 ( $t=2,4$ ) for  $m=2-4$  as a function of transform size. (a) Encoding time (b) Transform time (c) Storage time.

The Microstructure of Performance - Study 2

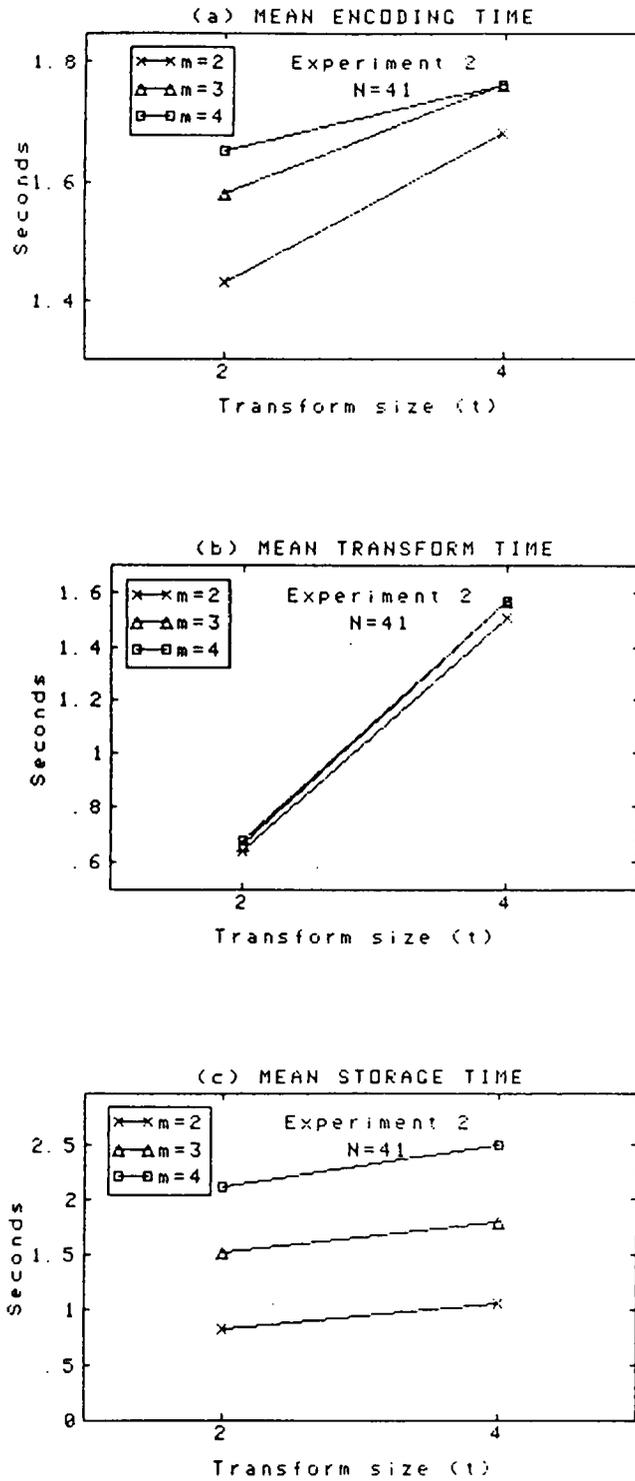


Figure 4.4 Mean component times for experiment 2. (a) Encoding time (b) Transform time (c) Storage time.

experiments, and see what aspects of the data generalise between the two subject populations.

First, let us compare performance between the various conditions as  $\underline{m}$  and  $\underline{t}$  are varied, both within the current experiment, and with the data obtained in experiment 1, bearing in mind the differences in procedure and subjects between the two conditions. As in experiment 1, the mean of the median time for the encoding, transformation and storage will be considered initially. Fig 4.3 (a) to (c) show the main components of the data along with the corresponding data from experiment 1. Figure 4.4 (a) to (c) shows the data from this experiment alone on a scale more suitable to distinguish between the conditions used, and table 4.1 summarises the results of analysis of variance on these components.

#### 4.3.3 Mean Component Duration

If we look at the data for the mean time spent in each phase irrespective of the cycle position, we can see that as before there are strong effects of both  $\underline{m}$  and  $\underline{t}$  in all three components, however this time there is no sign of an interaction between the two. It will be remembered that the  $\underline{t}=1$  conditions were responsible for the greater part of the interactions between  $\underline{t}$  and  $\underline{m}$  in experiment 1, and it was argued there that the resources required to perform the task are likely to be different for  $\underline{t}=1$ . Consequently it will be easier to compare the results of the present experiment with that of experiment 1 if we ignore the  $\underline{t}=1$  conditions from experiment 1. To facilitate this comparison, table 4.2 shows a reanalysis of experiment 1 with the  $\underline{t}=1$  condition

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	<u>m</u>		<u>t</u>		<u>m x t</u>	
	F(2,80)	p	F(1,40)	p	F(2,80)	p
Encoding	9.3	.0005	30.8	<.0001	2.1	.13
Transform	4.9	.001	617.2	<.0001	1.9	.16
Storage	69.3	<.0001	29.4	<.0001	<1	-
E1	1.5	.23	29.1	<.0001	4.2	.017
T1	13.6	<.0001	443.4	<.0001	4.6	.013
S1	29.9	<.0001	13.3	.001	<1	-
Rec	30.4	<.0001	27.9	<.0001	5.8	.005
OL	1.2	.29	<1	.53	1.7	.20
Out dur	178.8	<.0001	7.1	.01	<1	-

Table 4.1 Anova results for experiment 2: Memory load (m) by Transform size (t).

	<u>m</u>		<u>t</u>		<u>m x t</u>	
	F(2,16)	p	F(1,8)	p	F(2,16)	p
Encoding	11.0	.001	<1	-	<1	-
Transform	9.9	.002	181.3	<.0001	5.1	.02
Storage	30.1	<.0001	55.7	<.0002	<1	-
E1	8.5	.003	<1	-	<1	-
T1	12.9	.0007	175.6	<.0001	1.6	.23
S1	28.0	<.0001	30.8	.0008	1.0	-
Rec	14.3	.0005	8.2	.02	<1	-
OL	1.6	.23	13.8	.006	<1	-
Out dur	108.4	<.0001	1.6	.24	3.9	.04

Table 4.2 Anova results for experiment 1, re-analysed excluding t=1 conditions: Memory load (m) by Transform size (t).

## The Microstructure of Performance - Study 2

removed. It can be seen from this that the interactions between  $\underline{m}$  and  $\underline{t}$  were indeed due to the  $\underline{t}=1$  condition, although there is still a trace of an interaction with the transform time, but at a much reduced level of significance. In addition, there is no main effect of  $\underline{t}$  on encoding time when  $\underline{t}=1$  is removed, as may be expected from examination of fig 3.2. This is in contrast to the increase between  $\underline{t}=2$  and 4 in the current experiment. However reference to the data for  $\underline{m}=1$  in both this experiment (fig 4.1) and experiment 1 (fig 3.2) hints that performance on  $\underline{t}=2$  may be intermediate between  $\underline{t}=3$  and  $\underline{t}=1$  (although any difference was non-significant by Scheffe post hoc comparison in both experiments), before it levels off at  $\underline{t}=3$ . As before it is not possible to compare the absolute values of E with those from the  $\underline{m}=1$  data because of differences in practice between the two sessions.

Comparison with the data from experiment 1 (fig 4.3) shows that subjects in this experiment are almost twice as slow as those in experiment 1 (1644msec vs 928msec overall mean encoding times -  $\underline{t}=3$  and 5 only for experiment 1). Although the patterns are the same in both groups for T and S (ignoring  $\underline{t}=1$  in experiment 1), the levels of performance are again rather different. For example, the mean transform rate in experiment 1 is 282 msec/item and in experiment 2 is 443 msec/item. Storage time increases by 254 msec/item as  $\underline{m}$  increases in experiment 1 (ignoring  $\underline{t}=1$ ) and a massive 684 msec/item in experiment 2, and as  $\underline{t}$  increases from 3 to 5 in experiment 1 S increases by 97 msec while in experiment 2 the increase in  $\underline{t}$  from 2 to 4 requires 301 msec extra time.

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These storage times of course include the later components which we saw from experiment 1 tend to increase as the load on the system increases.

However, to pre-empt the next section, even if we look only at the first storage time, performance is still substantially poorer in experiment 2. As  $m$  increases,  $S$  increases at a rate of 92msec/item in experiment 1 and 383 msec/item in experiment 2. The increase in storage for the first item due to increases in transform size amounts to 67 msec in experiment 1 as  $t$  increases from 3 to 5, and 241 msec in experiment 2 as  $t$  increases from 2 to 4. Performance is thus very much poorer for the subjects in experiment 2, suggesting that they are less well able to set up their cognitive system into an appropriate state to carry out the task. There are a variety of possible reasons for this. For example, they may have difficulty in deciding in advance exactly what mix of resources they require; they may have trouble optimising transfer between resources; They may have a less well developed repertoire of resources (this is similar to the argument put forward by Shiffrin and Schneider (1977) that older or better subjects have a better repertoire of automatic processes); they may have insufficient capacity to utilise for resource allocation, either because their overall capacity is less than the other group of subjects, or because a less efficient resource configuration (for the reasons mentioned above) would require more capacity than they have available. These possibilities will be discussed in more detail at a later stage.

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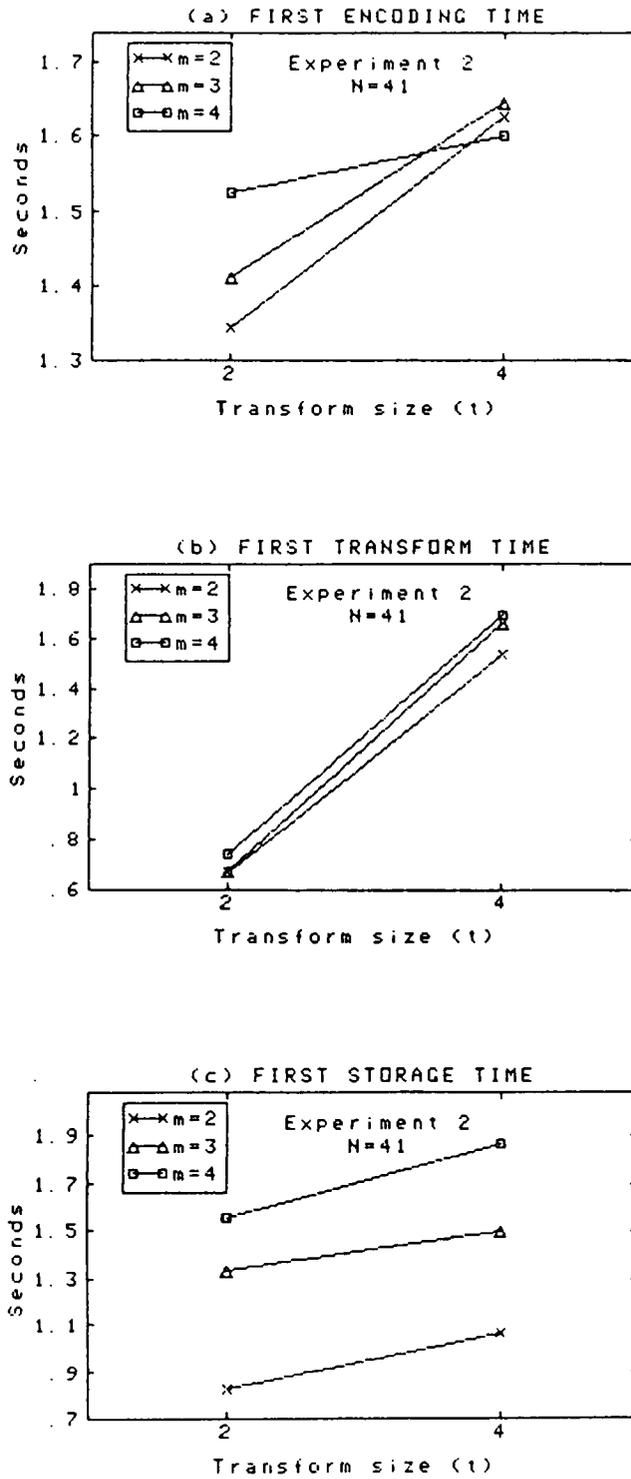


Figure 4.5 Data for the first cycle only of experiment 2: (a) Encoding time; (b) Transformation time and (c) Storage time as a function of memory load and transform size.

#### 4.3.4 First Cycle Data

One of the more important aspects of the data in experiment 1 was that the difficulty of the expected task showed a strong influence on the performance data even in the earliest components of the task before any memory load had been acquired. We have already touched on this issue in the previous section as regards the current experiment. Fig 4.5 shows that the patterns of data for this experiment confirm this tendency for transformation and storage time. The initial encoding time does not differ with levels of  $m$ , although the interaction shows that it differs when  $t=2$  but not when  $t=4$ . This runs counter to the data examined to date, in that there has been no tendency for such effects to reduce as task difficulty increases in any component. One possibility is that as the difficulty of the task increases, it becomes impossible to efficiently set the system up for all the task requirements at once, and greater emphasis has to be placed on the more immediate task requirements, possibly even to the extent of concentrating on immediate requirements to the detriment of an overall balance among task requirements. Thus at the beginning of the task the transformation is the most immediate factor, and when a large transformation is required, there is less capacity to prepare properly for the expected memory load, especially when this is also large. Thus whatever the size of expected load it has little effect on the first encoding time - task difficulty is such that complete preparation cannot take place. This inefficient allocation of resources would imply more trouble in coordinating resources and longer times switching between transformation and storage - somewhat analogous to a virtual

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memory system on a digital computer. In addition we might also expect more errors if active switching between resources interferes with stored information.

Given the argument just presented, we should expect a cusp in performance as task difficulty increases, owing to a change in emphasis on the available resources. If we look at the first transformation and storage times and in particular the effect of  $\underline{t}$  for  $\underline{m}=3$ , there is a tradeoff between an increase in slope of transformation time and a (non significant) decrease for storage time compared to the other two  $\underline{m}$  conditions. For the conditions studied there is thus a sharp increase in transformation time as  $\underline{m}$  increases from 3 to 4 for  $\underline{t}=2$ , or as  $\underline{m}$  increases from 2 to 3 for  $\underline{t}=4$ . This is in contrast to experiment 1 where there was a more gradual increase in T as difficulty increased. The implication of this pattern of results is that there is a strategy shift in terms of allocation of resources as task difficulty increases.

The subjects in experiment 1 seemed to be able to 'fine tune' their resources to a greater extent than those in the current experiment, thus there was a smoother transition in performance as difficulty increased. A conclusion of this sort must of course be treated with a certain amount of caution, since it seems likely that there would be a continuum of fine tuning abilities, and indeed resource capabilities across subjects, which makes conclusions from group averages rather suspect. We are however at an advantage in this respect, having the data from two experiments to compare, especially as they contrast very

different ability levels. This should allow us to spot the major differences which accompany changes in strategy due to different levels of performance.

#### 4.3.5 Final Phases

Fig 4.6 shows the effect of  $\underline{t}$  and  $\underline{m}$  on the final three phases of the task: the recall phase, response latency and response duration. The recall time shows the interesting cusp in performance which has been noticed in other parts of this experiment. In particular, the times for  $\underline{t}=4$ ,  $\underline{m}=3$  and 4 seem to be relatively slower than might be expected on the basis of the patterns observed in experiment 1. We must however be cautious here since we do not know for certain that the  $\underline{t}=2$  condition does not share some of the qualities discussed in the previous chapter for the  $\underline{t}=1$  condition, thus comparison of changes from  $\underline{t}=2$  to 4 in this experiment with 3 to 5 in experiment 1 may not be completely legitimate. Nonetheless the sort of cusp which was only noted in transitions from  $\underline{t}=1$  in the previous experiment seems to be appearing in this one in less systematic places. The argument was put forward in experiment 1 that a very different combination of resources was required for  $\underline{t}=1$ . Similarly in the current experiment, it seems likely that the very different ability level of the subjects would lead to wide variability in resource availability and use. This in turn implies that some of these subjects may be more likely to show sudden deterioration in performance at a certain level of task difficulty, when they can no longer reliably configure their systems for the complete task requirements.

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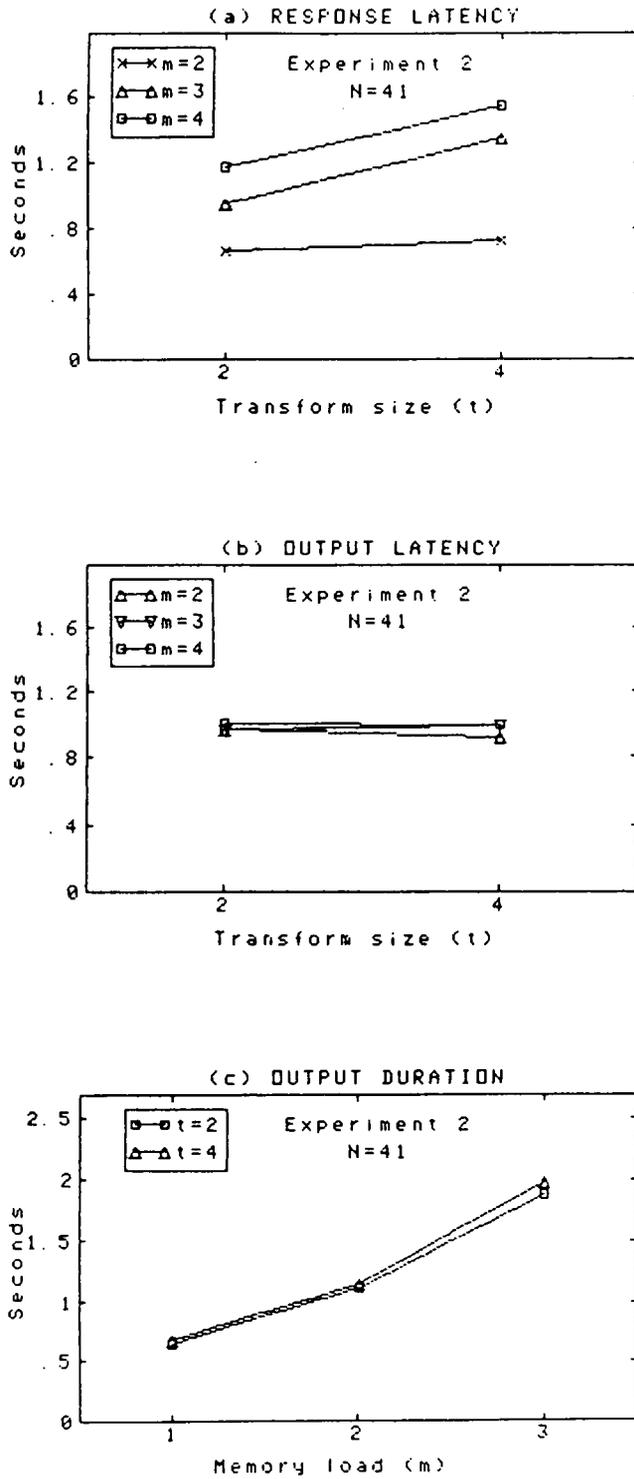


Figure 4.6 The three response phases for experiment 2 as function of memory load and transform size: (a) Response Latency, (b) Output Latency and (c) Output Duration.

The current experiment shows no effect of response latency, in contrast to a slight increase due to  $\underline{t}$  in experiment 1.

Response duration itself increases of course with size of the required utterance. However one trend which did not appear in experiment 1 is that of the non-linearity as the length of the utterance increases. Observations made while the experiment was being run, and listening to some of the tape recorded protocols suggests that subjects in this experiment were more likely to pause in the middle of their response so making the larger responses disproportionately longer. This implies that these subjects did not have their response prepared adequately for articulation, which lends weight to the argument presented earlier that this group have less well developed control processes for accurately preparing the system for its requirements. This in turn further supports the argument presented in the previous paragraph about less efficient control of resources to fulfil task requirements.

#### 4.3.6 Within trial data

Fig 4.7 shows how encoding, transformation and storage times for each condition are affected as the trial progresses. In general the overall pattern is very similar to that obtained in experiment 1 (figure 3.4), although of course the level is rather different and the fact that only two transformation sizes were used gives a slightly different pattern in the results of the analyses of variance (Table 4.3). Again for comparison with experiment 1 without the  $\underline{t}=1$  condition, table 4.4 shows the data of experiment 1 reanalysed omitting the  $\underline{t}=1$  condition.

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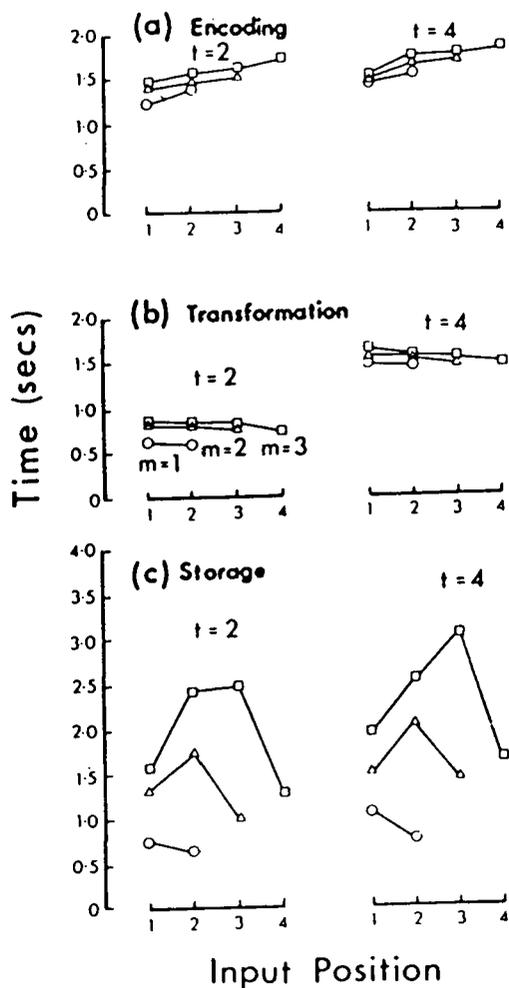


Figure 4.7 Time to carry out each phase of the task in experiment 2 as a function of Memory Load, Transform Size and Input Cycle for (a) Encoding time, (b) Transform time and (c) Storage time.

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		$\underline{m} = 1$			$\underline{m} = 2$			$\underline{m} = 3$		
		df	F	p	df	F	p	df	F	p
Encoding	Cycle	(1,40)	10.4	.003	(2,80)	8.4	.0008	(3,120)	3.5	.01
	Cyc x $\underline{t}$	(1,40)	< 1	-	(2,80)	< 1	-	(3,120)	< 1	-
Transform	Cycle	(1,40)	6.4	.015	(2,80)	15.3	<.0001	(3,120)	17.2	<.0001
	Cyc x $\underline{t}$	(1,40)	< 1	-	(2,80)	6.3	.003	(3,120)	4.7	.004
Storage	Cycle	(1,40)	11.2	.002	(2,80)	27.1	<.0001	(3,120)	35.5	<.0001
	Cyc x $\underline{t}$	(1,40)	6.7	.013	(2,80)	2.4	.09	(3,120)	1.9	.14

**Table 4.3** Anova results for Cycle x Transform Size analysis for experiment 2. For  $\underline{t}$ , in all cases  $F(1,40) > 9$ ,  $p < .004$ . (Except  $\underline{m}=3$  Encoding -  $F(1,40)=6.6$ ,  $p=.013$ )

		$\underline{m} = 1$			$\underline{m} = 2$			$\underline{m} = 3$		
		df	F	p	df	F	p	df	F	p
Encoding	$\underline{t}$	(1,8)	< 1	-	(1,8)	< 1	-	(1,8)	< 1	-
	Cycle	(1,8)	1.6	.25	(2,16)	1.6	.24	(3,24)	2.8	.06
	Cyc x $\underline{t}$	(2,16)	< 1	-	(4,32)	< 1	-	(6,48)	< 1	-
Transform	$\underline{t}$	(1,8)	175.8	<.0001	(1,8)	175.5	<.0001	(1,8)	172.9	<.0001
	Cycle	(1,8)	2.4	.16	(2,16)	7.7	.005	(3,24)	3.8	.02
	Cyc x $\underline{t}$	(2,16)	13.6	.006	(4,32)	< 1	-	(6,48)	< 1	-
Storage	$\underline{t}$	(1,8)	14.7	.005	(1,8)	9.8	.01	(1,8)	8.3	.02
	Cycle	(1,8)	< 1	-	(2,16)	14.6	.0004	(3,24)	11.4	.0002
	Cyc x $\underline{t}$	(2,16)	< 1	-	(4,32)	< 1	-	(6,48)	3.9	.02

**Table 4.4** Anova results for Cycle x Transform Size analysis for re-analysis of experiment 1, excluding  $\underline{t}=1$ .

4.3.6.1 Encoding Time

Encoding time increases more reliably with cycle in this experiment. There is a significant increase for all  $\underline{m}$ , and no interactions with cycle. Thus as far as E is concerned, as load on the system increases, it is more likely to be reflected in encoding time with this group of subjects than in those of experiment 1. The trend was similar, however, in experiment 1 with the exception of the  $\underline{t}=1$  condition, but did not quite reach significance. The current group of subjects seemed to be less able to access the alphabet than the group of university students, which is probably at least part of the reason, both for the generally slower encoding time and for the greater increase as the trial progressed, resulting in greater load on the system.

	$\underline{t}=2$	$\underline{t}=4$	Cycle
$\underline{m}=4$	63	140	1-2
	-2	26	2-3
	55	60	3-4
Mean slope	35	70	
$\underline{m}=3$	9	98	1-2
	37	48	2-3
	Mean slope	23	78

Table 4.5 Decrease in transformation time from cycle to cycle in milliseconds, and mean slope of decrease over the trial.

4.3.6.2 Transform Time

There is a very strong reduction in transformation time as the trial progresses. The same trend was noted in experiment 1, where it was most apparent in a sudden dip on the final cycle. Unlike experiment 1 however, there is an interaction between transform size and cycle, in that there is a greater reduction in the transform time for  $\underline{t}=4$  than for  $\underline{t}=2$  as is shown in table 4.5. This reduction is not even however, nor is it concentrated on the final cycle as was the case in experiment 1. It is in fact greatest between the first and second cycles, and in general the more difficult the condition, the greater is the reduction in transform time. Although the transformation time starts from a higher level in the more difficult conditions, it does in fact fall to a level below that of the easiest conditions. For example, The final transform for the C44 condition is 68 msec faster than the first transform time for the C24 condition ( $t=1.82$ ,  $p=.07$ ), and (non-significantly) 20 msec faster than the second transform time for that condition. For example, in the most difficult condition ( $\underline{t}=4$ ,  $\underline{m}=4$ ), there is a fairly sharp dip on the second cycle, as well as a lesser one for  $\underline{t}=2$ ,  $\underline{m}=4$ . This dip much earlier in the cycle argues against the hypothesis of resources being unloaded in the final cycle which was one possibility suggested in the previous chapter. However if that hypothesis is modified by the argument presented earlier in this chapter that the relative emphasis placed on resources is modified in the light of immediate task demands even if it means future needs will suffer, it may still be tenable. If this is

the case, the implication is that subjects in experiment 1 were de-emphasising resources in a controlled way, when it was a sensible strategy, whereas subjects in this experiment are doing so because they do not have sufficient capacity available to optimise the balance of resources for present and future needs. An alternative, or possibly additional reason for a decrease in transformation time, is that as the load on the system increases, the activation of the transformation resource achieves a more optimal level. It has often been claimed that the optimal level of activation is higher for 'simple' tasks than complex tasks. For example, Hamilton, Hockey and Rejman (1977) showed that simple transformation as a stand alone task became faster when activation was increased by the use of white noise. This could account for the decrease in transformation time as task difficulty increases, thus increasing activation. It would not necessarily be expected that in a complex task of this nature even a simple component would behave in this way, especially as we have already shown that the system is set up on the basis of overall task demands, rather than simply to respond to immediate task requirements.

The reduction in transformation time is also consistent with the view of Kahneman (1973) who suggested that cognitive effort increases with the demands of the task. This increase in effort may allow the transformation process to work more effectively, thus reducing its duration. Although it is often possible to attempt to explain such phenomena by recourse to concepts such as activation, effort or arousal it tends to be rather

unsatisfactory since the concepts are not well defined, and in some situations appear to be synonymous, and in others distinct. The important point for present purposes, however, is that they may help to point us towards previous work which may be relevant to understanding the rather paradoxical increase in speed with increasing task difficulty.

#### 4.3.6.3 Storage Time

As before, the most spectacular effects are due to storage time. The pattern is very similar to that obtained in experiment 1, and the most difficult conditions show the same sharp increase in storage time in the middle of the problem with a reduction after the final letter has been transformed. In this case however, the interaction between transform size and cycle is minimal, only reaching significance for  $\underline{m}=2$ . In experiment 1 the interactions between  $\underline{t}$  and cycle were due almost entirely to the  $\underline{t}=1$  condition having a flat profile as a function of cycle. Reference to table 4.4 shows that in that experiment there was little sign of this interaction when only  $\underline{t}=3$  and 5 are considered, with the exception of  $\underline{m}=4$  which retains marginal significance. The overall pattern of storage times is very similar to that obtained in experiment 1. The one exception is the  $\underline{m}=2$  condition where it reduces rather than increases in experiment 2. This difference is probably due to the fact that these two phases represent rather different processes which are differentially affected by the overall levels of performance in the two experiments. The main difference is in the overall level of performance, where

subjects in the  $m=4$  condition are taking up to 1.6 secs longer for the third cycle in the most difficult condition - more than twice as long as the comparable position for experiment 1 where  $t$  was in fact greater. With this large difference in time it seems likely that subjects are doing more than simply rehearsing - they may be using the extra time not only to rehearse the latest sequence to be stored but also to prepare and allocate resources for the next cycle. The main contrast with experiment 1 is that subjects there seemed to be more prone to organise resources for the entire task in advance, whereas in the current experiment, efficient allocation of resources to handle all foreseeable requirements is not possible for the less able subjects, and they have to spend time actively switching resources to and from working memory to carry out subcomponents of the task.

#### 4.3.7 Errors

The three types of error discussed in chapter 3 will be examined first of all (transformation errors, procedural errors and recall errors). In addition since the corpus of errors is larger, a more detailed examination of the distribution of errors in the more difficult conditions will be undertaken.

##### 4.3.7.1 Transformation errors

As in experiment 1, the number of transformation errors (ie counting forward the wrong number of places) is very small (less than .4% in every condition).

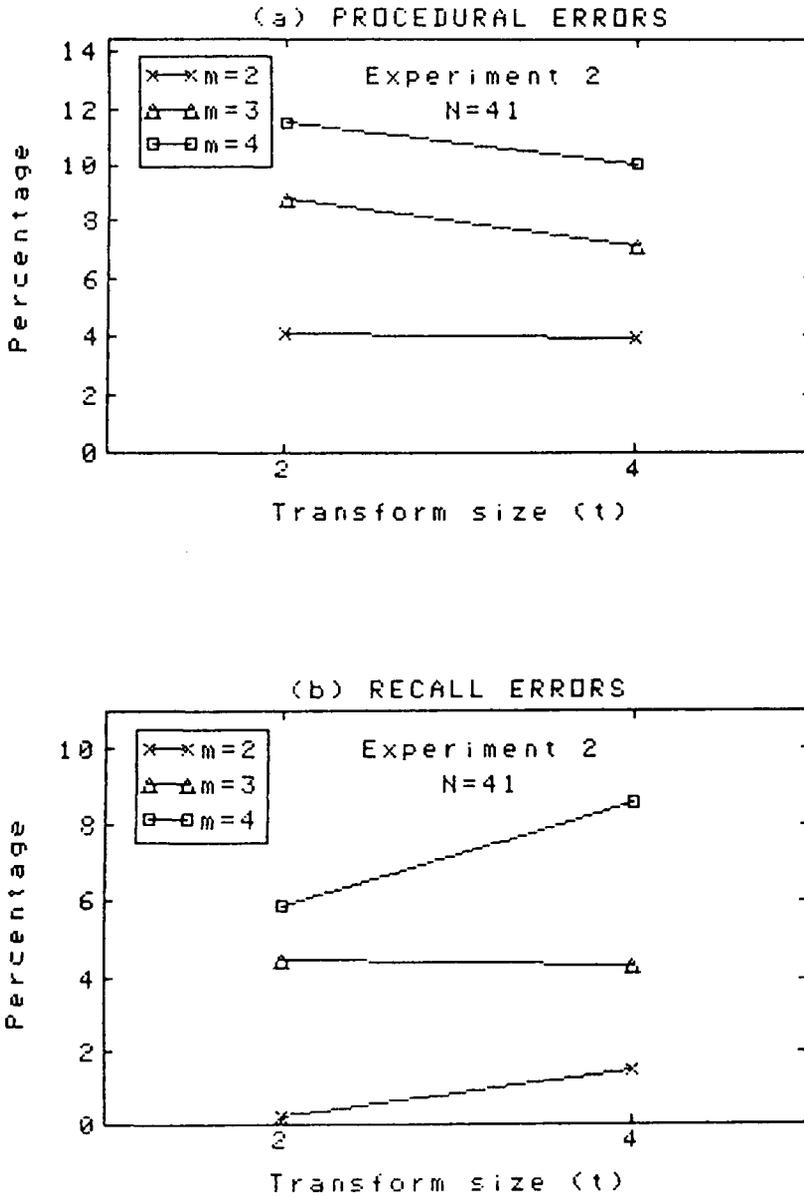


Figure 4.8 Errors in experiment 2 as a function of memory load and transform size: (a) Procedural errors expressed as a percentage of the total number of trials required and (b) Recall errors expressed as a percentage of the total number of letters transformed.

#### 4.3.7.2 Procedural errors

Fig 4.8(a) shows the distribution of procedural errors (that is errors on which a trial was not completed because of extraneous noises, the button being pressed at the wrong time etc - see chapter 2 for a fuller description). Unlike experiment 1, this type of error did vary with condition. The number of errors increases as  $\underline{m}$  increases ( $F(2,80)=9.99$ ,  $p=.0001$ ). This is in accord with the suggestion made earlier that active switching between resources during the trial is likely to lead to more errors. There is however no effect of  $\underline{t}$  nor is there any trace of an interaction ( $F<1$  in both cases). In addition the overall error rate is lower with these subjects ( 8% as against 12% in experiment 1).

#### 4.3.7.3 Recall Errors

The third type of error is the recall error, where subjects finished the trial but incorrectly recalled items to which they had earlier transformed correctly. Fig 4.8(b) shows this type of error. In this case there is again a strong effect of increasing errors as  $\underline{m}$  increases ( $F(2,80)=24.5$ ,  $p<.0001$ ), and in addition there is a hint of an increase with  $\underline{t}$  ( $F(1,40)=4.1$ ,  $p=.05$ ). Despite the curve for  $\underline{m}=3$  decreasing as  $\underline{t}$  goes from 2 to 4, the interaction is not significant ( $F(2,80)=2.2$ ,  $p=.11$ ), although the slightly anomalous dip with increasing  $\underline{t}$  supports the hypothesis put forward in a previous section that this transition represents a cusp where a change in the resource allocation strategy takes place. This could for example be a reflection of greater effort

being expended in this condition compared to the easier ones, thus improving performance (remember that this is the same condition where the storage time for the first phase did not increase as rapidly as expected, and the transformation time was longer than expected). This apart, these error rates and patterns are broadly comparable with those obtained in experiment 1, if the  $t=1$  conditions are ignored in experiment 1.

#### 4.3.8 Distribution of errors

Since the overall number of errors is greater in this experiment with the larger number of subjects, it is possible to look in more detail at the distribution of errors as a function of the input position, as well as the relationship between the position of the erroneous response in the alphabet and the correct response. Only the C44 condition will be considered to avoid undue complexity of presentation and analysis, and because it is richest in terms of number of errors.

##### 4.3.8.1 Errors as a Function of Input Position

Fig 4.9(a) shows the total percentage of errors in the C44 condition as a function of input position. It can be seen that errors peak at the third cycle, and are much lower in the final cycle. The shape of the serial position curve produced is reminiscent of that obtained in traditional immediate serial recall studies (eg Atkinson and Shiffrin 1971, Baddeley 1976). The list length in this case is of course smaller, and such an

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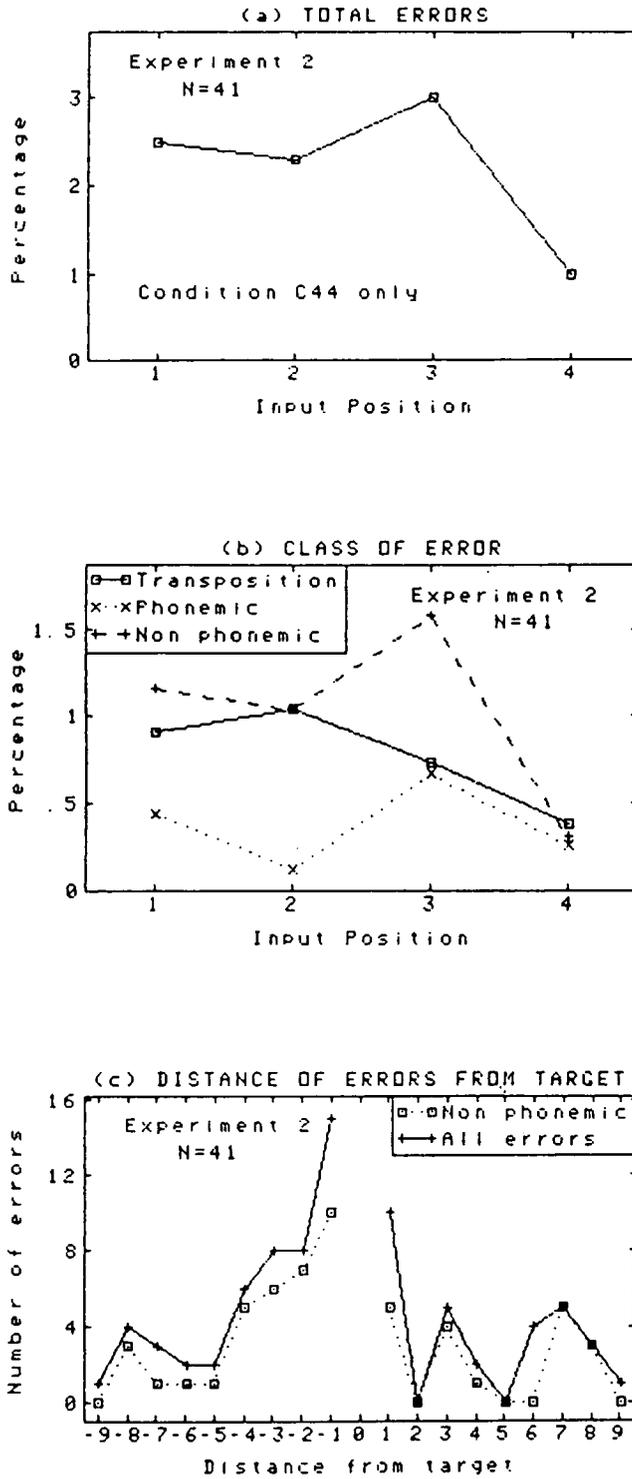


Figure 4.9 Errors in condition C44 of experiment 2. (a) Total errors as a function of input position (b) subdivided by class of error (c) distance of errors from target.

interpretation is confounded with the other activity which the task entails. The pattern of difficulty is also reflected in the storage times across cycles (Fig 4.7(c)), where the third cycle is by far the longest. Subjects obviously know this is where information is most likely to be lost, and so spend more time to try to minimise the loss. The third item occurs at a time when the overall load on the system is highest, and also has less rehearsal than the earlier items. The last item of course never has an intervening transformation to interfere with it, and so is comparatively well remembered.

One problem with the data presented in this fashion is that transposition and intrusion errors are collapsed together. Fig 4.9(b) shows how the pattern of results looks when the errors are classified as to whether they are transposition errors, phonemically similar to the correct response, or intrusions which are not phonemically similar to the correct response. It can be seen that both types of intrusion errors show essentially the same pattern as has already been discussed, and in fact the phonemically similar errors are fairly infrequent. The pattern of the transposition errors however shows that items early in the response are more likely to be recalled out of sequence than later items. These items have been relatively well rehearsed, so presumably are more active in memory, even though their order tagging is not intact, and so are more likely to be recalled somewhere in the sequence.

4.3.8.2 Distance of Errors from target

The data in the previous section leaves one question unanswered - where do the intrusion errors come from? The previous section showed that phonemic confusions account for relatively little of the overall error rate, and that they follow a similar pattern to other intrusion errors over task cycles. Fig 4.9(c) shows the intrusion errors for the C44 condition as a function of their distance from the correct target. This shows that the errors peak in the vicinity of the correct response. There are two separate effects apparent here. The letters adjacent to the correct response are the single most likely confusions - despite the fact that all errors reported here were transformed correctly initially. Secondly, a letter which was processed during the transformation is more likely to be recalled than other letters (including the stimulus letter). Thus, the most likely errors are items which were processed during the transformation on that particular cycle, or letters which are directly adjacent to the correct response. Note that the greatest peak for the letter immediately preceding the correct one is likely to be due to a combination of these effects.

It is clear that the act of articulation itself is not the 'memory' (or at least not the only memory) which is used to access the correct response. Certainly, any items which have been so activated are likely to appear in the response as an error, but the particular likelihood of the error to be in one of the adjacent items to the correct response seems to imply some more direct involvement of a long term memory trace. It is well

known that the long term store has strong associative properties and that these are greater the more closely associated items are (eg Collins and Loftus 1975). It therefore seems likely that the long term store is important in mediating performance beyond simply providing a chunk of alphabet for the articulatory store to count through.

A frequent error takes the form of incorrectly responding with the letter adjacent to the required one. This therefore gives indirect support for the hypothesis proposed in experiment 1, that the  $t=1$  conditions are a special case and require fewer resources than the more difficult transformations. Adjacent letters seem to be so strongly associated that they are capable of influencing the pattern of errors, so it seems reasonable that this same association can be used constructively in the  $t=1$  condition.

#### 4.4 SUMMARY

This chapter has presented data from an experiment very similar to that presented in chapter 3, but with a larger number of less homogeneous subjects of lesser ability than the subjects of chapter 3, and with a slight difference in the precise conditions used in the experiment. It has discussed the results obtained from this group of subjects and compared and contrasted them with the results obtained in experiment 1. The major conclusions of experiment 1, that preparation for the expected cognitive load affects the allocation of resources very early in the trial, and

that increasing storage load affects the temporal structure of the task profile were confirmed. In addition this experiment and reanalysis of experiment 1 added weight to the argument that the  $t=1$  condition in experiment 1 was rather different in terms of resource requirements than the more difficult transformation conditions, since it was confirmed that many of the interactions between  $m$  and  $t$  were indeed due to this condition. The distribution of errors in relationship to the required response also added weight to this argument, showing that there does seem to be a special association between adjacent letters in the alphabet. Minimal resources were thus required for the single transformation, and so very little effect of interference with increasing memory load was noted in these conditions.

The decrease in transformation time as the trial progressed was also replicated in this experiment, and it became clearer that this decrease was not in fact confined solely to the final cycle of the trial. So although an interpretation based on release of resources is still not totally ruled out, additional support is provided for an account based on increased effort as task difficulty increases (Kahneman, 1973). On this basis, the decrease in transformation time would be due to the transform resource becoming more efficient with increases in effort. It is necessary to consider such an explanation in conjunction with the set of resources which are available at any one time. Subjects in the current experiment were very much slower than in the previous one, and in addition the transitions in temporal structure of the data did not show such smooth changes as

difficulty increased. These cusps in experiment 2 were interpreted as being due to less efficient use and allocation of resources as the load on currently active resources increased through the task.

#### 4.5 SKETCH OF A MODEL OF PERFORMANCE

The previous chapter concluded with a summary of the main theoretical concepts which are necessary to understand the impact of the alphabet transformation data, and the previous section of the current chapter has outlined the major implications of the data presented in this chapter. This section summarises the main properties which we would now expect of a model of performance based on the data presented so far. It will not be spelt out in great detail at the moment as the data from later experiments to be reported are likely to have important influences on its precise form. The main features however will be briefly discussed. Since much of the relevant data was discussed in the previous chapter, this section will attempt to focus on the requirements of the model rather than the data which justifies them.

##### 4.5.1 Resource Configuration

A set of appropriate resources must be selected and configured in a suitable way for carrying out the task to be performed. These resources consist of a selection of processes and a number of representations upon which they act. For the alphabet transformation task, plausible candidates for these resources are processes to carry out such functions as: encode visual input;

transform  $n$  places forward; store a sequence in some form of short term store; retrieve a sequence from the short term store; rehearse the contents of a short term store. The representations include: a long term memory which contains the overlearned alphabet sequence as well as the set of available processes; a short term store which can be used as a work space to carry out the transformation, and a short term store to maintain the current sequence to be recalled later.

The precise task requirements and the ability of the subjects determine how the resources will be configured. The patterns of interaction shown with the  $t=1$  condition in experiment 1 suggest a qualitative difference in the configuration of resources required for that condition, whereas the more gradual increases with increases in difficulty shown in the rest of the conditions are more suggestive of a gradually increasing load on a single set of resources. The slower performance times, coupled with less smooth transitions between conditions in experiment 2 suggested that these subjects were responding rather more to immediate task demands, being less able to handle the complex set of resources required by the task.

#### 4.5.2 Resource Configuration and Maintenance

The first cycle data in both this and the previous chapter suggests that the system preconfigures all the resources required for the task as a whole at the beginning of the trial if it can. This is in contrast to the assumptions which seem to lie behind much current thinking. For example, the cost-benefit analyses of



Posner (1978) are more concerned with looking at how quickly the system can use new information - dynamic allocation of resources is in fact a requirement of the task in these cases. It may be that such dynamic factors can only be observed in relatively simple tasks where there is sufficient free capacity to allow them to work efficiently.

Although seldom specifically investigated, there is some evidence in the literature that the overall level of task difficulty can be detected in performance even when the immediate demands at the point of testing are low. For example, Broadbent (1982) has pointed out that it is not appropriate to determine a baseline level of performance by presenting a probe between trials in a primary task. He cites Paap & Ogden (1981) to demonstrate that in such a situation subjects who are expecting a primary task are slowed down at that point despite the fact that there are no immediate demands to perform the primary task. This of course implies that they already have the system set up for the primary task and remaining resources are less able to deal with the probe task.

#### 4.5.3 Dynamic Memory Load

Although it has been argued that resources are set up in advance of the trial being carried out, there is also ample evidence of dynamic effects on performance time as the actual memory load increases from cycle to cycle. There are two distinct reasons for this. The first and most obvious is that the load on

particular resources may change as the trial progresses. The clearest example of this is the effect on storage time. As the sequence to be remembered increases, a larger sequence will have to be rehearsed, taking longer to carry out the stages of the task which use the rehearsal process. The second reason is that the extra overall load on the system as the number of items stored increases causes a general slowing down of the task steps involving other resources, perhaps because extra executive control is required as suggested in the previous chapter, or perhaps because of some other aspect of limited capacity.

#### 4.5.4 Executive Control

Two distinct forms of executive control should be considered. The first emphasises the selection and configuration of a suitable set of resources for the task in hand, and the second emphasises the communication between these resources once they have been configured. A similar distinction is made by Logan (1985).

To carry out a given task, suitable resources must be recruited and configured in such a way that the available workspace is not overloaded, and that relevant information can flow between these resources. So, one aspect of an efficient configuration will be the efficiency of planning what resources are needed, and the implementation of these plans. This aspect of planning is the main thrust of Norman and Shallice (1980); Shallice (1982) also emphasises the importance of being able to configure appropriate plans to carry out non-routine tasks. An important suggestion from the current studies is that the complexity of the resources

which have to be configured have consequences from the earliest phases of the trial. Moreover, the cusps in performance as difficulty increases, referred to earlier for experiment 2, were argued to reflect difficulty with such planning.

Another but separate aspect of control processes is that of communication between resources. If information has to be passed between resources as in the present series of experiments (and indeed to be able to make any response in most experiments), there must be a way of passing the output from one resource to the input of another. An example in the context of the current experiments would be transferring the result of a transformation to the end of a recall list already in memory. Similarly, communication may be required to let one resource know that another has finished, and to expect some input: for example, monitoring the transformation process to determine when it is complete. Such communication does not necessarily imply discrete stages, one of which must finish before the next can start, as is illustrated by McClelland's (1979) cascade model which demonstrates how the processing carried out by the different resources can overlap in time.

#### 4.5.5 Efficiency of Individual Resources

As well as the overall configuration of resources required and the flow of control between them, we might also expect the efficiency of individual resources to be important in determining the performance observed. Such differences in efficiency may be

## The Microstructure of Performance - Study 2

observed between subjects or indeed within a single subject as a function of learning. There are at least three types which are likely to be relevant.

First, a particular resource may be identical in its characteristics between different people or on different occasions in one person, but simply be executed faster. This is easy to envisage for the encoding or transformation phases of the current task. Indeed, one component of this was highlighted in the discussion of effort earlier, where it was suggested that individual resources may increase in efficiency as the overall task difficulty increases.

Secondly, there may be a qualitative difference between the resources which do a similar job, which may have implications for the observed execution speed. For example, it may be possible to carry out the transformation phase either by counting directly through a long term memory representation, or by setting up a rhythm template which automatically synchronises the count with the required transformation size.

Third, it is possible that an operation which can be carried out using a single resource could be replaced by a number of separate resources. The data presented of course suggest that the latter would be particularly inefficient for a number of reasons. It would effectively involve a larger resource configuration, with the associated problems of coordination of executive control which have already been argued to provide overheads to performance. This level of description invites parallels with

the automatic and controlled processing described by Shiffrin and Schneider (1977). As an example, consider the difference in storage times between the two subjects in figure 3.7. One subject shows minimal increases in storage time, whereas the other shows much longer and steadily rising times (more typical of the average pattern). One interpretation of this might be that the subject who shows no change is using a single resource which is passed the result of the preceding transformation and immediately places that on the end of the stored recall list. The other subject may have to use multiple resources to carry out the same operation. For example, she may have to store the transform result; retrieve the stored list; add the new item to the end of the list; and store the new list.

A final point worth considering is the relationship between the activity of the system as a whole and the efficiency of the underlying resources. The arousal arguments outlined in chapter 1 would have us believe that any change in overall activity would have equal effects on all resources in use at that time. The data presented in this chapter cast considerable doubt on that assumption. Rather, it seems more likely that changes in activity may have differential effects on different resources. The clearest example of this in the current data is the reduction in transformation time as memory load increases, with no corresponding reduction in the time taken to carry out other task phases. This means that overall task performance cannot generally be predicted from a simple Yerkes-Dodson inverted U relationship (eg Hamilton, Hockey & Rejman (1977)). However such

predictions may be possible for the efficiency of individual resources. The effect on observed behaviour consisting of a variety of different resources acting together would then be the apparently uninterpretable multivariate mix that we often observe. Such an interpretation has important consequences for understanding the effect of stressors on performance; such issues will be considered further in a later chapter.

#### 4.5.6 Capacity Limitations

It has long been argued that the attention (working memory?) system has limited capacity. The multiple resource arguments (eg Navon & Gopher (1979), McLeod (1977), and arguments concerning 'unlimited' processing by automation of processes (Shiffrin & Schneider (1977), Schneider & Shiffrin (1977)) do not in fact necessarily provide evidence against this. First of all, there is no evidence that the amount of processing which takes place can be expanded infinitely, and such a view certainly is counter-intuitive. It seems more likely that the relevant variables concerning limitations are not considered when these authors show that learning can indeed take place, and once a task becomes well practiced, it can appear to occur automatically. Broadbent (1982) points out that in most such experiments, the direction of the non-significant effects which are taken to show automaticity is in the direction which would indicate that some (small) load is still made on the system.

In terms of resource allocation, the efficiency of the system for any given task will depend on whether or not there is sufficient

capacity to configure a complete optimal system. For example a very difficult task may require more resources than the system can handle simultaneously. This will result in complete breakdown of performance at worst, or very inefficient performance at best. Low ability may be a reflection of the same phenomenon, because of capacity limitations due to the factors mentioned above requiring more capacity than the system has available. Note that capacity here is likely to be fairly flexible, for example similar to the notions of Kahneman (1973).

It is tempting to consider the poorer performance of subjects in experiment 2 as being due to such capacity constraints. However, it is clear from the previous section that other effects could also be responsible for similar degradation of performance. Indeed, we very quickly get back to the same basic problem as faced researchers interested in memory span (eg Miller, 1956) - what unit do we use to measure capacity?

#### 4.5.7 Individual Differences

The preceding sketch of the most important concepts necessary to understand performance in the alphabet transformation task indicates just how complex and how many degrees of freedom there are likely to be in configuring and using the cognitive system to carry out such a task. For example, we might expect differences between subjects in terms of the actual resources they have available; their ability to configure and use available resources; or more general limitations in available capacity. Similar arguments are put forward by Daneman, Carpenter and Just

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(1982) in relation to poorer reading comprehension in younger or less able readers.

The impact of such differences on measured performance in the alphabet transformation task are clear from comparing the two subjects shown in figure 3.7. The strong internal consistency within a single subject only serves to emphasise the clear differences between the subjects. We would expect such differences between subjects to be even more marked when the data from experiment 2 is taken into consideration. The next chapter looks more closely at such individual differences.

## CHAPTER 5

### INDIVIDUAL DIFFERENCES

#### 5.1 INTRODUCTION

Although experiments one and two have shown extremely reliable patterns of data across the varying conditions explored, the previous chapter ended by suggesting that there may nevertheless be considerable individual differences in performance. The complexity of the task clearly gives ample scope for such individual differences, and the profiles for individual trials shown for two subjects in experiment one (figure 3.7) suggest that such differences may indeed be detectable in the data.

More generally, chapter one outlined a number of cases where understanding individual differences has proved to be important in interpreting data from a variety of complex tasks. For example, Hitch (1978) found a better understanding of mental arithmetic by considering different strategies for carrying out problems, and Daneman and Carpenter (1980) found a measure of working memory span a useful correlate of individual differences in reading.

Rather than being most concerned with understanding specific tasks, some approaches have emphasised understanding individual differences as an end in itself. One of the oldest and most established ways of measuring individual differences is the use of intelligence tests. Although successful in its own right,

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this approach has no real theoretical basis which tells us what the components of intelligence actually are. Instead it has relied on extensive normative psychometric data which is justified purely on the basis of its internal consistency.

The past 30 years have seen increasing dissatisfaction with this psychometric approach to intelligence and have emphasised attempts to understand its nature by moving away from a technological approach to intelligence to one taking into account psychological theory and experiment (Cronbach (1957), Eysenck (1967)). More recently, Hunt and his co-workers have done much to embed individual differences studies within the framework of cognitive psychology by looking at the relationship between performance on information processing tasks and intelligence as measured by ability tests (eg Hunt (1980), Hunt (1978), Hunt, Lunneborg and Lewis (1975), Hunt, Frost and Lunneborg (1973)).

Hunt (1980) has pointed out that in general performance on a very wide variety of cognitive tasks is positively correlated, and that there seems to be a pervasive correlation of about 0.3 to 0.4 between performance on these tasks and intelligence as measured by psychometric tests. Hunt (1980) suggests that the most appropriate information processing concept to explain this pervasive but small correlation is that of attentional resources. By taking this correlational approach, Hunt has emphasised an attempt to understand what intelligence tests measure in information processing terms. Valuable as this work has been, the small (albeit reliable) amount of variance accounted for

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indicates that much remains unexplained. Perhaps this is a consequence of using the concept of intelligence as measured by intelligence tests as a baseline.

In contrast, the componential analysis approach of Sternberg (1977, 1983 etc) has made no use of traditional intelligence testing to provide a baseline, but has tackled the problem by regarding intelligence as the combination of fundamental 'components' of information processing and has examined individual differences in terms of differential performance on these components, the isolation of which has been the major part of his work. Another important contrast is that Sternberg has focused on the level of reasoning and verbal comprehension to provide his basic data, whereas Hunt has been more concerned with 'lower level' issues such as speed of access to memory and speed of processing.

The work reported here can be regarded as similar in approach to Sternberg in that it attempts to understand performance by splitting the task into discrete stages, each of which is conceptually simpler than the task as a whole. However, the level of explanation which is appropriate to understand the components in the alphabet transformation task is closer to that of Hunt. One important part of the current work is its emphasis on the complexity of the task, especially in the more difficult conditions. Although each component may be fairly simple, many operations have to be coordinated correctly to carry out the complete task successfully.

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From the data presented so far, it is clear that the most difficult conditions give us the most sensitive lever on the performance profile of the subjects, not only because of the comparatively large number of data points for each trial, but also because the high cognitive load imposed on the subject on these trials is likely to tax the subjects cognitive system to the limit and give us more reliable information about individual differences in ability to cope with a demanding task environment. (Compare performance on  $\underline{m}=4$ ,  $\underline{t}=1$  and  $\underline{t}=5$  in experiment 1). A similar argument has been put forward by other authors (eg Hasher and Zacks (1979), Hunt (1978), Hunt and Lansman (1981)), that a task with high attentional requirements is likely to be a more sensitive vehicle for understanding the structure of the system, and in particular for differentiating the performance of individuals. With this in mind, we shall consider only the  $\underline{m}=4$ ,  $\underline{t}=4$  task at this stage and look more closely at the profiles of individual subjects. (Only experiment 2 will be considered for the moment as the subjects in experiment 1 did not carry out the C44 condition, so direct comparison is not possible).

Two approaches to determining what individual differences can be detected in the data will be considered. The first will focus on isolating subgroups of subjects who exhibit similar patterns of performance. If distinct patterns of performance are observed in such subgroups we may be in a better position to understand what differences in resources or their management underlie differences in performance. The second approach will investigate any relationship between performance on the alphabet transformation

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task and an independent measure of individual differences - intelligence test scores. Considering both of these approaches together should help to highlight the extent to which intelligence test scores are likely to be able to predict global or local aspects of performance in a task of this complexity.

### 5.2 ISOLATING SUBGROUPS - TOTAL TIME

On the basis of the wide range of total times taken to complete each problem in this group of subjects (from 13 to 38 seconds), one way of organising the data is simply in terms of the total time taken by each subject to carry out the task. Subject 11 is excluded from this analysis because of her excessive error rate. The remaining forty subjects have been divided into three groups of fast (13 subjects), average (13 subjects) and slow (14 subjects), on the basis of their total time to complete the C44 task.

#### 5.2.1 Patterns of Performance

Fig 5.1 shows the profiles of the time structure of the task components for these three groups. It can be seen that the basic patterns obtained in the group data (see fig 4.7) still hold. Transformation time decreases slightly as the trial progresses in each group; encoding time increases slightly (not in the slowest group) and storage time shows its characteristic rise and fall in each case, although as we move from the fast to the slower groups the slope of the rise and fall becomes considerably more

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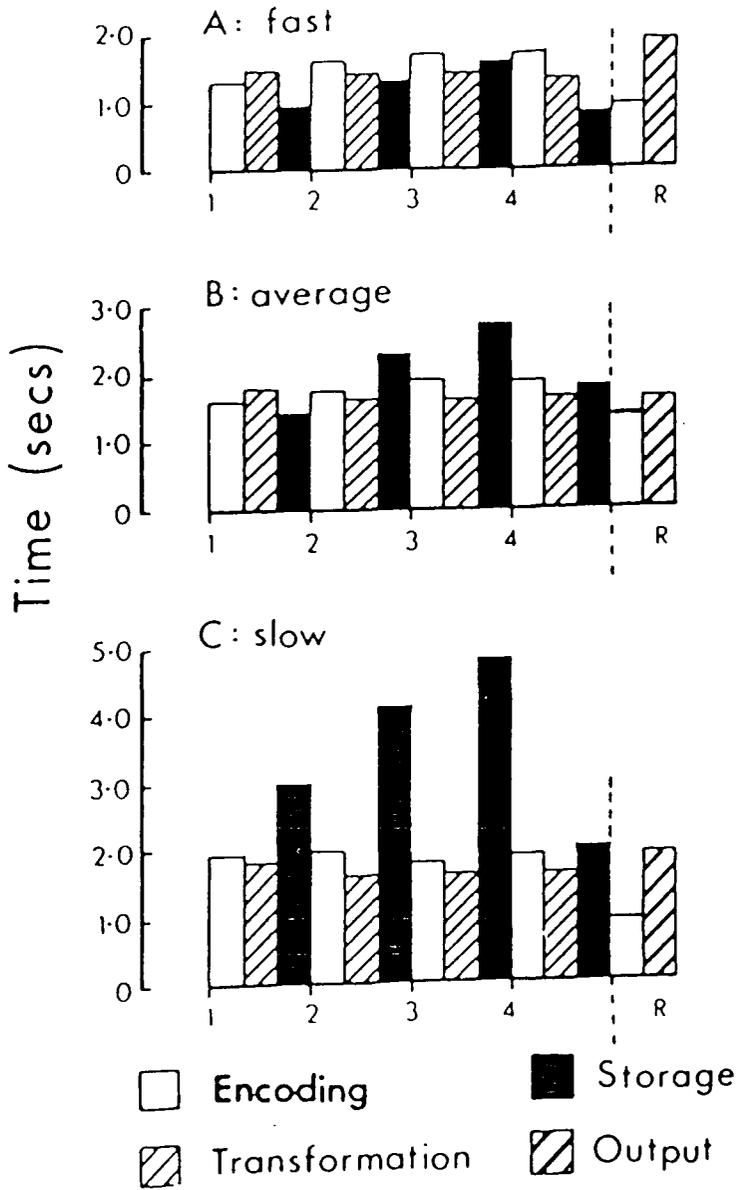


Figure 5.1 Profile of temporal structure for each speed subgroup

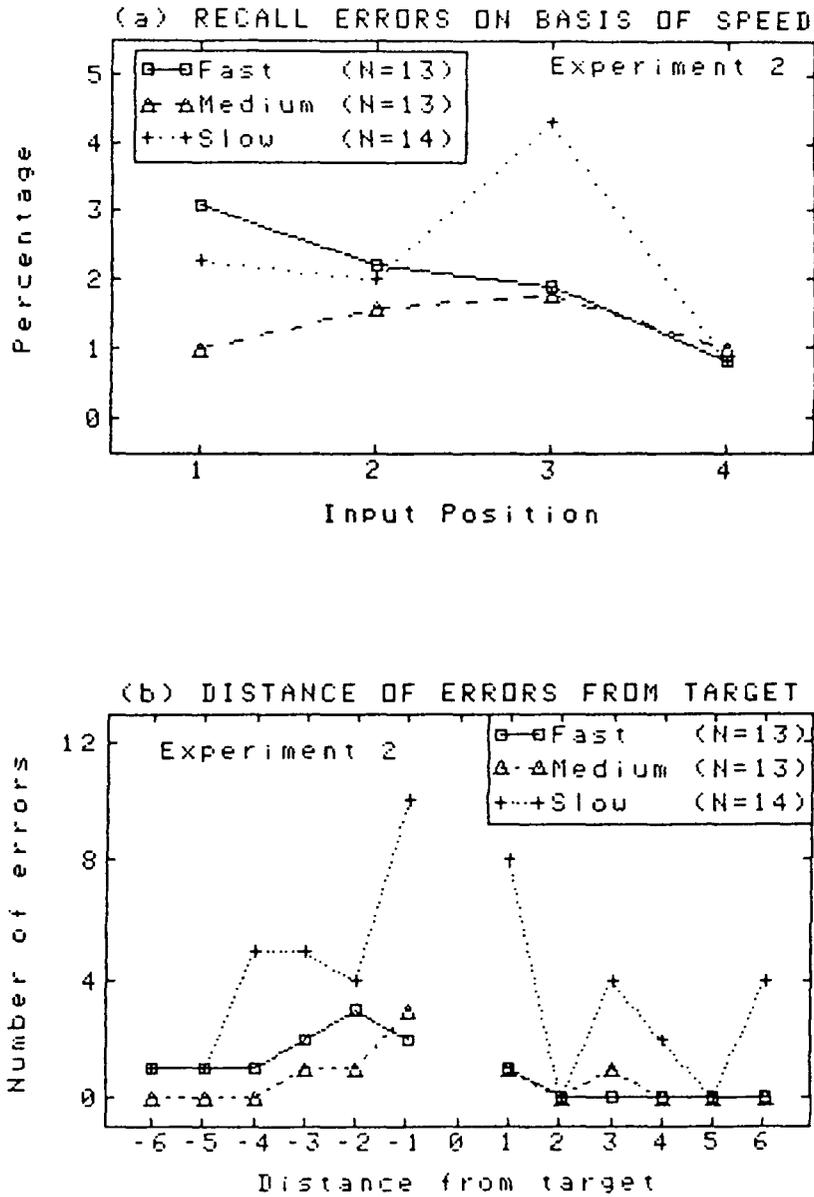
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pronounced. This data shows quite clearly that the large differences between subjects in the total time required to finish each problem is due mainly to much longer being taken over the storage phase of the task. Although the other components also tend to be slower in the slow group, the differential is much less than that attributable to storage time. This is consistent with the features of the data already discussed in the previous two chapters, where it was shown that as task difficulty increased (both in terms of  $m$  and  $t$ ), storage time increased at a much faster rate than the other times. It would seem reasonable that increases in perceived difficulty due to either increases in task difficulty or decreases in subject ability should have similar effects, as indeed seems to be the case.

### 5.2.2 Errors

Looking at individual differences between subgroups in this way, we would expect information about errors to be informative. For example we might expect fewer errors in the slowest subgroup thus indicating performance operating at different points on a speed accuracy dimension. Alternatively we might expect more errors in the slowest condition, indicating that this group find the task more difficult. Fig 5.2(a) shows the percentage of errors as a function of input position for the C44 condition for each of the three subgroups. It is immediately clear that neither of the above hypotheses are upheld. The slowest subgroup do in fact make more errors overall, but this is due to more errors in the third cycle, and indeed this feature of the pattern of errors

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**Figure 5.2** (a) Errors as a function of input position for each speed subgroup.  
 (b) Identity of errors as a function of the target letter for each speed subgroup.

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discussed for the entire group in the previous chapter seems to be due entirely to this slowest subgroup. This reinforces the view that an interpretation of errors based solely upon what we know about serial recall is unlikely to be adequate. We would have to take account of other features such as subjective task difficulty.

The fastest subgroup in fact makes most errors early on, and this number decreases as the trial progresses. The pattern of errors for this group look as if they are due simply to decay of the memory trace. This implies that this group relies minimally on rehearsal, a hypothesis which is upheld by the relatively fast storage times in fig 5.1, thus the earlier items are more likely to be lost. Note however that despite this, the overall error rate is less than for the slowest subgroup, so the data cannot be accounted for simply by different strategic approaches to the task.

The middle speed subgroup makes fewest errors, and indeed comparison between this group and the fastest group seems to indicate that a speed accuracy tradeoff may explain a considerable amount of the difference between these two groups. In particular the first item is recalled much more reliably in this group than in either of the other two groups, indicating both reasonable ability in meeting the task demands and a relatively cautious strategy with regard to rehearsal.

The overall distribution of errors between the groups confirms the superiority of the middle speed subgroup with regard to

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errors in a rather striking fashion. Ten out of the 13 subjects in this subgroup made 1 or fewer errors out of a maximum possible of 40, whereas only 2 subjects in each of the other two subgroups achieved this ( $\chi^2=15.5, p<.001$ ). Thus the difference between the two fastest groups could be accounted for by differences in the strategic approach to the task by groups of approximately similar ability.

Another interesting aspect of the data is the complete lack of difference between the subgroups in the number of errors on the final cycle. This item suffers no interference from intervening transformations, and consequently its recall is much less affected by any differences in strategy or ability than are the earlier items.

In chapter 4 it was pointed out that the distribution of errors as a function of the target letter suggested that letters which had been activated, either because they formed part of a transform sequence, or because they were closely associated with a target letter, were very likely candidates for an erroneous response. Figure 5.2(b) shows such errors as a function of the speed subgroups of subjects. It is clear that the pattern observed is largely due to the slowest subgroup. This suggests that this subgroup is less able to store the specific item required, possibly because of the generally greater difficulty they have in managing the various components required to coordinate the task. They may rely more on the trace of the transformation process itself rather than try to add yet more

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resources to handle the explicit storage requirements of keeping the required letter separate from other ongoing processing activity.

### 5.2.3 Very High Error Rates

The data discussed so far emphasise the extreme flexibility of the human information processing system. Even subjects of relatively low ability can generally perform this fairly complex task adequately by progressing through it fairly slowly and not continuing until they are sure they are prepared for the next item, and more able subjects can allocate resources in a fairly flexible way to optimise different features of the task. However it is worth briefly mentioning at this point one subject (subject 11) who had immense difficulty with this condition. She had an error rate of over 50% and only managed to complete one trial successfully and so has been excluded from the analyses presented in this chapter. Her performance in the easier conditions was quite acceptable (eg an error rate of 15% in the C42 condition, which was comparable with several other subjects), however the extra cognitive requirements of the C44 condition seemed to be too great for her. An interesting feature of her data for this condition was that her trials were relatively fast, for example the total time for her one correct trial was just over 20 seconds, which placed her about the middle of the fastest group. She was obviously having great difficulty preparing her system for the task requirements and did not seem to be able to adjust to task difficulty in the way the other subjects did. It seems likely

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that this is the sort of system overload which might force some subjects in this group to use a different resource allocation strategy resulting in the less than smooth transition between conditions discussed in the previous chapter. However, it would seem that this particular subject was not able to make the appropriate adjustments to enable her to adapt to the increasing task difficulty. It is not clear whether she was simply unable to find an appropriate strategy, and thus may be able to carry out the task with specific training, or whether she had some more fundamental problem whereby she would be unable to carry out a task of such complexity under any circumstances.

### 5.3 INTELLIGENCE AND ALPHABET TRANSFORMATION

A different approach to understanding individual differences is to look at correlates with performance on some test external to the main task of interest, and see if it can be used to predict performance. The introduction to this chapter pointed out that intelligence tests are commonly used as an index of individual differences, and have a well established background. The work of Hunt suggests that they might be useful correlates of the control aspects of the alphabet transformation task. This section explores the role of intelligence in understanding individual differences in performance on the alphabet transformation task. In particular, one of its aims will be to look at the relationship between intelligence and the subcomponents of the task to see if we can find a differential effect of intelligence on the microstructure of performance.

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### 5.3.1 Procedure

Scores on the AH4 test of general intelligence (Heim 1970) which consists of verbal and spatial reasoning subscales, were obtained for all of the subjects in experiment 2. Most of the subjects (about 80%) were tested in a single group, and the remainder were tested individually or in small groups at a later date.

### 5.3.2 Prediction of Performance by Intelligence

Table 5.1 shows the correlations<sup>1</sup> between mean value of each of the main task components and intelligence for the C44 condition. The correlation matrix shows that the intercorrelations between the task components are very low, as is their correlation with intelligence. It seems rather puzzling at first that in a task as difficult as this, the correlation with intelligence should be so low, especially bearing in mind that on the arguments presented at the beginning of this chapter we would expect the most difficult task to be the most sensitive to individual differences.

	E	T	S	Tot	Err
Err	-.05	-.08	.11	.14	
AH4V	.02	.10	-.22	-.14	-.33
AH4S	.19	.00	-.16	-.04	-.02
AH4T	.13	.05	-.19	-.09	-.16

Table 5.1 Correlation between time, error and intelligence scores.

E, T and S are mean time on encoding, transformation and storage; Tot is total time per trial; Err is number of recall errors in C44 condition; AH4V, AH4S and AH4T are AH4 Verbal, Spatial and Total scores.

<sup>1</sup> Pearson correlations are used throughout in this thesis.

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The most probable reason for this apparent anomaly is that subjects are indeed using different strategies, thus leading to no consistent pattern in the relationship between performance and intelligence. For example, different subjects operating at different points on a speed accuracy trade off dimension would mean that any simple correlation with IQ would be likely to be hidden. Similarly, if different levels of IQ were likely to lead to different strategies of emphasis on different task phases, no simple relationship is likely to exist between IQ and performance.

### 5.3.3 Intelligence and Subgroups of Subjects

Splitting the subjects into three groups in an earlier section of this chapter seemed to enable us to identify possible strategy differences. We may get more information about the relationship between intelligence and performance if we use these subgroups as a means of reducing the heterogeneity of strategies. First of all, it would be useful to know to what extent we can discriminate between the subgroups on the basis of intelligence.

Table 5.2 shows the median scores on the AH4 for each subgroup of subjects, and the group as a whole, and table 5.3 shows the number of subjects who fell above and below the grand median total AH4 score in each of the three subgroups. A median test (Seigel (1956)) shows that there is indeed a difference between the subgroups. The slowest subjects are more likely to have lower AH4 score, and the fast and medium groups are more likely to have higher scores.

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	AH4V	AH4S	AH4T
Fast	43 (13)	51 (17)	93 (30)
Medium	45 (7.5)	46 (7)	92 (15)
Slow	39 (4.5)	45.5 (9.5)	85 (13.5)
All	41.5 (8)	46 (11)	90.5 (15.5)

**Table 5.2** Median and (inter-quartile range) for each subgroup, and the group as a whole on AH4 Verbal, Spatial and Total scores.

	Below	Above	Tot	
Fast	4	9	13	
Medium	5	8	13	
Slow	11	3	14	
Tot	20	20	40	chi-square (df=2) = 7.2 p < .05

**Table 5.3** Median test on three subgroups on the basis of total AH4 score.

	AH4V		AH4S		
	Below	Above	Below	Above	
Fast	5	8	4	9	13
Medium	4	9	6.5	6.5	13
Slow	11	3	8	6	14
Tot	20	20	20	20	40
chi-square (df=2) = 7.2 p < .05			chi-square (df=2) = 2 ns		

**Table 5.4** Median test on three subgroups on basis of both verbal AH4 score (AH4V) and spatial AH4 score (AH4S)

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We might expect that since the skills required for the task are more verbal than spatial, being primarily concerned with manipulation of the alphabet, that there would be a greater difference between the conditions on the basis of verbal intelligence scores. Table 5.4 shows that this is indeed the case. As with total AH4 score, the subjects in the slowest groups are more likely to be of below average intelligence on the basis of a median split of verbal ability scores, but there is no difference between the groups on the basis of spatial ability.

### 5.3.4 Intelligence and Performance Within Subgroups

It should also be fruitful to look at the relationship between performance and intelligence within each subgroup. If heterogeneity of strategies has been reduced within each subgroup we might expect to obtain different patterns of correlations within each subgroup which would help us to interpret the factors which influence the strategy used.

		E	T	S	Tot	Err
FAST	Err	.12	.05	-.19	.05	
	AH4V	.06	.12	-.10	.16	.30
	AH4S	.17	.14	-.12	.25	.42
	AH4T	.12	.14	-.11	.22	.38
N=13						
		E	T	S	Tot	Err
MEDIUM	Err	.02	-.17	.04	.52	
	AH4V	-.37	-.05	-.01	-.64	-.61
	AH4S	.03	-.44	-.14	-.40	-.09
	AH4T	-.13	-.32	-.10	-.54	-.32
N=13						
		E	T	S	Tot	Err
SLOW	Err	-.20	.09	-.04	.05	
	AH4V	.40	.22	-.15	.10	-.54
	AH4S	.55	.32	-.06	.30	-.21
	AH4T	.57	.32	-.12	.25	-.41
N=14						

Table 5.5 Correlation between time, errors and intelligence scores for the three subgroups.

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Table 5.5 shows the correlation between performance, errors and intelligence for each of the three subgroups. Although the number of subjects in each subgroup is rather small for reliable correlational analysis, and many of the correlations do not reach significance, it is nevertheless possible to get some idea of the direction of various interrelationships in the data and so gain insights into likely strategic differences between the groups.

There are two aspects of the patterns of correlations within these subgroups which are worthy of note. First of all, the correlation between intelligence and errors is positive for the fastest group and negative for the two slower groups. The rather surprising positive relationship in the fastest group and the absence of any strong positive correlation with the time data suggests that the higher error rate with increasing intelligence is not simply due to a speed accuracy trade off, but is due to there still being substantially different strategies within this subgroup which we are not separating out by the rather crude division of subjects used. This conclusion is further supported by the high inter-quartile range in this subgroup. However, since all of the relevant correlations with the exception of the storage time ones are positive, there is a hint that one of the strategies present within this subgroup can be identified with a speed accuracy tradeoff where some higher intelligence subjects are prepared to make more errors for an increase in speed of performance.

Secondly, further consideration of the relationship between speed of performance and intelligence for the medium and slow groups

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shows hints of quite different strategies. In general, in the medium speed subgroup, intelligence correlates negatively with time, especially total time to complete the trial. Thus as we might expect, subjects of higher intelligence are able to complete the task more quickly, and in this group also make fewest errors. Assuming these subjects are adopting similar strategies, they seem to be separated by ability rather than a speed accuracy trade off. However if we consider the slowest group (who, as was shown earlier, are of lower intelligence than the other groups), there is a tendency for intelligence to correlate positively with time to carry out the task (most apparent with encoding time). In this group the more intelligent subjects are the more they seem to realise that they are having trouble with the task, and slow down their performance even more to ensure that they are able to get through the trial with reasonable success. This in turn leads to fewer errors in this subgroup, suggesting that a speed accuracy trade off may be responsible for a considerable amount of the difference between the performance of the members of this subgroup.

### 5.3.5 Intelligence and Complex Performance

When considering a task of this complexity, it appears that intelligence cannot be used to predict performance in any simple way. The major problem is that a number of strategic approaches to the task are available to subjects. The patterns of performance observed are a function of both the strategy adopted and of the ability of the subject. If, as in this case,

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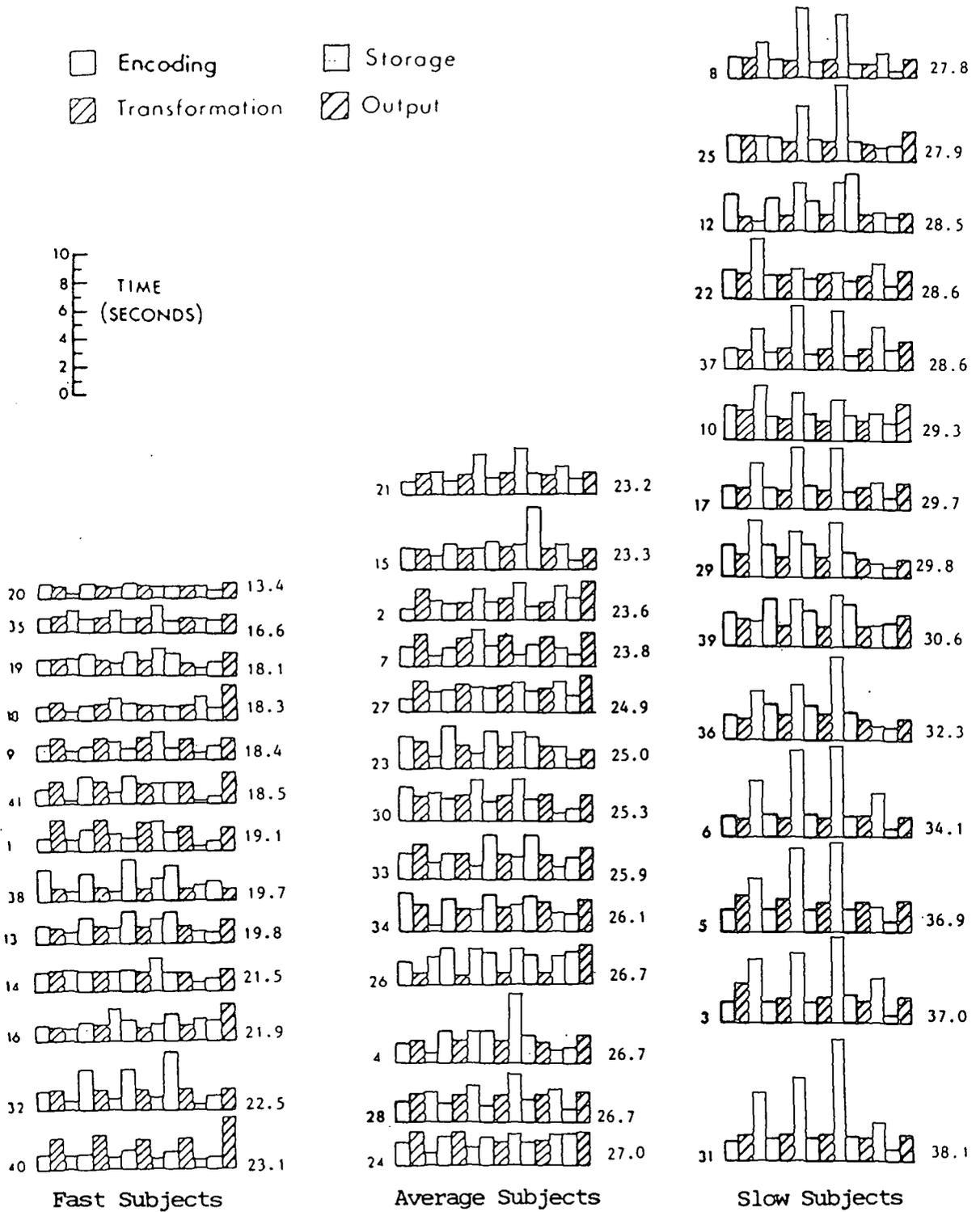
intelligent behaviour implies quite conflicting patterns of performance with different strategies, then any attempt to predict any details of performance from intelligence is bound to failure.

However, the present data does hint that in some circumstances a multi-pass application of intelligence measures could be more informative than the usual single pass. If different strategies can be identified and isolated, separate correlations within each of the resulting subgroups may be meaningful. There was also some hint of a relationship between the type of strategy adopted and intelligence. In these circumstances, the intelligence measure itself might be appropriate for selecting subgroups. If the heterogeneity of strategies was thus reduced, then intelligence could be a valuable tool in understanding such behaviour within each subgroup.

### 5.4 ISOLATING SUBGROUPS - PATTERNS OF PERFORMANCE

Earlier sections of this chapter showed that reasonable insight into some of the factors influencing the performance of subgroups of subjects could be obtained simply by splitting the group up on the basis of the total time taken to perform the C44 condition. Fig 5.3 shows the profiles for each subject ordered by this total time. It can be seen that the subgroups obtained on a simple time basis are still not as homogeneous as might be hoped for in terms of the precise pattern of performance shown by a number of individuals. In particular, a number of subjects show patterns

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**Figure 5.3** Performance profiles for individual subjects ordered by total time to complete the C44 task. The subject number is to the left of each profile and the total time taken to complete the trial is to the right.

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which are in direct conflict with those reflected by the means for the groups to which they belong. For example some subjects (eg 22, 10 , 29) seem to show a decrease in storage time rather than the more usual increase. Other subjects (eg 38, 32) show considerably longer encoding times. In addition the previous section suggested that there were still likely to be differences in strategy within these subgroups on the basis of patterns of intercorrelation between performance, errors and intelligence, which were not open to a clear interpretation, particularly in the fastest subgroup. A more systematic way to investigate subgroups of this kind, based on the pattern of performance rather than on a single variable is likely to allow us further insights into more subtle aspects of the data, and provide us with a more homogeneous classification within subgroups. Indeed, such an approach of deriving what he calls 'minitypologies' from data is strongly advocated by Kareev (1982) as a more satisfactory method of exploring individual differences than using correlations with external tests.

### 5.4.1 Cluster Analysis

There are a variety of multivariate classification techniques available which are potentially useful in answering this sort of question. One of the simplest and most easily interpretable is hierarchical cluster analysis (see Everitt (1974) for a lucid but comprehensive description).

Cluster analysis can be used to help simplify any type of data

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which differs on a number of dimensions. For example Friendly (1977) has used it to infer how memory for particular items is structured by using cluster analysis to find regular patterns in the order in which the items are recalled. In this case we want to use it to classify subjects into groups who show similar patterns of performance.

For present purposes, cluster analysis will regard the 40 subjects as separate groups initially. It then finds the two who are closest on a particular metric of similarity and joins them together to make a new cluster. By continuing this process, the number of clusters are gradually reduced to one. However, by reference to a dendogram - a diagram which traces the clustering solution, it is possible to see the structure of the data which has been revealed by the analysis. The precise number of clusters which it makes sense to consider will depend on the nature of the data and the purposes to which the results are to be put.

A variety of metrics can be used to indicate the "closeness" of clusters. Two of the simpler ones are Euclidean distance - in this case it would amount to the actual distance between two subjects in 14-dimensional space - and correlation which will emphasise the shape of the profiles as an indicant of similarity. Another complication is that there are a variety of ways of determining the vector used to represent a new cluster which has been formed by joining two old ones. The simplest methods here are 'single' and 'complete' linkage. In these methods the distance between groups is defined as the distance between their

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closest or furthest members respectively. Other methods which use more sophisticated means of determining the distance between two clusters exist. One useful one for use with Euclidean distance is Ward's method (Ward 1963). This algorithm works by attempting to minimise the increase in the error sum of squares when forming the next cluster.

As different clustering techniques have different properties and not enough is known about the expected structure of the data under consideration here to choose any particular one a priori, a selection of techniques were applied and the results compared. (It is common practice to use single and complete linkage methods together - if they produce similar clusters then one can be fairly certain that the solution represents real clusters in the data.)

### 5.4.2 Analysis of Alphabet Transformation Data

The performance profiles (14 measures) for forty subjects from experiment 2 (subject 11 was discarded for the present analyses as she had great difficulty with the C44 condition with a consequent high error rate (90%)) were fed into a cluster analysis. The data was analysed using both single and complete linkage methods with both Euclidean distance and correlation as metrics, with Ward's method included for Euclidean distance. The single link solutions led to a common problem with this algorithm, that of 'chaining', where items tend to be added one at a time to produce one large cluster (see Everitt 1974), rather

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than differentiating the data in any way. This suggests that the data is not organised into simple discrete clusters, and in fact may really be a continuum in multidimensional space. This does not invalidate the method in general however, as it can still be a useful way of simplifying the data by classifying it into a smaller number of subgroups, so for present descriptive purposes the utility of the method lies in the assistance which it gives in making sense of subgroups of the data.

Similarly, when the solutions produced by using Euclidean distance as the metric were compared with those obtained from using correlation as the metric, some anomalies were clear. Since correlation only reflects the pattern of the 14 measures irrespective of their level, the very fast subject 35 for example, was classified in the same group as the very slow subjects 5,6 and 31. Since speed of performance is one of the variables we wish to consider in classifying the subgroups, the correlational metric does not therefore appear particularly satisfactory for the present data. Moreover, a comparison of the two methods shows that the Euclidean distance measure clustered by Ward's method gives a more even spread of clusters, and in particular does a better job in splitting up the cases - represented by almost half of the subjects - where the storage times are relatively long. With the correlation metric these form one large cluster relatively early in the solution process.

Consequently, only the results obtained from the Euclidean distance metric will be discussed further since these allow both

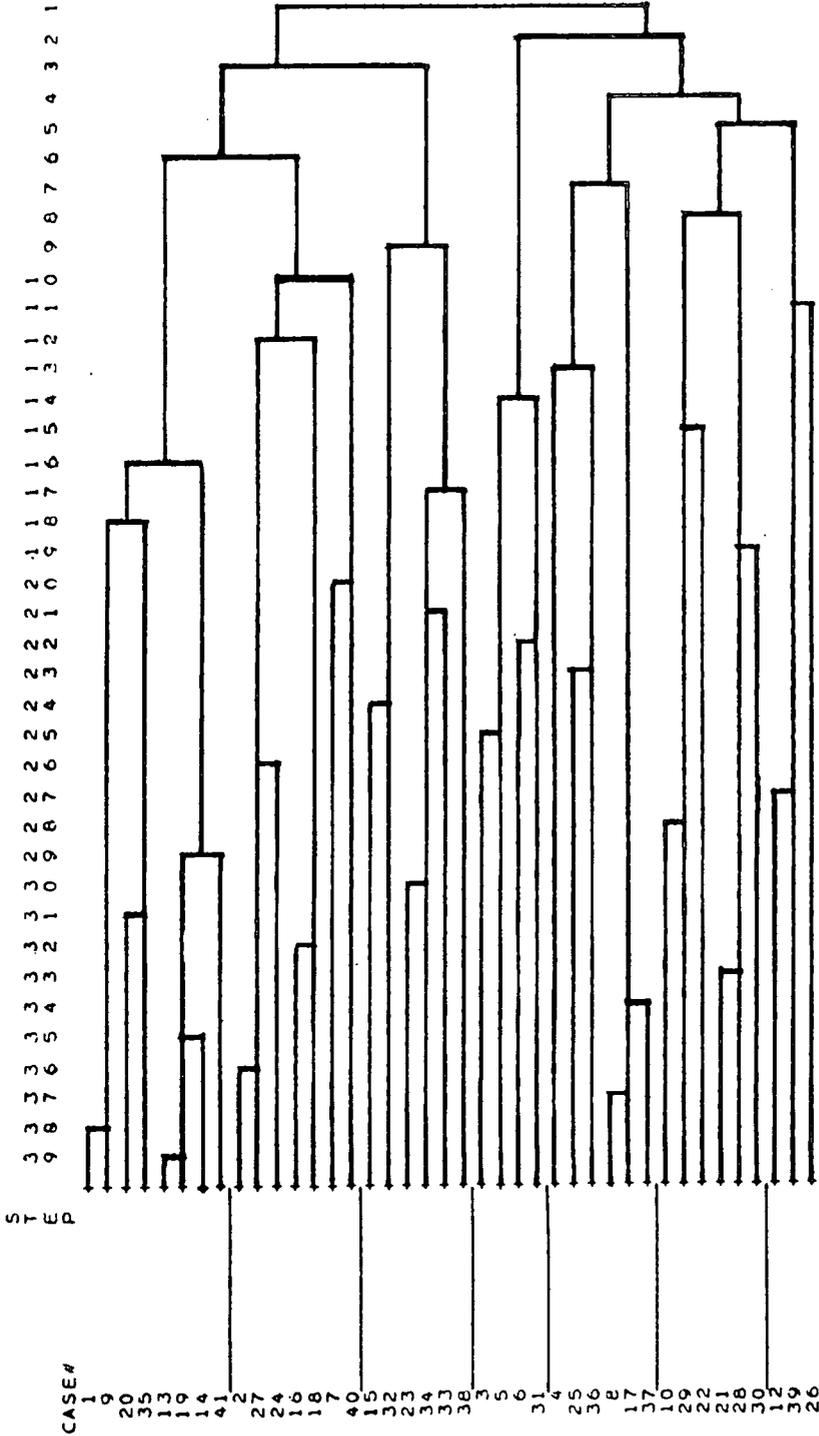
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the shape of the distribution and its level to influence the final solution. Ward's method was chosen as the most appropriate clustering algorithm, first of all since this method is less prone to be led astray by an aberrant 'tail' of a cluster such as might be produced by one of the long storage times, and secondly as it produced a solution similar to that for complete linkage anyway.

The dendrogram showing the complete clustering solution using Ward's method for Euclidean distance is shown in fig 5.4. The profiles for each subject, along with the total time taken to complete the problem, are shown in fig 5.5 in the order implied by the clustering solution

Before we refer to a more simplified picture of the data one last caveat is in order regarding the reliability of hierarchical clustering processes in general. Once a case is assigned to a cluster it cannot be reassigned in the light of later iterations. So, for example, looking at the profiles in fig 5.4, subject 1 looks as if she would fit more snugly into cluster 2 and subject 13 looks as if she would be more at home in cluster 3. It will be noted in fig 5.5 that both of these subjects were assigned to clusters very early in the clustering process. Ward's method of clustering actually tends to minimise the likelihood of this type of misclassification, and for the present descriptive purposes was regarded as giving a sufficiently good structure to the data to justify its use in helping to understand the types of variation in performance profiles which underlie subgroups of subjects.

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**Figure 5.4** Dendrogram of the clustering solution using Wards method and Euclidean distance. CASE# represents the subject number. The vertical bars at the bottom show the seven groups discussed in the text.

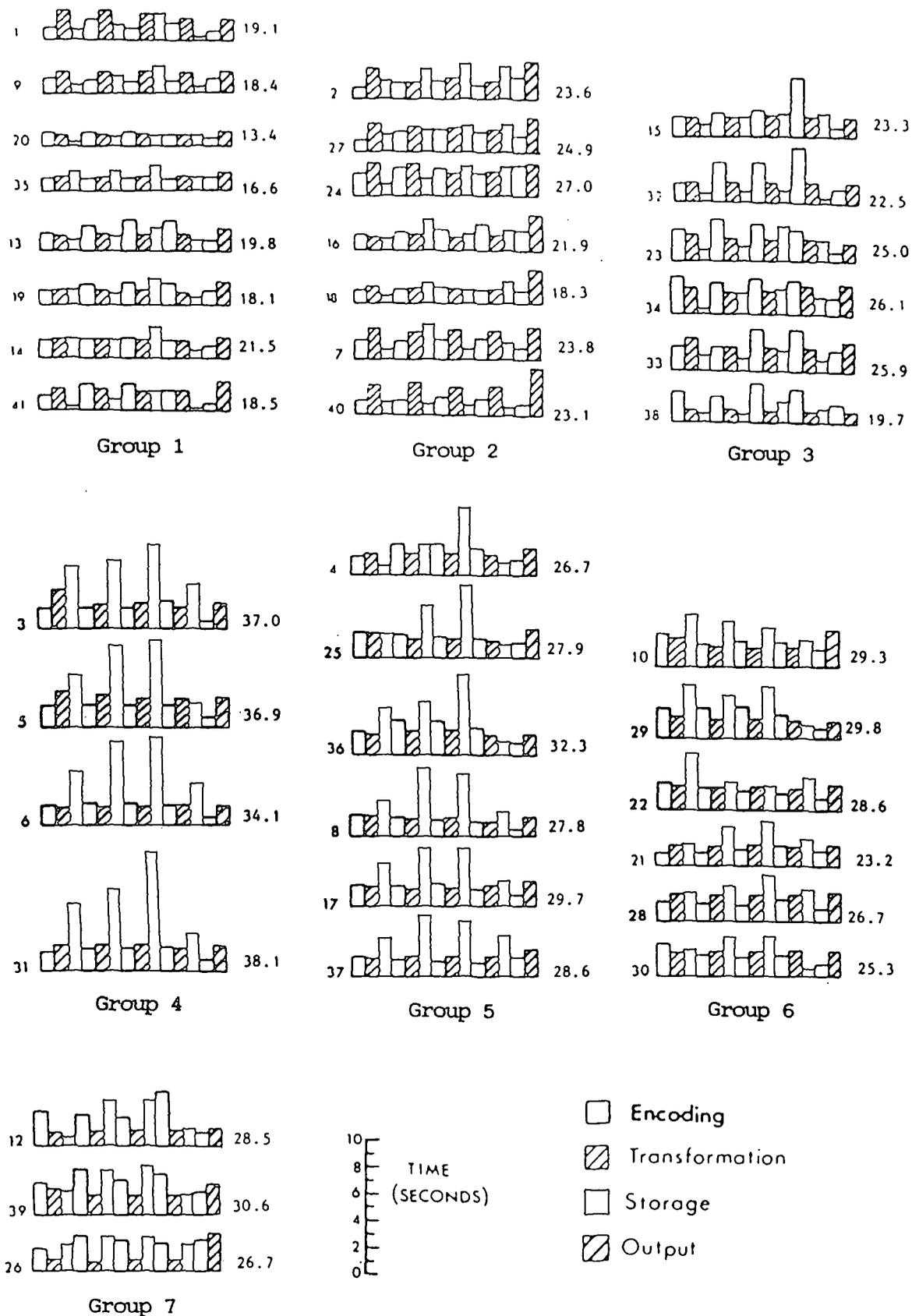


Figure 5.5 Performance profiles for each subject in the order implied by clustering, using Ward's method and Euclidean distance. The subject number is to the left of each profile and the total time taken to complete the trial is to the right.

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### 5.4.3 Characteristics of Subgroups

Fig 5.6 shows the mean profile and number of subjects from the first seven clusters identified by the cluster analysis. Seven clusters were chosen as appropriate as this seemed to be the best compromise between having a reasonable number of subjects in each cluster while not hiding important patterns in the structure of the data. The resulting clusters highlight a number of aspects of the data which have important implications for understanding the range of strategies adopted by the subjects, since they highlight patterns which were hidden in the earlier crude division and which are often difficult to pick out of the full set of unstructured profiles.

#### 5.4.3.1 Storage times

The pattern of storage times as the trial progresses - starting relatively fast and then rising as the load increases, and falling immediately before the final recall is apparent in all of the groups except cluster 6, where it is relatively stable as the memory load increases, and cluster 2 where the final time does not drop. Despite this similarity of the shape of the storage time profile across groups, storage time is also the source of the major differences between the groups. In clusters 4 and 5 storage time is by far the largest component of the solution time for the task, whereas in clusters 1 and 2 it is comparable to the other phases in duration. Not only is the overall level of storage time higher in clusters 4 and 5, but the rate of increase as the memory load increases is also much greater. A look at fig

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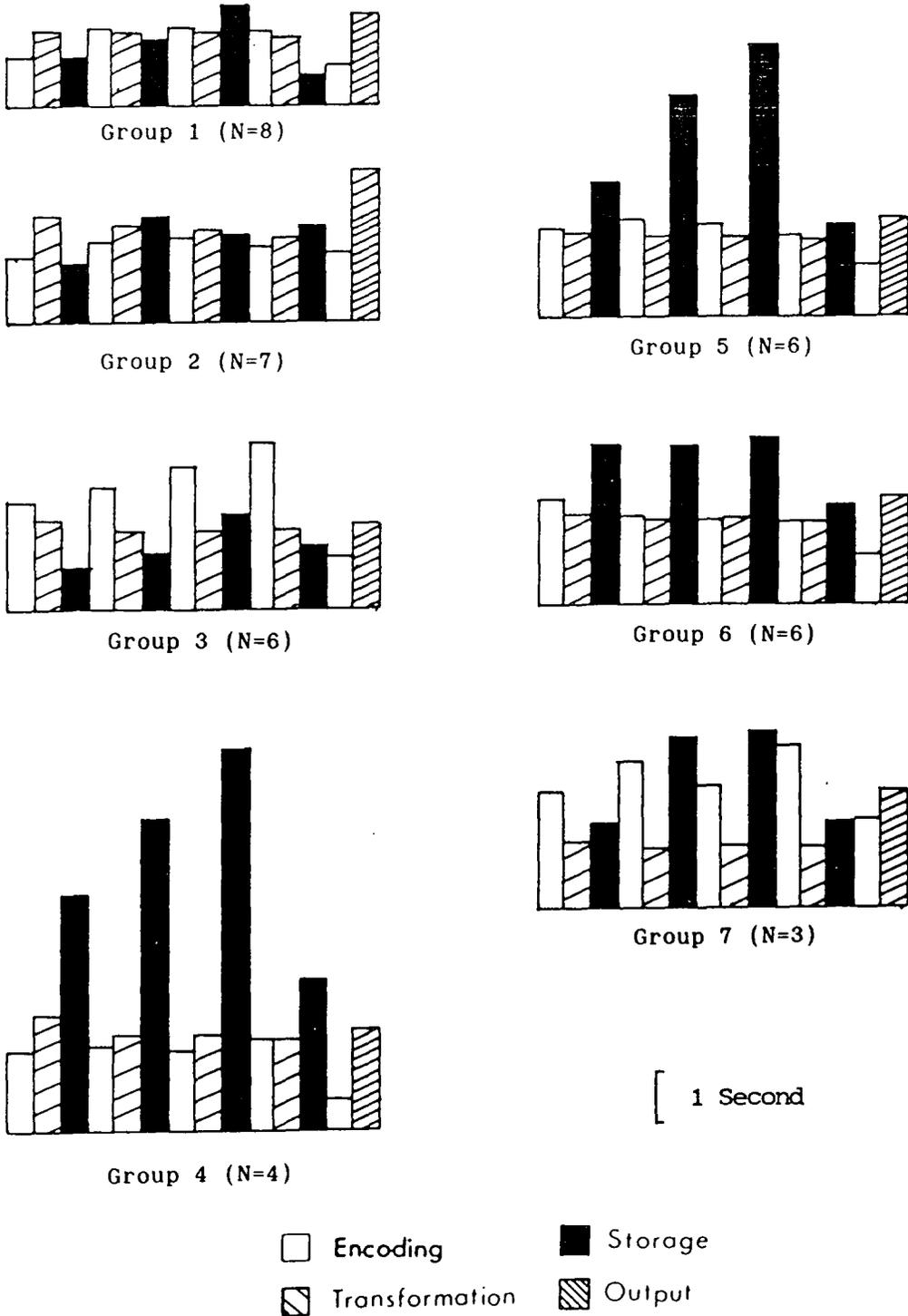


Figure 5.6 Mean profile for each of the seven groups identified by the cluster analysis.

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5.4 reveals that the apparently flat slope of the first three storage times in cluster 6 is due to the fact that this cluster contains the only subjects whose storage time actually decreases as the trial progresses. This, averaged with other subjects who show the normal pattern of increasing storage time, produces the atypical pattern.

### 5.4.3.2 Fast Subjects

Cluster 1 represents a group of subjects who are fast in all components of the task, although a look at the individual subject profiles in fig 5.1 shows that actual patterns of the profiles are less homogeneous than is the case with most of the other clusters - they are clustered together mainly on the basis of relative efficiency in all of the components. Note that subjects in the clusters which have slow storage times also tend to be relatively slower than cluster 1 in the other components as well - it is not purely a case of trading time spent in various components off against each other.

### 5.4.3.3 Emphasis on spoken phases

Cluster 2 subjects spend more time on the spoken phases of the task. Their transformation times are considerably greater than those of any other group, except perhaps cluster 4. In addition the time they spend outputting the final response is the largest of all the groups. This may be due to these subjects being less efficient at using articulation to assist with problem solving.

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### 5.4.3.4 Slow encoding times

Clusters 3 and 7 show considerably more emphasis on the encoding times than any of the other groups. This, combined with relatively short storage times, especially in cluster 3, and the fact that the shape of the encoding time profile as the trial progresses is very similar to the characteristic storage time profile tends to suggest that these subjects were prone to pressing the button to request the next letter before they were really ready for it. Although this is probably true to a certain extent, it should also be noted that these subjects are also the slowest in commencing to transform the first letter in the trial. This tends to suggest that they were not simply disobeying instructions not to request a letter until they were ready for it, but genuinely had difficulty either in knowing when they were ready for the next letter, or in accessing the appropriate place in the alphabet to start transforming from - or indeed, possibly even both.

### 5.4.3.5 Strategies and Abilities

With a relatively complex task such as this, one would expect that different patterns of response may be due not only to the ability of the subject to perform the transformation and memory components of the task efficiently, nor even the ability to coordinate the control processes necessary to switch between the transformation phase and the memory phases of the task. Subjects may also modulate performance by allocating resources to one part of the task in preference to another. For example they may feel that they need more preparation to get ready for the expected

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load and start off relatively slowly in the early components of the trial as subjects 10,29 & 22 appear to doing (fig 5.4), or conversely may start off fairly quickly and spend more time later consolidating the items they know when they feel that the actual memory load they are experiencing is becoming too great as many of the subjects who show rapidly increasing storage times seem to be doing. They may place emphasis on one component over the others. For example subjects in cluster 2 in fig 5.6 spend relatively longer in the transformation phase. Such distribution of resources could be due either to the cognitive style of the subject, or to the particular abilities possessed by an individual, so cluster 2 may indeed be rather poor at transforming letters.

### 5.5 SUMMARY

This chapter has examined individual differences in the patterns of performance in the alphabet transformation task using three different ways of looking for structure in the data. A simple split on the basis of total time was useful in providing some understanding of different strategic approaches to the task and differing levels of ability, but it was unable to distinguish some aspects of patterns of performance which could be seen by visually examining the individual subjects' profiles.

The intelligence of the subject was found not to be a good predictor of performance in any simple way, but showed promise when combined with some means of reducing heterogeneity of strategies.

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Finally, a rather more sophisticated division of patterns of data based on cluster analysis gave a considerably richer structure to particular patterns of performance which were obscured by the cruder classification. This allowed more direct focusing onto understanding how particular strategies and abilities were reflected in the performance profiles since it took account of patterns of performance as well as the overall level of performance.

To fully understand individual differences in data of this complexity clearly requires a number of complementary techniques. Partitioning such multi-dimensional data on any subset of dimensions will inevitably mean that variation along an orthogonal dimension cannot be seen. However, even the simplest method used here clearly had considerable value in increasing our understanding of the data. The more complex method produced better structured subgroups, but still contained some anomalies. So, for some purposes it might even be most appropriate to examine the patterns of performance of each subject individually.

### 5.6 IMPLICATIONS FOR MODEL OF PERFORMANCE

Broadly speaking, we can distinguish two sources of individual differences. The first is in differences in the efficiency of particular resources. There is considerable support this being important in the literature, especially when considering general classes of processing. For example, Carpenter and Just (1985) were able to find two groups of subjects who differed markedly on spatial ability, and consequently showed very different patterns

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of performance on a spatial transformation task. Similarly, MacLeod, Hunt and Mathews (1978) showed a relationship between verbal and spatial ability and performance on a sentence picture verification task (Clark and Chase, 1972). In the current study, the clearest differences due to resource efficiency are in the longer transformation times shown by the subgroup in cluster 2. There may also be such differences at the root of some of the longer storage times, but this is more ambiguous since the storage phase is likely to reflect a number of different resources.

The second major source of individual differences is in the control processes. The previous chapter identified two distinct roles of control processes, both of which are likely to be important in determining individual differences. The first is in selecting the appropriate resources for carrying out the task, and configuring them suitably. It is clear from the range of patterns observed in the data that a number of such strategies are used, and the problems exhibited by subject 11 in selecting an adequate strategy emphasise the importance of being able to select a strategy suitable for the abilities of the individual. MacLeod, Hunt and Mathews (1978) showed that one determinant of strategy selection is indeed the abilities of the individual. They found that people who were relatively high on spatial ability were more likely to choose a visuo-spatial strategy for solving the sentence picture verification task (Clark and Chase, 1972), whereas those relatively high on verbal ability were more likely to choose a verbal propositional strategy. However, this

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preference does not necessarily mean that the subjects would be unable to use their less preferred strategy to carry out the task. Mathews, Hunt and MacLeod (1980) showed that subjects can be instructed to use the alternative strategy with reasonable success, although their response times tended to be slower with the less preferred strategy. This would suggest that the more difficult a task becomes, the more important it is to select an optimum strategy for the resources available.

The second aspect of control is the dynamic passing of information between the resources which are being used. Difficulty at this level is likely to be one of the major reasons for the increase in storage time typically observed in the alphabet transformation task. It was noted earlier that the slower groups of subjects are most likely to show relatively greater increases in storage time. Reference to figure 3.10 indicates that although such dynamic control processes are important in coordinating the passing of information between all phases of the task, they are likely to be especially important in the storage phase since the processes required to update the stored list are particularly complex. Other evidence for such control processes being important factors in individual differences comes from work on dual task performance. For example, some researchers have claimed that 'time-sharing' ability is a dimension along which subjects vary (eg Ackerman, Schneider and Wickens, 1984; Damos and Smist, 1983; Damos and Wickens, 1980). It seems likely that an ability to coordinate multiple resources to carry out separate tasks 'concurrently'

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will be associated with an ability to handle multiple resources required for a single complex task. Indeed, such a correlation has been reported by Hunt and Lansman (1981). In what they call the 'easy to hard paradigm' they showed that when subjects perform an easy primary task combined with a secondary task, the dual task performance leads to better prediction of performance on a harder version of the same primary task than the easy primary task on its own.

So far, we have seen how examining the task microstructure enables us to get a better view of the factors which underlie performance, and how these can vary between individuals. The next section will move on to examining how well such techniques can assist us in understanding any variations in performance under external influences such as variations in stress or arousal.

## CHAPTER 6

### THE EFFECT OF STRESSORS - ALCOHOL

#### 6.1 INTRODUCTION

Previous chapters have discussed temporal changes in the microstructure of performance in the alphabet transformation task as a function of variables which increase task complexity - ie memory load and transformation size, and also as a function of individual differences in resource availability and control. Chapter one indicated that a technique which allowed monitoring of the microstructure of performance could potentially provide much useful input to a variety of problems in the stress literature, such as the sometimes contradictory impairments or benefits in performance under stressors. If for example it were possible to show a dissociation between these impairments and benefits within a single task, this would provide strong evidence that stressors affected different processes differentially. It would be considerably less likely that different strategies were being used as is possible if slightly different tasks are compared, or if some kind of interaction with task requirements is taking place. For example, Hockey (1970a, 1970b) showed that noise tended to improve performance on items that were perceived as being most important to the task at hand and to cause a decrement in performance to less relevant stimuli. The first experiment to be discussed with this methodology looks at the effects of alcohol on performance. Before discussing the

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experiment proper however, we will briefly summarise the major findings which relate to the effect of alcohol on performance.

### 6.2 EFFECTS OF ALCOHOL

#### 6.2.1 Alcohol and Skilled Performance

Much of the research on the effects of alcohol has been motivated by a concern for the effects of alcohol on driving behaviour (see eg Walls and Brownlie, 1970), or airline pilot safety (eg Collins and Chiles, 1980). The effects go well beyond those of cognitive processing with which we are concerned here. For example, it has been claimed that the major effects of alcohol which transform a safe driver into a dangerous one are more concerned with changes in personality (Elbel and Schleyer, 1956). Certainly, the effects of alcohol on judgement and risk taking are well established. For example Cohen, Dearnaley, and Hansel (1958) showed that Manchester bus drivers under the influence of alcohol were not only prepared to drive their bus through a narrower gap than a control group, but in some cases were willing to attempt to drive the bus through a gap up to 14 inches narrower than the bus itself!

Even restricting our interest to the effects of alcohol in laboratory tasks, the effect of alcohol on performance is relatively complex both on sensory processing and motor tasks (Colquhoun, 1976) and memory (Birnbaum and Parker, 1977a). In general however, impairment of performance seems to be the norm with medium to high alcohol doses. With low doses (usually less

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than 30mg), occasional, but by no means universal, beneficial effects have been noted, especially on the absorption phase of the blood alcohol curve (when the blood alcohol level is increasing), (Drew, Colquhoun and Long, 1959). Beneficial effects have also been found with low doses of alcohol counteracting sleep loss (Wilkinson and Colquhoun 1968), and indeed the incidence of road accidents has been found to be lower in drivers with moderate blood-alcohol levels (up to .03%) than for drivers with no alcohol (Borkenstein, Crowther, Shumate, Zeil and Zylman 1964).

Despite these beneficial effects of alcohol, the general trend is of impairment of both sensory processing and motor skill (Carpenter 1961), often materialising as a speed accuracy trade off. For example, Wilkinson and Colquhoun (1968) found increased errors with no decrease in reaction time. A study by Jennings, Wood and Lawrence (1976) found no effect when very fast reactions were required and error rates were high anyway, but as more time was allowed for response, the alcohol conditions did not improve their error rate to the same extent as was found with the non-alcohol conditions.

### 6.2.2 Alcohol and Memory

Similarly, there is a tendency for alcohol to impair memory performance. The precise nature of the impairment tends to be rather complex (see Birnbaum and Parker, 1977b). It has been suggested that it is due to the disruption of encoding operations (Birnbaum, Johnson, Hartley and Taylor, 1980). However, Hartley,

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Birnbaum and Parker (1978) found no support for an explanation based on simple processing failure. A solution to this apparent contradiction has been proposed by Hashtroudi, Parker, DeLisi and Wyatt (1983). They suggest that it is not the processing itself which is necessarily affected, but the way in which it is used. Specifically they suggest that the integration of new with old information is impeded under alcohol intoxication.

For tasks more concerned with primary memory, there is no consensus on the effect of alcohol. For example, Jones and Jones (1977) show no effect of alcohol on recency, whereas Rundell and Williams (1977) show a decrement. Again, there is no consistent data on the effect of alcohol on memory, far less any consensus on the theoretical framework within which it is best viewed.

### 6.2.3 Alcohol and Psychological Theory

In general, the treatment of the effects of alcohol in the psychological literature has been rather patchy and atheoretical. In the absence of a coherent psychological theory, the work which has been driven from the applied end has produced little in the way of guidance to exactly what effect alcohol has on performance beyond rather general impairment on particular kinds of tasks. For example, the main conclusion of Collins and Chiles (1980) was that the data they presented did not contradict the 'eight hour rule' - ie, that pilots should not fly an aircraft within eight hours of having consumed alcohol. Similarly little attempt has been made to encompass the effects of alcohol within more

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mainstream psychological theory. One exception to this has been within the 'levels of processing' framework of Craik and Lockhart (1972). Some of the studies mentioned in the previous section have been driven at least partially from the levels of processing framework (eg Hashtroudi et al (1983), Birnbaum et al (1980)). Craik himself has attempted to account for the effects of alcohol more directly within the framework (Craik 1977). However, he was not very successful in integrating the effects of alcohol, for at least two reasons. First of all, the similarities which Craik claimed for the effects of aging and alcohol seem to be more a product of the theoretical framework than any real phenomenal relationship between aging and alcohol intoxication. Secondly, the framework itself does not account for existing data on memory in as satisfactory a way as might be hoped (Baddeley 1978). Thus trying to account for the complex effects of alcohol within such a framework may be doomed to failure from the start.

### 6.2.4 Alcohol as a Stressor

Consideration of alcohol as a stressor has always been fraught with difficulties. For example, it can be regarded as either a stimulant or a depressant depending on the dosage and possibly the position on the absorption curve (see Wesnes and Warburton, 1983). It can thus not be considered comfortably within an arousal account of performance, even ignoring the inadequacies of such an account of stressors in general (see Chapter 1).

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### 6.2.5 Alcohol and patterns of performance

Rather than affecting fundamental cognitive processes, the effects of alcohol have often been considered as affecting the choice of strategy or consistency in using an adopted strategy (eg Hockey, 1984; Baddeley 1981a). As such they might be regarded as affecting control processes. Detecting such changes in strategy is difficult in relatively simple tasks. However, the alphabet transformation task may well be a useful vehicle to investigate such strategic effects since the pattern of performance which encompasses memory, internal processing and control processes can be monitored.

### 6.3 STUDY 3

Experiment three was designed to look at the effects of a moderate dose of alcohol on performance, both in terms of its effect on basic memory and transformation components in isolation, and in terms of the patterns of performance induced in the more complex versions of the alphabet transformation task.

#### 6.3.1 Subjects and Design

Thirty six university students of average age nineteen years took part in the first session of the experiment, which lasted for about forty five minutes. Twenty of these were matched into two groups of ten matched pairs on the basis of their performance in the first session, to take part in a second session of approximately two and a half hours duration about two weeks later. The matching was done primarily on the total times, but a visual examination of the overall pattern of performance on the

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task components was also carried out to ensure that subjects who were obviously using different strategies to carry out the task (see chapter 5) were not matched with each other. All subjects were tested in the afternoon and were requested to have a light lunch on the second day, and to consume no alcohol before attending the testing session, to minimise differences in the effect of alcohol between subjects.

### 6.3.2 Procedure - Session 1

Session one familiarised the subjects with the alphabet transformation task and obtained performance data on the C44 condition for matching purposes. Each subject received six practice blocks to gain familiarity with the task (C14, C22, C32, C34, C42, C44). This was followed by the two C44 blocks on which performance was matched.

### 6.3.3 Procedure - Session 2

The ten matched pairs of subjects returned approximately two weeks later for the second session. The basic design treated alcohol as a between subjects factor, although some baseline measures were available before administration of alcohol and so can be regarded as within subjects measures. One of each pair was assigned to the 'alcohol' group and one to the 'non-alcohol'. The session was split into five parts. The first two re-familiarised subjects with the alphabet transformation task and obtained basic transformation speed and memory data before the administration of alcohol. The third administered either alcohol or a placebo and allowed time for the alcohol to take effect.

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The final two parts assessed basic transformation and memory abilities under alcohol and obtained the main performance data on the more complex alphabet transformation conditions.

### 6.3.3.1 Session 2: Part 1 - Practice and Baseline Transformation

The first part consisted of four blocks of practice trials (C13, C24, C42 and C44) followed by one block each of  $m=1$ ,  $t=1$  to 5 in a random order to assess transformation speed in the sober state.

### 6.3.3.2 Session 2: Part 2 - Immediate Memory Assessment

Since it is difficult to assess memory in isolation from the other components of the alphabet transformation task, a free recall paradigm was used to obtain some measure of relatively 'pure' memory abilities. Subjects were presented with sequences of nine random letters, one per second, presented on a Commodore PET microcomputer. No letter appeared more than once in any sequence. After the sequence had finished they recalled the items on a pre-prepared response sheet which had one slot for each of the nine serial positions which had been presented. Subjects were instructed to recall the items in any order they chose, but to try to place them in the slot corresponding to the position in which they had been presented. Five practice trials were given, followed by fifteen experimental ones. Subjects indicated that they were ready to start each trial by pressing the space bar on the microcomputer keyboard.

### 6.3.3.3 Session 2: Part 3 - Administration of Alcohol

Both the alcohol and non-alcohol groups were then given a drink

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which they were told contained 'some alcohol'. The alcohol group were given a dose of 1.5ml/kg body weight of 70 (UK) proof gin (corresponding to 0.5 ml/kg of pure alcohol), mixed with fruit squash. The non-alcohol group were given an equivalent volume of fruit squash with a small quantity of gin floated on the top to give the subject the impression that some alcohol was present. Both groups were requested to consume the drink over the next five minutes with regular small sips. Subjects were then left for 40 minutes to allow the alcohol to take effect. Previous work has shown this to be around the optimum time to achieve peak blood alcohol levels. The blood alcohol level of each subject was measured with an alcometer after 20 minutes and again after 40 minutes. The non-alcohol group all gave readings of zero. For the alcohol group, the mean levels achieved were 0.046% after 20 minutes, and 0.045% after 40 minutes. The blood alcohol level was measured again after part 4 of the testing schedule. Typically this was 60 to 70 minutes after ingestion of the alcohol, and the blood alcohol level had reduced to a mean of 0.034%.

### 6.3.3.4 Session 2: Part 4 - Alphabet Transformation

Forty minutes after ingestion of the alcohol, subjects were given the main testing session on the alphabet transformation task. This commenced with one block of C22 for practice. This was followed by five blocks of  $m=1$ ,  $t=1$  to 5 in random order. Finally two blocks each of C24, C42 and C44 were presented, again in a random order. At the end of this part of the testing, the

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blood alcohol level was again measured. The mean level was 0.034%.

### 6.3.3.5 Session 2: Part 5 - Immediate Memory II

Finally, subjects were given the free recall test again. This consisted of fifteen trials, each of nine letters, with no initial practice.

## 6.4 RESULTS

The data will be discussed in three sections: (1) the immediate memory task, (2) performance on the  $m=1$  alphabet transformation condition and (3) performance on the more complex versions of the alphabet transformation task. Analyses of variance were carried out on the data. Since no data was available for the complex conditions before the ingestion of alcohol, all the main analyses are based on the differences between the two groups after alcohol was administered to maximise comparability between the analyses. (The analyses before alcohol was administered are presented separately for the immediate memory and transformation conditions to show that performance in the two groups was the same before the ingestion of alcohol). All analyses involving the alphabet transformation task treat the two groups as consisting of matched pairs of subjects. However, since the matching was done on the basis of the alphabet transformation task, it is inappropriate to treat the free recall data in this way, so it is analysed treating the two groups as independent samples.

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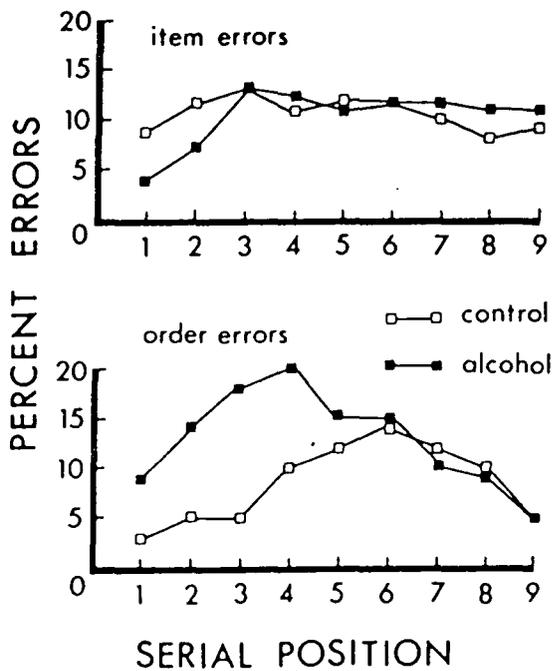
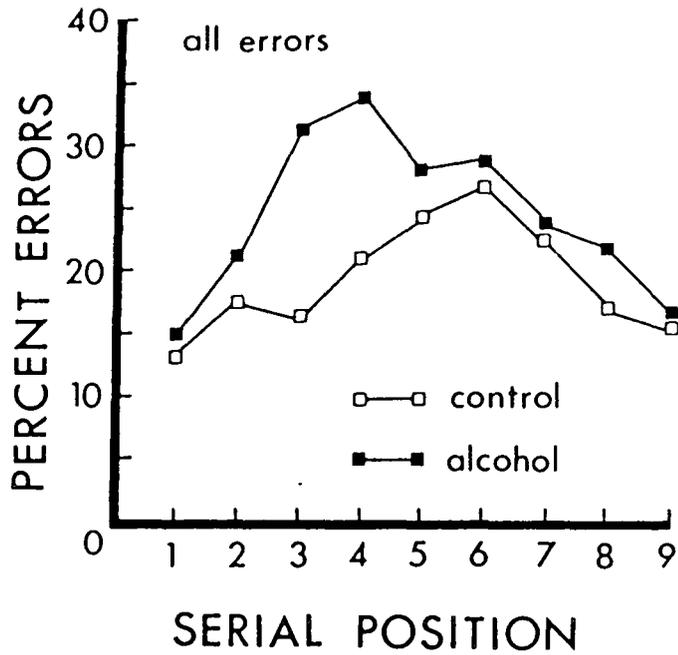


Figure 6.1 Immediate memory errors as a function of serial position. a) All errors. b) Item and order errors separate.

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### 6.4.1 Immediate Memory

The percentage of errors which occurred in each serial position were measured. Figure 6.1(a) shows the total percentage errors in the two groups in part five of the session, the post alcohol phase. It includes all cases in which the correct response did not appear in the correct position on the response sheet. Figure 6.1(b) splits up these errors depending on whether they arose from recalling an item which did not appear at all in the sequence (item errors), or simply from an item being recalled in the wrong position in the sequence (order errors). It appears that the serial position effect observed in the total errors is due mainly to order errors, there being no evidence of a serial position curve for item errors. The patterns observed are similar to other studies where item and order errors have been scored separately. Hitch (1974) showed a fairly similar pattern of performance between item and order errors with visually presented letters using a probe for recall, except that the proportion of item errors was very low. This can be explained by the fact that he used a subset of only twelve different letters. Once subjects became familiar with the set relatively few item errors would be expected. A study reported by Fuchs (1969), which sampled from a set of some 220 words, found the ratio of item to order errors as well as their pattern much more similar to that in the present study.

A summary of the results of the analysis of variance is presented in table 6.1. It can be seen that there was no difference between the groups before alcohol was consumed. After

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		Before		After	
		F	p	F	p
Total	Alcohol	<1	-	1.2	.28
	SP	21.4	<.0001	9.5	<.0001
	Alc x SP	1.1	.38	2.2	.03
Item	Alcohol	<1	-	<1	-
	SP	22.0	<.0001	2.3	.03
	Alc x SP	1.2	.33	2.9	.006
Order	Alcohol	<1	-	2.5	.13
	SP	7.2	<.0001	8.0	<.0001
	Alc x SP	1.2	.28	4.8	<.0001
df are:		Alcohol		1,18	
		Serial Position		8,144	
		Alcohol x SP		8,144	

**Table 6.1** Analysis of variance of errors in serial position recall test. The matching done on the AT task is ignored and the groups are treated as independent. There are ten subjects in each group and each subject had 15 recall trials of nine items each before ingestion of alcohol and after ingestion of alcohol or a placebo.

consumption of alcohol, there was still no main effect of alcohol with any of the scoring methods (although the non-significant difference between the groups is in the direction normally reported in the literature - a decrement under alcohol). However the interaction between alcohol and serial position was significant for all three methods. Considering the total number of errors (fig 6.1(a)), the greatest effect of alcohol is around serial positions three and four. When the composition of the errors is examined, however, there are clear differences between item and order errors. The alcohol group make fewer item errors at the beginning of the sequence and more at the end, whereas they make many more order errors at the beginning of the list.

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Note that this combination of types of errors leads to the statistical strength of interaction between serial position and alcohol consumed being considerably weaker than either of the components which make it up.

The lack of an overall effect of alcohol on memory in free recall seems to be relatively unusual (or at least unreported). There are however a number of studies which report the greatest effect in the early to middle serial positions in auditorally presented verbal learning paradigms (eg Baddeley, 1981a; Weingartner et al, 1976). At first sight that seems compatible with the present results. However, these studies did not test for memory of position in the sequence, and so the most appropriate comparison is the item measure in figure 6.1(b), which shows no serial position effect, has no trace of a difference between the alcohol and no alcohol groups but shows a different pattern of errors of this type with relation to serial position - the alcohol group making fewer errors in the primacy portion of the curve and more in the recency end. The serial position effect is in fact due to order errors and is particularly pronounced for the alcohol group.

The differences observed in the pattern of performance between experiments, and in particular the trade-offs in patterns of errors observed between the alcohol and no alcohol conditions in the present study suggest the importance of strategic effects in carrying out even a relatively simple task such as free recall of a list of items (cf Baddeley, 1981a).

There are three main directions from which one might expect

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strategic differences to come - the way the subject structures the input stimuli; the nature of the internal representations which are used and the retrieval strategies used. Subjects in the present experiment were given no instructional constraints on any of these.

First of all, the way the subject organises the list can affect later recall. If the subject chunks the stimuli into regular sized groups, performance tends to be improved (Ryan, 1969). In particular, groups of three would be expected to lead to optimum performance in the present experiment (cf Wickelgren, 1964).

Subjects presented with visually presented verbal material seem to be able to use either a visual or an articulatory strategy to memorise it. Evidence for use of an articulatory strategy comes from the phonemic similarity effect (eg Conrad and Hull, 1964). Since memory for similar sounding consonants tends to be impaired, it appears that an articulatory rather than a visual encoding is being used. However, the phonemic similarity effect disappears both when the articulatory system is loaded up with internally generated articulatory suppression (Baddeley and Hitch, 1974), and when unattended speech is presented to the subject (Salame and Baddeley, 1982). Despite the fact that the articulatory system seems to be put out of action by either of these manipulations, subjects are still able to recall items reasonably well, presumably mediated by a visual store.

Thirdly, the retrieval strategy used to recall the items can have a marked effect on the pattern of errors. For example Broadbent,

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(1975), Broadbent et al (1980) have shown that recalling the final items first tends to enhance performance if presentation was visual, but to impair it for auditory presentation.

Incidentally, the different pattern between modalities of presentation indicates that an analysis based only on time since presentation, or number of intervening items, such as used by eg Tulving and Colotla (1970) to attempt to separate 'primary' and 'secondary' memory components (Waugh and Norman, 1965), is likely to be over simplistic.

In the present study, subjects were free to use whatever grouping strategies they wished to organise the incoming stimuli, and they were permitted to retrieve the responses in any order they wished. We do not have a direct measure of retrieval strategy actually used to see if that would indeed distinguish between the two groups. It is possible that subjects in the alcohol group did not make such an active attempt to maintain or improve their performance compared to the members of the non-alcohol group. This would be consistent with the interpretation of Hamilton and Hockey (1970), who showed that the ratio of recency errors to primacy errors in a nine digit recall task tended to increase as the session progressed. They interpreted this as a shift from active to relatively passive processing as the session progressed. A combination of the alcohol group being less active in their processing combined with a tendency to retrieve the final items first, rather than in the order of presentation as Hamilton and Hockey required could well explain the difference between the groups. An attractive alternative explanation offers

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itself when the internal representation used is considered. Since the major difference between the two groups is in the number of order errors made and the visual system tends to be less good at encoding time and hence order, the alcohol group may be more prone to relying on a visually based approach to the task, and less on articulatory rehearsal.

### 6.4.2 Simple Transformation Measures

Baseline measures of the effect of alcohol on transformation rate were obtained from the  $m=1$  condition, with the transform size varying from one to five letters. As with the immediate memory data, subjects were tested both before and after ingestion of alcohol. Since the matching between the groups was done on the basis of alphabet transformation profiles, the two groups were treated as matched pairs for the analyses of variance. There was no hint of any difference in the transform time between the two groups before ingestion of alcohol ( $F < 1$  for both main effect of group and interaction with transform size). Figure 6.2 compares the pattern of performance observed in the two groups after administration of alcohol (or placebo). The alcohol group were slower overall in carrying out the transformation ( $F(1,9)=7.0$ ,  $p=.025$ ), and there was a strong indication in the interaction between group and transform size ( $F(4,36)=2.4$ ,  $p=.06$ ) that the rate of transforming was also slower in the alcohol group. The mean transform rate was 390 msec/item for the alcohol group and 330 msec/item for the control group. This reduction in processing rate is consistent with that found by eg Jennings et al (1976).

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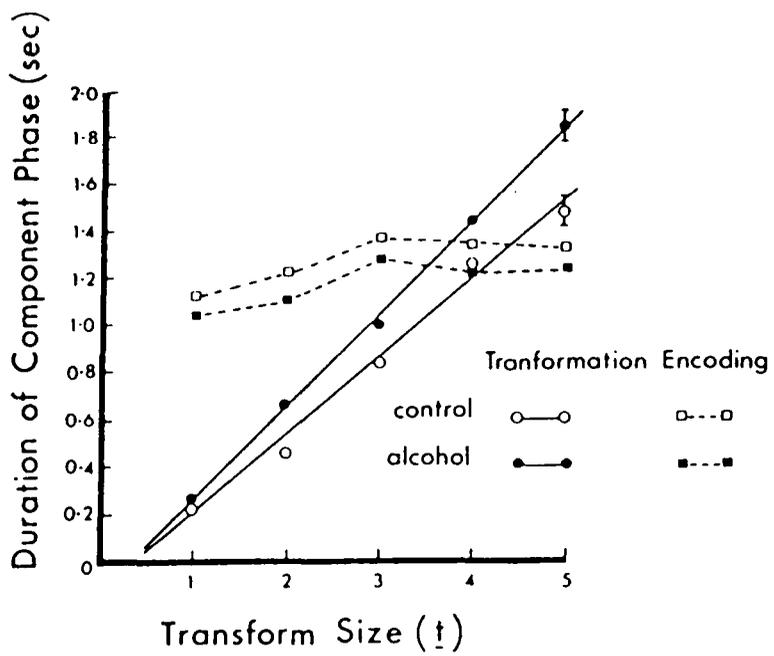


Figure 6.2 Encoding and transformation times for  $m=1$  condition

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There is a small but non-significant difference between the two groups in the encoding time (figure 6.2), such that alcohol group is marginally faster than the control. The consistency in the difference for all five transform sizes suggests that the lack of significance is not simply due to noise in the data collection. This will be considered in more detail after the results of the more complex alphabet transformation conditions have been considered.

### 6.4.3 Complex Alphabet Transformation

#### 6.4.3.1 Microstructure of Times

Three of the more complex alphabet transformation conditions were used; C24, C42 and C44. Although all subjects had experienced at least one block of each of these conditions as practice, there is insufficient data to carry out an adequate analysis of performance in the same subjects before and after ingestion of alcohol. However, the simpler measures of both memory and transform rate indicate that there were no initial differences between the two groups. Table 6.2 shows differences in time for each component of the task between the two groups (The absolute times for each group are also shown). Positive values of the time difference indicate the alcohol group being slower. The direction of the difference for both encoding time and transformation time is the same as was observed in the simple transformation condition in the previous section, and is consistent both across phases in each condition and between conditions. There appears to be rather greater variation in the

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storage component, although it tends to be slower in all but the most complex C44 condition. However, a matched group analysis of variance on each component revealed that the differences were not significant for any of these more complex conditions. Reasons for this will be discussed in greater detail later.

### C24

Cycle	Encoding		Transform		Storage	
	1	2	1	2	1	2
Alcohol	1.21	1.38	1.54	1.39	.74	.54
Placebo	1.30	1.47	1.29	1.32	.85	.60
Alc-Plac	-.09	-.09	.25	.07	-.11	-.06

### C42

Cycle	Encoding				Transform				Storage			
	1	2	3	4	1	2	3	4	1	2	3	4
Alcohol	1.29	1.48	1.54	1.47	.69	.67	.66	.61	1.04	1.66	1.73	.76
Placebo	1.37	1.56	1.70	1.60	.59	.61	.58	.54	1.05	1.58	1.91	1.13
Alc-Plac	-.08	-.08	-.16	-.13	.10	.06	.08	.07	-.01	.08	-.18	-.37

### C44

Cycle	Encoding				Transform				Storage			
	1	2	3	4	1	2	3	4	1	2	3	4
Alcohol	1.24	1.47	1.40	1.37	1.57	1.54	1.49	1.38	1.21	1.78	2.35	1.04
Placebo	1.39	1.57	1.51	1.54	1.40	1.40	1.37	1.37	1.06	1.73	2.13	1.09
Alc-Plac	-.15	-.10	-.11	-.17	.17	.14	.12	.01	.15	.05	.22	-.05

Table 6.2 Time taken as a function of phase and cycle for alcohol and placebo groups for C24, C42 and C44. The bottom line in each condition shows how much slower the alcohol group is.

#### 6.4.3.2 Errors

It might be expected that if alcohol affected speed accuracy trade off criteria in subjects (cf Jennings et al 1976), that

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differences between the groups would be detected in error rates. Table 6.3 shows the error rates for both response errors and for trials which were abandoned. There was no sign of a difference in either type of error as a function of alcohol level.

	Response Errors		Abandoned Trials	
	No alc	Alc	No alc	Alc
C24	0	1	4	6
C42	1	2	16	18
C44	4	3	12	13

Table 6.3 Percentage errors in each condition. There is no significant difference between the alcohol and no-alcohol groups ( $F < 1$ ).

### 6.5 DISCUSSION

The simplest manipulations show strong effects of alcohol. However, things become less clear with the more complex conditions. This section will first of all discuss the contribution of the present study to the understanding of the cognitive effects of alcohol, and then will consider implications of this on the nature of performance in more complex situations, and on methodology for measuring such performance changes.

#### 6.5.1 Cognitive effects of alcohol

The simple transformation measures ( $m=1$ ) showed that alcohol had the most reliable effect on the transformation component itself.

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This is consistent with the deficits which tend to be found in verbal memory (discussed earlier in this chapter) , and which are likely to be a result of impairment of the articulatory system (cf Baddeley and Hitch 1974). In addition, since an important component of articulation is a motor one, this is also consistent with the more general motor impairment which tends to be found under alcohol intoxication.

The immediate memory measures also fit well with this interpretation. It seems likely that a heavy reliance on an articulatory strategy would be beneficial in facilitating recall of order information because of the inherent seriality of the articulatory system. The deficit found in the early serial positions for order information would be indicative of decay of information from such a system. However, since item information is not lost, and indeed if anything is improved in these same positions (cf Weingartner and Murphy 1977), we are seeing not a general deficit in performance, but a change in the strategy being used. A shift towards reliance on a visuo-spatial representation could explain the data. Such a representation has no inherent seriality and therefore is less appropriate for representing order information, but is likely to be quite adequate for representing item information.

Further support for a differential effect of alcohol on verbal and visual processing comes from two other sources. A recent study by Hartley and Coxon (1984) used the sentence verification task of Clark and Chase (1972), but measured the comprehension

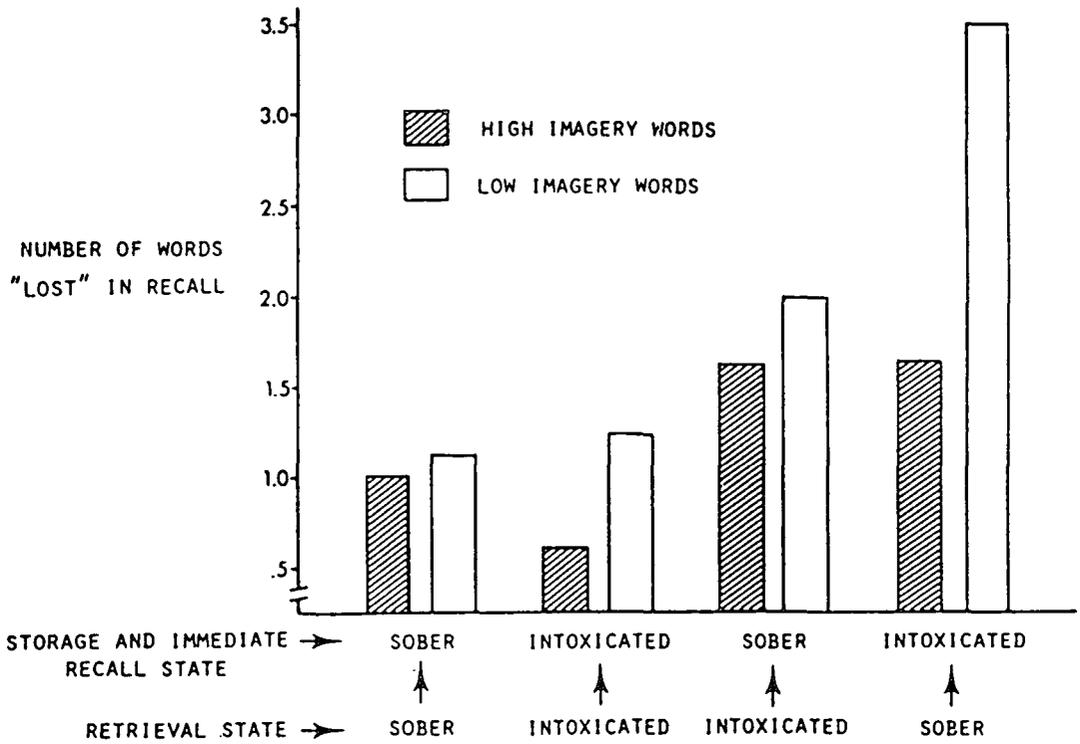
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and verification times separately, following the technique of MacLeod, Hunt and Mathews (1978) to enable them to find two groups of subjects, one of which used a verbal strategy to carry out the task and the other a visuo-spatial strategy. When alcohol was administered to these two groups, performance was indeed poorer for the group using the verbal strategy as would be expected from other studies in the literature. However, the group who used the visuo-spatial strategy actually carried out the task more quickly under the influence of alcohol.

A second study which also suggests visuo-spatial processing being comparatively little affected by ingestion of alcohol was carried by Weingartner, Adefris, Eich and Murphy (1976). They looked at memory for high and low imagery words under a delayed recall paradigm since they were primarily interested in state dependent memory. Figure 6.3 shows the number of each type of word which was recalled on an immediate recall test, but not on delayed recall. The important aspect of the data for present purposes is a much larger discrepancy between high and low imagery words for the conditions in which learning took place under alcohol. Although the situation in this experiment is not directly comparable either with the study of Hartley and Coxon or with the data presented in this chapter, especially because of the delayed aspect of recall, it nevertheless suggests a relative advantage for highly visuo-spatial processing under alcohol intoxication.

These two studies help to support the plausibility of the interpretation of the order errors in the simple memory data. If

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**Figure 6.3** Number of high and low imagery words recalled in immediate but not delayed recall under combinations of intoxicated and sober states. From Weingartner et al 1976.

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a visuo-spatial strategy is less affected by alcohol intoxication, subjects may be biased towards using such a strategy when intoxicated. However, order information is less well represented visuo-spatially and so more errors of this type occur. (Note that no strategy change seems to take place in the Hartley and Coxon study. However, subjects were selected in that study for stability of strategy, and so change under adverse conditions would be less likely.) The decrement in transformation time shows that the articulation component is particularly badly affected under alcohol. Since this is likely to be a component of verbal strategies in memory tasks as well, it points to a particular decrement which may account for some of the effects generally attributed to alcohol in most memory studies.

### 6.5.2 Alcohol and complex performance

Although not significant, the patterns of performance in the more complex alphabet transformation conditions look remarkably consistent both between themselves and with the  $m=1$  conditions. All fifteen measures (across the various conditions) of transformation time are slower under alcohol, and all fifteen measures of encoding time are faster. This stability of performance overall is probably a result of very stable performance by each individual subject, with considerable variation between subjects leading to the overall data being unreliable statistically. A major component of the differences between subjects is likely to be a strategic difference (cf chapter 5). If different subjects are allocating resources

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differently, any group measures are not likely to reflect performance reliably. The more reliable results in the simplest  $m=1$  conditions could be due to less scope for strategic variation since there are fewer task components, and the task as a whole is less demanding.

At this level of analysis, the encoding and transform times are both relatively constant across conditions. However, looking at the storage times, the predominant strategy would appear to be to carry out the whole task as quickly as possible for the moderately difficult C24 and C42 conditions, since storage times tend to be shorter on average. For the C44 condition however, the storage times tend to be slower. This could be a reflection of the subjects under the influence of alcohol being less able to cope with the greater task difficulty in this condition - a strategy of bulldozing through the trial as quickly as possible no longer works.

### 6.5.3 Implications for experimental design

In the present study, although subjects were matched at the beginning of the experiment, strategies may well develop differently even between the two members of a matched pair, or possibly even as a result of alcohol intoxication. Thus alcohol may not only affect components of the task in simple ways, but may affect the strategy actually used to carry out the task. In the immediate memory measures it was possible to infer what such strategy variation may look like. In more complex performance

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however, there are many more possible ways of combining cognitive resources, and so the task of disentangling them becomes considerably less tractable, especially in a between subjects design. The next chapter will discuss how a within subjects design might be more appropriate for looking at the effect of a stressor on the components of a task such as this one.

## CHAPTER 7

### THE EFFECTS OF STRESSORS - NOISE

#### 7.1 INTRODUCTION

The previous chapter examined the effects of the stressor alcohol on performance. It showed strong effects of alcohol on performance in general, but was rather disappointing with regard to the alphabet transformation task in particular. This seemed to be largely due to problems of interpreting complex performance in a purely between subjects design where shifts in strategy might be important components of any effects which occurred. The present chapter continues with the theme of understanding the effect of stressors on the microstructure of complex performance, but attempts to overcome the problems of the previous chapter in three ways. A within subjects methodology is used so that data will be obtained from a single subject with and without the effect of the stressor. This should help to minimise the chance of any differences being hidden by variations in strategies. The stressor used in this chapter is noise. This has the advantages that it is easier to administer than alcohol, especially for a within subjects design, and there is a considerably larger literature in cognitive psychology exploring the effects of noise. Finally, this larger literature provides better baseline data allowing us to focus squarely on the effects of noise on one of the more complex conditions of the alphabet transformation task. Before discussing the experiment, let us first briefly summarise some of the known effects of noise.

7.2 THE EFFECTS OF NOISE

The literature on the effects of noise on performance has shown much confusion and disagreement over the interpretation of noise effects. The concept of arousal has been extensively invoked to explain the effects of noise on performance, the assumption being that loud noise increases arousal. As discussed in the introductory chapter, a unidimensional arousal system gives an inadequate picture of the effects of stressors. For example, Broadbent (1983) has argued that the interaction between noise and time of day shown by Loeb, Holding and Baker (1982) would require arousal to be higher in the morning than the afternoon, which is in contrast to the more generally supposed view that arousal is higher in the afternoon. Similarly, Wilding and Mohindra (1980) argue that it is inappropriate to view the effects of noise from within an arousal framework first of all because of the lack of consistency which exists in the arousal literature, and secondly since even ignoring the lack of consistency, an arousal approach does not specify the precise mechanisms which are involved. It therefore seems more appropriate to consider the effects of noise as a distinct type of stimulus which may interact with cognitive processing. Looking at the noise literature from this viewpoint identifies two main approaches which tend to be taken in attempting to understand what the nature of such an interaction might be. The first of these thinks of noise as primarily affecting basic cognitive processes, and the second focuses more on noise being involved in strategic changes to the way in which a task is carried out. These are briefly summarised in the next sections.

## The Effects of Noise

### 7.2.1 Noise And Basic Cognitive Processes

#### 7.2.1.1 Short term memory

It has been argued that noise reduces the effectiveness (or capacity) of short term memory (eg Eysenck 1982). For example, Hamilton, Hockey and Rejman (1977) showed impaired recall in noise on a running memory span task, where subjects were required to recall the last eight items on lists of unpredictable length. Hockey (1984) points out that decrements seem particularly marked as the tasks become more `intellectual` (eg reasoning, computation, comprehension and reading).

One important variable stands out as being different from the rest. When the order in which items were presented is important, noise tends to enhance rather than impair recall. This is borne out by numerous studies which show that when items have to be recalled in the order in which they were originally presented performance is better in noise (eg Hockey and Hamilton 1970; Dae and Wilding 1977; Millar 1979). In addition, the use of order as a retrieval cue seems to be enhanced in noise. Hamilton, Hockey and Quinn (1972) tested recognition of paired associate lists by testing the lists in a random order, different from the order of presentation, as is usual in this paradigm, or by testing in the same order as the lists were originally presented. They found that noise facilitated the latter condition. Thus noise seems to improve both the recall of order information and the utility of order information as a cue to recognition. What aspects of the short term memory system might lead to such patterns of results?

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### 7.2.1.2 Verbal and spatial processing

The previous chapter suggested a strong distinction in the effects of alcohol between verbal and visuo-spatial processing. One consequence of this was that ordered recall, which was argued to be a function of verbal/articulatory processing, was worse under alcohol while spatial processing was improved. The reverse seems to be the case with noise. The previous section suggests that since recall of order is improved under noise (and this tends to be primarily on verbally mediated tasks), that verbal processing is enhanced by noise. Conversely, in tasks where spatial location has to be remembered, noise impairs recall (eg Hamilton and Hockey 1970; Davies and Jones 1975; Daee and Wilding 1977). In a similar vein, Hartley, Dunne, Schwartz and Brown (1986) have shown impairment of spatial and enhancement of verbally mediated strategic approaches to the Clark and Chase (1972) sentence verification paradigm. Thus noise seems to act in the opposite direction to alcohol in its specific effects on verbal and spatial processing. Such a differential effect of noise and alcohol is broadly in line with the conclusions of Colquhoun and Edwards (1975), who explained them in terms of noise being arousing and alcohol de-arousing. However, considering the effect of a stressor in terms of its influence on specific classes of resources is likely to be more informative than resorting to non-specific concepts such as arousal.

One apparent paradox springs out of the distinction between different visuo-spatial and verbal effects. Mohindra and Wilding (1983) show a slower rate of rehearsal under noisy conditions.

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This rehearsal presumably takes place in a system such as the articulatory loop (Baddeley and Hitch 1974). This might be expected to lead to reduced memory for verbal material since the articulatory loop is claimed to be limited temporally rather than by a fixed number of items, and so slower rehearsal rates should imply a smaller capacity in terms of number of items. However, the prime advantages for noise appear in the form of ordered recall as mentioned above, or a reduction in impairment of recall of acoustically confusable items (eg Wilding and Mohindra 1980; Millar 1979). A reduction in the capacity of the articulatory loop may seem rather inconsistent with this improved performance. Mohindra and Wilding (1983) reconcile this by claiming that the reduction in capacity will lead to less opportunity for confusion between items in the loop, and thus better overall recall in certain situations (eg with acoustically confusable items, or ordered recall). Less specifically they have also suggested that the 'quality of the information in the loop is improved in noise' (Wilding and Mohindra 1980, 1983). This latter point will be discussed further in the final chapter.

### 7.2.1.3 Noise and Masking

Thus far, some of the effects of noise have been discussed, but what mechanism might be responsible for these effects? One particularly interesting approach which is worth mentioning at this stage since it attempts to summarise much of the noise literature with a relatively simple model is that of Poulton (1977). The basis of the model is that noise primarily acts to

## The Effects of Noise

mask auditory feedback and inner speech, and that when improvements in performance are observed they are due to increased arousal canceling out the masking effect. Refinements of the theory (Poulton 1978, 1979) propose that the arousal component changes over time with habituation to noise, and produces a carryover effect which is responsible for performance after the noise is switched off. These are claimed to 'account for all the known effects of continuous noise on performance' (Poulton 1979). However, even ignoring the problems of the nonspecific nature of the concept of arousal which have been discussed earlier (and which Poulton (1977) himself alludes to), the precise shape of the arousal function which he invokes does not have any real empirical basis. Although the masking component of this view has been effectively discredited as a sufficient explanation by Broadbent (1978) and Millar (1979), both of whom emphasise the importance of an attentional component, it seems likely that it is still a useful concept to consider in understanding the effects of noise. One particularly intriguing possibility is that rather than noise masking inner speech, it induces a strategy of articulation to mask the effect of the noise. Indeed Poulton (1977) himself suggests that noise may produce 'more vigorous inner speech', a suggestion which has been pointed out to be inconsistent with his own view (Broadbent 1978), but would be consistent with this alternative view. Further evidence to support such a view comes from Millar (1979) who showed that the combination of noise and articulatory suppression was if anything better than suppression alone; Salame and Baddeley (1983), who showed that suppression could even

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counteract effects of irrelevant Arabic speech sounds, and Wilding, Mohindra and Breen-Lewis (1982) who showed that in noise maintenance rehearsal tends to be adopted unless instructions induce an alternative strategy.

### 7.2.1.4 Interference between Noise and Task

One effect of `irrelevant` stimuli which is now pervasive in the psychological literature is the Stroop effect. This can be generalised to say that a person trying to choose between two actions or percepts is likely to find it more difficult when some irrelevant stimulus arrives that is more associated with the wrong action or percept (Broadbent 1983). Where noise fits into such a view is not entirely clear. It could be argued that since white noise (the usual stimulus in noise experiments) consists of a wide range of frequencies, it has the appropriate information content (when appropriately filtered) to interfere with specific speech sounds. It is certainly true that when specific speech sounds which consist of words related to the task stimuli are presented, performance is drastically impaired, with the impairment being a function of the degree of similarity of the `irrelevant` words to the task stimuli (Salame and Baddeley 1982). However, even when meaningless sounds which are nevertheless speech sounds, for example from another language, are used (eg Colle and Welsh 1976; Colle 1980; Salame and Baddeley 1983), performance is still reliably impaired. If we return to the masking analogy of Poulton (1977), it would appear that there is a gradation of degradation depending on the

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similarity of the noise stimuli to the task stimuli. It may indeed be the case (as admitted by Millar 1979), that one component of the effect of white noise is masking of (or interference with?) some kind of internal representation of the stimulus. It certainly seems to be the case that the greater the phonemic similarity between the noise stimuli and the task stimuli, the greater the interference. White noise may be one end of this continuum.

### 7.2.1.5 Focused Attention

The notion that loud noise focuses attention has a long history in psychology. Within the arousal framework, Easterbrook (1959) suggested that increased arousal led to greater attentional selectivity by decreasing the range of peripheral cues attended to. This hypothesis tends to have been tested using dual task performance as the prime measure of selectivity. Within the noise literature two main variants have been used - incidental learning as the secondary `task` or tracking with a simple visual or auditory task as the secondary task (Eysenck 1982). In cases where the secondary task was incidental learning, it is very frequently a visuo-spatial task. This was the case with four out of the five studies cited by Eysenck (1982). The fifth tested incidental recognition memory for a piece of prose and was not affected by noise. Given the discussion in the previous section which suggested that visuo-spatial processing tended to be impaired in noise, it is not clear that such data can be clearly interpreted as showing focusing attention towards a primary task, but rather may also be influenced by the nature of the

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processing which the tasks require. The other class of studies, in which subjects know while carrying out the task exactly what they have to do for both the primary and secondary tasks indeed tend to show a bias towards the primary task and away from the secondary task under noise (eg Hockey 1970a, 1970b). However, the effect is not simply a change in the allocation of resources between the two tasks. The precise components of the task are also important in determining exactly how attention is allocated. The secondary task in these cases involved monitoring an array of six lights for occasional flashes. Hockey (1970a) demonstrated that the decrement in the secondary task was due to increased detection of central light detections, but impaired peripheral detections. Hockey (1970b) showed that this was not simply the result of narrowing the spatial area which was monitored since when the more peripheral lights were made more probable, the pattern reversed and subjects made more errors in the central and fewer in peripheral locations. This dissociation between physical and attentional space is well established in the attentional literature (see eg Posner 1978). The important point for present purposes however, is that noise does indeed appear to increase attentional selectivity in many situations, although the precise mechanism by which this occurs is not altogether clear. It has been suggested earlier in this section that in some cases it may be an artefact of the type of processing required for the different tasks used. However this is not an adequate explanation for differences in the patterns observed in a single secondary task with the probabilities of target locations

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manipulated (Hockey 1970a, 1970b). This type of problem (and a number of others) can be better understood by considering the role of noise on the strategic approach taken to the task.

### 7.2.2 Strategic Response to Noise

The previous section pointed to some potential explanations for the effects of noise in terms of its effect on basic cognitive processes. It also pointed out that there is some evidence to suggest that considering noise as affecting the strategic approach to the task taken by a subject may be a fruitful way to consider noise effects. It has certainly been frequently suggested that noise may be influential on the strategy adopted by the subject rather than on some universal component of memory (Wilding and Mohindra 1983, Hockey (1984), Smith, Jones and Broadbent 1981, Broadbent 1983, Breen-Lewis and Wilding 1984, Smith 1983a). The reasons given for this however have been many and varied. This section examines a number of ways of looking at how strategies might change which can and have been taken.

#### 7.2.2.1 Noise affects some strategies but not others

The previous section suggested that noise impairs some processes and improves others. We would thus expect that strategies which relied heavily on impaired processes would show impaired performance while those which relied most heavily on processes which were improved by noise would show an overall improvement. This is clearly demonstrated by the study of Hartley et al (1986) referred to earlier in which subjects were pre-screened for their

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preferred strategy, verbal or spatial, in solving a sentence verification task. Noise improved performance in those who adopted the verbal approach to carrying out the task and hindered those who adopted the spatial approach.

A similar example can be taken from Smith (1983b). He compared performance on the running memory task of Hockey and Hamilton (1977), requiring subjects to remember either the last eight or the last five items in the sequence. The different task requirements biased subjects towards very different recall strategies, and subsequent apparently different effects of noise. With eight items to be recalled, subjects tended to recall the last items first, and then try to get the rest. Noise improves recall of the final items and impairs that of the earlier items in the sequence. With five items to be recalled, subjects tend to start recalling about five items back and recall in the direction of the end of the list. In this case noise impairs the final items in the list and has little effect on the earlier ones. To fully understand the results it is crucial to understand the recall strategy used. This strategy is presumably a function of the ease with which people are able to judge how far back in the list they have to start recalling.

### 7.2.2.2 Noise affects strategy selected

A number of authors have suggested that noise actually influences the strategy which is selected. The reasons given for this have varied from a product of differential effects on component

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processes, through the way in which the task is perceived, to a direct effect on the control processes which determine strategy selection. This section summarises the main emphases which have been made in this approach.

### 7.2.2.2.1 Changes in effectiveness of component processes

If the effectiveness of the processes which are called on to carry out a given task are changed in noise, subjects may be expected to change to a strategy which relies more heavily on processes which are less affected (Jones, Chapman and Auburn 1981). This could be a component of the improved order recall which is often observed with noise and verbal stimuli. If subjects tend to shift towards an articulatory rather than a visuo-spatial means of coping with the task, order would be better encoded.

The above view stresses the effects of changes which result from effects of noise on internal components of the cognitive system. Similar changes in the strategy adopted can also be a consequence of external manipulations such as instructions, the type of task the subject is performing (or is expecting to perform). For example Breen-Lewis and Wilding (1984) and Lewis and Wilding (1981) have shown that subjects who are told to expect a recall test do better in noise than quiet, while subjects expecting a recognition test perform worse on a subsequent recall test in noise than is the case in quiet.

The way feedback from the task is evaluated may be influenced by noise. For example, noise may alter the perception of

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competence, with associated changes to try to maintain the perceived status quo (Jones, Chapman and Auburn 1981).

Alternatively it may shift the balance of a speed accuracy trade-off function, which could explain the increased rate of work and concomitant increase of errors which is often observed (eg Hockey 1979).

### 7.2.2.2.2 Changes in use of resources

The previous section emphasised strategic changes as a consequence of changes in the efficiency of the individual resources which make up a given strategy. Another approach is to consider noise as directly affecting the control processes which determine how a given task will be carried out. Some variations on this theme claim that noise improves the dominant strategy at the expense of a less dominant one. This may be the strategy associated with the primary task in a dual task situation (eg Hockey 1970a, 1970b). It may be the strategy which is most appropriate to carry out the task (eg Wilding and Mohindra 1983) (but Breen-Lewis and Wilding (1984) did not find any improvement on recognition performance on a group of subjects told to expect a recognition test). It may be the strategy which the subject has greatest predilection towards (eg Schwartz 1975). The concept has even been invoked to explain improvement under noise in finding instances of dominant categories (ie high frequency) in semantic memory tests (Eysenck, 1975). Smith (1982), Broadbent (1981), Broadbent (1983) suggest another variant of this theme which emphasises rather more active control on the

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part of the subject. They propose that noise favours more investment in the strategy which best repays effort, so that the part of the task which suffers most severely is the one that in the absence of noise would be given the lowest priority. All of these approaches are similar in concept, although not in detail, to the funnelling of attention notion which was discussed earlier, except here it is control processes which are funnelled rather than aspects of perceptual space.

### 7.2.3 Summary

The explanation for the effects of noise can be split into two approaches: those emphasising differential effects of noise on basic cognitive processes, and those emphasising the effect on the control processes which are responsible for organising these basic processes to carry out a given task. There are clearly consistent and contrasting effects of noise on verbal-articulatory and visuo-spatial processes, (eg Hartley et al 1986), and equally clearly in biasing towards particular strategies as shown by the effect of task priority (eg Smith 1982). However, in many situations it is not clear what the relative contribution of these effects is to task performance, since it is often difficult to disentangle interactions between strategic variation and the processes on which the strategies rely. Indeed in some cases it is possible to argue that apparent variations in strategy are entirely due to changes in the efficiency of the underlying processes. In the light of such complex patterns, Hamilton, Hockey and Rejman (1977) and Hockey,

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MacLean and Hamilton (1981) have emphasised the need to consider the effects of stressors as putting the cognitive system into a particular state, which can be defined as a multidimensional pattern of effects on particular components of the system.

Hockey and Hamilton (1983) have exemplified this mainly in terms of the tasks used, but Hockey has also emphasised the need to consider such state changes within 'a realistic functional model of cognitive behaviour' (Hockey 1979).

The most salient effects of noise for present purposes are potential effects on the strategy adopted and relationship between verbal, particularly articulatory, processing and non-verbal processing. Let us now consider how we would expect these to influence performance in the alphabet transformation task.

### 7.3 NOISE AND ALPHABET TRANSFORMATION

The major advantage of the alphabet transformation task is that it will enable us to see how the various components are traded off against one another within a single task, or if in fact all components are equally affected in a task of this difficulty. Let us consider first the effect we might expect on each of the individual components in the light of the preceding argument and then any additional effects we might expect from their combination within the one task.

Encoding time has been argued earlier to consist of visual encoding of the stimulus, access time to long term memory, and possibly also searching through the chunk thus retrieved to find

## The Effects of Noise

the starting letter. The visual encoding component could lead us to tentatively expect an impairment in noise, if the visuo-spatial memory decrements discussed earlier are in fact due in part to encoding difficulties. There is however no direct evidence that this is the case. If we regard this as memory component of the task we would expect an impairment in noise (eg Hamilton, Hockey and Rejman 1977; Hockey 1979). However, the search part may also be regarded as a throughput component, which the same authors would expect to be enhanced by noise.

Similarly, the enhancement of retrieval of dominant items from semantic memory (Eysenck 1975) may also be relevant to the current situation, predicting an enhancement under noise.

Transformation time is probably the `purest` of the components, but even so a precise prediction cannot be made. If we regard it as a throughput variable in the sense of Hamilton, Hockey and Rejman (1977), we would expect it to improve. However, given the role of articulation in this part of the task we might expect it to be slower in noise (Mohindra and Wilding 1983).

Storage time reflects memory and organisational components of the task. Again on the basis of the throughput/memory distinction we would expect an impairment. Similarly, from the organisational point of view we might also expect impairment. For example Jones, Chapman and Auburn (1981) suggest that noise `interferes with ongoing plans and intentional behaviour`.

The recall latency and output stages might be expected to show a decrement under noise since they primarily involve retrieval from

## The Effects of Noise

memory. By the same argument an increase in errors might be expected.

As the trial progresses, the memory load will increase (but remember that previous chapters showed effects of expected memory load even on the very first component of the task). We might expect an increasing memory load to lead to greater impairment in noise if for example the focusing of attention which has been frequently noted is in fact a result of a reduction in capacity of the system (eg Eysenck 1982). If however, attention is redeployed (eg Hamilton, Hockey and Quinn 1972) then we might expect any differential effects on the task components to be emphasised.

Hamilton, Hockey and Rejman (1977) showed that in a paper and pencil version of the alphabet transformation task, the simplest conditions were faster in noise and the more complex conditions which relied more heavily on the memory component were slower. The preceding discussion has assumed that the distinction between throughput and memory processes will still be observed in the component patterns. It is however possible that a general decrement results in the more complex situations, which will be reflected in all components of the task. If we consider the redeployment (rather than reduction) of attention argument, we might expect in this task that all available attention must be used, therefore there is nowhere to redeploy it to or from since the components are not primary and secondary tasks, but rather all part of a single task. A related argument says that since

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fast throughput typically observed with noise is often accompanied with an increased error rate, the task demands are such that an increased error rate will not be acceptable since it will cause an error on the whole trial rather than simply the component on which it actually occurred. Thus there will be a tendency to counteract any shift in a speed-accuracy tradeoff function which noise might otherwise encourage.

### 7.4 STUDY 4

Experiment four was designed to look at the effects noise on performance. It concentrates on the patterns of performance observed in a complex version of the alphabet transformation task to ensure that sufficient stable data can be collected to detect any consistent changes in the patterns of performance which might occur.

#### 7.4.1 Subjects

Six university students (three male, three female) were recruited for three consecutive days. Each of the first two days involved a preliminary session of about one and a half hours duration. The third day consisted of four experimental sessions of about one hour each with one hour break between them.

#### 7.4.2 Procedure

Session 1 introduced the subject to the alphabet transformation task with six blocks, each of five correct  $m=1$ ,  $t=4$  practice trials. This was followed by three fifteen minute periods of

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$\underline{m}=4$ ,  $\underline{t}=4$ . Each period consisted of as many blocks of five correct trials as the subject could get through in the time. The last block started before the end of the period was always finished, so the actual time spent in each period was always greater than fifteen minutes. Subjects were informed that fast accurate work would gain them a substantial bonus of up to two pounds per hour over and above the standard one pound per hour which they were to be paid. This was calculated on total number of correct trials they could complete in each fifteen minute period. Subjects were reminded about the bonus before the start of each session. The bonus scheme was introduced since a pilot study had shown remarkably little effect of noise in well practiced subjects. It was reasoned that if subjects could be encouraged to work as near to their limits as possible at all times, any effect due to noise would be more likely to become apparent.

The second session gave subjects further practice, again starting with six blocks of  $\underline{m}=1$ ,  $\underline{t}=4$  to remind them of the basic procedures required. This was again followed by three fifteen minute periods of  $\underline{m}=4$ ,  $\underline{t}=4$ , but this time subjects were introduced to the white noise. This was presented through headphones from the audiometer. For the first two periods subjects were subjected to the background level of 45dBA. For the third period they experienced the full level of 95dBA.

The four main experimental sessions were all run on a third day. Each session lasted approximately one hour with one hour break between sessions (sessions took place at approximately 10.00-

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11.00, 12.00-13.00, 14.00-15.00 and 16.00-17.00 hours). Each session comprised two practice blocks of  $m=4$ ,  $t=4$  followed by alternating sequences of quiet-noise-quiet periods, or noise-quiet-noise, with 5 minutes break between them. The order was the same for all subjects with quiet starting sessions 1 and 3 and noise starting sessions 2 and 4. The background noise level of 45dBA was used throughout, increasing to 95dBA in the noise periods. Subjects were given two minutes to adjust to the noise level before starting each period.

### 7.5 RESULTS

#### 7.5.1 Group Results

Table 7.1 summarises the mean number of trials completed in noise and quiet conditions, mean error rates, and mean solution times. This fairly gross level of analysis shows no differences between noise and quiet conditions.

	Condition	No of trials			Solution time (Sec)
		Correct	Errors	Abandoned	Correct Trials
Mean	Q	280	54	51	10.2
6 Ss	N	283	57	42	10.3

Table 7.1 Mean summary data for all 6 subjects

To investigate the finer grain of the temporal microstructure of the task, analyses of variance were carried out to examine the effects of noise on each of the main task components as the trial progressed. Figure 7.1 shows the mean times for each of the components and table 7.2 summarises the results of the analysis.

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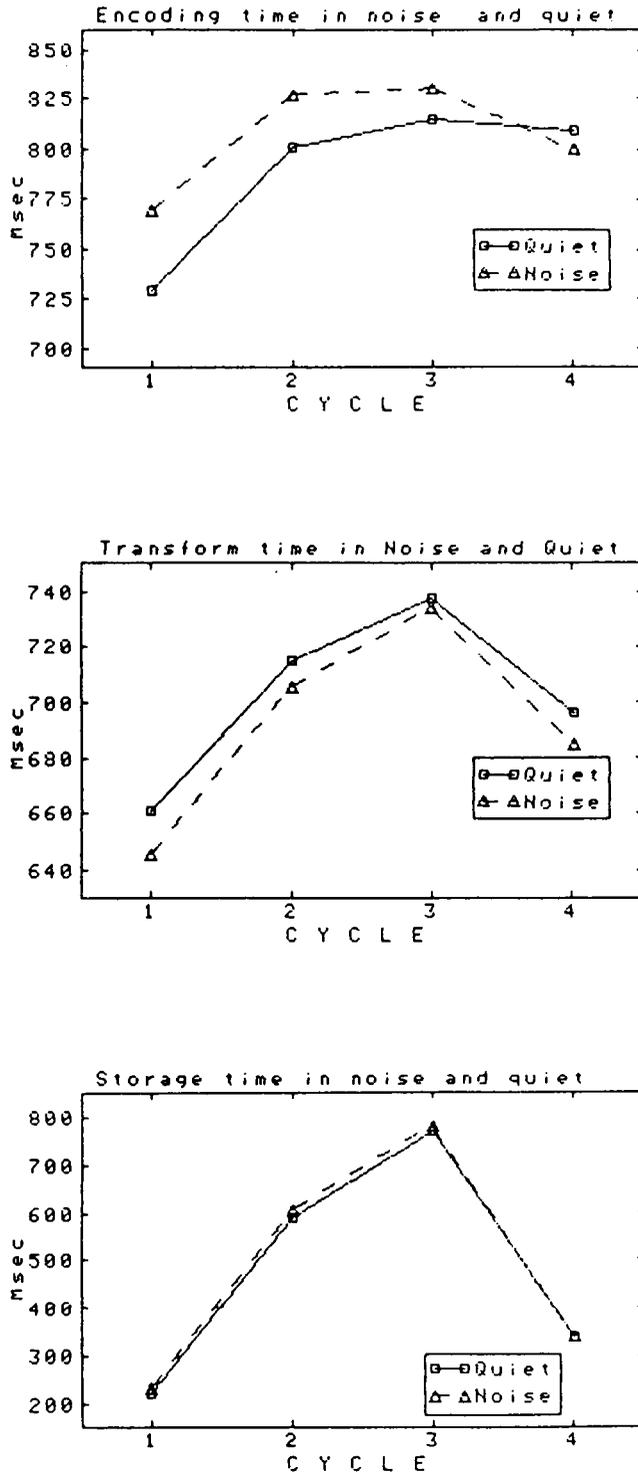


Figure 7.1 Mean time for each component in noise and quiet.

## The Effects of Noise

		Encoding		Transform		Storage	
		F	p	F	p	F	p
Noise	(df 1,5)	5.12	.07	<1	-	<1	-
Cycle	(df 3,15)	1.45	.27	7.04	.004	6.2	.006
Noise x Cycle	(df 3,15)	5.11	.01	<1	-	<1	-

Table 7.2 Summary of analysis of variance of effects of noise across cycles for each phase of the task

The basic pattern of change as the trial progresses in each component is essentially as observed in the earlier studies, except that transform time builds up to a peak in the middle of the trial rather than getting progressively faster. However, the overall solution times are rather faster than noted earlier, probably as a consequence of the extended practice on only one condition, as well as the incentive scheme. The only effect of noise is observed in the encoding time where noise slows down the time taken, especially in the early phases. This result would be consistent with the possibilities discussed earlier that differentiation decreases as the trial progresses since more and more available resources are necessary to carry out the task, and strategic redeployment is therefore not possible in a correct trial. In the early parts of the trial, the memory components of the encoding phase are indeed impaired, but no effect is seen on the storage components since the variance is normally considerably greater in this phase anyway. The direction of effect on the transformation component is consistently in the direction of throughput being faster in noise for all cycles, although statistically it is non-significant.

Although these results are not particularly discrepant from

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patterns which might have been expected from the literature reviewed earlier, they are not particularly striking when compared to the extremely reliable effects reported in earlier studies using this task. It might have been expected that the transformation component in particular would show reliable effects of noise given the strongly conflicting predictions of its role as a throughput variable (Hockey 1979) and its role in using articulation to assist memory (Mohindra and Wilding 1983).

There are a number of reasons why such weak effects might have been found. First of all, with a within subjects design such as this, rather than adopt distinct strategies for each experimental conditions, subjects may adopt some intermediate strategy which is a reasonable compromise for all condition to which they are exposed in a given experiment, thus diluting any effects which might be observed between these conditions. This will of course balance out against the size of individual difference effects (see previous chapter). This is essentially a generalisation of the view expressed by Poulton (1982). He suggested that asymmetric transfer may occur in within subjects designs, depending on the order in which conditions occurred, and the strategies which were called upon to tackle them. A second view is that when looking at group data, particularly in a situation with so many ways of tackling the task, we are averaging across a number of different strategies which subjects independently adopt (irrespective of the noise manipulation), and thus are not really seeing a pattern of performance which would be exhibited by any individual. A similar view has frequently been aired more

## The Effects of Noise

generally in the cognitive psychology literature (eg see Claxton 1980). This view has some credence given the discussion of individual differences in this task in earlier chapters. The most obvious way to resolve this conflict is to examine the patterns of performance exhibited by each subject individually. If the former view is correct (or if there is no real effect of noise anyway) then individual subjects should show similar patterns to the group data. If however there are in fact differences between subjects in their response to noise we might expect strong but different patterns of response in the different subjects.

### 7.5.2 Individual Subject Data

Table 7.3 summarises the number of correct and error trials for each subject in noise and quiet. There is no consistent effect of noise. Table 7.4 shows the total solution time in noise and quiet based on all correct trials completed. The only reliable effect is a definite slowing in solution time under noise for subject 1 ( $t(488) = 5.32, p < .0001$ ). All other subjects show no effect in total time spent on the task ( $t < 1.6$  in all cases).

To examine the microstructure of performance, separate analyses of variance were performed for each subject for each of the three main phases across task cycles. Figure 7.2 shows the data for each subject as the trial progresses. Since the full data is rather complicated, we shall concern ourselves primarily with the overall effect of noise on each component. A summary of the

## The Effects of Noise

Subject	Condition	No of trials		
		Correct	Errors	Abandoned
1	Q	243	75	25
	N	247	53	22
2	Q	267	53	73
	N	264	58	45
3	Q	296	53	35
	N	320	65	10
4	Q	261	69	72
	N	257	80	72
5	Q	305	19	19
	N	310	19	12
6	Q	307	54	80
	N	301	66	91

**Table 7.3** Number of trials completed, and errors for each subject.

	Subject					
	1	2	3	4	5	6
t	5.32	.31	1.65	1.24	.53	.97
df	488	529	614	516	613	606
p	<.0001	.75	.10	.22	.60	.33
Quiet	11.19	11.28	9.79	8.99	11.60	8.22
Noise	12.15	11.34	9.63	9.10	11.53	8.32

**Table 7.4** Comparison of total time taken in noise and quiet for each subject.

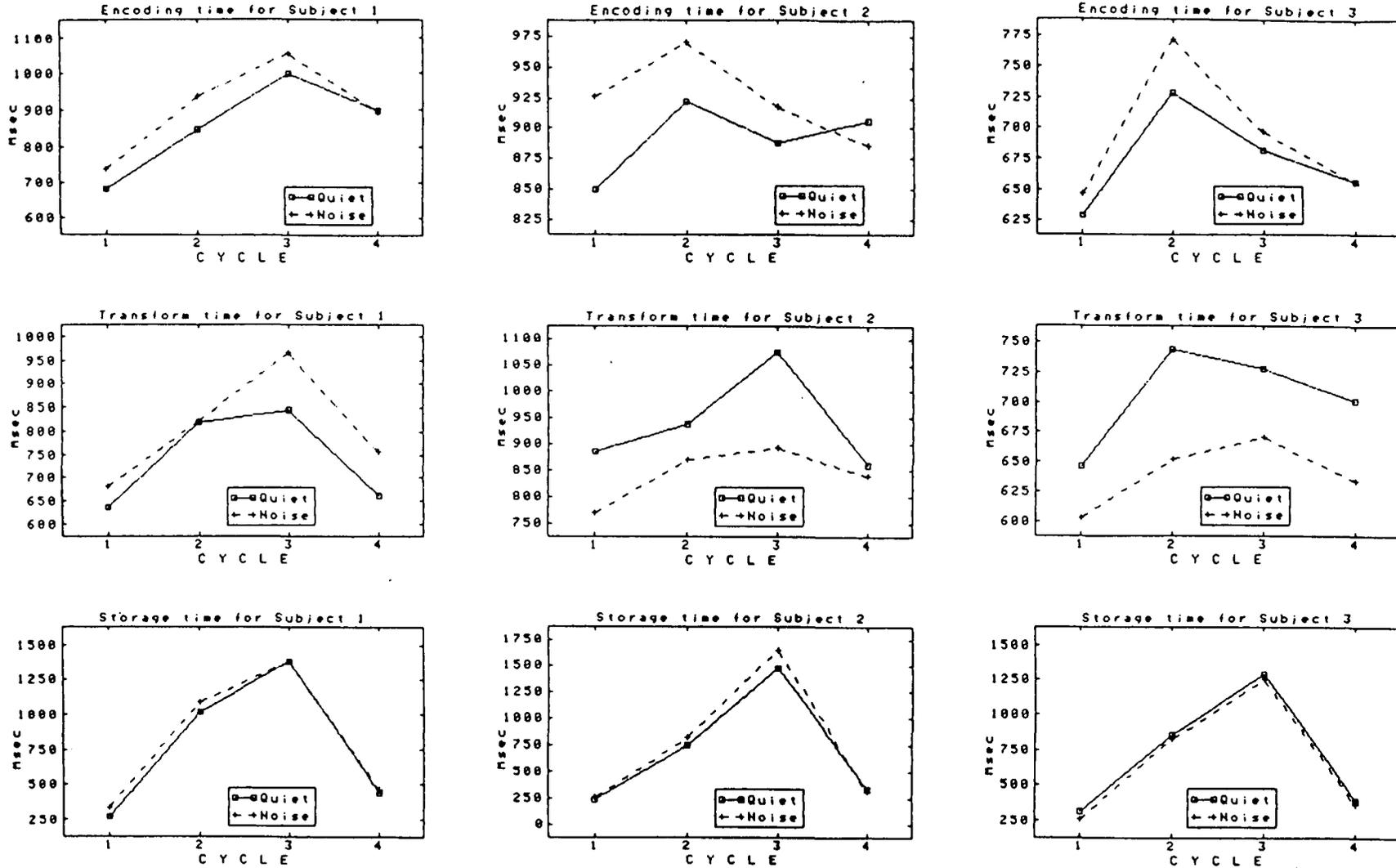


Figure 7.2(i) Individual data for subjects 1-3.

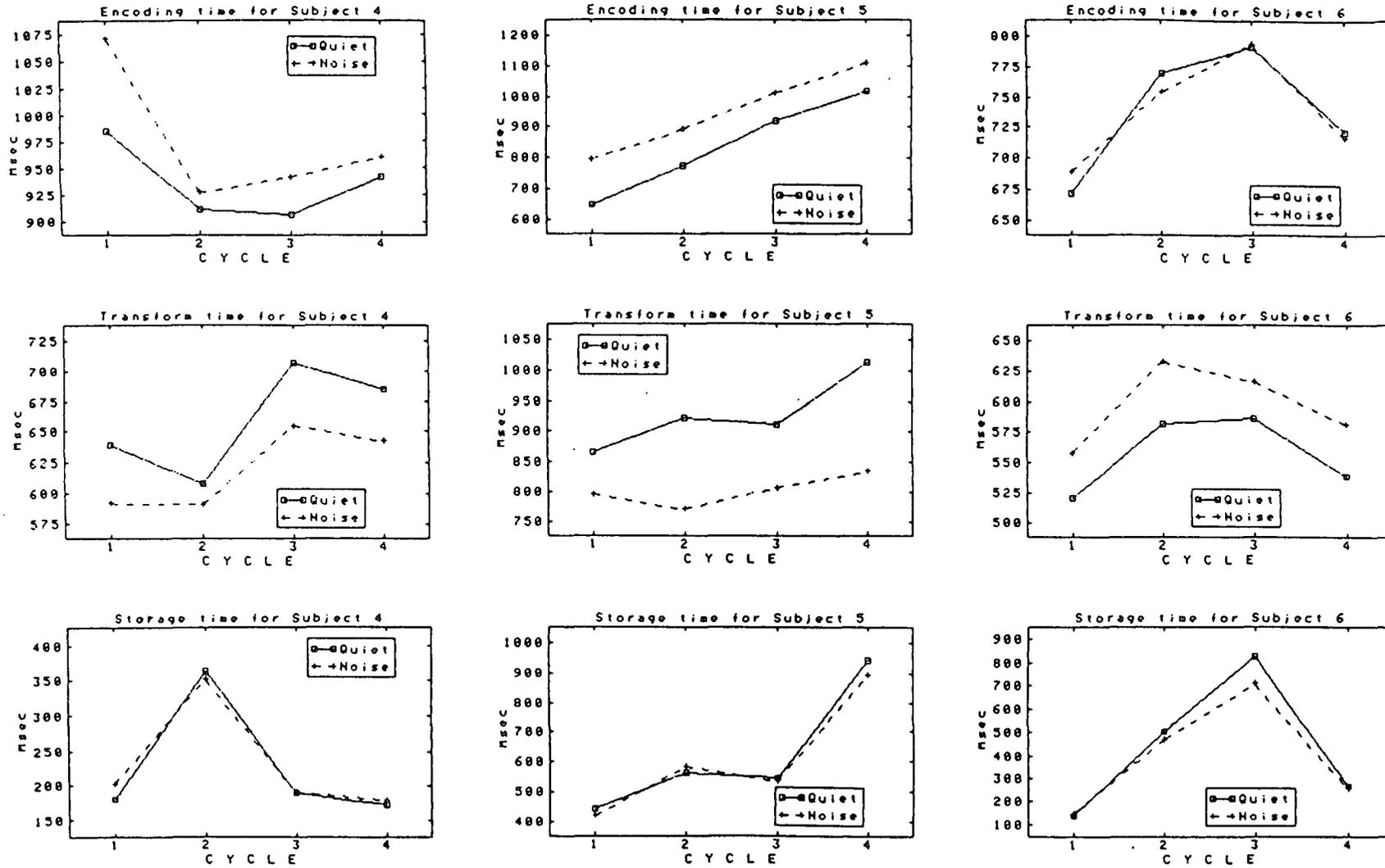


Figure 7.2(11) Individual data for subjects 4-6.

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Subject	1	2	3	4	5	6
ENCODING						
Quiet	859	892	674	935	839	738
Noise	905	925	693	975	951	738
Q-N	-46	-33	-19	-40	-112	0
TRANSFORM						
Quiet	741	939	704	659	927	557
Noise	807	843	640	620	802	597
Q-N	-66	96	64	39	125	-40
STORAGE						
Quiet	773	698	707	226	621	436
Noise	817	766	670	231	607	400
Q-N	-44	-68	37	-5	14	36

Table 7.5 Overall mean times (msec) for each component and their differences, for each subject. Negative differences indicate noise is slower.

Subject	1	2	3	4	5	6
df Noise	1,488	1,529	1,614	1,516	1,613	1,606
df Cycle						
Noise x Cycle	3,1464	3,1587	3,1842	3,1548	3,1839	3,1818
ENCODING						
Noise	7.06**	4.47*	9.96**	13.96***	46.38***	0.00
Cycle	73.64***	3.42*	79.05***	25.14***	132.56***	45.59***
Noise x Cycle	1.33	2.35	2.11	2.53	1.16	.84
TRANSFORM						
Noise	14.91***	29.95***	70.35***	11.88***	60.41***	57.55***
Cycle	47.00***	21.47***	26.76***	22.31***	13.08***	76.82***
Noise x Cycle	2.64*	5.39**	2.44	.87	4.67**	1.53
STORAGE						
Noise	1.95	3.25	1.46	.67	.81	3.46
Cycle	254.83***	288.42***	948.00***	292.44***	272.69***	293.96***
Noise x Cycle	.29	1.10	.13	1.95	1.41	2.58*

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

Table 7.6 Analyses of variance of each component for each subject across the the trial.

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relevant means and their difference is shown in table 7.5 and table 7.6 summarises the analyses of variance. It can be seen that all but one of the subjects show a decrement in encoding time with noise, although none show the interaction with cycle which was seen in the group data. As indicated by the group data, storage times show little sign of being affected by noise. However, the effects on transformation time are very strong indeed for all subjects. But it is immediately apparent why no effect was seen in the group data since two subjects show a strong impairment of transform time with noise, and four show a strong improvement. However, no subjects show an improvement in noise for the output phase, and four out of the six show an impairment (table 7.7). This suggests that the memory retrieval component of the output phase is indeed impaired by noise while the throughput emphasis in the transformation component results in performance speeding up.

	Subject 1	2	3	4	5	6
OUTPUT						
Quiet	1191	851	1027	778	1236	734
Noise	1516	838	1094	949	1294	844
Q-N	-325	13	-67	-170	-58	-109
t (df)	5.51(488)	.39(529)	2.42(614)	4.17(516)	1.28(613)	4.56
p	<.0001	.70	.016	<.0001	.20	<.0001

Table 7.7 Mean times (msec) for output phase. Negative differences show noise is slower.

The only subject who showed a general decrement under noise was subject one, and of course this was reflected in a difference also being apparent in the total solution times. All other

## The Effects of Noise

subjects (with the possible exception of subject 6) showed an improvement in transform speed and a decrement in encoding time.

If we consider the discussions in the introduction of this chapter relating to the effect of noise as 'focusing attention', the general argument has been that attention is focused, for example, on a primary task and away from a secondary task as measured by time to respond to each task or errors. It has already been pointed out that there is less scope to redistribute attention in the current task since all aspects of it must be performed accurately to complete it. One possibility related to the focusing phenomenon is that rather than task component priorities changing, the variance associated with these components may reduce. If this were the case, the implication would be that attention is focused onto the task itself and the effect of any extraneous (or random) distractors would be reduced (note the contrast with Broadbent (1958), who viewed noise itself as a distractor).

Table 7.8 summarises the direction in which noise significantly affects the variance of each component of the task. Since some of the components vary significantly across the cycle, it is not appropriate to use the overall variance. The variance for each component, for each cycle has been compared in noise and quiet with the F test, and an effect has been noted if at least two of the four components were significantly different in the same direction at better than  $p=.05$ . For comparison, a summary of the differences between means is also shown. Again, the pattern of

## The Effects of Noise

results is far from clear cut, but it does have a number of interesting components. One subject shows increased variance with noise. This is subject 1 again, who also showed a general decrement in the means of each component and total time. This is one case where a theory of noise as a distractor would appear very tenable. However, subjects 3 and 5 show quite the opposite. They both show a decrease in the variance of all components under noise. This would be more compatible with the version of the focusing of attention theory mentioned above.

	Differences of MEANS			Differences of VARIANCES		
Subject	E	T	S	E	T	S
1	-	-		-	-	
2	-	+		-	+	-
3	-	+		+	+	+
4	-	+			+	-
5	-	+		+	+	+
6		-		-	+	-

**Table 7.8** Summary of direction of significance differences of means (from ANOVA), and variances (at least two of the four components show difference). Impairment in noise (slower or greater variance) is shown by '-', improvement by '+'.

The storage component now shows differences as a function of noise, but they are not completely consistent. The two subjects who show a reduction of variance in all components are the only ones who show a reduction in the storage component. The other three subjects who show an effect show greater variance. This could again be interpreted as distracting effects of noise (especially on planning - cf Jones, Chapman and Auburn (1981)), since the storage component is the one which is most appropriate for pauses to recover from any excessive degradation of

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performance. It is clearly not a universal decrement since all of these subjects show reduced decrement in the transformation component.

Finally the patterns observed in means and variances are not simply due to the usual correlation between means and variances in reaction time studies. Subjects 3 and 5 show reduced variance for encoding, but increased means under noise and subject 6 shows reduced variance for transformation although the mean is longer.

### 7.6 DISCUSSION

The group results showed relatively weak effects of noise which were not inconsistent with established findings in the literature. However when individual subjects were examined, it was clear that although each subject showed very stable data, none were accurately reflected in the group data. This is very similar to the experience of Hartley et al (1986), who only found an effect of noise when they separated subjects on the basis of whether they used a verbal or visuo-spatial strategy. Looking at individual components, the only one which showed a consistent effect of noise was the encoding phase. The impairment produced is consistent with the view that the short term memory aspects of this phase are predominant. The lack of effect on the storage component for the group is confirmed on the means (but not the variances). However, it is clear that the lack of group effect on the transformation component is due to different subjects showing quite different patterns of performance on this component.

## The Effects of Noise

Despite the lack of consistency between subjects, each individual shows remarkably stable performance. However, there seem to be clear differences between individuals in their susceptibility to noise. For example, subject 1 shows a consistent decrement reflected even in total time which showed no effect for any other subject. This effect of individual differences in susceptibility to noise has seldom been demonstrated in laboratory studies, but is consistent with the findings of a number of questionnaire studies (eg Langdon 1976; Weinstein 1978) which have reported strong correlations between measures of annoyance and self ratings of sensitivity to noise.

It was suggested earlier that the within subjects design used may in fact bias subjects towards a single intermediate strategy which could cope with both noise and quiet conditions, and thus may dilute effects of noise. One source of evidence for this type of contamination comes from the storage times. They are considerably shorter than those found in earlier experiments. If the effect of noise is in fact reduced by concurrent articulation as was suggested earlier, subjects may strive to minimise the times when no articulation takes place. If they find that they can still carry out the task adequately when reducing the storage time in noise, they are likely to stay with this more efficient strategy in the quiet condition as well. In other words, noise may induce a strategy change which once discovered, can also be used to increase efficiency in conditions where no noise is present.

## The Effects of Noise

It was argued in an earlier chapter that since the articulatory loop is likely to be the predominant resource used for the transformation phase of the task, some other resource may be used for storing intermediate results for final recall. For example, Frick (1984) showed that digit span can be increased if subjects are forced to use both auditory and visual stores to hold the items, so clearly it is possible to combine a variety of different resources to improve performance even on a simple task. If the other resource used here was visuo-spatial and was enhanced by noise as discussed earlier, we might expect it to be reflected in a shorter retrieval time or a decrease in errors. There is no evidence for either of these. Indeed retrieval was reliably slower for four of the six subjects. If the argument about noise improving visuo-spatial processing is correct, it would imply that the code used to store these intermediate results is not visuo-spatial, but possibly some more abstract code.

The data shows no redistribution of attention to some task components at the expense of others. It has already been pointed out however that this is less likely in a closed system task such as this compared to the dual task situations in which such a phenomenon is normally found. However, the tendency for the variance to decrease in noise could be related. It would seem reasonable that increased focusing of attention would also decrease variance, by reducing the influence of task irrelevant stimuli (in this case) or a secondary task. Two of the six subjects show a decrease in variance in all task components, and

## The Effects of Noise

all subjects except the one who shows a general decrement in noise show a decreased variance in the transformation component. In fact unusually for reaction time data, some phases show an increased mean accompanied by a decreased variance. This would suggest that it might be fruitful for other authors to consider patterns of variance induced by noise manipulations as well as shifts in means.

The transform phase showed its usual extremely stable performance, as well as very reliable effects for each subject as a function of noise. However, subjects showed no consistency in the direction of the effect. Two of the six subjects showed the impairment in articulation time which was predicted by the findings of Mohindra and Wilding (1983). The other four showed the opposite effect, more consistent with the views of Hamilton, Hockey and Rejman (1977) which would emphasise the role of that phase as a throughput variable. It may be that both effects are important, and the precise balance of the two for any individual determines the pattern of performance which is observed.

The differences in the means in one direction for transformation and the other for encoding times for four of the six subjects is consistent with the view that noise does indeed impair some basic processes and enhance others. To relate these differences back to the noise literature on rather simpler tasks, the distinction between storage and throughput, rather than verbal and visuo-spatial processing seems most relevant to understand the distinction in this case. It would be possible to explain such a pattern as being due primarily to the way in which control

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processes use basic processes. However, in the light of other work based on rather simpler tasks where the role of control processes is less obvious, it seems reasonable to conclude that at least some effect of noise is indeed found on basic processes.

Equally however, the present data shows that a view based solely on changes in basic processes is not sufficient in itself to explain the data. The general effects found across the board, in the overall decrement in subject one and the decreased variance in subjects three and five, seem more readily explained by changes in control processes, since they have a systematic effect on all components.

It is clear that the patterns of change induced by noise are by no means simple or straight-forward. Indeed, the present data do not contradict the view of Jones, Chapman and Auburn (1981) that 'individual differences are a more important variable mediating response to noise than is the level of noise per se'. Although the present study cannot claim to be a systematic study of individual differences and noise, it serves to illustrate the different patterns of results which can emerge from the administration of noise, even in laboratory settings, and thus the range of differences with which an adequate theory of noise effects must be able to deal.

## CHAPTER 8

### ADDITIONAL CONCURRENT MEMORY LOAD

#### 8.1 INTRODUCTION

The previous two chapters have shown the effects of external stressors on performance. However, it is not completely clear what the precise cognitive effect of either alcohol or noise actually is, or indeed even if they can be described on a single dimension. Previous work does not agree on an appropriate framework within which to examine such effects, and variation between individual subjects in the data presented suggest that for the case of noise in particular, no simple change in cognitive functioning is apparent.

It is not clear whether the complexity observed is a result of the effects of alcohol and noise being fairly non-specific, or whether any manipulation which changes the state of the system will inevitably have pervasive consequences beyond the resources which it most directly affects. Chapters 3 and 4 showed that relatively consistent effects could be seen when the transformation size and memory load were varied. In both cases, changes in the pattern of response could be easily detected throughout the trial, not only in the components which were most closely associated with a given manipulation. Equally however, this pervasive effect of both manipulations could easily be understood by considering how they might interact with one another. An increase in transformation time would inevitably

## Additional Concurrent Memory Load

mean that a longer period of interruption to memory processes would be necessary, and this would be likely to influence the temporal patterns of the memory components. Similarly, manipulations of memory load in these chapters affected the overall length of the trial, showed effects of both the planning required for the expected load and of the actual load at any point in the trial. Since the task requirements included these dynamic aspects as well as a more static one of increased simple memory load, the pervasive effects of that manipulation on performance could be due to these dynamic changes which an increased memory load induced rather than (or as well as) simply the increased load itself.

A constant additional memory load which had to be maintained for the duration of the trial would not necessarily have the dynamic overheads of the memory manipulation reported earlier. It would not have overheads in necessarily increasing the length of particular components which might in turn increase others as was the case with the transformation manipulations. Finally, its influence would appear a priori to be closely related to the storage intensive components of the alphabet transformation task and not to the transformation components. Such a potential dissociation of influence on task components cannot be claimed for either alcohol or noise.

This chapter examines the effect of such an additional memory load on the alphabet transformation task. In many ways, the manipulation is conceptually closer to the alcohol and noise ones than it is to those reported in earlier chapters. A change is

## Additional Concurrent Memory Load

induced which might be expected to have a constant effect on the state of the system for the duration of the complete trial.

Consequently, a similar experimental methodology to that which was used successfully with noise will be adopted.

### 8.2 CONCURRENT MEMORY LOAD AND ALPHABET TRANSFORMATION

Despite the comparative simplicity of the manipulation and its similarity with one of the major components of the alphabet transformation task, the precise pattern of results which might be obtained from a constant additional memory load is not immediately obvious. The simplest argument would suggest that an additional memory load would detrimentally affect only the components with a strong memory component, storage times and possibly encoding times. This would be consistent with a multiple resources view of the system such as that proposed by Navon and Gopher (1979), if the resources required for the additional load overlapped with those already being used in the main task. Within the same framework, however, no change at all would be expected if otherwise unused resources could be brought to bear on the additional memory task. However, it seems reasonable in this case that given the task difficulty, few resources which are relevant for remembering will be unused. A potential problem with this view is that the data reported in earlier chapters showed an effect of memory load on the transformation time, which we would expect to have least requirement for memory resources. This may have been due solely to planning overheads rather than memory ones in these cases as

there were also shifts in the dynamic complexity of the task accompanying increased task cycles.

On the other hand, a view which emphasised a unitary limited capacity system (eg Norman and Bobrow, 1975) would predict less resources being available for the main task, and thus a general decrement in all phases. However, a similar view with the modification of the capacity limitation being 'elastic' (Kahneman 1973) could predict an improvement in at least some components of the task as a result of increased effort because of the greater memory load.

Even with this apparently straightforward manipulation, it is not immediately clear what pattern of results would be expected.

From previous chapters we would expect the transformation phase to be potentially the most interesting since it has been shown to be the most stable of all the components and in this case will be crucial in informing us whether or not a simple additional memory load does indeed interact with the throughput stages of the task.

### 8.3 STUDY 5

Study five was designed to investigate the effect of an additional concurrent memory load on performance of the C44 condition of the alphabet transformation task. The basic design is similar to the noise study reported in the previous chapter. The concurrent memory load consisted of four digits which had to be memorised before the start of each trial and reported at the end.

## Additional Concurrent Memory Load

### 8.3.1 Subjects

Five university students (three female, two male) were recruited. All subjects were given about one and a half hours of practice on one day and then on the test day were required to attend three sessions each of about one hour forty five minutes duration.

### 8.3.2 Procedure

The practice session introduced the subjects to the alphabet transformation task with six blocks, each of five correct  $m=1$ ,  $t=4$  practice trials. This was followed by fifteen blocks of  $m=4$ ,  $t=4$  trials. Subjects were informed that they would be paid a substantial bonus over and above the normal rate for fast accurate performance, to try to encourage them to work at the limits of their ability at all times (as in study 4).

The main experimental sessions were all carried out on a subsequent day. The first experimental session started with eight blocks of practice with an additional concurrent memory load. The additional memory load consisted of four different random digits presented before the start of each trial. *Subjects were informed that both digits and letters must be recalled correctly at the end of the trial.* Digits were chosen because they would not cause problems by being confused with the letters to be remembered. Using a similar pre-loading technique, Baddeley and Hitch (1974) showed no strong effects of an additional memory load with fewer than six digits, but the reasoning tasks they were investigating were considerably simpler than the current task. Pilot studies with this task, using experienced subjects suggested that performance with a load of six digits was so difficult that few correct trials would be

### Additional Concurrent Memory Load

obtained. Four digits seemed to be an optimum compromise which gave an acceptable error rate, while seeming to make the task subjectively more difficult.

Subjects were simultaneously presented with four digits on the screen and given as long as they wished to memorise them (the average time spent was 7.4 seconds). When they were ready, they pressed their response button to initiate an otherwise normal trial which was performed as usual. At the end, after recalling the full alphabet transformation response, the digits were recalled. The experimenter took note of whether they (and all aspects of the alphabet transformation) were correct, and signalled the computer accordingly. As in previous experiments, a block consisted of five correct trials, but this time the digits had to be correct also. As will be seen from the results, it was sometimes not possible to complete five trials correctly from the ten available in each block.

The use of fifteen minute periods as used in the previous study was not appropriate here, since the overheads of memorising the digits considerably increased the time spent on each trial in the memory load condition. Consequently, periods were defined as six blocks of the given condition in this case. (Subject five had considerable trouble with the additional load, and was only able to complete four blocks in each of these periods).

After the eight blocks practice with the memory load, the first experimental session continued with one period of six blocks with no memory load, and one period with the load. This session took

## Additional Concurrent Memory Load

approximately two hours for each subject, with short breaks between the periods. Each subject had two further sessions on the same day with a one hour break between sessions. These sessions started with two practice blocks with memory load followed by three periods alternating between load and no load (no load; load; no load in session two, and load; no load; load in session three for all subjects). Subjects thus had four experimental periods of each condition spread over the three sessions, giving a maximum of 120 correct trials for each condition.

### 8.4 RESULTS

#### 8.4.1 Group Results

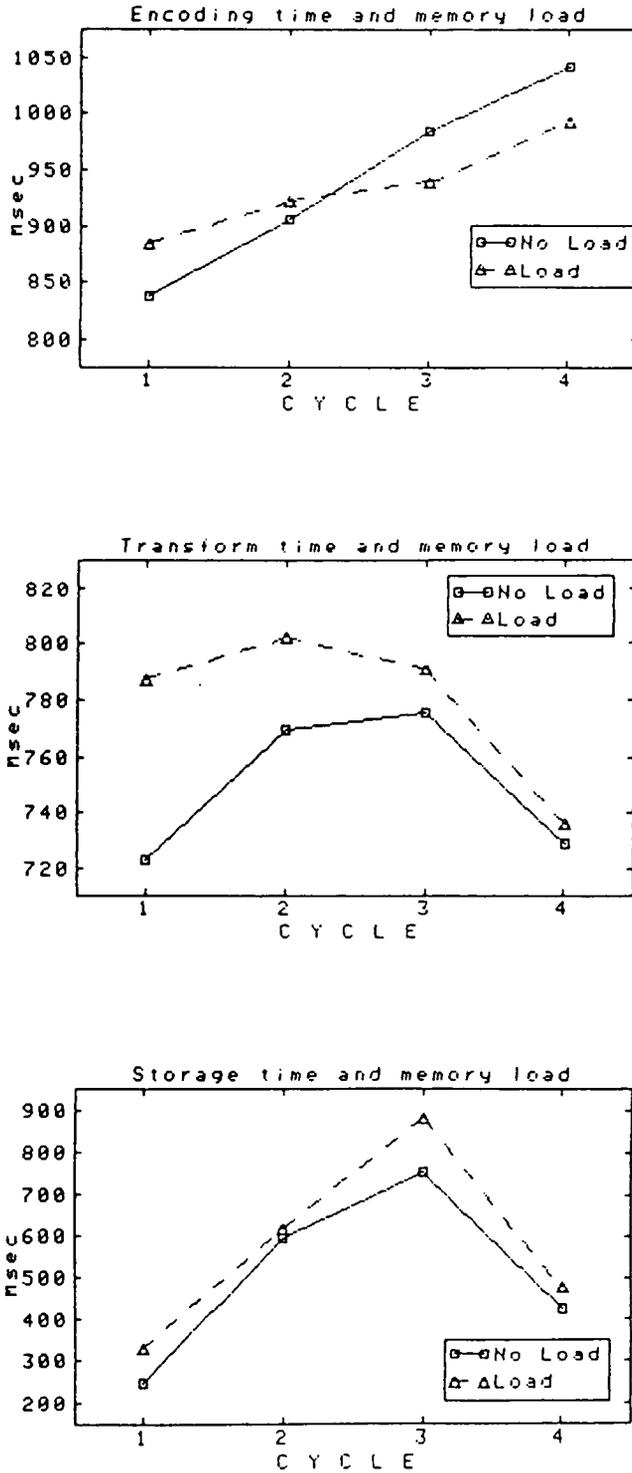
Table 8.1 summarises the mean number of trials completed with and without an additional memory load, mean error rates and the mean total solution times for each trial. The only difference at this level of analysis is that there are significantly more error trials with the concurrent memory load (  $t(4)=3.10$ ,  $p<.05$  ).

	Number of trials			Time(secs)
	Correct	Errors	Abandoned	Correct
No load	119	24	20	11.39
Load	103	45	20	11.77

Table 8.1 Mean summary data for all five subjects

Analyses of variance were carried out on each of the three task phases to investigate the effects of the memory load on the microstructure of performance as the trial progressed. Figure

## Additional Concurrent Memory Load



**Figure 8.1** Mean times for each task component with and without additional memory load.

## Additional Concurrent Memory Load

8.1 shows the mean times for each task component and table 8.2 summarises the results of the analyses.

	df	Encoding		Transform		Storage	
		F	p	F	p	F	p
Load	1,4	<1	-	1.35	.31	6.49	.06
Cycle	3,12	1.68	.22	2.29	.13	5.38	.01
Load x Cycle	3,12	<1	-	2.36	.12	<1	-

Table 8.2 Summary of analysis of variance of effect of memory load across cycles for each phase.

Although most components in fact show a tendency for the memory load condition to be slower, the only hint of a reliable difference is with the storage time. Although there are only five subjects, the data suggests that this manipulation has not produced any more consistency in its effects than was observed with the noise experiment, and that the apparently closer relationship of the memory load to particular components of the task has not produced a consistent difference in the pattern of responses shown by the subjects. A closer look at the patterns of individual performance should show whether this is due to no difference (apart from the error rate) in the patterns of performance, or whether subjects in fact show varied patterns of performance in response to the memory load as was the case with noise.

### 8.4.2 Individual Subjects Data

Table 8.3 summarises the number of correct and error trials for each subject with and without the memory load. All subjects show

### Additional Concurrent Memory Load

more errors with the load than without, even subject 5 who only did half as many correct trials with the memory load as other subjects.

Subject	Memory Load	Number of trials		
		Correct	Errors	Abandoned
1	No	120	20	20
	Yes	114	32	16
2	No	120	20	16
	Yes	110	59	21
3	No	119	32	13
	Yes	111	48	27
4	No	120	18	14
	Yes	120	21	8
5	No	118	32	38
	Yes	60	63	28

Table 8.3 Number of trials completed by each subject and number of error trials.

Table 8.4 shows the total solution times for all correct trials for each subject. The pattern observed is quite varied.

Subjects 1 and 3 show no effect. Subjects 2 and 4 show strong impairments with the memory load, and rather surprisingly subject 5 who had the large number of errors, shows an improvement.

Subject	1	2	3	4	5
No load	10.27	9.68	8.86	15.99	12.15
Load	10.31	10.54	8.93	17.60	11.48
Diff (No-Yes)	-.04	-.86	-.07	-1.61	.67
t	.17	3.77	.49	4.36	2.22
df	232	228	228	238	176
p	.86	.0002	.62	<.0001	.028

Table 8.4 Comparison of total time (secs) with and without additional memory load for each subject. Negative differences indicate memory load condition is slower.

### Additional Concurrent Memory Load

As before, to examine the microstructure of performance separate analyses of variance were performed for each subject, for each of the three main phases of the task across task cycles. Figure 8.2 shows the mean times for each condition as they change with task cycle and table 8.5 summarises the overall mean times and their differences for each subject for each phase. Table 8.6 summarises the results of the analyses of variance. With the exception of subject 5 who showed the very different error pattern, all of the interactions between memory load and cycle show the memory load condition being relatively slower at the beginning of the trial and less difference later in the trial.

Subject	1	2	3	4	5
<b>ENCODING</b>					
No Load	871	836	747	1363	1216
Load	810	797	757	1459	1169
No - Load	61	39	-10	-96	47
<b>TRANSFORM</b>					
No Load	627	691	528	1074	926
Load	681	775	507	1161	845
No -Load	-54	-84	21	-87	81
<b>STORAGE</b>					
No Load	651	561	563	866	385
Load	694	642	563	1057	374
No - Load	-43	-81	0	-191	11

**Table 8.5** Overall mean times (msec) for each phase and their difference for each subject. Negative differences indicate the memory load produces slower performance.

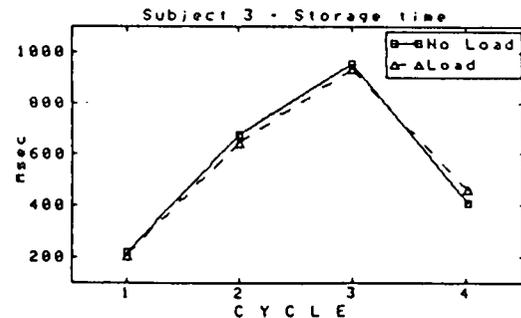
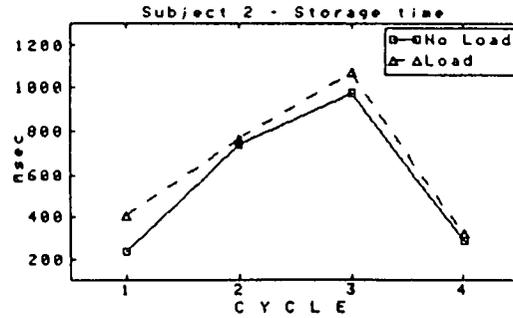
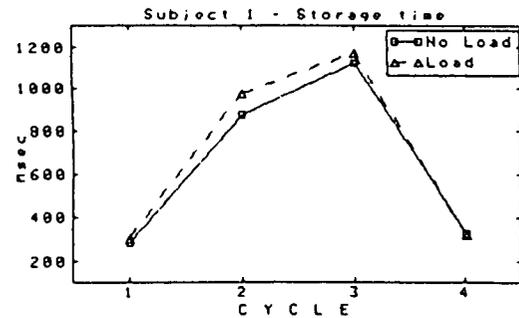
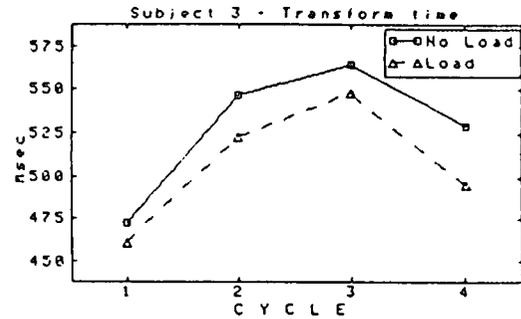
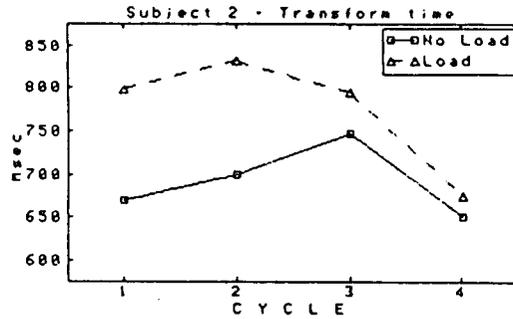
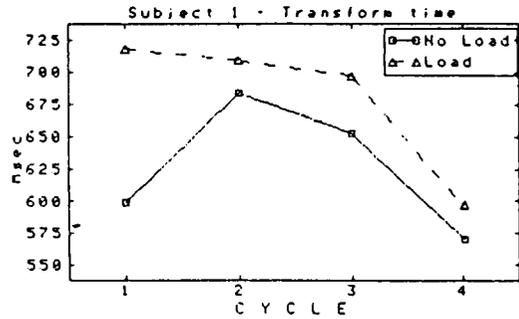
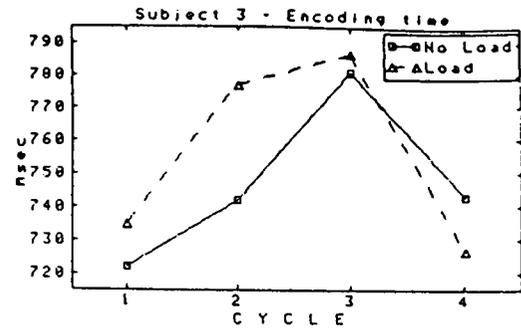
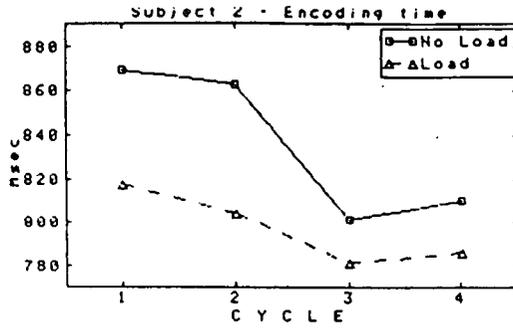
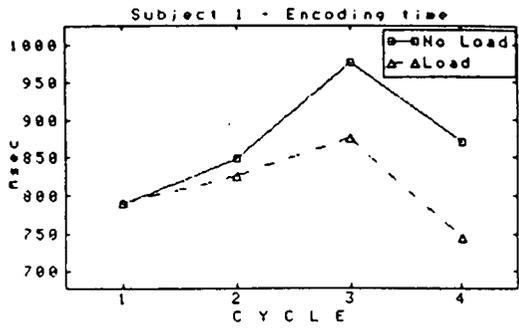


Figure 8.2(1) Individual data for subjects 1-3.

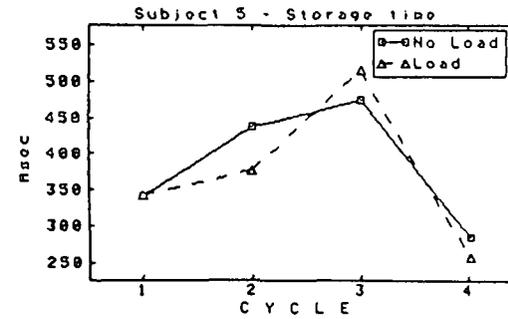
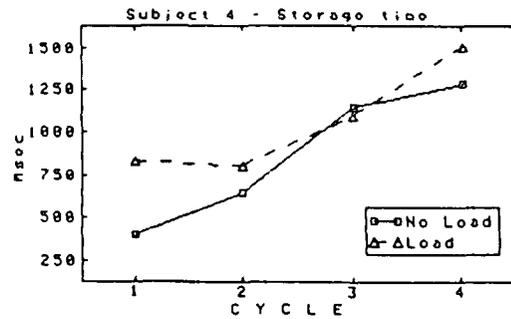
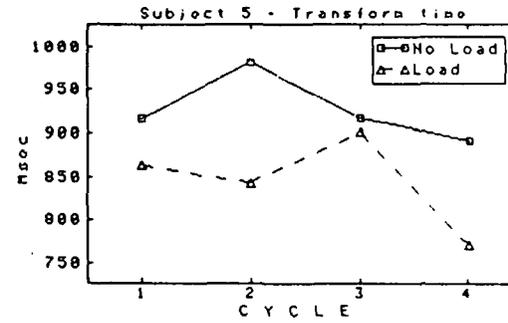
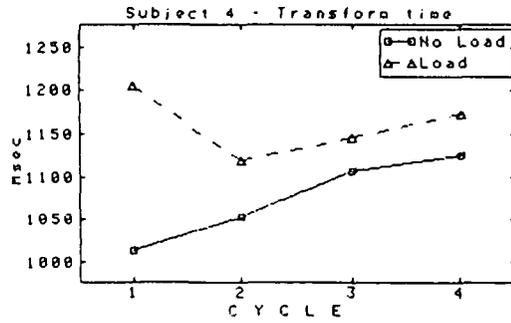
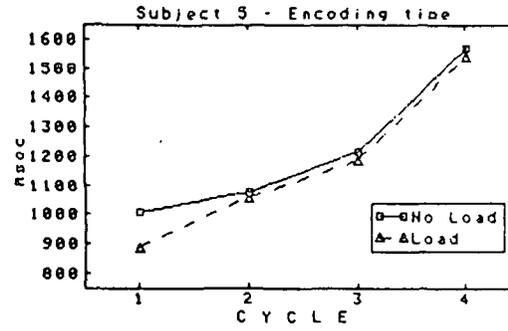
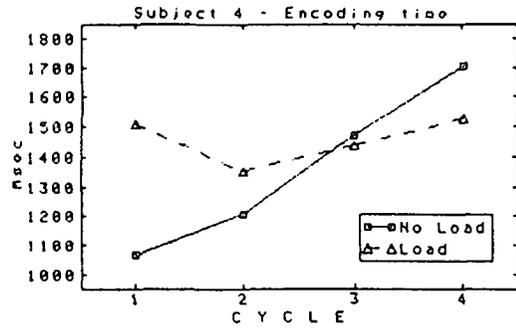


Figure 8.2(11) Individual data for subjects 4 & 5.

Additional Concurrent Memory Load

Subject	1	2	3	4	5
df Load	1,232	1,228	1,228	1,238	1,176
df Cycle, load x cycle	3,696	3,684	3,684	3,714	3,528
ENCODING					
Load	9.50**	6.28*	<1	6.16*	1.37
Cycle	10.03**	3.38	5.45*	23.82***	76.44***
Load x Cycle	2.47	<1	<1	17.00*	<1
TRANSFORM					
Load	20.97***	43.88***	3.25	7.34**	20.38***
Cycle	27.65***	19.73***	15.90***	1.13	7.03**
Load x Cycle	5.64*	6.53*	<1	2.07	3.97*
STORAGE					
Load	<1	4.66*	<1	14.08***	<1
Cycle	108.6***	103.2***	245.1***	78.39***	14.92***
Load x Cycle	<1	<1	<1	5.8*	<1

**Table 8.6** Summary of F values from analysis of variance of each component for each subject across the trial.

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

Subject 5 is the only one who shows a faster response in the memory load condition for all phases, although this is only significant for the transformation phase (remember that she also showed a faster total time). Given her high error score, this temporal pattern clearly does not indicate superior performance with the memory load, but rather indicates that she was unable to successfully handle the additional load and suggests that she may have been attempting to carry out the trial as quickly as possible to minimise decay of the memory trace of the digits. Note the similarity to subject 11 in chapter 4 who had great difficulty with the C44 condition. Subject four shows a clear decrement in all phases, again mirrored by his total time score. Subject three shows no effect on any major component, although his output time is slower (table 8.7). Subjects one and two show

### Additional Concurrent Memory Load

an improvement in encoding and a decrement in transformation time, while two also shows a decrement in storage and output of response.

Subject	1	2	3	4	5
OUTPUT					
No Load	1136	874	829	1517	1008
Load	1114	1158	974	1656	914
No - Load	22	-284	-145	-139	94
t	.29(232)	4.00(228)	3.16(228)	1.57(238)	1.30(176)
p	.77	.0001	.002	.12	.20

Table 8.7 Mean times (msec) for output phase. Negative differences show memory load is slower.

The data from the noise experiment showed rather interesting patterns of changes in variances under noise. Table 8.8 summarises the direction of effects on both means and variances, in the same way as before, for the current experiment. Again there is a tendency for variances to decrease in the more difficult condition. The major exception is subject 4 who shows a general decrement in both mean time and variance of each phase. Also worth note is subject three, who although showing no effect on the mean times of each phase does show a decrease in the variance of both transform time and storage.

Subject	Differences of MEANS			Differences of VARIANCES		
	E	T	S	E	T	S
1	+	-		+	+	-
2	+	-	-	+		-
3					+	+
4	-	-	-	-	-	-
5		+		+	+	

Table 8.8 Summary of direction of significant differences of means (from ANOVA) and variances (at least two of the four components show difference). Impairment by extra memory load (slower or greater variance) is shown by '-'; improvement by '+'. .

## 8.5 DISCUSSION

The additional memory load clearly affected performance as measured by both errors and time. However, the time effects could only be found by examining the microstructure of performance for each subject individually. Effects from a memory preload of only four digits contrasts with the findings of Baddeley and Hitch (1974). They found that a memory load of six items was required to produce measurable interference with a primary reasoning task. In this case however, the task is rather more complex and is likely to require considerably more resources. For example Baddeley and Hitch (1974) argued that the smaller memory loads could be held in the articulatory loop, and it was only when the number of items to be remembered increased to such an extent that the central executive had to be used to assist recall that interference with reasoning occurred. In the present case, the articulatory loop is likely to play a role in the main task, and so will not be available as a free resource for the secondary memory task.

The time course of the individual components shows no encouragement for the view that maximum interference would be seen with the storage and encoding phases which have the greatest memory requirements and so might be expected to suffer most from an additional memory load. The increase in storage time which might be expected from additional memory requirements was significant for only two of the subjects, although none showed a significant decrease in the time taken for this component. Encoding time was decreased for two subjects, and increased for

## Additional Concurrent Memory Load

one, so again a simple interpretation based on the extra load slowing this component is unlikely. Finally, the transformation time is in fact most reliably affected, all subjects (except subject 5 who seemed qualitatively different anyway) show an increase in the time taken under the additional load. This is of course consistent with the pattern observed in earlier experiments where the increase on the memory load from the alphabet transformation itself was reflected in an increase in transform time. The effects on encoding and storage time however are not consistent with the effect of memory load in these earlier experiments, and so we cannot conclude that any form of memory load will have similar effects, but rather the role of the memory load in the task as a whole seems to be most important.

Similarly, the single limited capacity view which predicted a general decrement, although consistent with the error data, is not borne out by the improvement shown for the encoding phase time by subjects 1 and 2, and the general improvement in time by subject 5. A similar account which includes the concept of effort could be more compatible with the data, but leaves unanswered the problem of what effort actually is and why it varies so much between subjects.

When an interaction occurred between task cycle and memory load, it was invariably due to the memory load causing a greater decrement early in the trial, the difference disappearing or even crossing over towards the end of the trial. This pattern suggests that early on when the load on the system is not great

### Additional Concurrent Memory Load

that there is indeed an increase in the time taken with the additional memory load. However, later on a strategy is adopted such that the task is carried out as quickly as possible to minimise decay of the growing (digit plus letter) memory load. Note that this pattern seems most prevalent with the transformation component. A decrease in the time taken for this component as the trial progresses is not surprising given the memory decay argument, but it is more worthy of note that it is often greater in the memory load condition at the beginning of the trial.

The difference between subjects is also quite striking. Two extremes are shown by subjects 4 and 5. Subject 4 was slower in all components with the additional memory load (and also showed the interaction with task cycle, discussed in the previous paragraph, most clearly). Subject 5 was significantly faster overall, and in the transformation phase (but had a very high error rate). This pattern is consistent with subject 5 adopting the speed to avoid memory decay strategy in such an extreme form that task performance was very severely affected. She may have been trying to minimise time spent on the whole alphabet transformation task to minimise decay of the digit load, whereas other subjects were selectively manipulating the time spent on the task components and being more successful in balancing between where they could afford to save time and where they could not.

There seems to be a tendency for the variance of the distribution of times to decrease under the extra memory load. This is

## Additional Concurrent Memory Load

similar to the effect noted with noise in the previous chapter. However, there are distinct differences between the noise manipulation and the memory load when the actual duration of the components is considered. The most prominent of these is the transformation phase where the two manipulations show opposite trends. This difference between the two experiments is important if they are considered in terms of arousal. Increased effort has been argued to be arousing (eg Kahneman 1973, Hasher and Zacks 1979), as has noise. However, this opposite pattern of results again casts serious doubts on the utility of such an explanatory concept as arousal as it has been couched in the literature.

More appealing, however, is the notion that a manipulation which stresses the system (such as noise and increased task difficulty) will focus attention. This focusing aspect of noise was discussed in the previous chapter. Similar claims have been made for increased effort (eg Kahneman 1973, Dornic 1977). It seems reasonable to assume that if such focusing took place, it would primarily affect the variance of the distribution of the time spent on the task or task component rather than the mean directly. Given the positive skew which is typically found with time measures, a decrease in the mean would often be found with such a reduction in variance, even if there were no change in the `real` average time (for example as indicated by the mode) taken by the component being investigated. If however, a redistribution in the time taken by individual components also takes place - for example because of masking due to noise, or interference from an additional memory load, the `real` average

## Additional Concurrent Memory Load

time may in fact shift considerably. The fact that the mean and variance can indeed shift independently is illustrated in this experiment and in the noise experiment. The most striking examples are the cases where the variance decreases while the mean time increases since these cannot be explained away by the correlation between mean and variance which results from a positive skew, but must be due to resources being used differently under the two conditions.

## CHAPTER 9

### GENERAL DISCUSSION

#### 9.1 INTRODUCTION

This chapter summarises the major points investigated in this thesis. It discusses how the patterns of data observed in the microstructure of performance fit into existing psychological models and then suggests the characteristics which would be required of a framework which was sufficiently comprehensive to encompass the complexity which is apparent, and presents a simple framework which embodies these requirements. Finally, some directions for future research are discussed, both in terms of theoretical development from the proposed framework, and in terms of other domains to which the methodological techniques used here might fruitfully be applied.

##### 9.1.1 Summary of Studies

The alphabet transformation task allowed us to look at the microstructure of performance on a complex task. The parametric properties of the task were examined as a function of the two major variables involved - size of transformation and number of items to be transformed and remembered. Chapter three examined these properties on a sample of university students and chapter four replicated the major patterns of results on a less homogeneous sample of young teenagers. Chapter five examined the data of chapter four in more detail, with particular reference to

## General Discussion

individual differences in the patterns of performance produced by subgroups of subjects, and how these patterns were related to intelligence.

The basic characteristics established, the remaining chapters examined how useful the task would be to increase our understanding of the cognitive effects of stressors. It was argued that examining the microstructure of performance might be useful in better understanding some of the contradictory findings which have been traditionally discussed within the arousal framework. Chapter six looked at the effect of alcohol on performance. Although the data on relatively simple tasks was fairly clear, there were no consistent differences apparent in the more complex tasks. However, this relatively disappointing result gave useful insights into the kind of methodology which might be more appropriate for such investigations. Chapter seven investigated the effects of loud noise on performance, but using a within subjects design instead of the between subjects one which had been used in the alcohol study. This was considerably more successful, but indicated the need to consider individual differences to fully understand the data. A similar observation was made in chapter eight, despite the fact that the manipulation, a constant additional memory load, might have been expected to have much less complex effects than those of a stressor such as noise.

### 9.1.2 Interpreting the Data

In all of the experiments reported it is clear that understanding

## General Discussion

how time was distributed within the microstructure of performance gave a much richer picture than simply considering the overall solution times. In particular, the consistent effects of increasing task difficulty on the very first cycle indicated that resources were set up for the expected task demands rather than being allocated as and when they were required for immediate use. As far as the individual task phases were concerned, the transformation time was a very sensitive measure since it tended to have very little variance, but was affected to some extent by all of the manipulations used, although not necessarily in ways which were completely predictable a priori. This stability was particularly important in the later experiments where the manipulations used often had fairly small effects, the details of which differed between individuals. The encoding and storage times were of course also informative measures, but storage time in particular although having a high variance often showed very large differences as a function of task difficulty both within a trial and between conditions.

Although parallels were drawn with appropriate parts of the literature when discussing the phenomena observed in each study, it was clear that no approach discussed was capable of dealing easily with all of the major findings. Existing models tend to be derived from relatively constrained paradigms which are concerned with narrow issues. In many ways the situation has not changed much since Newell (1973) bemoaned the fact that 'the current experimental style is to design specific small experiments to attempt to settle specific small questions' (a

## General Discussion

view reiterated several years later by Claxton (1980)). The consequence of this is that an attempt to invoke the resulting models to explain a more complex task must be doomed to failure. A more integrated single model would be much more satisfactory. The current set of studies therefore highlights certain issues which are particularly difficult to handle. The next section discusses how useful current approaches are likely to be in providing a coherent understanding of the patterns of data obtained.

### 9.2 MODELLING COMPLEX PERFORMANCE

In discussing the results obtained from the alphabet transformation task, although many parallels have been found between various aspects of the data and the psychological literature in general, no one theoretical approach has seemed adequate to capture the richness found in the data. This section considers the areas where the existing models which seem most appropriate have their shortcomings and attempts to derive a simple framework which has sufficient scope to cover the major requirements of the current data. The implications of such a framework will then be discussed in a wider context than the current data.

Existing approaches which are adequate as a starting point must be able to deal with issues of both attention and memory since it is clear that both are important when considering how the system is able to combine the various subtasks in an appropriate way,

## General Discussion

and how it is able to store intermediate results for later retrieval. Theories which focus on one side or the other are therefore not going to be adequate. So, for example, an approach which emphasises particular attentional phenomena such as automatic and controlled processing (eg Shiffrin and Schneider, 1977) cannot easily encompass the memory requirements.

Similarly, an approach which emphasises memory such as the levels of processing approach ( Craik and Lockhart, 1972) gives no framework in which to handle the attentional requirements of a suitable model. Both of these more focused directions may of course have useful things to say about the detail of certain parts of a broader model, but they do not provide sufficient breadth in themselves.

### 9.2.1 Multiple Resources

Recent years have seen the development of a number of approaches which might appear to have adequate scope. For example, Allport (1980a, 1980b) has proposed that the cognitive system consists of a large number of content specific resources. Similarly, Navon and Gopher (1979) have proposed a very flexible theory of multiple resources, based on an analogy with an economic system. However, as Eysenck (1982) points out their theorising is still at an early stage. At present they tend to discuss resources in the abstract, so no a priori guidelines exist which would allow their 'resources' to be mapped onto a specific task such as the one currently under consideration. Indeed, the authors of this approach now also seem less enamoured with its possibilities (see Navon 1984), particularly on methodological grounds.

## General Discussion

### 9.2.2 Symbol Manipulation

More recently, relatively radical suggestions have been made of completely novel ways to think about the cognitive system. Kolers (Kolers and Roediger, 1984; Kolers and Smythe, 1984; see also Roediger, 1980b) has argued that the 'spatial metaphor' of mind has funnelled research in inappropriate directions, and that a process-oriented view based on symbol manipulation offers greater insight. Although this approach will undoubtedly be invaluable in highlighting to the unwary the dangers of taking a particular metaphor too far, Allport (1984) has already argued that the major criticisms do not apply to the general characteristics of the current information processing approach, but to specific subsets of that approach. In addition, it is not clear at this stage how well their alternative can make use of the vast amount of data which already exists, or how it could be investigated empirically (see Brooks, 1984). As far as the present work is concerned, the major criticism of this approach is that in attacking a school which it claims makes excessive reliance on internal representations, it takes the opposite extreme and relies excessively on understanding cognitive processes. It has already been argued here that a wide range of cognitive tasks (of which the alphabet transformation task is one) require understanding of both processes and the representations upon which they act.

### 9.2.3 Distributed Architectures

A recent conceptualisation which might be regarded as similar in

## General Discussion

concept to Navon and Gopher's (1979) multiple resources has evolved from the verbal learning and psycholinguistic literature. The resources involved have been better specified, however, mainly because they have been derived from the vast databases which exist in the verbal learning tradition. Monsell (1984) views the system as a collection of heterogeneous 'capacities', and Barnard (1985) describes the system in terms of 'interacting cognitive subsystems'. Both of these views have in common the notion that the system consists of a number of independent domains, each with its own storage and processing resources. One important feature of these formulations is that they take specific account of the control of resources. Monsell (1984) assumes that control processes are simply one end of a continuum of processes and so essentially are no different from any other process. Barnard (1985) makes the more radical claim that control processes fall out of the architecture of the system, and are essentially a byproduct of the flow of information. This general approach has much to recommend it. In particular, it removes any remaining vestiges of the homunculus arguments which have accompanied theories specifically embodying a central executive.

However, these authors describe a rather detailed system where the detail is determined by the types of task they draw upon to derive their arguments in the first place. Given the verbal learning and psycholinguistic bias from which these approaches spring, it is inevitable that some of their key concepts fit more easily into that tradition than into the type of task with which

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we are concerned here. For example, Barnard lays much weight on the 'morphonolexical subsystem', which provides a structural description of a linguistic sequence. The specific strengths of such approaches therefore lead to an uneasy tension between the parts of the system which are ill-specified and those which are well- (perhaps even over-) specified when domains outside the immediate scope in which they were originally formulated are considered. It may therefore be more appropriate for present purposes to look towards a more general framework within which the current data can more comfortably fit.

### 9.2.4 Working Memory

The framework which was invoked most frequently when discussing the various studies presented here tended to be the working memory framework originally proposed by Baddeley and Hitch (1974), since it provided a fairly simple language in which to describe the main phenomena observed. In its current incarnation, this framework consists of a central executive with two slave subsystems (eg Baddeley, 1983) (see fig 9.1), the articulatory loop and the visuo-spatial scratch-pad.

The articulatory loop is undoubtedly the best explored component of the system. This is not surprising given first of all the predominance of verbal learning paradigms used in the sixties to study short term memory, and the subsequent work of Baddeley, Hitch and their co-workers which have explored the articulatory loop specifically within the working memory framework.

Essentially the loop is regarded as a store of limited temporal

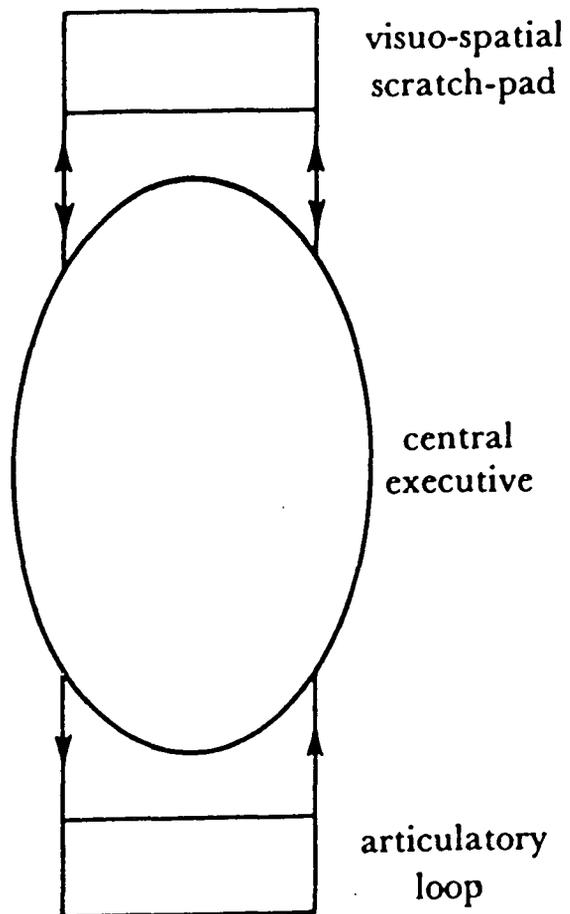


Figure 9.1 The Working Memory System (from Baddeley, 1983)

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duration in which any material capable of articulation can be stored. Relating this to the alphabet transformation task, we would assume that this is where the transformation phase of the task is carried out. It would be unlikely that it was used extensively for storing the intermediate results since subsequent articulation of a transform sequence would be assumed to destroy such material.

It was suggested in chapters 6 and 7 that some form of visual storage may be involved in storing the intermediate material. The visuo-spatial scratch-pad could be a candidate for such a system. It is clear that some kind of visual short term memory exists (eg Phillips and Christie, 1977; Baddeley and Lieberman, 1980) however its precise properties are less well explored than those of the articulatory loop.

The third component of the working memory system, the central executive, is not regarded as a unitary system, but rather as the 'area of residual ignorance' (Baddeley, 1983). This is where control processes are located; other as yet unexplored peripheral subsystems and even consciousness (Baddeley 1981b). The approach has been to peel off subsystems from the central executive, and essentially to avoid creating a myriad of supposed subsystems until they have been shown to be necessary by a sufficient amount of converging evidence. While this approach is very laudable, progress has probably been held back by the amorphous nature of the central executive which results since any phenomenon which is difficult to explain can be attributed to it, rather than be

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explored more systematically. For example the assumption that the central executive also includes storage capacity makes it easy to explain away the relatively good memory performance which can be obtained despite articulatory suppression (eg Baddeley and Hitch 1974) without really understanding what is going on. Despite these misgivings, the general framework offers considerable scope for teasing apart the system in a systematic way.

### 9.2.5 The Maltese Cross

The working memory hypothesis has clearly evolved primarily from memory research, although it has embodied within the central executive properties which might be more easily identified with traditional attentional concerns. Indeed Baddeley (1981b) is quite clear that an adequate working memory theory must also be a theory of attention. A very similar formulation to the working memory one has recently been presented by Broadbent (1984a). Although presented as a model for memory it is derived from the pioneering work of Broadbent (1958), which was particularly concerned with attentional issues. An important aspect of Broadbent's formulation is that it goes some way towards meeting the criticisms of working memory put forward in the previous section, in that rather less is lumped into a single conceptual entity like the central executive. The strong form of the model regards the memory system as a central processor which has access to four main classes of passive storage representations (see fig 9.2). The central processor is regarded as a unitary processing

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mechanism in keeping with Broadbent's claim that there is no evidence for multiple processing. He regards claims for multiple processing to always be explicable by time sharing (eg Broadbent 1982). The major evidence for the classification used in dissociating the various arms of the cross comes from interference studies, the assumption being that if the same arm is used to represent some crucial component of two tasks then interference will occur, whereas if separate arms can be used then no interference will occur. Such a scheme is obviously very attractive to explain a situation such as the alphabet transformation task where different internal representations are required within a single task, and some form of control processing is required to co-ordinate them.

One of the major features of the Maltese Cross framework, and one which makes it particularly appealing in the current context, is the initial attempt at a clear separation between process and representation. Unfortunately, Broadbent (1984a) considerably weakens the position again by claiming that 'much storage of information' is found in the processing system. Nevertheless, the framework as a whole has the potential for being rather more powerful than the working memory formulation. It is more comprehensive, taking more explicit account of long term memory and more abstract storage codes, and despite the caveat just mentioned, has greater potential for considering representation and processing separately.

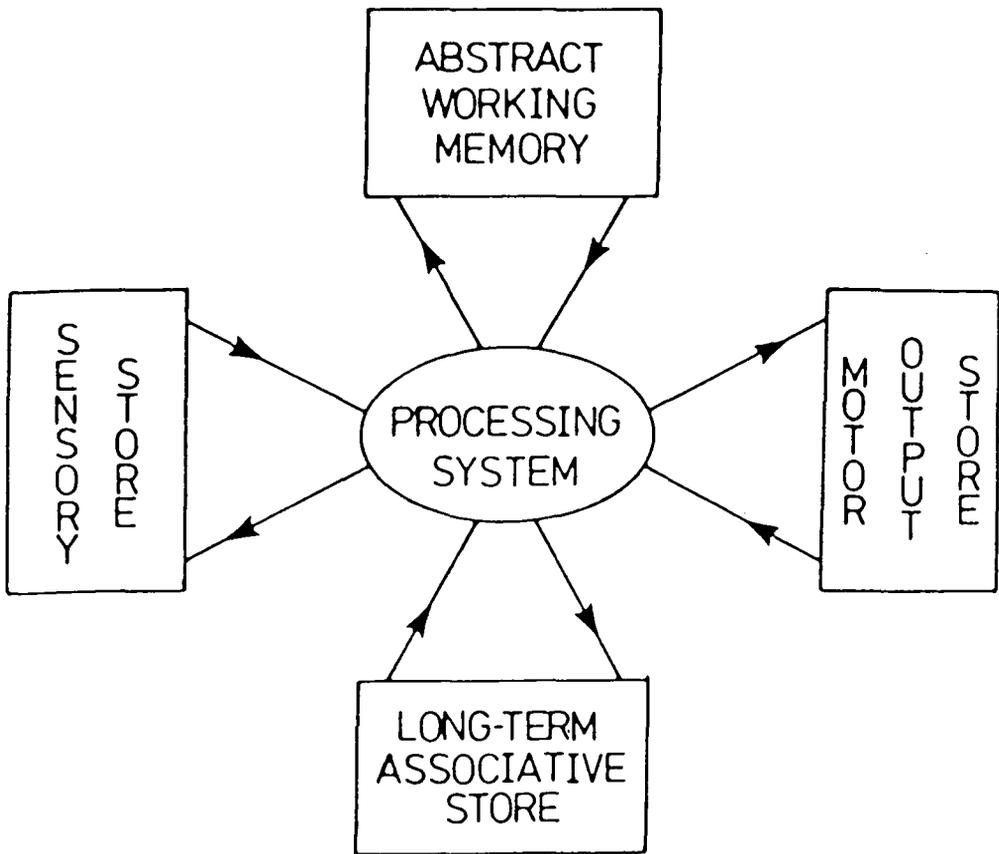


Figure 9.2 The Maltese Cross (from Broadbent, 1984)

9.2.6 Beyond the Maltese Cross

Probably the greatest weakness in the Maltese Cross formulation is the lack of consideration given to the role of long term memory in 'short term memory' tasks (short term memory here refers to the nature of the task rather than a theoretical construct - cf Crowder 1976). Certainly Loftus, Loftus and Hunt (1984) suggest that a consideration of long term memory as something more than simply an associative store is necessary to provide a more complete understanding of the human information processing system. Equally, however, they acknowledge the inability of long term memory models in isolation to encompass working memory phenomena.

Broadbent (1984b) himself goes to great lengths to emphasise that he does not regard the four classes of representation as four and only four memory stores. Rather he sees the role of an adequate theory to subdivide the postulated mechanisms as far as necessary. So for example, FitzGerald and Broadbent (1985) suggest that it may be advisable for some purposes to consider an articulatory component of the motor output store separately from other more general components. Similarly, the sensory store may consist of a visual store, an auditory store and a kinesthetic store. The long term store may be regarded as having a component similar to a logogen system (Morton 1969). Recent activation of part of such a system would persist so that subsequent activation of the same part would take less time to reach a given threshold. Surely it is reasonable to assume transitory short term activity in the long term store as well as the more permanent contents.

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This would avoid having to assume storage of recent events in the central processor. Broadbent also assumes that longer term storage exists in the central processor. For example he argues that the fact that 'two' and '2' can be treated as equivalent is a property of the central processor. To determine such similarity it is surely necessary to first of all access some form of long term memory before any knowledge of identity or any other aspect of the stimulus can be determined. Once such access has occurred, it is likely that other highly related parts of long term memory will also be activated (eg Anderson 1983). One of the most closely related parts will surely be another symbol with identical meaning. Certainly Broadbent is quite correct to point out that a distinction between this type of long term memory and the importance of the co-occurrence of events in cuing memory is important, but by his own argument there is no reason why such a distinction cannot be made by subdivision of the long term memory arm of the cross rather than being a property of the central processor. In short, it would appear that a strong version of the Maltese Cross which completely separates processing and representation would be tenable if more account were taken of the role of long term memory in short term memory phenomena. The next section outlines a reformulation of the model to take more explicit account of this.

### 9.2.7 The Cross of Lorraine

Figure 9.3 shows a schematic of the reformulated model. A particular point of emphasis is the distinction between the

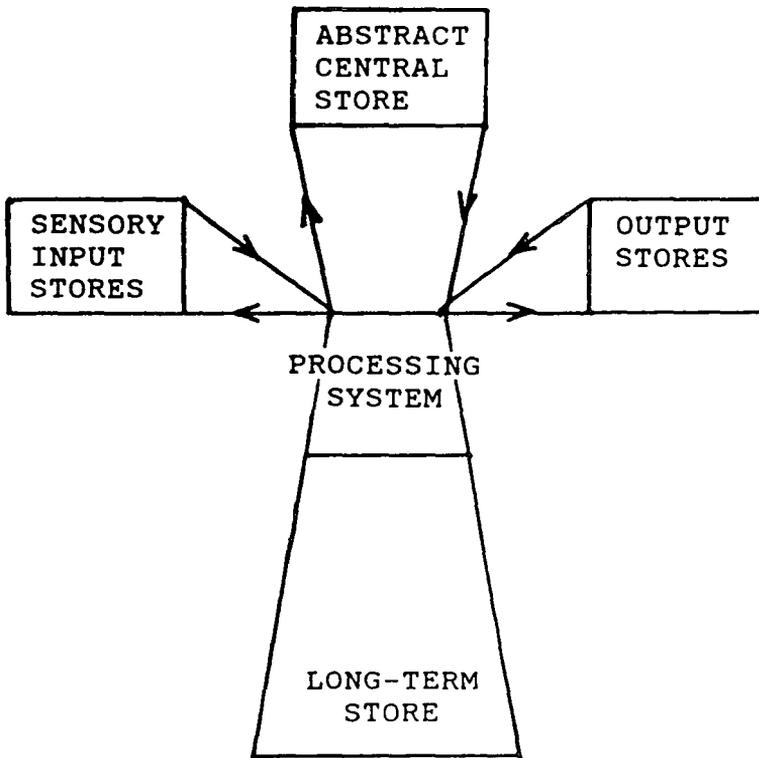


Figure 9.3 The Cross of Lorraine

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ephemeral short term memory stores and the long term memory system. The long term memory system contains all components which rely directly on previous experience for their existence, whereas the short term memory stores are transitory codes which have no permanent content. Some of the characteristics of the long term system were discussed in the previous section. Note that the processing system also resides in this section. It is not difficult to see why this should be the case. The processes which can be called upon at any time to carry out a given task must have been laid down in long term memory previously and are activated by a particular task description. To take a concrete example based on the alphabet transformation task, processes must be available to transform the required number of places, to store intermediate results, possibly to rehearse intermediate results and to retrieve the string for final output. In addition, since the precise requirements of memory load and transform size can vary, some form of higher level control processor must also be available. This could either be a dynamic system which monitors the progress of the lower level processes, or a system which sets up the contingencies which will allow the lower processes to interact appropriately.

It should be noted here that although the contents of the processing system are described as a number of specialised processes this does not necessarily imply that the system is best regarded as a distributed system of the type suggested by Monsell (1984) or Allport (1980a, 1980b). The important point is that there is a limit to the amount of processing which can occur at

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any given time and this is emphasised by having a single processor which sets these limits. A similar point is made by Hitch (1980) in discussing the characteristics of the system proposed by Allport (1980a, 1980b).

As well as the processing system, long term memory contains the associative properties discussed by Broadbent as well as the properties discussed in the previous section which Broadbent assigned to the central processor. Depending on the precise nature of the task which we wish to understand, we might wish to subdivide this long term memory in other ways - for example to distinguish between episodic and semantic memory (eg Tulving 1984).

The short term stores have three major classifications. The input stores contain a representation of sensory input - possibly a unitary input register (eg Hitch 1980), or in some situations it may be useful to think of separate stores, for example for visual and auditory input. The output stores are primarily used to buffer speech or other motor responses. Although these stores are discussed in terms of their role as transducers between the cognitive system and the outside world, they also appear to have more subtle roles in memory. For example, it appears that a representation of acoustic input can be used to assist retrieval of recently presented items (Crowder and Morton 1969).

As far as output stores are concerned, the articulatory loop which has been so well explored by Baddeley and his colleagues appears to have a role both as an intermediate storage device and

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as an output buffer for the speech system. Similarly, Reisberg, Rappaport and O'Shaughnessy (1984) have shown that memory span can be increased by using the motor output required to tap the fingers as an additional memory store, thus leading to the notion of the output store as an 'activity based' store. An important point to note here is that it would be wrong to consider the entire arm of the cross labelled 'output stores' a single limited capacity system, given that the 'fingers' memory can actually increase overall span. This point is further reinforced by the lack of interference between articulation and other output activity shown by FitzGerald and Broadbent (1985).

The abstract central store has a less obvious role in the system. Broadbent (1984a) argues for its necessity in a rather negative fashion, namely that there is evidence for some form of storage that is neither sensory nor motor, for example when performance is barely affected by a preload of digits to be later recalled (Baddeley and Hitch 1974), or when meaningful trigrams such as IBM are recalled as a single unit thus apparently increasing memory span (Broadbent and Broadbent 1981). It is not clear how compelling these arguments are, especially the latter which can easily be construed as an effect of long term memory representations. However if we consider tasks slightly removed from those of immediate concern which involve what Bartlett (1958) referred to as closed system thinking where symbols are manipulated internally to achieve a novel result, then the need for such a store becomes more apparent. If we assume that long term memory contains only traces which have been laid down in the

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past, then some other system must be required to allow the flash of insight that sometimes occurs when the relationship between two memory traces is recognised (eg Johnson-Laird and Wason 1977). Such a system must be able to manipulate the abstract codes of long term memory traces and may indeed also be useful for handling some of the more abstract aspects of short term memory.

### 9.3 INTERPRETATION OF DATA

This section considers the interpretation of the alphabet transformation data within a framework such as that just discussed. There are three main components to the data which must be considered. First, what memory resources are available and how are these used in the studies presented. Secondly what resources are required for the transformation. Third, how are the various resources coordinated to carry out a complex task.

Once some understanding of the way in which the task is carried out is obtained, some more general considerations must be made of the way in which the patterns of performance observed are affected by different abilities or strategies, whether natural or induced by an outside influence such as noise or alcohol.

#### 9.3.1 Memory Representations

It is clear that a number of different memory representations are available and that these can be used very flexibly to carry out a given task. This is particularly apparent in tasks using a

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memory preload followed by some other task which requires working memory resources. Even with a six digit preload (which is close to normal total memory span), it is still possible to carry out another task with no perceptible effect on the accuracy of the memory recall (eg Baddeley and Hitch, 1974; Klapp, Marshburn and Lester, (1983). These studies make it clear that the assumptions of a unitary short term memory (eg Atkinson and Shiffrin, 1968) were an artefact of excessive reliance on free recall as a technique for investigating short term memory phenomena (eg see Crowder, 1982).

Even if we consider only memory span tasks, however, it is clear that a single memory representation is not used. Evidence for each arm of the cross being potentially involved is easy to come by. Differences between the primacy and recency portions of the free recall curve provide one source of evidence. Atkinson and Shiffrin (1971) argued that the recency portion of the curve was due to retrieval from sensory input storage, while the primacy portion reflected retrieval from long term memory. The rehearsal processes which they assumed mediated transfer to long term memory have been shown to not necessarily imply such transfer (eg Craik and Watkins, 1973). An alternative is the articulatory loop (which corresponds to a component of the output stores in the Cross of Lorraine formulation). One line of evidence for this is that under articulatory suppression the early items in the list are recalled less well, and the later items are unaffected (Richardson and Baddeley, 1975). Finally, Baddeley & Hitch (1974) argued that if the capacity of the articulatory loop

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was exceeded, or under conditions of articulatory suppression, the central executive was able to store some of the material. In the current formulation, this would correspond to the abstract central store since representations and the processes which act upon them are considered to be separate entities.

The weakest argument left in the above is the role of the long term store in mediating free recall, since the formulation of Atkinson and Shiffrin has been largely discredited. Particularly striking examples of such a role are given by Chase and Ericsson (1981, 1982). They trained a subject to attain a digit span of 80 items. To achieve this he appeared to rely on the contents of long term memory, particularly running times such as world records and personal times for races of various distances. It obviously took considerable time to build up such a span (about 250 hours), but it highlights the fact that it is possible to use long term memory for such a task, and indeed less sophisticated use of similar strategies may well be a component in more normal span measures.

It is clear that a relatively simple system such as the Cross of Lorraine has sufficient scope to encompass the variety of representations which are likely to be used in carrying out a complex task such as the alphabet transformation task. So for example if we assume that the output store is not appropriate for storing intermediate items since it is used in the transformation phase, then it would appear most likely that the abstract central store would be used, or on the other hand it may even be possible to make use of the sensory stores. With an additional memory load

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as used in chapter 8, the items may be stored in the same store as used for the main task thus requiring considerably more maintenance of that store. Alternatively, they may be stored elsewhere. The sensory store seems an unlikely candidate since it seems to be particularly prone to interference from subsequent items (see discussion of recency above). If the preload input had been auditory, the sensory store would have been a more plausible candidate. Frick, (1984) showed that splitting presentation of digits between auditory and visual input could lead to increased span. Similar arguments as were applied earlier to the output store would therefore also be likely to apply here. With the visual presentation used for both preload and letters to be transformed, the long term store is a more likely candidate for storing the digit preload. In particular since the digits were presented simultaneously on the screen, associations between any of them which already existed in long term memory could be activated for use to assist with later recall, in the same way as was discussed for the high digit span subject of Chase and Ericsson.

### 9.3.2 Transformation

The relationship between the transformation process and the various components of the framework are less clear. This is mainly because the precise nature of processes available is open-ended since they are assumed to be contained in long term memory, and so new ones can presumably be acquired. One aspect of this acquisition of new processes is likely to be a reflection of

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processes attaining 'automaticity' (eg Shiffrin and Schneider, 1977; Logan, 1979). However, it is not sufficient to simply say that a transformation process exists. We want to be able to say something about the likely nature of the representations required to enable the process, the form of representation produced, and the intermediate processing which mediates these representations.

All too often the representation is implicit in the description of the process itself, as was the case with the levels of processing framework ( Craik and Lockhart 1972). Far from implying a 'proliferation of stores as an explanatory device' as Roediger (1984) suggests, the explicit separation of processing and representation actually serves to constrain the details of the explanation produced. One need look no further than the discussion of 'procedures of mind' (Kolers and Roediger, 1984) to see how open ended is a discussion of cognition based solely on processes. Conversely, the excellent work within the working memory framework (Baddeley and Hitch (1974) has shown, first of all that the structural properties of at least part of the cognitive system can be well defined, and secondly that such constructs can be extremely useful in more general contexts than the immediate theoretical domain from which they evolve. For example the concept of independent structural representations has been useful in understanding components of reading (eg Baddeley and Lewis 1981), and in understanding clinical deficits in patients (eg Vallar and Baddeley 1984). Attempting to understand the transformation component in the alphabet transformation task is thus likely to be most fruitful if we consider the

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representations upon which the processes act.

First of all, before the transformation phase can begin (at least as measured in the present series of studies), a long term representation of the starting letter must have been accessed. Since articulation is used as a device for counting the appropriate number of letters, it would appear that the articulatory store is required for the task, and since it is unlikely that the articulatory store could be used both for the transformation process itself and for intermediate storage of items to be recalled later (see previous section), the result of the transformation must be stored in some other representation. (This will presumably be done in the storage phase of the task). Thinking only of the representations which must be required and ignoring the memory load which will build up over several cycles, the transformation and its immediately associated activity is clearly fairly complicated in terms of its representational requirements. The reason for this complexity becomes clearer if we consider what might be required for a process which 'counts forward  $n$  places through a list in long term memory'. It appears that this is impossible to carry out (at least in relatively unpracticed subjects) purely in long term memory and so some other representation has to be used to enable the process. The output store seems to be the candidate in this case. It is possible that this is because this particular store involves time-based activity which can be used as a marker to move through the non-temporally coded representation in long term memory. Indeed the phenomenal experience after very little practice in

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the task is one of counting against a rhythm template rather than actively counting the required number of letters. If this were the case, it can be seen that there may be two sources of information available from which to obtain the appropriate result of the transformation. One is the final letter articulated, and the other would be the 'position' in long term memory activated by the end of the rhythmic utterance. The former notion is conceptually relatively straightforward, since the required item must be available in an articulatory code. The latter deserves more discussion.

One line of evidence for some direct role of long term memory in determining the output from the transformation comes from the error data in figure 4.9. The most likely item to be recalled in error was either the one immediately before, or the one immediately after the correct one (remember that the initial transformation had been correct). Errors from the set of items between the stimulus and the correct response could of course be easily accounted for by assuming incorrect retrieval from the articulatory store. This is less plausible in the case of an error from an unarticulated item such as the one immediately after the required target. However, it would be consistent with reading the result of the transformation direct from an activated region of long term memory where items closely associated with the correct one are also active. The importance of rhythm in timing for motor skills is well known (eg Shaffer 1982), and it can also act as a cue for memory recall (Buxton 1983). Indeed, the very low variance typically associated with the

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transformation component in the present studies is consistent with some clock based system being involved. In addition, rhythm can be a useful cue in differentiating between different streams of information (eg Handel, Weaver and Lawson, 1983). Thus two conceivable roles for rhythm can be envisaged in the current context. It could act as a marker to count through long term memory, and it could be useful in separating the transformation and storage components of the task. Support for some kind of separation such as this comes from the small number of errors which can be attributed to items which appeared in the middle of a transformation being recalled in the final response - perhaps rather surprising since all of the items were from the same set of letters, and so would be expected to be prone to interference.

The present data cannot easily distinguish between the roles of the output system and the long term store in carrying out the transformation, although it is clear that both must be involved. Further experiments could easily investigate some of the issues. For example if subjects were required to articulate a meaningless sequence instead of the actual letters while transforming, some of the notions of rhythm as a marker for long term memory could be tested. If a rhythmic sequence which was compatible with the size of transform required showed similar performance to articulating the letters themselves then we could conclude that the rhythm is the most important aspect of the articulation, and could further test this by requiring an inappropriate rhythm to be articulated and predict a breakdown in performance. An even more powerful test might be to allow articulation of the letters,

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but require the subject to tap a different rhythm while articulating. The difficulty of handling more than one rhythm at a time has recently been highlighted by Klapp et al, (1985). If the rhythmic aspects of the articulation are as important as the items articulated, then considerable difficulty might be expected, whereas if the rhythm is relatively unimportant we would expect tapping to have little effect.

Finally, the process which coordinates these different representations to carry out the transformation must be considered. It must be able to monitor the state of the relevant representations, pass information from one to the other and pass control to the next process required for the next stage of the task (or possibly to a supervisory process which coordinates the processes involved in a particular task). The importance of such control processes will become more apparent in the next section.

### 9.3.3 Planning and Preparation

One of the most striking phenomena observed in the first two studies was the effect which the expected task difficulty had even on the earliest cycle of the task where the actual load on the system was identical across conditions. All phases were significantly slower when difficulty was increased either by increasing the size of the memory load or by increasing the transform size. This implies that some resources are allocated in advance of being required and so cannot be used for other more

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immediate needs. This is consistent with the view put forward by Logan (1978, 1979) who suggested that preparation is responsible for the interactions observed between memory load and choice reaction time parameters. However, he made this deduction from overall reaction times, and so it not clear from his data whether the preparation took place before any processing had started or whether it was a dynamic process which allocated resources as and when required during the execution of the task. The current data strongly suggest the former view as being an important component. The pervasiveness of such an effect is backed up by the data of Paap and Ogden (1981) discussed in an earlier chapter, where probe reaction times taken between trials still showed effects based on the difficulty of the block of trials which was currently in progress.

To better understand the patterns of data obtained in the alphabet transformation task it will again be fruitful to consider representational and processing demands separately. It will be remembered that the easy conditions in chapter 3 ( $\underline{m}=2$  and  $\underline{t}=1$ ) showed results which seemed to be qualitatively different from the more difficult conditions. These conditions would also be expected to require fewer different resources. For example when  $\underline{m}=2$ , no process would be required to add a new item to the end of a list in intermediate storage, and when  $\underline{t}=1$ , the direct association between the stimulus and the response would obviate the need for a counting process to carry out the transformation. Thus when either of these simple conditions was present, the increase in slope as the other parameter increased was minimal

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for both encoding and storage times. However, when both parameters were larger there was a substantial increase in the time required for these components. If only the more difficult conditions are considered (see chapter 4), the interaction between t and m disappears for encoding and transform times. Thus, following the logic of Logan (1979), this would suggest that no new resources have to be loaded when difficulty is increased in this range. The remaining main effects therefore suggest increases due purely to increased demand on the representational components of the model. However, note that even here there is evidence for the first cycle being affected by the expected load, suggesting that 'space' has to be reserved for expected memory loads as well as for all processes which are going to be used during the trial. The consequence of trying to carry out a difficult task is thus that in general any sub-process will be executed more slowly the more activity there is in the system which is irrelevant for that subtask (although it may be relevant for the task as a whole).

The largest effects seem to occur when additional resources are required to carry out the task, whether these be additional processes or additional (or 'larger') intermediate storage representations. The notion of limited capacity has often been invoked in such circumstances to explain data from very diverse sources from the number of 'chunks' which can be held in short term memory (Miller 1956) to the amount of information which can pass through an attentional bottleneck (eg Broadbent 1958, Deutsch and Deutsch, 1963; Treisman 1964). However, the question

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remains, exactly what is limited? Although it is clear that there is some upper limit to the amount of processing which can take place concurrently, attempts to evaluate this have been remarkably unsuccessful. For example, Kahneman (1973) proposed an 'elastic' capacity view, where the precise capacity of a unitary pool could be adjusted by factors such as arousal and task difficulty. Other theorists have proposed multiple capacity theories (eg Navon and Gopher 1979), where the system consists of a number of independent resources, each with its own capacity limitation. The notion of limited capacity therefore seems reasonable, but it is not clear what is actually limited.

If we now consider the various components of the cross, some forms of limitation which are implied by this framework become apparent. The input and output stores both appear to be limited by properties of both temporal decay and interference. For example, the articulatory loop is known to have a capacity of about two seconds (eg Baddeley, Thompson and Buchanan (1975), and Sperling (1960) demonstrated a visual sensory store with a short time duration. In addition however, if the material in the articulatory loop is phonemically similar, then interference occurs, and if an irrelevant suffix appears at the end of a list to be remembered, the recency effect is reduced. Even considering only input and output stores then, it can be seen that fairly complex patterns of behaviour could be achieved depending on how the stores were used for the task and the precise nature of the material to be remembered. If we now consider the role of the long term store and the processing

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system, the situation becomes even more complex. The amount which can be recalled from the long term store is determined more by the structure of the store than by any external measure such as number of items recalled. This is amply illustrated by the 80 digit memory span discussed earlier (Chase and Ericsson, 1981).

The processing system is probably the most interesting component to consider. Extra load on this system seemed to have the largest effects on the data from the alphabet transformation task. Let us consider the likely nature of these processes. The primary roles of processes were defined earlier as being necessary for maintaining a representation or mediating between different representations. There must also be a higher level control process (or control processes) which are responsible for the particular configuration of resources required for any given task. The precise nature of the processes available will depend on previous experience. For example it is clear from work on 'automation' of processing (eg Shiffrin and Schneider 1977, Spelke, Hirst and Neisser 1976) that many of the overheads of a given task, or given combination of tasks can be reduced with appropriate practice. If we assume that a limited number of processes can be active at any one time (cf Allport 1980a), and that as the system becomes overloaded, the efficiency of all loaded processes decreases the reason for such phenomena can be understood. With practice processes which are used together can become a single process for the purposes of the processor, and so efficiency is increased (eg Logan 1979).

The issue of how processes become automated is really outside the

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scope of the present work, but it is probably worth making a few comments which are relevant for the framework being advocated. The practice required to produce 'automation' is clearly not a simple function of time on task. For example Mowbray and Rhoades (1959) had to practice subjects for several hundred sessions to eliminate the difference between a two and four choice reaction time. Similarly, many people even after a lifetime of practice are unable to attain the skill in games such as tennis whereas others seem to be 'naturals'. On the opposite extreme, one trial or even no-trial learning can take place. For example young children can often have their memory span improved immediately by telling them how to use subvocal rehearsal to assist them (Flavell 1970). Similarly, Shiffrin and Schneider (1977) argue that older or better subjects tend to have a better repertoire of existing control processes. The 'automation' of processing is thus far from simple. The important point for present purposes however is that it appears to be possible to have a number of processes active at once, but if there are too many (or they try to do too much) the efficiency of the system suffers. Parallels can be drawn here with a form of production system (eg Newell and Simon 1972). We can regard the processes in the processor as a production system. The nature of the task will determine what productions are loaded. Each production which is loaded will constantly poll the relevant representations with which it is concerned looking for a pattern which will activate it. When it is activated, it will carry out the required action. However, if a number of processes are active at once, each will be

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continuously looking for a cue to fire it and so less processing will be available for the process which is currently fired. An interesting parallel can be drawn here with the input and output systems. This analogy implies a similar time based limitation to the processor. It is much more difficult to put a figure on such a time however until we understand better the nature of the resources with which we are concerned. The implication from this analysis is that in practical terms, the saving which takes place with automation is in less monitoring of irrelevant information rather than faster execution of the most basic resources. Another implication of such a view is that although the system proposed shares many features with distributed processing systems (eg Monsell 1984, Allport 1980a, 1980b) it is preferable to present it as a single processor into which appropriate programs can be loaded, since the limitations which the system contains are a result of time-sharing on a single processor.

### 9.3.4 Adaptation to Dynamic Demands

The foregoing might imply that once the system is set running performance would be relatively stable. Storage time would possibly be expected to increase as the storage load to be maintained increased (but see the remarkably stable performance across cycles shown by group 6 in fig 5.6). The small increases noted in encoding time over the trial could also be explained by the storage resources having more monitoring to do as the response was built up and so by the arguments in the previous section slowing down all other resources. However, the decrease

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noted in transform time across the trial in chapters 3 and 4 cannot be explained this way. Rather, dynamic tuning of the resources must be taking place. For example if a stored representation of the output sequence is more likely to be lost as its length increases, it would be worthwhile risking carrying out the transform more quickly to minimise the time for which that representation is not serviced. It might not be possible to interrupt the transform process to monitor the other representations which are being maintained. Since it appears to be based on the temporal rhythm, any interruption might interfere with the process and so speeding it up is a more efficient trade off than allowing it to be interrupted. The fact that the transform process can be speeded up is clear both from the data in chapter 3 and 4 and in particular from that in chapters 7 and 8. In these latter chapters the rate of transformation was considerably faster than the earlier ones. This is probably due to more extended practice on a single condition, so that these subjects may have been working close to the maximum possible rate. It should be noted that in general the subjects in the later studies did not show the same characteristic drop in transform time as the trial progressed. Rather the shape of the curve mirrored the actual task load represented by the storage time. It may be that in better practiced subjects the arguments concerning the allocation of time between resources hold even for the transform time - possibly because it cannot be improved any further. Note however the tendency for a reduction in transform time to reappear in the constant additional memory load condition when the overall demands of the task were changed by requiring an

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additional memory load to be maintained. Overall then there does appear to be evidence for a dynamic adaptation to the precise demands imposed by the task, but this seems to be modified by practice.

### 9.3.5 Strategic Variation and Differences in Ability

The discussion so far has focused on the aspects of the data which appeared to be fairly uniform. However there was also considerable evidence for large differences between individuals. Chapter five showed a number of distinctive patterns of performance which were related to the abilities of the individuals concerned. The stress manipulations of chapters 7 and 8 showed particularly varied effects which differed in direction as well as magnitude between individuals.

It is not clear what differences between the groups are due to ability differences and which are strategic. One problem is the obvious differences in the way in which subjects cope with a task which is verging on the limits of their performance. For example subject 11 in chapter 4 and subject 5 in chapter 8 both showed extremely high error rates in the most difficult conditions with which they were faced. Their approach to the task was to carry it out as quickly as possible, but they were obviously not able to monitor their progress sufficiently well to ensure a reasonable error rate. Conversely, other subjects responded to task difficulty by working very slowly. This tended to be reflected in particular in very long storage times. Group 4 in

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fig 5.6, and the lower IQ subjects in chapter 5 in general tended to show this pattern. The most obvious explanation for such a pattern is that these subjects were having trouble with control processing. If they were unable to function efficiently with all the required control processes loaded at once, they may have had to use very inefficient strategies such as swapping resources in and out of the processor. This itself would of course require additional resources and thus decrease speed even further. Presumably the storage phase would be used to manage this additional work which would explain its size. It is not clear whether these subjects would actually have reduced capacity in the processor or whether they simply had inefficient resources, so that more resources would be required to carry out the task than was the case with better subjects. However, at least the Cross of Lorraine framework supplies an appropriate language to discuss the possibilities, and future work within such a framework could explore measuring components of the task individually, and try training to improve performance to investigate the nature of the limitation for these subjects. A similar problem is apparent for the data of chapters 7 and 8. It is not clear whether the patterns observed are a function of different strategic responses to noise and the additional memory load, or whether these manipulations actually affect different people in different ways. One important implication from these chapters, however, is the reduction in variance which seemed to be associated with increases in task difficulty. This could occur if the monitoring carried out by active resources could be controlled independently of the processing taking place. If this

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were the case, it could be an explanation for the effects of increased effort discussed by Kahneman (1973). In addition, if this monitoring was reduced too much, breakdown in performance as noted above could also be explained.

### 9.3.6 Changes in System State

An alternative to strategic changes resulting from a stressor such as alcohol or noise (or at least an explanation for some of them) is that the stressor differentially affects certain components of the system and reduces their efficiency. One example of this is that alcohol is known to affect motor performance. This might lead to less reliance on the output store, and greater use of some other store. The increase in transform time in the alphabet transformation task and the increase in order errors in the free recall task are consistent with this hypothesis. The results with noise were certainly not consistent across subjects, but the internal consistency produced by each individual was impressive. It is possible that noise has a different effect on different people, as was discussed in chapter 7. For example some people may introduce a new process to counter the effects of noise, and thus show poorer performance on all components of the task (eg subject 1 in chapter 7). On the other hand noise may mask feedback from articulation to an acoustic store (cf Salame and Baddeley 1982), and this lack of feedback monitoring may speed up the process (subjects 2, 3, 4 and 5). So it may be that such monitoring is not strictly necessary for the task, and the noise suppresses it.

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Alternatively, the increase in encoding time and decrease in transform time may be a result of redivision of labour between the two task phases, so that some extra activation of the memory trace of the relevant portion of the alphabet is carried out by the encoding phase to allow the transform phase to occur more quickly. (This could also apply to the data in chapters 3 and 4).

### 9.4 FUTURE DIRECTIONS

One of the major implications of this work has been to highlight the importance of understanding how mental resources are managed. It has emphasised understanding the control processes which determine how mental resources are organised, and how information might be passed between them. Inevitably, some important aspects have been outside the scope of the current work. We might expect a better understanding of these control processes to give us a better understanding of learning (and certain forms of forgetting) - for example, a framework such as the one presented may have the scope to encompass what Rabbitt (1979, 1981) calls a model for change.

Another direction which may well be fruitful would be to examine the existing data in even more detail. The present work showed the extra value (and indeed the necessity) of looking at individual subjects. Looking at individual trials could also be enlightening. It would be interesting to see if glitches in the temporal pattern could predict errors (or vice versa), or to see how recovery from a potential problem takes place - for example

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if a particularly long time is found in one component, how are subsequent components in the same trial affected? This would be particularly relevant for understanding the role of the monitoring which active resources were assumed to carry out (see previous section).

The fact that the present work was based on a single experimental paradigm obviously means that it is unclear how far some of the conclusions can generalise. It would be useful to apply some of the methodological lessons (both looking at the microstructure of performance and designs which are likely to be successful) to other domains of equivalent complexity. Two obvious candidates are mental arithmetic (cf Hitch 1978) and the 'working memory span' which Daneman and Carpenter (1980) have successfully used to predict reading ability. More extensive evaluation of a performance model which results from such work should then be done against the rich but fragmented literature which presently exists. If the fragmentation can thus be reduced that is surely a step forward.

Probably the greatest problem which considering complex performance brings is understanding individual differences and strategies. It is quite clear that over-simplified models which result from much of our present work are inadequate to apply to real life problems (eg Simon 1967). Looking at complex problems at least alerts us to these inadequacies. If we can understand how mental resources are organised in such complex problems in such a way that we can evolve today's knowledge into a form which

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is more universally useful, then the last thirty years work on information processing psychology will not have been wasted. Hopefully the present work is one small step on that road.

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