Working memory constellations

Neil Gerald Morris

How to cite:

Morris, Neil Gerald (1986) Working memory constellations. Doctoral thesis, Durham University.

WORKING MEMORY CONSTELLATIONS

Neil Gerald Morris

Thesis submitted for the degree of
Doctor of Philosophy
Department of Psychology
University of Durham
1986

WORKING MEMORY CONSTELLATIONS

Neil Gerald Morris

ABSTRACT

Evidence is presented that supports the view that most models of short-term memory cannot account for the flexibility of the primary memory system. It is argued that the working memory model outlined by Baddeley and Hitch (1974) is, however, a potentially adequate model. Working memory, in this thesis, is depicted as a system that assembles 'constellations' consisting of the central executive and one or more sub-systems. This view suggests a formulation that is considerably more complex than the 1974 model.

The empirical studies examine the role of the visuo-spatial scratch pad in the formation and maintenance of working memory constellations. It is concluded from these studies that the scratch pad is independent of the articulatory loop but is usually coupled to the central executive except during maintenance rehearsal. Furthermore, it can be used concurrently with the articulatory loop to process spatial aspects of highly verbal tasks. However a constellation consisting of the executive, the loop and the scratch pad is vulnerable to a wider range of interference effects than a simpler constellation. Paivio (1971) suggested that 'dual coding' leads to better memory performance, however, this is only the case when no distractors are present.

The final two chapters present some speculations on how working memory research might proceed in the future. It is concluded that the current trend towards collecting convergent evidence and the emphasis on testing theory in applied situations should give us insights into memory that were not available to Ebbinghaus and other early memory researchers.

Acknowledgements

I would like to thank my supervisor, Bob Hockey, for his help and advice throughout the course of this research. Cathy Thompson, Martin Spencer and Melanie Vitkovitch provided invaluable help with computer programming. I would also like to thank the technical staff of Durham University Psychology Department, especially Neil Corr and Malcolm Rollings, for their help in the design and construction of the apparatus used in this research. Professor P.M.A. Rabbitt, Dr. G. Granger and Dr. J. Findlay kindly provided the facilities necessary for this project. The research was funded by the S.S.R.C. It is not possible to name individually the subjects who made this research possible as a large number of Durham University students kindly agreed to participate in these experiments.

My thanks are also due to a number of individuals at UWIST, Department of Applied Psychology. Dr. Dylan Jones greatly improved the manuscript by providing criticism of an earlier draft. The UWIST Human Performance Research Group were most helpful in giving up their time to proofread the thesis, especially Stella. I have been unable to assemble a sufficiently large working memory constellation to acknowledge everyone. My apologies are due to all those who have been helpful and have not been named above.

DECLARATION

I hereby declare that the work in this thesis is entirely my own and that no part has been previously submitted for a degree in this or any other university.

STATEMENT OF COPYRIGHT

Neil Morris
1986

A man should keep his little brain-attic stocked with all the furniture that he is likely to use and the rest he can put away in the lumber room.

Sherlock Holmes
The Five Orange Pips

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Convergent Evidence for a Multi-Process Working Memory System

1.1 Summary

William James distinguished between long-term and short-term memory and this distinction was explicitly retained in more recent models using information processing paradigms (e.g. Broadbent, 1958). Furthermore, the idea that there may be more than two memory stores that are not discriminated on purely sensory modality grounds is implicit in the psychometric testing literature although this distinction is frequently disguised as 'abilities' rather than 'memories'.

With the advent of the concept of working memory and in the face of neuropsychological fractionation of the system the idea that 'memory' is a multifaceted system has become commonplace. Single trace theories of memory have largely succumbed to a structuralism that emphasises the functional relationship between components.

Structuralist models of semantic memory have long been in vogue but short-term stores have tended to remain black boxes existing parasitically on long-term memory. Early two store theories depicted primary memory (short-term store) as the gateway to, and the output buffer from, secondary memory.

Recent research has emphasised the intimate relationship between memory and attention. This work suggests that it would be unwise to consider these aspects of cognition in isolation. Rather, one should attempt to model the information processing domain as an integrated system with a number of discrete structures operating in concert.

1.2 Introduction

In 1974 Baddeley and Hitch proposed that short-term or temporary memory was a working memory system with a number of components. These were a central executive and two slave systems; the articulatory loop and the visuo-spatial scratch pad (spatial working memory). The central executive has at least two components; a general workspace and an attentional mechanism that allocates resources. The articulatory loop is said to hold speech-like material while the visuo-spatial scratch pad is involved in imaginal processing. There is a considerable body of convergent evidence that this departure from the dichotomous view of memory is necessary(Atkinson and Shiffrin, 1968).

The term working memory refers to a 'mental work space' analogous to the concept employed in computer science to delimit the current capacity of a processor i.e. the amount of information that can be held without off-loading to a peripheral storage device. It is inherent in such a model that capacity is limited and that long term storage involves an independent system that can access a temporary store(s) and is accessible to such a store(s).

Such a distinction was made by James (1892). "Memory proper, or secondary memory as it might be styled, is the knowledge of a former state of mind after it has already once dropped from consciousness; or rather it is the knowledge of an event, or fact, of which we have not been thinking, with the additional consciousness that we have thought or experienced it before" (page 287).

This distinction, the dichotomous view of memory, has a long history in psychology. Such a distinction was made by Broadbent (1958) when he modelled cognitive processes using information processing terminology. The term 'working memory' was introduced by Atkinson and Shiffrin (1968) although this distinction has not received universal approval. Gruneberg (1976) argued that the evidence for the dichotomous view of memory could be more parsimoniously explained by a single store theory. However a large body of evidence has accumulated which suggests that both these views are over simplified and that it is now necessary to model memory as a complex multiple store system.

Evidence for this view can be derived from the psychometric literature, nomothetic studies of attention and memory, and physiological and neuropsychological studies of memory. This distinction has also led to a debate on the nature of mental representation. This thesis reviews this evidence and empirically examines the role that the visuo-spatial scratch pad plays in assemblies, or constellations, of working memory components.

1.3 Intelligence and Short-term Memory

Psychometricians interested in intelligence have used batteries of tests to discriminate between different 'mental abilities'. Although some workers have suggested that there is a single intelligence factor (general intelligence) it is not the case that any such factor has been able to account for most of the variance (Hunt, 1980). Factor analytic studies (however they have been weighted) always reveal a considerable residual variance that cannot be assigned to an error term.

A working memory model assumes that performing the tasks presented in a test of some cognitive ability requires a short-term representation while mental operations are performed on the material. Thus if it is the case that a general factor cannot account for the variance then one must postulate specific abilities and specific cognitive structures to handle this processing. An alternative would be to postulate that the tests merely differ in difficulty.

Many specific abilities have been postulated but a considerable proportion of these have been clustered into verbal and spatial (imaginal) abilities. This distinction between verbal and imaginal encoding is not a recent innovation in psychology and is especially prevalent in the psychometric testing literature. Francis Galton (1822-1911) constructed a questionnaire which he had completed by students and men of various professions. It specified various situations in which they were to try to elicit images. For example, there was a request to call up from memory the scene of their breakfast table that morning. His subjects were to say whether the image they had was dim or clear, well defined or ill defined, naturally coloured etc.

(Galton, 1883). This test was refined and extended by Betts (1909) to include other sensory modalities.

Thurstone (1938) included a space factor in his analysis of intelligence factors and later developed the Flags Test (Thurstone and Jeffrey, 1956) as a measure of spatial thinking. As early as 1908 Binet and Simon included tests of digit span and object identification although a single M.A. (mental age) value was reported. They noted however that some children would perform badly on one test at one age but not another, thus it is implicit in this that these sub-tests measured the developmental course of different abilities.

Even during the so-called behaviourist era with its stress on simple S-R (stimulus-response) pairings and the rejection of mentalistic terms (Watson, 1919) it is clear that there was a strong European movement that stressed individual differences and rejected the idea that there was only one type of 'thinking'.

In Britain, Spearman (1923) postulated a two factor theory of intelligence derived from factor analysis of intelligence tests. He isolated a general intelligence factor 'g' representing common variance in correlations of tests with diverse contents and argued that the remaining variance was accounted for by specific abilities required to perform specific tasks.

Intelligence tests that require little access to long term memory i.e. those tapping mechanistic processes (Hunt,

1978) would seem to require a working memory system to solve the problems posed in the test. Thus a single short-term store model should not predict the emergence of separate abilities unless, as was noted earlier, these merely reflected differing degrees of difficulty.

Crucially, then, studies should demonstrate that some subjects will score high on ability A and low on ability B while others show the converse effect. Under such circumstances specific abilities representing some of the residual variance should reflect different processes. Such research meets the requirements for a model as proposed by Underwood (1975). "The theory must assume at least two intervening processes, and these processes must interact in some way to relate the independent variables to the dependent variable ... A single process theory must always be isomorphic to empirical relationships ... As a theoretical concept, it is superfluous and has no predictive power" (Underwood, 1975, page 131).

With respect to short-term memory individual differences act as a crucible in theory construction by proving at least one of the intervening processes i.e. a measure of the orthogonality of the memory structures involved. Note, however, that as such there is no identification of the actual structures used. It is necessary to establish the functions of 'g' and the functionally specific structures independently of the test scores.

A psychometric test may measure, for example, digit span. If this is compared to serial recall of digits in a memory experiment then the correlation is uninteresting because the two activities resemble each other too closely and could be explained by a single process theory. However a comparison of digit span with mental arithmetic performance would be interesting. There are prima facie grounds for believing that they use the same processor but the demand characteristics of the two tasks are different. However such comparisons frequently fail to show such correlations. There may be too little overlap of common processing to account for the variance. The problem lies in the different aims of the psychometrician and the cognitive psychologist in designing their tasks. Cattell (1971) expresses this well. "Not nearly enough steps and aspects of the learning and recall process - such as immediately committing to memory ... rate of retrieval, and other manifestations important to the memorization process - have been used by psychometrists, who have tended to confine themselves to some total learning effect" (page 42, cited by Eysenck, 1977, page 274).

However the construct validity of these tests is not crucial to the argument presented here, provided that it is accepted that test performance requires short-term memory capacity. If these tests do measure short-term processes then there is a strong case for a short-term memory system that has a number of components and these structures can be functionally specified without reference to specific psychometric tests. Psychometric data can be used as part of a body of convergent evidence for rejecting the view that there are only two memory structures.

Construct validity is of course essential when the memory structures are specified. The conclusion that can be drawn is simply that a two store model of memory cannot always account for the residual variance when two or more mechanistic tests are correlated

A Spearman type model would require a central, general processor, the locus of 'g' involved in all or most cognitive processes and a number of processors with greater functional specificity. Thus 'spatial' test and 'verbal' test scores should correlate but there should be substantial residual variance that reflects different modes of processing. The evidence is consistent with this (Dempster, 1951).

If Spearman is right and there are orthogonal abilities which are not purely artifacts of the factor analysis loadings employed then a problem solving system should possess some functionally specific subsystems which are used when individuals perform these tasks.

1.4 Neuropsychological Studies of Memory

Data from psychometric studies suggest that there are memory structures with considerable functional specificity. A materialist philosophy requires that these hypothesised structures should have some physical location (which may nevertheless be quite diffuse) within the brain.

Consequently some lesions should impair or destroy these structures and this should be reflected in behavioural data.

Neuropsychological studies typically employ designs that use double dissociations. Patient A must, for example show a deficit in performance on task X but not task Y relative to a control group while a different lesion should produce the opposite finding if the memory structures involved are specific and the deficit is not merely a reflection of different degrees of difficulty between tasks X and Y. Such double dissociations are found in the psychometric literature and we would expect to find comparable results in the neuropsychological literature. Also individuals with lesions should show deficits on appropriate psychometric tests but perform within the normal range on most intelligence tests (to ensure that cognitive deficits are not global and, also, to ensure that they can comprehend the demand characteristics of the procedure). Finally, sensory impairment should be ruled out.

1.4.1 Hemispheric Differences. A massive body of literature, some of which is reviewed by Milner (1971), has demonstrated that the site of a lesion is crucial to the type of memory pathology exhibited. In particular, left hemisphere lesions tend to produce a variety of deficits in verbal processing while right hemisphere lesions produce non-verbal deficits but leave verbal processing intact.

This is demonstrated with great clarity in studies using epileptic patients who have undergone left or right anterior lobectomy. Left temporal lobectomy (in 'right handers') selectively impairs the acquisition and retention of verbal material (Milner, 1967) while comparable lesioning to the right temporal lobe leaves verbal memory intact but impairs memory for visual and auditory patterns that are not easily verbally recodable (Milner, 1968).

Within hemispheres the location of the lesion is crucial to the nature of the disorder within a processing domain so that, for example, specific kinds of verbal deficits are associated with particular left hemisphere regions and different spatial deficits are associated with different loci of lesions within the right hemisphere. The fractionation of these processing domains by lesioning is discussed further in the appropriate sections on verbal and spatial processing.

This hemispheric specialisation is by no means as clear cut as the above examples would suggest. The left hemisphere has been implicated in spatial processing, especially the left parietal lobe (Warrington, 1971) and the right hemisphere has some language processing capability (Lambert, 1981).

However the literature does suggest that the left hemisphere, in particular, is highly specialised to process verbal information. Thus these findings provide compelling evidence for the view that verbal and non-verbal information are analysed at neuroanatomically distinct sites at some point in the memorial process.

1.4.2. Verbal Processing. The literature on aphasias (language disorders) suggests that the verbal processing domain can be fractionated into functionally independent locations. Lenneberg (1969) has distinguished between three different language skills which seem to depend on different physiological processes. These are reflected by speech production, cognitive and word presence aphasias. Speech production aphasia is demonstrated by patients who cannot speak but who can listen and comprehend. A double dissociation can be obtained with this disorder and cognitive aphasia, a condition in which patients can say words but cannot speak intelligently or comprehend speech.

Word presence aphasia leaves comprehension and speech production intact but there are problems with locating the words necessary for reasonable speech. A double dissociation with this aphasia has not been demonstrated (Beatty, 1975).

Speech production aphasia is a motor problem while cognitive aphasia appears to be a semantic processing problem. One should not be surprised that a double dissociation obtains. Speech production is largely a mechanistic process while cognitive aphasia requires impairment to the structure of, or access to, long term semantic memory. It is the 'mechanistic' processing impairments that are crucial to the fractionation of working memory.

It was noted earlier that Baddeley and Hitch (1974) have argued that there is a short-term memory component that acts

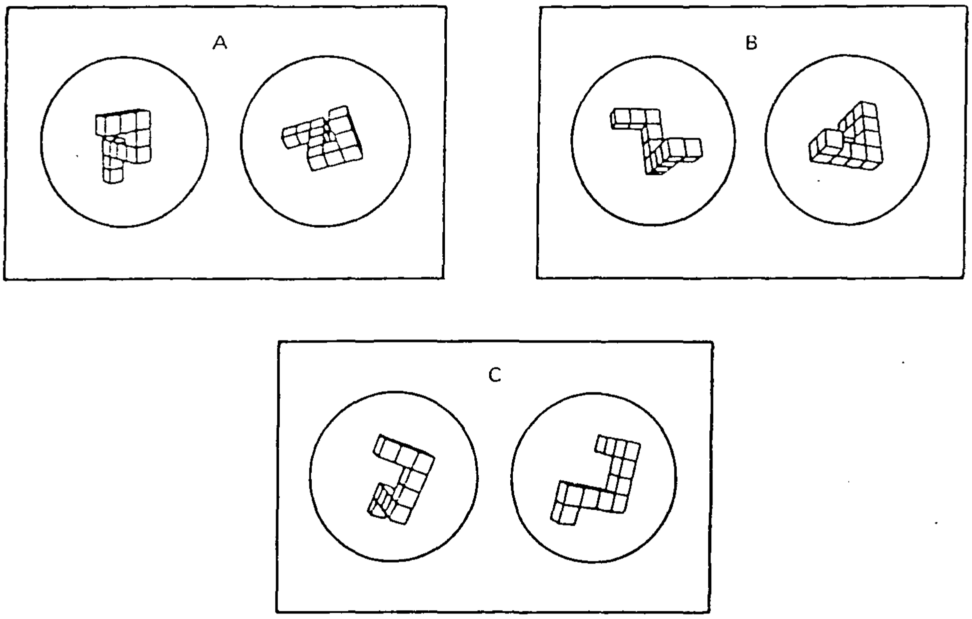
For the time being it is sufficient to note that physiologically 'spatial processing' is distinct from 'verbal' processing. One would expect this as organisms that have no demonstrable verbal capacity nevertheless possess cognitive structures that allow them to engage in spatial processing. In this sense spatial processing structures can be seen as more 'primitive' than verbal processing structures (in that they must have preceded verbal structures in evolution). Thus one can argue that verbal processing is a relatively recent evolutionary innovation whereas spatial processing, however rudimentary, is a fundamental capability of all organisms. In a nutshell, spatial processing is essential if an organism is to interact with its environment whereas verbal processing seems to be a species specific adaptation.

1.5 The Nature of Mental Representation

Paivio (1971) argued in favour of a dual coding hypothesis, which implied that "images and verbal processes are viewed as alternative coding systems, or modes of symbolic representation" (Paivio, 1971, page 8). Such a distinction was also suggested by Brooks (1968) who required subjects to use oral or directional responses (pointing) to make visuo-spatial and verbal decisions about the visual and verbal properties of stimuli. He reported a selective interference effect with subjects responding more rapidly with a verbal response to visuo-spatial tasks and pointing to verbal tasks than in the other two possible conditions. Thus it appears that responses involving a spatial component interfere in a selective manner with the retrieval of information from mental images.

Shepard and his colleagues (see Shepard and Cooper, 1982) suggested that mental images could be 'rotated'. Typically, using stimuli of the kind illustrated in Figure 1.1. he found that it took longer to respond "same" to a pair of figures that had greater angular disparity than figures which were closer in orientation. The explanation offered was that subjects had to form an image of one of the line drawings and 'mentally' rotate it to the same orientation as the other drawing. This is clearly a non-verbal task as there is no reason to believe that it would take longer to verbally describe a large angle. Indeed a verbal description of, for example, 180 degrees of rotation should be easily generated (by relabelling "up" as "down" etc.) but the response latencies forthcoming from empirical studies do not support such a propositional view.

Figure 1.1. Mental Rotation.



Examples of pairs of perspective line drawings presented to the subjects. (A) A "same" pair, which differs by an 80 degree rotation in the picture plane; (B) a "same" pair, which differs by an 80 degree rotation in depth; and (C) a "different" pair, which cannot be brought into congruence by *any* rotation. From Shepard and Metzler (1971).

This sort of task has been used in tests of spatial ability (e.g. the "Space" test in the P.M.A. battery) which tend to share little common variance with verbal scales but demonstrate independent spatial factors and a large 'g' component (Macfarlane-Smith, 1964). The large 'g' component in tests requiring mental rotation is consistent with the view of Phillips (1983) that 'visualisation' requires general resources. Phillips' visualisation task is arguably 'purer' than mental rotation tasks but probably involves some of the sub-systems used in this activity. Phillips' work is discussed in detail in Chapter 2.

The literature reviewed so far indicates that there is a prima facie case for examining the proposition that the brain uses more than one form of representation for memories. The psychometric and physiological evidence suggests that there are a number of memory structures using different processes and the literature from cognitive psychology, on the whole, is also consistent with this view (with detractors from this view falling back onto arguments based on a parsimony that is becoming increasingly untenable).

In what forms might these representations be encoded and stored? Pylyshyn (1973) argues for propositional representation. For Pylyshyn images and words are different classes of concept phenomenologically but they can be stored in a interlingua, a common format that is not available to conscious inspection (this is analogous to Chomsky's deep structure in generative grammar). Kosslyn and Pomerantz

(1977), however, opt for analogue or pictorial representation of images.

The nature of representation remains an unresolved issue. However it might be interesting to tentatively assume that long term storage is propositional (like digital storage on 'disk') while short term memory systems at least behave as if representations of images are pictorial.

A more concrete analogy to this is the hologram. A hologram as a structure is a photographic plate but the process of generating a holographic image from this involves an optical system (with a screen for the real image) which is an altogether different structure. Damage to the plate results in a blurred image because the interference patterns 'encoded' are made coarser (Interference patterns are created by signal and reference beams of coherent light falling on the plate). Damage to the screen produces a 'torn off corner' which is analogous to visual neglect. Thus the screen provides an analogue, pictorial representation of propositionally encoded information.

By a similar analogy memory can be seen as a computer system in which permanent storage is propositional (or digital) but working memory employs peripheral devices representing the current conscious activities of cognitive processors (analogous to loudspeakers, VDU's etc.) and it is at least as if these conscious processes are in analogue form.

In summary memory processes that are conscious do differ in some ways from deep structures and this is reflected in behavioural responses and neuroanatomical structure. Short-term memory stores act as peripheral display devices with an executive(s) that activates and maintains the surface structure after generating it from deep structure.

It was noted at the beginning of this chapter that the central executive also has an attention component. Thus an adequate working memory model must also provide an account of how the attentional mechanism operates. The next section reviews attentional studies and the significance of this work is discussed in Chapter 8.

1.6 Attention and Short-Term Memory

William James included a chapter on attention in his 1892 textbook. Since then it has remained a central theme in psychology and even survived the suppression of Watsonian behaviourism (Lovie, 1983). The early work on 'attention' was largely introspective. However more recently a strong empirical tradition has developed.

Cherry (1953) introduced the technique of shadowing. Subjects were required to wear headphones and they listened to two different messages presented one to each ear (dichotic listening) and he found that when they were required to attend to one message, i.e. to verbally report one message, the other was ignored but certain features of the unattended message were detected. In particular, subjects noticed when the unattended voice changed in pitch, e.g. when a male voice was substituted for a female voice. This ability to ignore sources of auditory information is described, for obvious reasons, as the 'cocktail party effect'. Broadbent (1958) used this work as a basis for postulating his filter theory of attention (Lachman, Lachman and Butterfield, 1979).

This early work led to a heavy emphasis on the information processing aspects of human cognition and models of memory and attention began to incorporate information flowcharts and limited capacity processors. This influence has remained and is reflected in the close links between ergonomic studies of human performance and the cognitive psychology of mechanistic processes.

The point that these studies make is that, under certain circumstances, we cannot do two or more things at once. This has two implications. Firstly, at some stage(s) of cognitive processing the processing is serial (as opposed to parallel) and, secondly, processing capacity is limited. Theories of attention attempt to show how we handle, or fail to handle, these limitations. There are two fundamental ways of doing this. Attention can be selective i.e. some information is filtered out or simply ignored. The second method of coping is to temporarily hold sources of information before a bottleneck (analogous to a telephonist putting you on 'hold'). Both of these processes require memory. Selectivity of attention usually requires a decision about the salience of potential input which requires access to semantic memory and being put on 'hold' obviously requires a short-term memory system.

Broadbent's (1958) filter theory postulates that people receive more information than they can process. Broadbent handles this by placing a short-term sensory store after sensory registration. This information is then fed, still in parallel, into a selective filter and then into a limited capacity perceptual system (short-term memory) at which point the information becomes 'conscious' and can pass onto long-term memory and/or result in an output. Selectivity occurs in the filter and thereby reduces the information load to manageable proportions. The filter is tuneable, i.e. it can be set to accept information of a certain type or from a certain source (e.g. from one ear). Thus in the Cherry experiment information from both ears enters the short-term sensory information register but one ear is filtered out so that an output (in this case shadowing one message i.e. repeating aloud the message from the 'selected' ear) is not interfered with by the other information source.

When it appears that we are attending to two sources at once Broadbent argues that we are multiplexing, i.e. time sharing between parallel channels and then feeding information out of the selective filter serially. In effect we are rapidly retuning the filter to accommodate multiple sources of salient information. Some crude (non-semantic) information does pass through the filter, thus we do detect, for example, changes in the pitch of the unattended speech.

It is explicit in Broadbent's model that there is no semantic processing prior to filtering, thus the meaning of the material presented to the unattended ear should not enter consciousness. However Moray (1959) demonstrated that subjects often recognised their own names when these were presented to the unattended ear. This was consistent with the view that all inputs are at least superficially analysed semantically before they are kept from consciousness.

Triesman (1964) argued that the filter is selective across a whole continuum of inputs, some of which need not necessarily be simple physical characteristics (pitch, volume, etc.). It is the case, she argued, that the filter attenuates rather than completely blocks information. The degree of attenuation is decided by feedback from consciousness acting on the filter. This feedback is semantic and input to the filter semantically related to the current contents of consciousness is attenuated to make it more perceptable than otherwise. Broadbent (1971) conceded this point but held to his position that consciousness is a serial process.

Deutsch and Deutsch (1963) rejected the filter concept and assumed that everything is fully processed whether it is attended to or not (Neisser, 1976). Selection occurs only at the stage of memory and action. Thus subjects in selective listening studies perceive both voices but forget the unattended message so rapidly that it has little impact on consciousness (perhaps because it is subject to articulatory suppression from the repetition of the attended message - see the section in the next chapter on the articulatory loop). Therefore the activity of the analyzing units detecting words in the subjects' vocabulary is not conscious. Information is processed without our being aware of it.

One of the major criticisms of introspective reports in the study of attention is that we can only introspect on the contents of consciousness. Preconscious aspects of 'thinking' are not available and consciousness seems to be only the tip of the iceberg in cognitive processing. Neisser (1963), in a discussion of intuitive thinking, sums this up succinctly. "The thinker arrives at an answer, which may be right or wrong, with little if any awareness of the process by which he reached it" (cited Dixon, 1981, page 258).

Dixon (1981) strongly supports the view that there is much semantic processing before consciousness. With respect to theories that require little preconscious processing of semantic information he makes the following comments. "According to this sort of theory, recognition of a word, say, depends on its conscious perception. Despite the fact that the primary purpose of attentional mechanisms is presumably to prevent overload of the limited capacity channel of conscious experience, that which must surely be the most capacity consuming task of all (exploring the meaning of incoming information) occurs, according to this sort of theorizing within, not before, conscious representation. Evidence from a diversity of research areas including subliminal perception, perceptual defence .... pattern masking and reading, suggest that these theories of attention are mistaken. Words, not to mention other stimuli to which we may ultimately attend, do not have to be consciously perceived in order to be recognised.

The filter or regulator or central processor or whatever it is that controls entry into awareness does not operate solely on the basis of such relatively irrelevant criteria of linguistic stimuli as their gross physical characteristics, but rather on the results of extensive preconscious monitoring and analysis" (Dixon, 1981, page 259).

A rather different approach to attentional capacity was taken by Kahneman (1973). He conceptualised attention as a phenomenon with limited 'energy', the expenditure of which was described as attentional effort. His system had a general purpose limited capacity processor which allocated attentional 'energy' to where it is needed.

He offers the following analogy. "When you push a slice of bread into the toaster, this increases the load on the general electric supply. Without a countervailing change, the new load would cause the voltage supplied to all users to drop. However, the generator that supplies the current is equipped with a governor system which immediately causes more fuel to be burned to restore the constant voltage. In this manner, the total power that the generator supplies varies continuously as a function of the load which is imposed by the momentary choices of the consumers of electricity ... as a user of electric power you rarely control the amount of power that you require in a continuous or graded fashion.

All that you decide is that a certain aim is to be achieved .... How much power is drawn depends on the structure of the elements that you switch on .... the same rule applies to mental work as well. In general, we merely decide what aims we wish to achieve. The activities in which we engage determine the effort we exert .... (However we cannot simply) try as hard (on) a relatively easy task as .... when the task becomes more demanding" (page 14).

Furthermore, "some effort is exerted even when task demands are zero. The continuous monitoring of our surroundings probably occupies some capacity even in the most relaxed conscious state. This is labelled spare capacity ... (S)pare capacity decreases as the effort invested in (a) primary task increases .... (S)uch change of allocation occurs whenever arousal is high" (page 16). The role of strategy development is likely to be of great importance in the production of an adequate working memory model. This point will be discussed further in the final chapter of this thesis.

For Kahneman the processing demands of a difficult task not only requires the allocation of limited capacity resources but increased physiological arousal which results in greater attentional selectivity (Hockey, 1970) because spare capacity normally used for mundane, general monitoring of the environment is mobilised. This is subjectively experienced as an increase in concentration with a resulting neglect of extraneous information. Errors still occur in simple (low load) task performance because they are 'under-arousing'. Over arousal produces errors because attention has narrowed to a point where some salient features of the task are neglected.

Logan (1980) has suggested that "From the point of view of capacity theory, attention and short-term memory may be the same thing; both are central in the architecture of the information processing system, both have limited capacities that can be allocated strategically, and both have been implicated in the control of behaviour" (page 388). He argued that the central processor, when tasks are repetitive, is implicated in the setting up of a program of analysis of the stimulus, rather than in executing the information processing stages that mediate between stimulus and response (Logan, 1979). This is consistent with Baddeley's view that the central executive has a work space and a resource allocation device.

Cognitive processing has temporal and spatial constraints. The organism can only spatially monitor a limited amount of the visual field within a certain time course. As was noted earlier this will vary with level of arousal. The relationship between spatial and temporal capacity is likely to be complex given that an infinite number of spatio-temporal trade offs are possible. If Logan is right, i.e. if attention and short-term memory are intimately related in the structure of the information processing domain, then it is likely that they will share much neural hardware and it would not be appropriate to consider them to be separate processes. Rather they should be seen as different facets of a unified process. Such a view would require that, for example, ostensibly pure attentional tasks would require at least some minimal memory capacity which would be used to set up a program of analysis. That is, some memory capacity would be required to hold the 'plan' (Miller, Galanter and Pribram, 1960).

Included in such plans would be a representation of the strategy to be deployed in performing the task. The priming effects reported in the literature (see for example Posner, 1978) suggest that plans are formed rapidly and they may be short-lived unless they are reinforced by successful performance. A successful plan may be stored in long-term memory; thus repeated practice on a task reduces the amount of central capacity required for performance. Prior warning of the spatial location of a cognitive load, for example, can produce orienting of attention with an increase in arousal, narrowing of attention and greater efficiency in response over short S.O.A.'s (stimulus onset asyncronies). Deficits in performance are found with long S.O.A.'s because this orienting behaviour is not maintained and invalid orienting cues (e.g. a cue indicating that a stimulus will appear on the right with subsequent stimulus presentation to the left) also produce delayed responses (Posner, 1978).

All the models reviewed have processors that attempt to maximize performance by selectively using limited capacity resources, the allocation of which is dictated by task demands. Cognitive failure (poor performance) occurs when the task demands are too demanding or when the organism adopts an inappropriate allocation of resources. Such resource allocation mechanisms are described as control processes. Within the working memory model such processes are under the control of a central executive.

1.7 Overview

The working memory model emphasises the structure of memory stores and defines functionally how they allow the organism to process information in real time. Its relationship with semantic memory still remains obscure but, given our current limited knowledge of the nature of memory, it is sufficient that we should try to offer a cogent account of the mechanistic processes of short-term memory in parallel with research into semantic memory (even if we cannot relate the two endeavours in a way that is not overly presumptuous).

Developing a model of working memory that can meet the aforementioned criteria is an ambitious project and one that is not likely to reach fruition in the near future. Thus a large element of speculation is inevitable. Nevertheless, it is a basic contention of this thesis that it is worthwhile to speculate in this way. The empirical evidence offered here attempts to tackle a small number of a large set of problems inherent in an adequate working memory model.

The system is seen as a multifaceted complex system using numerous control processes which are carried out in a variety of memory structures under the control of an executive (whose structure will remain largely undefined).

Taking one such structure, the visuo-spatial scratch pad, the experiments reported here attempt to address questions about the relationship of the scratch pad to the executive and to working memory as a whole.

1.8. An Outline of the Thesis.

In Chapter 2 the literature on working memory is reviewed and methodological problems inherent in this approach are discussed.

Chapter 3 introduces two versions of a memory task that demonstrates the orthogonality of two working memory slave systems - the articulatory loop and the visuo-spatial scratch pad.

In Chapter 4 the relationship between the central executive and the visuo-spatial scratch pad is examined.

The emphasis in Chapter 5 shifts from the fractionation of the system to a demonstration of how it can operate using simple constellations.

Taking a rather simplistic task Chapter 6 demonstrates how the scratch pad can be used in an integrated manner with other components to perform a specific aspect of complex problem solving.

Chapter 7 presents a theoretical discussion of how an adequate working memory system might operate. The concept of working memory constellations is introduced.

In the final chapter, Chapter 8, some speculations on the future development of the working memory model are presented and a summary and overview of the thesis is provided.

Chapter 2

Working Memory: A Dozen Years of Research

2.1 Summary.

In 1974 Baddeley and Hitch proposed a model of working memory that has made a significant contribution to the advancement of memory research and our understanding of a wide range of cognitive processes. This chapter examines methodological considerations and reviews the elaborations to the model that have been necessary in the light of a dozen years of research.

2.2. Introduction.

Atkinson and Shiffrin (1968) proposed that transient memory traces act as a working memory i.e. a store that engages in processing information in real time. It became clear, however, that the plethora of information processing capabilities of complex organisms, especially humans, could not be accounted for by a simple short term/long term memory dichotomy (see Chapter 1 for a review). Baddeley and Hitch (1974) suggested that working memory was a system with a number of components. To reiterate, their model proposed that the short-term system consisted of a central executive and two slave systems; the articulatory loop and the visuo-spatial scratch pad (spatial working memory). Since the initial formulation of the model its originators have produced a number of reviews updating the model (Baddeley, 1976; Hitch and Baddeley, 1977; Hitch, 1980; Baddeley, 1981; 1982a; 1983; Hitch, 1984).

A succinct summary of the relationship between these three components has been provided by Baddeley (1981). "The central executive which formed the control centre of the system was assumed to select and operate various control processes. It was assumed to have a limited amount of processing capacity, some of which could be devoted to the short-term storage of information. It was able to unload some of the storage demands on to subsidiary slave systems of which two were initially specified, namely the Articulatory Loop, which was able to maintain verbal material by subvocal rehearsal, and the Visuo-Spatial Scratch Pad, which performed a similar function through the visualization of spatial material" (page 18).

2.3 THE RATIONALE UNDERLYING THE METHODOLOGIES EMPLOYED

There are two sources of interference in the working memory system because it has both general and functionally specific processors. Typically, dual task paradigms are employed. This involves presenting a subject with two tasks to be performed concurrently. Some concurrent activities have general effects, i.e., they affect most of the components of the system because central executive control is impaired. They also have specific effects, i.e. they compete for the resources of specific sub-systems. Most experiments using concurrent tasks use double dissociation designs to 'partition out' the general effects. Failure to do this does not allow one to fractionate the system because the effect may be purely general.

The use of concurrent activities in working memory research is crucial because it is explicitly a limited capacity system. The primary task, usually a memory task, uses stimuli that have characteristics that can be encoded in a specifiable form (e.g. words that are all phonemically similar) and performance on this task should be well above chance expectations. With the addition of a concurrent activity performance should either remain largely the same or be impaired depending on the hypothesis being considered.

Finally, evidence for the existence of a specific component should be convergent i.e. not all be derived from a single manipulation. Thus, for example, word length effects, the phonemic similarity effect and lesion studies all provide evidence for postulating an articulatory loop. Any single finding does not provide compelling evidence for the existence of a working memory component (although it may be indicative).

We cannot exactly specify the cognitive processes underlying a particular concurrent task like, for example, visual tracking. This means that it is difficult to assert that tracking is a spatial interference task. However convergent evidence from neuropsychological studies, for example, allow us to fractionate the system and demonstrate that spatial processing deficits need not be accompanied by more general deficits. The same primary task may be differentially impaired by different concurrent tasks in 'normal' populations. Thus a number of rather inexact manipulations (dual task paradigms, lesion studies, psychometric comparisons etc.) can be used to converge on a particular processing domain.

The next section reviews the evidence for the existence of the working memory components that have been specified so far. The studies cited demonstrate the diversity of the sources of evidence which working memory researchers have drawn upon.

2.4 THE CENTRAL EXECUTIVE

The central executive is depicted as having at least two components. It has an attentional mechanism and a general work space. The general work space is usually used in conjunction with one or more slave systems. Baddeley (1981) has noted that "it is .... probably fair to regard the Central Executive as the area of our residual ignorance about working memory" (page 21). In fact, there is a considerable amount of residual ignorance associated with the other components also. It is this residual ignorance that requires us to postulate a general processor - we simply do not have the techniques, yet, to fractionate the system further. In fact heavy memory loads assumed to load the general store have remarkably small effects on other cognitive processes (Baddeley, 1981). Thus it does seem likely, as Baddeley predicts, that further components of the central processor will be fractionated.

If one draws an analogy between working memory and a factory then the central executive's memory component or general "work space" can be compared to the [illegible] floor space in an industrial complex that is available for assembling components. The attentional component is the manager, or overseer, that co-ordinates the manufacturing process, and long-term memory is the warehouse facility.

When there is no overload of capacity then the manager (the attentional component of the executive) does not need to monitor production too closely. However, when there is too much incoming work for the operatives the executive may have to make decisions about how to allocate the work, particularly with respect to the use of specialised equipment (e.g. the scratch pad) and some of this load may well accumulate in the general work space. If the general work space overflows or the manager cannot delegate all of the responsibilities necessary because of its limited capacity within a given time, then performance (production) will become inefficient. Strategic allocation of resources is particularly important when dual-tasks are performed. That is when two activities are performed concurrently.

This analogy should not be taken too literally. It is a useful way, however, to think of the problems facing a memory system that must remain flexible to handle work loads requiring diverse operations, with fluctuating demands on the system, and often over quite brief time courses. The central executive must monitor functionally specific areas of floor space, forming assemblies that can be quite complex, require co-ordination, and may involve novel combinations of diverse processors to handle everyday problem solving situations. Less novel combinations may be activated by accessing 'plans' stored in long-term memory (see Chapter 1, Section 1.6). There are profound philosophical problems inherent in the postulation of a central executive. Such a formulation requires an homunculus. In an attempt to circumvent this difficulty, Allport (1980) has argued that we have production systems (PS's). In such a model "all of 'long-term memory' consists of modular condition - action rules, or Productions, as reflex-like units of know-how. The other principle component of a PS is a data base - or working memory - in which to represent the system's knowledge about the concurrent state of the world .... A Production rule becomes active whenever its condition is satisfied by the data base" (Allport, 1980, page 34.).

If this model is tenable then it must be able to explain all interference effects in terms of specified database elements. All such models do so by postulating that the two activities (assuming no output conflict) compete for some common data base element (which some other activities would not compete for). Thus counting aloud interferes with verbal memories because they compete for the resources of a content-specific processor not a general processor. Counting and verbal memory have some common database representation. Crucially then, a task that has nothing in common with a verbal memory task should not interfere with it.

At a superficial level Allport's model seems to be superior to the Baddeley and Hitch formulation. It is a working memory without the central executive and it thus lacks an homunculus. The problem is that we cannot specify the characteristics of a concurrent task sufficiently adequately to rule out the possibility that tasks A and B do have something in common however diverse they might be.

It is demonstrated by Experiment 6.1 in this thesis, for example, that visually tracking a sinewave seriously disrupts memory for auditorily presented consonants. Superficially, visual tracking has nothing in common with listening to and memorizing consonants. However, as even an apparently simple endeavour like this visual tracking task cannot be fully specified in terms of the underlying cognitive processes involved, any evidence apparently counter to Allport's view does not necessarily refute it. More than a decade of research has not clarified the nature of the central executive nor indeed abolished it. However, impressive advances have been made in understanding the nature of the other components.

2.5 THE ARTICULATORY LOOP

The articulatory loop acts as a slave system that receives serial input of speech-like material from the central executive, long term memory, or the ears. Basically it is assumed to act rather like a tape loop. It holds speech-like material and its capacity limitation is temporal.

When one rehearses a telephone number by silently articulating it repeatedly (rote rehearsal) until one can dial it, the number is being fed through this loop continuously before output via the central executive.

The representation is thought to be phonemic. Problems arise, using this loop, when similar sounding words are rehearsed, multi-syllabic words are entered and when subjects are given a concurrent articulation task to perform.

The acoustic or phonemic similarity effect results in poor memory for strings of letters or words that are phonetically similar so that, for example, the string DBCTPG is less well recalled serially than KWYLRQ (Baddeley, 1982a). This suggests that these strings are encoded phonemically and similar sounding words are therefore more confusable. This occurs with visual presentation also and the implication therefore is that the visual stimuli are recoded phonemically. Additional support for this suggestion is provided by Conrad (1970) who found that congenitally deaf children made phonemic errors, even though they had never been able to hear, provided that they had good speaking ability. Deaf children who were poor speakers did not show this effect. This suggests that the loop is articulatory in nature, not acoustic, and that individuals that have poorly developed articulatory skills tend to encode visually presented speech-like material in some other way.

The articulatory loop is limited temporally and its capacity seems to be around 1.5 seconds (Baddeley, 1982a).

Additional support for this was provided by Nicholson (1981) who demonstrated that, developmentally, rate of articulation increases with increasing digit span.

Ellis and Hennelly (1980) found that bilingual Welsh students had a shorter digit span for Welsh digits than for English digits. When the difference in time taken to articulate a digit in Welsh and English was taken into account the digit span difference disappeared. They argued that the discrepancy was caused by the amount of time it took to articulate Welsh digits which tend to have longer speech sounds.

If indeed it is the case that the store is articulatory in nature, then requiring subjects to articulate while performing other cognitive activities should occupy the loop and prevent its use in performing the primary task. Articulatory suppression typically involves asking subjects to repeatedly articulate a word (e.g. "the" or "and") or count while performing some memory task. When the loop is filled in this manner most of the errors in, for example, the serial recall of consonants are not phonemic in nature (Baddeley, 1966) and the time taken to articulate a word is no longer a good predictor of its probability of recall if presentation is visual (Baddeley, Thomson and Buchanan, 1975). Equally importantly articulatory suppression impairs performance on most verbal memory tasks.

This view of the articulatory loop as being a purely articulatory store is overly simple. It was suggested by

Vallar and Baddeley (1984) that the loop may have articulatory and phonemic components that can operate independently. Thus, the articulatory apparatus may remain operational even when the phonemic store has been damaged.

Furthermore, the abolition of the phonemic similarity effect with articulatory suppression only occurs with visual presentation. With auditory presentation the effect remains (Baddeley, Lewis and Vallar, 1984). It seems likely that articulatory suppression impairs the recoding of material into a phonemic code when material is presented visually.

It was argued by Baddeley et al (1984) that the loop has a phonemic store and that articulatory suppression prevents the control process of articulatory rehearsal. The Vallar and Baddeley (1984) study reported a case study of a patient who appeared to have no articulatory loop but she could still count. This suggests an intact articulatory apparatus decoupled from a damaged phonemic store into which it would normally feed data. A more detailed description of this study is presented in Chapter 1.

Baddeley argues that auditory presentation results in automatic access to the loop because recoding from visual representation is unnecessary. This explains the presence of the phonemic similarity effect with concurrent articulation and auditory presentation adequately. However this explanation cannot adequately explain the word length effect which does require articulation and should, therefore, not be dependent on modality of presentation. The word length effect is due to the physical constraint of rate of articulation whereas the phonemic similarity effect is due to confusions in coding.

Baddeley et al (1984, Experiment 5) however managed to abolish most of the word length effect with auditory presentation by requiring subjects to suppress articulation during presentation and recall. Baddeley concluded that with auditory presentation some articulatory encoding is still possible with suppression unless suppression is extensive. He notes that "if articulatory coding is to be avoided it is crucial that subjects be required to continue to suppress articulation throughout both presentation and recall" (Baddeley et al, 1984, page 245) and he suggests that the different patterns of results found with auditory and visual presentation is most likely due to "articulatory repetition of auditory items (being) a highly compatible skill that can be performed rapidly and with minimum processing demand" (page 245). With auditory presentation, phonemic representation is still possible. However the words could be stored in this manner without articulation so that at recall they can be rehearsed using the articulatory apparatus. This is prevented if articulatory suppression is continued.

The evidence reviewed is consistent with the view that the articulatory loop has two components - a phonemic store and an articulatory apparatus. The articulatory apparatus is obviously important when order information is salient (e.g. in serial recall) but less crucial in free recall.

The role of the articulatory loop in working memory does not seem to be as straightforward as it appeared in 1974. It does seem to be important in processing order information when order information is crucial (e.g. in counting and some aspects of prose comprehension). The loop, it seems, can be used for maintenance rehearsal but other components of the system can also be used for this purpose (Broadbent, 1981).

2.5.1 Reading and the Comprehension of Spoken Prose

If coding in the articulatory loop is speech-like then it seems likely that it is involved in inner speech, verbal reasoning and the comprehension of prose. Inner speech is often used to maintain information for a brief duration. We often rote rehearse, silently, a telephone number and, introspectively, this may be accompanied by inner speech. Under conditions of cognitive overload this rehearsal may even become overt. The process of learning to read also involves an early stage in which words are overtly articulated. This is less prevalent when greater competence has been achieved but such articulation may re-emerge when difficult prose is encountered(Hardyk and Petrinovich, 1970).

The articulatory loop seems to be important in the development of reasoning and comprehension but probably plays a lesser role in these activities when processing demands are small. Hitch (1980) has commented that "Given that sub-vocal rehearsal involves recirculating information through an articulatory loop, it is natural to suggest that this sub-system also serves as an output buffer in the production of overt speech" (page 175) and that "The analysis of speech errors suggests that several words are simultaneously activated prior to their production, supporting the general concept of an output buffer. More detailed analyses show correspondences between the properties of speech errors and errors of recall in the memory span paradigm, suggesting that the speech buffer can be identified with the articulatory loop" (page 176).

Bearing in mind the recent fractionation of the loop into articulatory and phonemic components the above statement seems to be reasonable. When articulatory suppression is performed overtly (e.g. counting out loud) it is obvious that the speech apparatus is committed to the loop and under such circumstances serial recall performance is impaired. Speech is clearly a serial process and, while there is obviously much more than mere articulation involved in this activity (e.g prior semantic processing), it would be unparsimonious to postulate a second articulatory apparatus for meaningful speech (Articulatory suppression typically involves articulation of a single arbitrary word or repetitious counting.).

Little work has been done on this but it is clear that an adequate account of speech production would have to consider other components of the memory system as well. The loop seems to be involved in the more mechanistic aspects of speech. However, while it would be unparsimonious to postulate a second articulatory apparatus, this is not the case when the phonological store is considered. The existence of more than one phonological store is suggested by studies of the role of working memory in reading.

Overt articulation can be observed when difficult prose is read. Also, children typically articulate aloud when they are learning to read. This suggests that articulatory encoding is particularly useful when reading skills are not well developed. However overt articulation results in very slow reading. Efficient, rapid reading is done silently and does not seem to involve a significant amount of covert rehearsal (sub-vocal articulation). Reading simple prose is not accompanied by electromyographic activity (Hardyk and Petrinovitch, 1970). Furthermore Baddeley and Lewis (1981) observed that it is still possible to "hear oneself" reading simple prose while counting. They speculate that there may be an "inner ear" or auditory imagery system that can still operate with articulatory suppression.

A tentative distinction can be made between an inner ear (holding acoustic information) and inner speech (an articulatory process). The articulatory process seems to be important in maintaining order information so that one would expect articulatory suppression to produce errors in the verbatim recall of material that is read, but not necessarily in comprehension of reading material. The apparent necessity of deploying the loop to comprehend very difficult prose illustrates this. Very difficult prose tends to involve logical or descriptive statements which are developed serially and which only remain logically valid when the seriality of the concepts is maintained.

Comprehension of difficult prose often involves serial reasoning and results in the accumulation of a heavy memory load. Articulation can be used to help maintain these serial relationships while comprehension proceeds. Indeed the main effect of articulatory suppression on reading is not to slow reading or to increase errors in comprehension, but to reduce the likelihood that the subject will detect transpositions (Baddeley, 1982c). Semantic anomalies are less well detected with articulatory suppression. Baddeley (1982c) comments "that subvocal articulation (is) an optional strategy that (is) useful for monitoring accuracy, but (is) probably not essential for comprehending the gist of a passage" (page 415).

The loop has been depicted as a speech-like system rather than an acoustic system. This contention is supported by the findings of Salame and Baddeley (1982) who demonstrated that unattended speech but not white noise disrupts memory for visually presented material (the unattended speech effect).

It was pointed out earlier that counting does not deafen the "inner ear". Baddeley speculates that there may be an acoustic store available in such circumstances. However one could speculate that there may be a number of acoustic stores e.g. one might use a different store for processing information about music and deploy a different mechanism for making diagnostic decisions about the significance of a noise in a plumbing system.

As Baddeley and Lewis (1981) point out, the study of reading tells us more about working memory than working memory tells us about reading. The study of reading, using the working memory framework, is in its infancy. A fuller review of the literature is provided by Jorm (1983).

2.5.2 Reasoning

One would expect that the loop should be deployed in solving reasoning problems. To test such a prediction Hitch and Baddeley (1976) gave their subjects verbal reasoning tasks to perform. They used the reasoning tasks developed by Baddeley (1968). An example of one of these problems is "A follows B? BA" to which the subject should respond affirmatively, similarly "A follows B? AB" requires a negative response. The response latencies and error rates were recorded. They argue that visual presentation of this task should require central processing resources and the articulatory loop. To examine this hypothesis subjects were required to hold a verbal preload of 2 or 6 items. Surprisingly these preloads had little effect on reasoning time or accuracy. Hitch and Baddeley argue that the preload may have been at least partially committed to a longer term store. Thus they then proceeded to use a concurrent verbal load. Such concurrent loading did slow verification time, as did the use of phonemic similarity in the verification task (e.g. "T follows B? TB") although visual similarity had no effect (e.g. "O follows Q? QO").

The articulatory loop does not seem to be necessary to perform simple verbal reasoning tasks. This is consistent with the evidence from studies of reading that the loop is an optional device (Baddeley, 1982c). No effect on verbal reasoning with a memory load was found by Evans and Brooks (1981) but response was faster with articulatory suppression. They suggest that articulation may slow reasoning in much the same way as it slows reading. When speed of response is stressed the loop may not be used.

The evidence for articulatory loop involvement in simple verbal reasoning is sparse. More complex reasoning activities, however, may require the loop. Thus, its role in mental arithmetic, a task whose difficulty can be systematically varied, may be more crucial. Greater electromyographic activity is found during mental calculation than during tasks involving arithmetic whose solution was accessible from long-term memory without calculation (Sokolov, 1972). This suggests that articulation is usually necessary to perform mental calculations of considerable difficulty.

It was argued by Hunter (1979) that mental calculation involves long-term memory which provides previously learned procedures for performing calculations and numerical equivalents (e.g. the knowledge that 6 x 3 = 18). Furthermore, he suggests that during mental calculation

"...people use.... working memory. They must keep track of their calculative route and not miss a step or lose direction. They must also carry out a shifting succession of operations concerned with short-term registration, retention and retrieval of numerical data. At any moment, they may be working out the answer to a sub-problem; at the next moment, they are retrieving that earlier answer to combine it with the newly-gotten answer. It is this track-keeping aspect which is the greatest burden in mental calculation, and which leads people to seek help from external memory-aiding devices. It is the aspect which compels people, who know the product of 6 and 6, to reach for paper and pencil when asked to multiply 666 by 666" (pages 6-7).

Under such circumstances the articulatory loop would be a useful device for holding the solutions to sub-problems. Sokolov's findings suggest that this is the case. Furthermore Hitch (1978) has reported introspective evidence that subjects do solve arithmetic problems in stages and that these are held in temporary storage unless the solutions to sub-problems are written down. Given that the loop is highly compatible with this sort of processing it seems likely that further investigation will identify a role for this sub-system in mental arithmetic especially in operations that involve counting.

In summary the existence of phonemic similarity effects and word length effects with visually presented material suggests that working memory has a phonemic system with an articulatory component. Evidence from neuropsychological studies and studies of the congenitally deaf support this distinction.

Studies that have attempted to demonstrate the role of the loop in reading, reasoning and comprehension have been disappointing. However, these activities usually involve rapid responses and the loop seems to be more useful in detecting errors. In a speed/accuracy trade off situation deployment of the loop results in a bias towards accuracy. When the demand characteristics of the situation require rapid processing other working memory components are more useful. Morris and Jones (in press) however have demonstrated, as one would predict, that deployment of the articulatory loop is essential when recall is vocal.

It is unclear at this time just how many components an adequate working memory model should have. Most of the work to date has been concerned with the loop. There is also a considerable body of evidence that the system also has a spatial working memory probably consisting of a visuo-spatial scratch pad and there is also evidence that there are a number of other components.

2.6 THE VISUO-SPATIAL SCRATCH PAD

Baddeley and Hitch suggested that this store was responsible for short-term representation of spatial information and it was thus implicated in the formation of imaginal representations, the use of location mnemonics and most non-verbal processes with spatial components. One might expect this system to be used therefore, for pictorial representation and object representation in other modalities (e.g. haptic representation). Baddeley and Lieberman (1980) argued that this system was spatial rather than specifically visuo-spatial.

2.6.1 Neuropsychological Studies

De Renzi (1982) provides an historical review of the neurological literature on spatial deficits. Badal (1888) provided the earliest known case history of a patient with spatial processing deficits. His patient manifested symptoms ranging from an inability to find her way around her immediate environment to constructional apraxia.

The early cases cited by De Renzi provided little information about the locations of lesions nor did they involve the use of matched controls or quantification of performance deficit. The more recent literature is a more appropriate source of data about the nature of the structural representation of spatial information. Given that so many deficits have been described, any literature review must be selective. This review examines, largely, visuo-spatial deficits although reference will be made to other modalities. Visuo-spatial deficits are those most likely to be associated with impairment of 'imagery'. The studies reviewed reveal that one must be very cautious in using the term imagery to imply that there is a single structure responsible for 'pictures in our heads'. The term 'imagery' has been used in two ways in the psychological literature. It refers to a form of representation i.e. imaginal encoding. The use of imagery can also be described as a control process i.e. as a memorial strategy. The former use of the word implies the use of a system that can hold such representations while the latter implies a decision to represent information in this way.

Thus words can be described as being highly imaginal (or concrete) or as having a low rated imagery value (or more abstract) and this distinction refers to the apparent ease with which such words evoke imagery (Paivio, Yuille and Madigan, 1968 have produced a list of rated imaginability for 925 nouns). However the rated imaginability of these words refers to their semantic properties not to their perceptual structure thus one would expect that high imagery words would be better recalled from long-term memory than low imagery words even when the subject did not adopt a strategy of using visuo-spatial or imaginal representation.

For this reason the examination of visuo-spatial representation is best carried out by using non-verbal materials to avoid confounding semantic representational properties with the control process of using a particular mode of quasi-perceptual representation (e.g. the maintenance of a visuo-spatial representation in the 'minds eye').

We do not really have an appropriate language to talk about imagery in a scientific manner thus there is a tendency to resort to ideas such as the minds eye (often disguised by using more esoteric language) when discussing such actions (imaging) and representations. However some lesions result in a loss of the ability to introspect about images and this has measurable behavioural consequences. Thus while we do not have suitable language or experimental sophistication to say unequivocally what we mean by imagery we can nevertheless observe some drastic effects on cognitive performance when visuo-spatial representation is impaired. Given that these impairments do not always result in verbal deficits (as measured by verbal ability tests etc.) it is worthwhile to examine visuo-spatial impairments as damage to a distinct multi-component processing domain.

Spatial deficits have been classified in a number of ways. One distinction is between personal and extrapersonal space orientation problems. The relationship between two or more objects irrespective of the observer's position is described as allocentric while the relationship of an object's spatial location relative to the observer's own body is described as egocentric. This distinction was made by Semmes, Weinstein, Ghent and Teuber (1963).

Within the visual modality Benton (1979) has distinguished between Visuo-perceptive, Visuospatial and Visuo-constructive disorders. A third method of classification is in terms of the location of the lesion. What is clear from the literature is that a wide range of visuo-spatial disorders occur and many of these can be dissociated within the spatial processing domain.

Exactly what should be classified as a visuo-spatial task is problematic but many of the diagnostic tasks used and the symptoms observed clearly have some sort of visuo-spatial component. This review examines only two of these properties because there is consensus that these are visuo-spatial in nature and double dissociations between them have been found.

Benton (1979) argues that "it is certain that there is a fundamental difference between defects in the identification of the formal characteristics of objects and defects in the localization of these objects in space" (page 187). The distinction is between form or shape and location. A spatial working memory system must be capable of processing both of these features and the dissociations obtained suggest that it should have independent components for each of these features. Furthermore, these processors must be able to function in an integrated manner in the intact brain, because it is usually the case that both form and location are important. Hence the scratch pad is analogous to the loop in that it can be fractionated into at least two components (and possibly many more). Particular emphasis will be laid on the use of the scratch pad to process locational information as the experiments reported in this thesis examine this aspect of visuo-spatial processing.

2.6.1.1 Face recognition

Perhaps one of the most obvious examples of complex form recognition is the ability to discriminate faces. This obviously involves, at some point, an analysis of selective features (otherwise we would have no real problems discriminating between the faces of other racial types [Luce, 1974]) and it is clear that any verbal encoding of features is also backed up by some visual representation. We can recognise faces from many novel orientations even after one brief previous encounter. However it is very difficult to accurately specify a face with a verbal description (See Davies (1978) for a review). A clinical condition called prosopagnosia or facial agnosia has been described. Patients suffer from an inability to recognise faces but also demonstrate a more general impairment of complex visual discrimination and a number of lesion sites have been associated with this disorder (Meadows, 1974). Two types of this agnosia can be discriminated. Patients may fail to recognise familiar faces or unfamiliar faces and a dissociation between these two deficits has been found (Benton, 1979). The latter deficit is particularly likely to result from some working memory deficit rather than a long-term memory problem with immediate recognition testing while the former should involve some long-term memory deficit (or access to long-term memory) also.

Excision of the right hippocampus and adjacent areas of the medial temporal cortex results in a deficit in the recognition of unfamiliar photographed faces but, interestingly, there is no deficit in recall or recognition of nonsense figures or complex geometric designs (Milner, 1974). It may be the case that the salience of facial recognition has resulted in specific neural mechanisms developing independently of shape recognition mechanisms.

2.6.1.2 Spatial Disorders

Defects of shape recognition in the visual modality (visual object agnosia) are rare and usually result from damage to the occipital lobes. There are also other perceptual disorders present (Walsh, 1978). Disorders of location, and the relationship between locations, in both allocentric and egocentric space are much more frequently observed. Visual neglect is also a common clinical phenomenon.

Unilateral spatial neglect (U.S.N.) has been described as a " .. syndrome consist(ing) of a tendency to neglect one half of extrapersonal space in such tasks as drawing and reading which require a good and symmetrical exploration of space" (Gainotti, Messerli and Tissot, 1972, page 545, cited in Walsh, 1978).

U.S.N. is particularly common in the visual modality. Bisiach and Luzzatti (1978) asked patients with right hemisphere stroke damage to imagine themselves standing outside Milan cathedral (all the patients lived in Milan). They were asked to describe the cathedral square. Generally, they described the right hand side of the cathedral square in detail but neglected to describe the left side of the square. A description of the previously ignored side of the building was forthcoming when they were told to imagine that they had walked round to the other side of the building but the scene previously described in detail was ignored. Baddeley (1982a) comments "The process of conjuring up and projecting images was intact, but the mechanism for representing or reading them off was faulty" (page 187).

Deficits in topographical memory have also been reported. De Renzi (1982) describes an early case history by Foerster in the 1890's. "Small objects and pictures were well recognised. However, the patient had a striking difficulty in remembering where objects were located and, consequently, in building up a picture of a route. Even three weeks after his admission to the ward, and in spite of the fact that he had been continuously in the same room, he was still unable to direct his gaze or point, when blindfolded, to the location of different pieces of furniture, such as the washbasin, the sofa, etc. or to walk to the toilet a few steps from his room. The amnesia for spatial configurations and relationships extended to notions acquired before the disease. For instance, he failed to described or draw the spatial arrangement of his office or home, or of well-known places in his city of residence. On a blank map of Europe he could neither point to the main countries, nor outline them. Yet geographical ideas could still be expressed, provided they involved merely verbal knowledge; for example, he knew that the railway line from Berlin to Vienna called at Breslau. When asked to draw

Italy, he smiled and said the boot, but drew a real boot and not the actual shape of the country. Foester correctly pointed out that the restricted field of vision could not account for the topographical disorientation, since people whose eyelids are closed for the treatment of eye disease learn within two or three days to find their way in the ward, and attributed the deficit to the loss of a particular ability - memory for places. This ability was thought to be primarily developed from visual information (although other sensory modalities would also contribute) and to be located in both occipital lobes. The pathological findings of this patient were subsequently published and showed bilaterial damage confined to the occipital and temporal lobes" (pages 211-212).

Allocentric spatial deficits have been reported following screening with the Corsi Block Test (described in Milner, 1971). De Renzi and Nichelli (1975) found patients with poor scores on this short-term spatial memory test who performed well on tests of spatial exploration and perception and preserved an ability to learn in a few trials a visual maze.

The neuropsychological evidence, suggests that there is a short-term storage system for visuo-spatial information and that this is a complex structure occupying sites in a number of brain structures.

The next section of the review examines the cognitive literature on short-term visuo-spatial representation.

2.6.2 Cognitive Studies

There is a massive body of literature on the role of imagery in human cognition. This has been reviewed by Richardson (1980). However research on the scratch pad has been largely confined to examining how it might be deployed to encode random patterns (because they are difficult to recode verbally) and its role in the use of imagery mnemonics. Recently, however, the role of the scratch pad in the representation of spatial descriptions has also been examined.

De Soto, London and Handel (1965) argued that linear reasoning situations may use spatial paralogic. So, for example, the following premises lead to the conclusion that "Mantle is better than Moskowitz".

Premise 1. Mantle is better than Mays.

Premise 2. Mays is better than Moskowitz.

This conclusion could be achieved by using purely verbal reasoning. However it could also be achieved by quasi-visual representation using spatial ordering. Thus, for example, one might form a representation in terms of "betterness" like this -

[1] MANTLE
[2] MAYS
[3] MOSKOWITZ

Such continuous descriptions i.e. descriptions that can be ordered spatially without linguistic transformations are more readily spatially recoded than discontinuous descriptions which require complex linguistic analysis to create a spatial ordering. This can be clarified by examples from Oakhill and Johnson-Laird (1984, page 54).

Continuous

[1] The pig is behind the hen.
[2] The hen is to the left of the sheep.
[3] The sheep is behind the cow.

Discontinuous

[1] The plate is to the left of the spoon.
[2] The cup is to the right of the fork.
[3] The spoon is behind the cup.

In the discontinuous example it is necessary to refer back to [1] in order that one may represent the relationship presented in [3]. In the continuous example the sentences allow representation without backtracking.

Oakhill and Johnson-Laird showed that visuo-spatial tracking (Pursuit rotor tracking) disrupted memory performance for both types of representation (which were auditorily presented and recalled by drawing the appropriate arrangement). However holding a near span digit load selectively disrupted performance on the discontinuous trials.

They concluded that visuo-spatial representation was used to perform both tasks (because tracking seriously disrupts visuo-spatial encoding) but a large verbal component also seems to be necessary to encode the discontinuous examples. Thus one employs the visuo-spatial scratch pad to encode spatial relationships between objects and this is achieved by using this system in conjunction with other working memory components when linguistic transformations are necessary.

2.6.2.1 The Baddeley Spatial Memory Experiments

Baddeley, Grant, Wight and Thomson (1975) reported three experiments. The first experiment used tasks designed by Brooks (1968). In the visual task condition subjects were required to classify, from memory, the corners of visually presented letters as top or bottom or extreme left or right. On half the trials subjects were required to perform a pursuit rotor tracking task while doing this classification. Subjects studied the figure until they had formed an image of the letter, at which point the letter was removed and classification with or without tracking commenced. A baseline condition of tracking only was also used.

In the verbal task condition the basic design was the same except that subjects retained sentences in memory (e.g. "A bird in the hand is not in the bush") and classified the words as nouns or non-nouns with or without concurrent tracking. Baddeley found that tracking had little effect on performance accuracy or decision time on the memory tasks, but time on target in the tracking task was reduced by the visual task but much less so by a verbal task. He concluded that imagery impairs tracking.

In the second experiment subjects were required to remember information in either an imaginary 4 x 4 matrix (a task used by Brooks, 1967) or a series of sentences.

Baddeley found that with tracking to a predetermined criterion, memory performance was massively impaired with the spatial material but not with the verbal material. The implication is, therefore, that the spatial task relies heavily on the scratch pad, which is impaired by tracking, while the verbal task does not.

The final experiment examined memory for concrete and abstract words with concurrent tracking. The predicted interaction between concreteness and tracking was not found. This suggests, argued Baddeley, that concreteness is a feature of long-term semantic registration rather than simply a quality that facilitates visual-like representation in short-term memory.

The scratch pad appears to be used for representing visual information when its location or its shape is highly salient. In a more recent paper, Baddeley and Lieberman (1980), it was argued that the use of the scratch pad was not confined to visual information processing because its use can be disrupted by spatial tasks requiring other sensory modalities. The 1980 paper reported five experiments which generalised the findings of the 1975 paper to non-visual tracking tasks and the use of imagery mnemonics.

Experiment 1 replicated the Baddeley et al. (1975) experiment using the 4 x 4 grid with a non-visual tracking task. Blindfolded subjects were required to shine a flashlight onto a photoelectric cell mounted on a swinging pendulum. The subjects were given auditory feedback, in the form of an intermittent tone, when they were on target. Spoken recall was required because subjects had to track during both presentation and recall. The results were similar to those found in Baddeley et al. (1975, Experiment 2) with tracking having a much more detrimental effect on spatial material than nonsense material.

Experiment 2 replicated the first experiment except that subjects were required to make brightness judgements instead of tracking. This, Baddeley argued, was a visual non-spatial task. He found that this produced a greater decrement on nonsense material than on spatial material. Baddeley concluded that "The fact that a spatial task disrupts performance in the imagery condition whereas a visual task does not implies spatial rather than visual coding" (page 527). Support for this contention was forthcoming from Kerr (1983) who found that congenitally blind subjects produced similar patterns of results to sighted subjects on a variety of imagery tasks. She concluded, like Baddeley, that "spatial imagery processing ability need not depend on visual perceptual experience or, in fact, on any specific sensory processing modality" (page 265).

Baddeley and Lieberman's third experiment examined the role of the scratch pad in the use of an imagery mnemonic. The "One is a bun" pegword mnemonic was used. This consists of associating images of objects with numbers. Thus the number 1 is associated with an image of a bun, 2 with an image of a shoe and so forth. When this has been learned, subjects are given new associates with the numbers and are then required to associate the new image with the previously learned association. So, for example, if the word cigar is presented as the first word on a trial the subject should perhaps imagine a bun with a cigar inside it.

The experiment had four conditions. Subjects had two types of learning instructions. On two blocks of trials they rote rehearsed the lists and on the other two blocks of trials they used the mnemonic. They were required to perform a concurrent pursuit rotor tracking task on one block in each learning instruction condition. The lists of words used contained five abstract and five concrete words.

Tracking had an effect that was specific to the mnemonic instruction condition. However, word concreteness did not interact with tracking but the type of instruction/concreteness interaction did reach significance. The basic findings were that tracking was particularly disruptive when imaginal encoding was used but this effect did not extend to specifically impairing memory for concrete words. This finding supports the distinction between "imagery" as a control process and concreteness as a semantic feature. The type of instruction/concreteness interaction supports the contention that concrete words are better recalled when imaginally encoded but this is probably a long-term memory effect largely independent of the use of the scratch pad.

Experiment 4 replicated the previous experiment using a location mnemonic which, it can be argued, is more spatial in nature than a pegword mnemonic. Instead of learning pegwords subjects were required to take an imaginary walk around familiar locations on a University campus. They were required to form imaginal associations between presented words and these locations. Serial recall was subsequently required. The results of Experiment 3 were broadly replicated except that there was no effect of concreteness. Baddeley speculates that visuo-spatial encoding is less appropriate with serial recall than with free recall or paired-associate learning and thus the concreteness of the material is less salient.

The most parsimonious explanation of these results is that tracking simply impairs organised learning more than rote learning (Rabbitt, cited in Baddeley and Lieberman, 1980). To counter this argument Baddeley replicated Experiment 4 using an alphabetical mnemonic. This was in the form A = 1, B = 2 etc. so for the category foreign cities, for example, subjects heard One - Amsterdam, Two - Berlin etc. There was also a random ordering condition which destroys the efficaciousness of such a mnemonic device. Both ordering and tracking produced significant main effects but the type of instruction/tracking interaction failed to reach significance. Baddeley argues that this suggests that the interference effect from tracking is largely confined to spatial tasks and not explicable purely in terms of organisational disruption.

In summary Baddeley found that tracking interferes with the control process of using spatial representation and its lack of an effect in the verbal domain implied that there is a specific spatial processing domain.

A major problem with the Baddeley experiments is that all the tasks used have a large verbal component. The spatial tasks require initial verbal encoding with transformation into spatial representations. This implies that the stimuli must first be represented in the central processor with subsequent rapid registration onto the scratch pad. Baddeley's results suggest that the tracking tasks do not greatly interfere with central processing but impair registration onto the scratch pad.

One would, however, expect tracking to occupy a considerable amount of central attentional capacity and thus it should have a marked effect on most short-term memory processes. This is difficult to reconcile with the lack of an effect in the Baddeley experiments (except 1980, Experiment 5). If tracking and verbal encoding both require central resources then verbal encoding will be better if a considerable amount of time is allowed for this even with concurrent tracking.

However if recoding into an imaginal representation is required in addition then the system will not be able to cope so easily. Thus dual coding places a heavier burden on the system moment by moment and this is reflected by the greater effect of tracking or poorer tracking performance. The first Baddeley et al (1975) experiment, however, is problematic for this explanation because in this experiment the visuo-spatial representation is formed before tracking begins. The type of tracking task used may be critical. Pursuit rotor tracking may not make heavy demands on the central executive.

It seems likely that most tracking tasks do have some specific effects on spatial representation but they may also have general effects when the central capacity is heavily burdened with a memory task that cannot be rapidly offloaded into a slave system or long-term memory. This is compatible with the view of Phillips (1983) who emphasises the role of central capacity in visual short-term memory. Phillips' research attacks the problem of visuo-spatial representation by using tasks that do not require an initial verbal memory registration.

2.6.2.2 Phillips' Visuo-spatial memory experiments

The basic procedure used by Phillips and Christie (1977a; 1977b) was to visually present 4 x 4 matrices to subjects with 8 of the locations randomly filled (5 x 5 matrices, however, were used in 1977b, Experiments 4 and 5). Thus subjects viewed a number of random patterns on each trial. They were given a recognition test with the series being presented in reverse order (so that the last pattern was presented first for recognition and the first pattern last). Subjects indicated whether the pattern at recognition was the same as at presentation. Distractors were created by randomly changing one filled location at test.

They were able to show that there was a marked recency effect of one item that did not depend on list length. This recency effect was abolished by three seconds of mental arithmetic but did not decay over a 10 second unfilled delay. Phillips argued that the recency effect was the result of a short-term visual memory with a capacity of one pattern. Because mental arithmetic knocked this out he reasoned that general resources were required to perform this 'visualisation'. However a phonemic categorisation task resulted in a main effect on recognition performance but there was no interaction (Phillips, 1983) indicating that this task did not have a selective effect on visualisation.

Phillips concluded that it is probably the case that visualisation can continue even when a demanding verbal task is performed. One possible explanation of this, Phillips speculates, is that " .... there could be separate specialization for the strategic coordination of linguistic and non-linguistic activities. The compatibility of language with most other activities makes this a possibility. The effect of phonemic categorization would then reflect linguistic contributions to the management of the visual memory task, but this would not imply that visualization was independent of strategic coordination. Alternatively, this result could be taken as support for Allport's view that all interaction is specific, and that there is no central executive or strategic coordinator." (1983, page 306).

The Phillips' experiments provide strong evidence for distinguishing between short-term and long-term visual memory. Avon and Phillips (1980) found that subjects could maintain the final pattern for some time but even brief interference prevented this. They interpreted this in terms of maintenance and elaboration. Maintenance rehearsal, they argued, was possible after brief pattern presentation but a long-term memory representation was necessary for elaborate coding and this could not develop from the short-term representation. Long-term representation occurred in parallel with visualization not subsequently.

Phillips' short-term visual memory seems to correspond roughly to Baddeley's scratch pad. Whether in fact the central executive is required to control it is discussed in detail in the experimental chapters of this thesis. However, if the scratch pad is only capable of maintenance rehearsal then activities requiring complex transformations must require other resources - probably the central processing capacity. If this is the case then it is probably also true that the executive is used when imagery mnemonics are employed. This implies that the executive and scratch pad only function independently with spatial tasks during maintenance rehearsal. It is also implicit in Phillips view that material enters long-term visual memory either directly or via the central executive and, presumably, that information retrieved from long-term visual memory must also pass through the executive before representation on the scratch pad.

The scratch pad seems to be part of a spatial processing domain in working memory that holds spatial or visuo-spatial information but engages in maintenance rehearsal only when decoupled from the central executive.

2.6.3 The Functions of the Scratch Pad

Little research has been done on the role of the scratch pad in applied situations perhaps because western culture tends to emphasise the verbal/linguistic domain of cognition. However, Kearins (1981) has indicated that spatial processing may play a very important role in other cultures. Aborigines, for example, seem to have very good "spatial memory" and this may reflect the rather homogenous environment in which they live. Subtle differences in the landscape do not seem to have resulted in the development of a large vocabulary of spatial descriptors. The Aborigines seem to rely much more on imaginal representation.

The physiological evidence indicates that the scratch pad may be complex and fractionable into a number of components. An exhaustive review of the neurological literature is provided by De Renzi (1982) and one is led to the conclusion that damage to the neurological substrate of the spatial processing domain has far reaching consequences on the performance of brain damaged individuals in their everyday life.

The spatial working memory system seems to be implicated in the development and updating of one's cognitive map of the environment. For example, Moar (1978) found that tracking interfered with subjects' cognitive representations of the relationship between locations in a familiar city whereas articulatory suppression had a much smaller effect. Mathematical skills may also involve this system. What is clear is that the scratch pad is not merely a curio that is only of interest as a laboratory phenomenon. It is worthy of the proverbial further research.

In general there has been little research on the role of the scratch pad in "everyday" cognitive activities (except its role in the use of imagery mnemonics). However a recent study by Hatano and Osawa (1983) suggests that expert abacus users seem to have developed a 'mental abacus' that holds a brief visuo-spatial representation of long strings of digits. Further research in such areas might prove fruitful. The literature has largely been confined to examining the nature of the scratch pad and in separating it from the verbal processing domain.

2.7 HOW USEFUL IS THE MODEL?

If working memory is a system involved in processing information in real time, e.g. a system that handles the current cognitive load in the specious present (James, 1890), then it should account for all "thinking" (or at least all conscious thought). Obviously no model developed in the forseeable future is likely to be this adequate. A compromise is necessary. The working memory model should be capable of reflecting the adaptability of human cognition i.e. it should not be specified in such a way that it underestimates the flexibility of short-term memory.

Commenting on working memory Baddeley (1982a) noted that its "flexibility allows one to capture much ... of the richness of the remarkable cognitive skills that we all display" (page 169). If one accepts the basic tenet of the theory of evolution that the successful organism is highly adapted to the ecological niche in which it lives, then it is clear that a crucial adaptation is its information processing efficiency, especially if the environment is highly labile.

The evolutionary significance of working memory has, largely, been ignored (Bruce, 1985).

An adequate human working memory model must reflect this remarkable range of cognitive activities that are carried out in day to day living. Also, it should be modelled in such a way that its mode of processing can be switched rapidly. Thus, for example, the central executive should be able to switch its monitoring and resource deployment extremely quickly to process sensory input that may indicate imminent danger.

The working memory model is theoretically inadequate but, given our degree of ignorance about the nature of memory, this is to be expected. It is merely less inadequate than other models. Working memory, should, like the levels of processing model, be seen as a framework for generating research and unifying previously disparate fields of cognitive psychology.

The slave systems have proved to be more complex entities than was at first imagined and their number is proliferating. This is only to be expected. Earlier memory models preserved their simplicity by failing to address most aspects of cognition. A model that attempts to explain diverse aspects of thinking is unlikely to be both simplistic and adequate. A panoramic memory model is also likely to be speculative but this is preferable to a model that simply ignores most aspects of cognition provided that the speculations have empirical testable consequences.

The future of working memory seems to be heading towards further fractionation of the system and there are indications that future research will show working memory to be a complex system. This is discussed further in the final two chapters. The current state of the art is such that we have strong indications that working memory is a useful model for investigating a wide range of cognitive activities but these indications also suggest that the model will need some elaborate modifications that will result in a loss of the structural simplicity that originally made the model so attractive. It was noted in the review of the articulatory loop that its role is not so clear cut now as it was in 1974. The other components may also prove to be more complex than originally imagined.

The next four chapters present some empirical studies which examine the relationship between the visuo-spatial scratch pad and the central executive and the articulatory loop. The final two chapters expand on the points made in this chapter and Chapter 1 and provide some speculations on the future development of the model. It is suggested that the flexibility of the system can only be captured by considering working memory constellations. Such a model is outlined in detail in Chapters 7 and 8.

Chapter 3

The Visuo-Spatial Scratch Pad

3.1. Summary

In their 1974 formulation of the working memory model Baddeley and Hitch postulated a visuo-spatial scratch pad. This was a short-term memory structure that was independent of the articulatory loop. The empirical investigation of this component of the system was subsequently undertaken by Baddeley (Baddeley et al, 1975; Baddeley and Lieberman, 1980). He concluded that the scratch pad was involved in imaginal processing and that the store was not modality specific i.e. that the scratch pad was a spatial processor not a visuo-spatial processor.

This chapter introduces a spatial memory task that is unlikely to be subject to verbal recoding. Three experiments are reported. These demonstrate that the visuo-spatial scratch pad and the articulatory loop are indeed discrete components. The relationship between the visuo-spatial scratch pad and the central executive is not discussed in detail. Further research examining this relationship is presented in Chapter 4.

3.2. Introduction

The visuo-spatial scratch pad has been less extensively explored than the articulatory loop.

It was postulated that this store was responsible for short-term representation of spatial information and thus it was implicated in the formation of imaginal representations, the use of location mnemonics and most non-verbal processes other than perhaps colour processing, gustation etc. Thus one might expect this system to be used for pictorial representations and object representation in other modalities (e.g. haptic representation). Baddeley and Lieberman (1980) argued that this system was spatial rather than specifically visuo-spatial. Nevertheless one would expect that in a 'normal', sighted population, in which the visual modality is of paramount importance, it would be deployed to process visuo-spatial information and spatial information from other modalities might well be habitually recoded into a visuo-spatial representation and if possible this representation would probably be recoded verbally.

The obvious way to examine this system would be to develop memory tasks that seem to have a large spatial component. Typically double dissociation experimental designs use this approach with an additional verbal disruptive task and a verbal memory task that is as nearly possible formally equivalent to the spatial memory task. Double dissociations have been reported by Baddeley et al (1975), Baddeley and Lieberman (1980), Brooks (1967) and Salthouse (1974). These studies indicate that verbal and spatial processing are independent although, as noted earlier, Phillips (1983) has suggested that there is a strong case for postulating a role for the central executive in spatial processing.

A number of tasks that interfere with spatial representations have been identified. Pursuit rotor tracking is disruptive (Baddeley et al, 1975) as are some other tracking tasks (Moar, 1978). Voluntary eye movements can also be disruptive (Idzikowski and Baddeley, 1984) and 'unattended pictures' seem to impair imaginal encoding (Logie, 1986).

The cumulative effect of all this evidence provides a good case for examining verbal and spatial domains of processing as separate entities. Evidence cited in Chapter 2 suggests that we may have to fractionate these domains even further.

It is clear, for example, that object recognition is not contingent on location information (Benton, 1979) although one might logically expect object representation to be reducible to complex locational representation. Haxby et al (1983) used Korsakoff amnesics to demonstrate independence of these two deficits. De Renzi et al (1977) demonstrated that patients with no evidence of unilateral visual neglect but with right hemisphere lesions were impaired in their performance on the Corsi blocks test, a widely used clinical test of 'spatial impairment' (Milner, 1971), but verbal interference introduced before recall did not <u>increment</u> the deficit. It should be noted however that all groups showed a deficit with verbal interference suggesting that the Corsi block test is not purely visuo-spatial task.

Evidence is accumulating that suggests that verbal and spatial representations are functionally independent at a neuroanatomical level (see Milner, 1978 and De Renzi, 1982 for an extensive review). The basic finding is that a number of spatial deficits can be observed in brain damaged populations that have no apparent verbal deficit. Thus there is a case for postulating the view that short-term memory can be fractionated into separate verbal and spatial domains although they may normally function in an integrated manner.

In particular, animal studies have resulted in the hippocampus being widely cited as being important in spatial representation (O'Keefe and Nadel, 1978; Olton, 1977) as have the parietal lobes (Walsh, 1978). This has also been demonstrated in humans for the hippocampus (Milner, 1965) and the hippocampus and parietal lobes (Corkin, 1965).

As noted earlier, it has also been suggested that the right hemisphere is usually responsible for spatial processing but these studies can be equally well explained in terms of bilateral representation (Ehrlichman and Barrett, 1983). Perhaps the most important caveat that the neuropsychological literature provides for cognitive psychologists is that terms as global as 'spatial representation' or 'imagery' do not accurately reflect the underlying functional properties of the spatial representational system(s). Indeed it may be a gross misrepresentation to lump together a variety of tasks that appear to tap a particular process when in reality a number of quite distinct memory structures are involved.

Nevertheless it may be appropriate, for the time being, to consider certain domains of processing (Baddeley, 1982b) provided results obtained using a specific task are not extrapolated in a rather cavalier manner to explain other memory phenomena.

Thus the spatial working memory system postulated by Baddeley and Lieberman (1980) may be a domain of processing, i.e. a conglomeration of sub-systems, used in an integrated manner to process spatial information. In the interests of parsimony, and due to our ignorance with respect to some of the components of these tasks, it is necessary to consider the system to be unified, at least for the present, with the proviso that tasks are as well defined functionally as possible. The analysis offered here is essentially functional and seeks to avoid an unending, spiralling reduction which may well result from neuropsychological research.

An appropriate memory task for examining this system should preclude verbal recoding which would prevent fractionation of the working memory system. Most imagery tasks tend to have a large verbal component so it is necessary to develop a somewhat simpler task than, say, a location mnemonic (see Yates, 1966 for a historical survey of such mnemonics). Object or location memory should be appropriate provided that the stimuli are not verbally recodable.

The memory tasks employed in the experiments reported in this chapter were developed to prevent verbal encoding and care was taken to ensure that they were obviously visuo-spatial in nature. Verbal recoding was reduced in two ways. The tasks were highly visual but rather abstract in the sense that it was difficult to accurately specify the stimulus properties in verbal terms. Furthermore trial duration was sufficiently brief to preclude elaborate verbal coding (Phillips, 1983).

For Experiment 3.1. a task similar to that employed by Phillips and Christie (1977a; 1977b, see Chapter 2) was developed. Subjects (Ss) viewed a square with a random pattern of five filled circles within it. A major difference between this task and the task used by Phillips and Christie was that no grid was present. If the circles had been presented in a grid then verbal labels analogous to grid references might have been assigned.

Three concurrent task conditions were used to introduce interference. In one condition subjects performed a concurrent articulation task. Articulatory suppression should be ineffective in disrupting performance on the primary task if verbal recoding does not occur. In a second condition a concurrent visual sine-wave tracking task was used. Visually tracking a sine-wave requires voluntary eye movements which seem to disrupt imaginal encoding (Idzikowski and Baddeley, 1984). It was hypothesised that sine-wave tracking, but not articulatory suppression, should disrupt visuo-spatial encoding. A third condition required subjects to perform both the articulatory suppression and the sine-wave tracking tasks. This condition was included to examine the possibility that a combination of the two tasks produced a larger performance deficit than visual sine-wave tracking.

3.3. Experiment 3.1.

3.3.1. METHOD

3.3.1.1. Subjects: 27 Durham University undergraduates were each assigned to one of three groups of nine.

3.3.1.2. Apparatus and Materials:

All stimuli were presented on three VDU's linked to a Sony videotape recorder. The area of screen which delineated the relevant field of vision was 15 cm x 15 x cm and subjects sat approximately 2 metres from the screen. Each stimulus was a filled circle and had a diameter such that 81 stimuli would fill the 15 cm x 15 cm display area.

At the preparatory stage stimulus materials were created by photographing a large square. A second square of the same magnitude but with a 9 x 9 grid superimposed was also photographed. Photographic reductions of both these squares were then made.

A film of the square with the grid was mounted behind each blank square transparency to facilitate the assignment of stimuli to the appropriate locations in the blank squares. Black Letraset circles with an appropriate diameter were then inserted into the selected locations. Five stimuli were assigned to each transparency. The locations were selected by assigning the number one to the top left hand location and the number 81 to the bottom right location. The five locations to be filled on a given trial were selected by using tables of random numbers (01-81) without replacement for each trial.

Additional transparencies were prepared with a Letraset cross in the central location (position 45). This location was never used as a stimulus location. In addition each transparency had a number of external markers that were not visible when the transparencies were subsequently mounted in slides. These markers allowed exact alignment of the transparencies. The slides were mounted in a carousel with a slide with a cross as a fixation point preceding each stimulus slide. Six empty slots were left after each fixation/stimulus slide pairing. The carousel was mounted on a Kodak slide projector with an automatic slide changer which presented each slide for one second. A further half second was required for the next slide to be selected. This had the effect of presenting a fixation slide for 1 second followed after a further half second by a stimulus slide for one second. There was then a further nine seconds before the next fixation slide was presented. This was the recall period.

These displays were video-taped and an auditory tone was subsequently dubbed onto the tape whenever a cross appeared. The cross/tone combination was used as a warning that a new trial was imminent.

A total of 15 trials were prepared. These consisted of one demonstration trial, two practice trials and 12 experimental trials. As noted earlier, the trials were presented on three VDU's.

Superimposed over the front of the VDU's were sheets of transparent plastic containing horizontal rows of dots above the stimulus square. A similar row was positioned below the square. These had directional arrows as illustrated in Figure 3.1. These transparencies were presented in all three experimental conditions although they were only salient to two of the conditions. The relevance of this will be made clear in the procedure section.

3.3.1.2.1. Recall Sheets

The recall sheets had blank 4.5 cm x 4.5 cm squares on them arranged in four rows of three squares and they were numbered, beginning at the top, left square, 1-12. Subjects were given a practice sheet and two further sheets for the experimental trials (one of these being a spare sheet in case of errors). One pattern was recalled in each square.

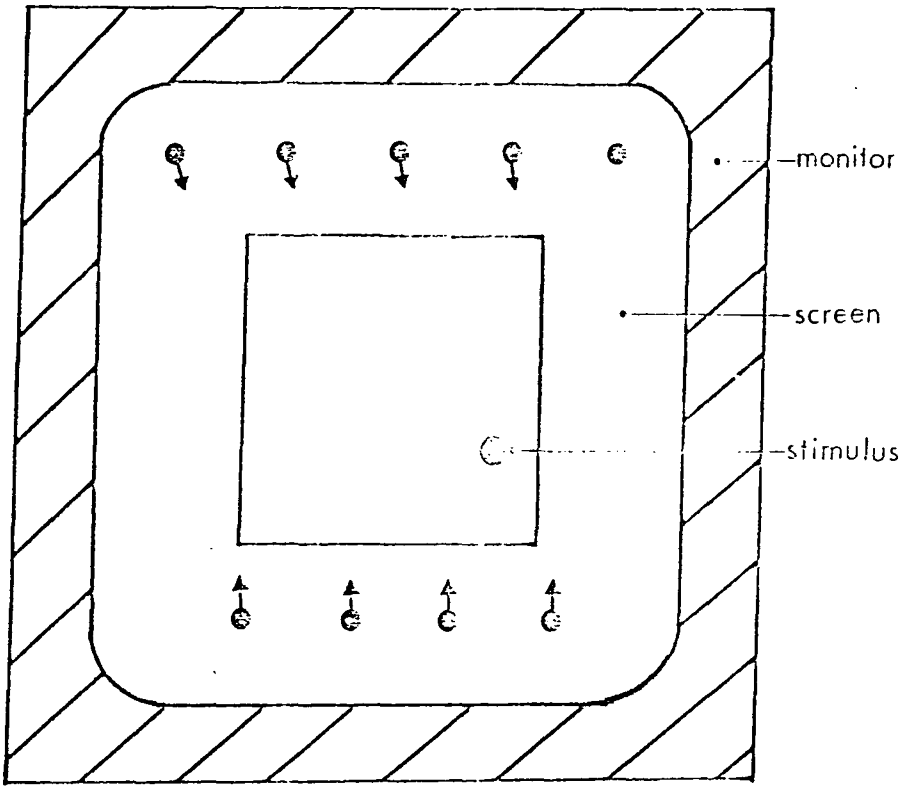


Figure 3.1. Diagram showing the arrangement of the visual tracking indicators.

3.3.1.3. Procedure

Ss were group tested with either one or two Ss to a VDU. At any session only one condition was run. The task was described to the Ss and demonstrated. Additional instructions were also given for each experimental condition.

Ss were required to recall the dot patterns in the squares on the recall sheets after each trial by placing exactly 5 crosses within the appropriate square. Crosses were used for responding as the intersection of the two lines allowed more accurate measurement of the Ss response than if dots were used (which could have varied in magnitude).

It was explained to Ss that there were 4 blocks of 3 trials and that there would be some concurrent activity on two of these blocks (on blocks 1 and 3 for alternate Ss in a condition and on blocks 2 and 4 for the other Ss). Because an even number of subjects was not used, due to subject pool limitations, four subjects received one ordering and five subjects received the other ordering. The ordering was decided by tossing a coin to decide which ordering would be given to four subjects. This method was also used in later experiments where appropriate. The concurrent activity blocks were indicated on the left of the sheet and the experimenter stopped the experiment after each block of trials to ensure that Ss knew what to do next. The trials used consisted of 6 control trials and 6 trials with a concurrent activity. All Ss experienced control trials.

The 3 conditions comprising the between S factor were designated as:-

(1) Eye movements.
(2) Articulatory suppression.
(3) Eye movements plus articulatory suppression.

3.3.1.3.1. The eye movements condition

Ss were told that on trials designated "task" (on the left of the sheet) they should follow the superimposed dot pattern with their eyes as soon as the square with the cross appeared and continue to do so until the recall tone sounded. The experimenter traced the pattern with his finger several times to indicate the speed of tracking required. Initially Ss followed the experimenter's finger movement with their eyes until they were satisfied that they understood the task. The rate of tracking required was such that Ss would track the sine-wave twice beginning when the warning tone was presented and ceasing when the recall tone was heard. It was stressed that they should perform the memory task as accurately as possible. All Ss reported that tracking did not create any perceptual problems. Ss practiced the tracking task on the practice trials and then the 12 experimental trials were run. The subjects moved their eyes, alternating between the top and bottom dots by following the arrows in the pattern designated in Figure 3.1. These numbers were not visible to subjects.

3.3.1.3.2. The articulatory suppression condition

Ss were instructed to use articulatory suppression (counting) on blocks of trials designated "task". Demonstration and practice trials were provided. Ss were told to count upwards from 300 "under your breath" and to do so as fast as possible. They practiced this aloud until they could count to at least 305; they were instructed to begin counting as soon as the cross appeared. Subjects situated at the same VDU always had the same condition ordering so that the experimenter was able to rather informally monitor the lip-movements of subjects.

3.3.1.3.3. The eye movements plus articulatory suppression condition

Ss were given both sets of instructions i.e. they were required to count and visually track the peripheral dots. They were practiced in these simultaneous tasks in an analogous way to the other two conditions.

3.3.1.3.4. Scoring

Scoring was carried out by using a transparent recall sheet with the 9 x 9 grid and the actual stimulus locations marked on it. Trials were scored on a minimum errors basis in terms of grid units (horizontal and vertical) so that a cross one grid space to the left and one grid unit above the presented location was scored as an error of 1,1 (one horizontal and one vertical deviation). The intersection of the two lines of the cross was taken as the subject's response. Ss were not allowed to use dots as responses as these could vary in magnitude. Each response was scored to the nearest target location unless this had already been scored. If this was the case then the next nearest target location was scored. Any borderline errors were scored as the lesser error. Any responses which were indeterminate (i.e., where it was not clear that a cross represented one location rather than another) were rescored until a minimum deviation was found. Horizontal and vertical errors were scored separately. It was felt that it would be overly presumptuous to lose this factor by analysing vectors when the effects of this are unknown in this instance.

Chance level performance on the visuo-spatial memory task was estimated by scoring all the data collected in Experiments 3.2. and 3.3. using the scoring key for Experiment 3.1. Different random locations were generated for Experiments 3.2. and 3.3. thus this should give a good estimate of chance level performance. The chance level performance errors per trial were Horizontal: 9.05; Vertical: 9.77.

3.3.2. Results

The means and standard deviations for all conditions and treatments are shown in Table 3.1. and the means are represented graphically in Figure 3.2.

3.3.2.1. Analysis of control conditions

Initially planned comparisons were performed on the control trial data. There are strong a priori grounds for assuming that there would be no difference because the same treatment was given to all subjects. Thus planned comparisons were used to test this stringently. Separate analyses were performed on the horizontal and vertical errors.

In the horizontal errors analysis all comparisons yielded an F ratio, with 1 and 24 degrees of freedom, of less than unity. However in the vertical errors analysis the eye movements condition group made a significantly greater number of errors in the control condition than the articulatory suppression group ($F(1,24) = 7.94$, $p<.01$). The eye movement group comparison with the both tasks group failed to reach significance ($F(1,24) = 2.18$, $p>.05$) as did the articulatory suppression group comparison with the both tasks group ($F(1,24) = 1.80$, $p>.05$).

Horizontal Errors

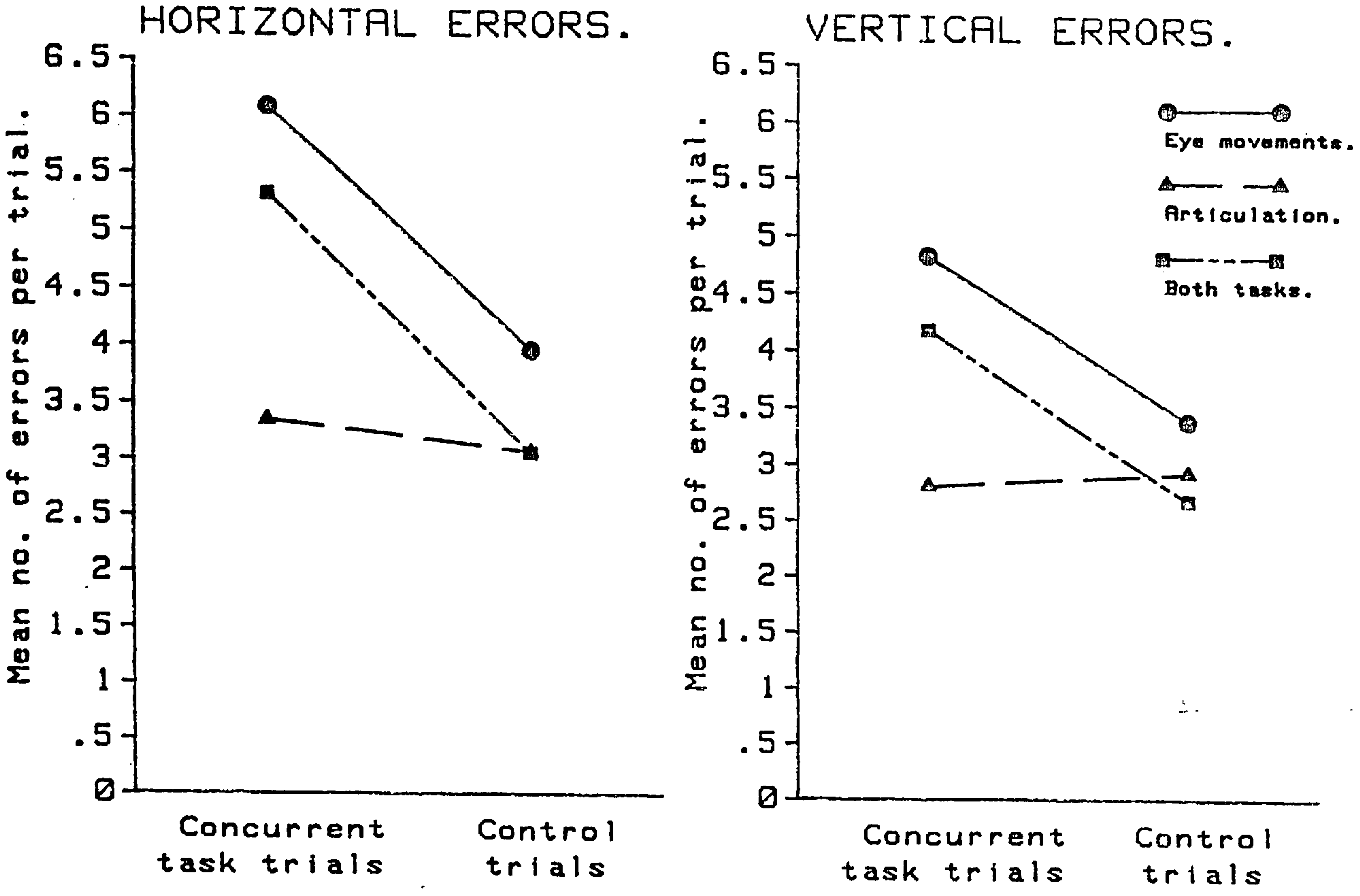
	Control	Concurrent task
EM group	3.33 (1.30)	6.07 (1.84)
AS group	2.78 (1.04)	2.87 (1.07)
Both group	3.33 (1.65)	5.04 (1.89)

Vertical Errors

	Control	Concurrent task
EM group	3.59 (0.61)	5.87 (1.78)
AS group	2.33 (0.85)	2.52 (0.64)
Both group	2.93 (1.25)	4.72 (1.10)

Table 3.1. The effects of concurrent visual sine-wave tracking (EM), articulatory suppression (AS) and both tasks on memory for 5 visuo-spatial locations presented simultaneously.

Figure 3.2. The effects of concurrent visual sine-wave tracking (EM), articulatory suppression (AS) and both tasks on memory for 5 visuo-spatial locations presented simultaneously.



HORIZONTAL ERRORS.

VERTICAL ERRORS.

3.3.2.2. Analysis of Variance and Post-hoc comparisons

Analysis of variance was carried out on all the experimental data with concurrent task as an independent groups factor. Again separate analyses of variance were performed on horizontal and vertical errors. Analysis of horizontal errors revealed significant effects of conditions ($F(2,24) = 19.50$, $p<.001$) and treatments ($F(1,24) = 19.50$, $p<.001$). The interaction was also significant ($F(2,24) = 5.77$, $p<.01$). A similar pattern of results was forthcoming from the vertical errors analysis. There were main effects of conditions ($F(2,24) = 15.00$, $p<.001$) and treatments ($F(1,24) = 30.94$, $p<.001$) and an interaction ($F(2,24) = 6.11$, $p<.01$).

In an attempt to identify the locus of the interaction effect, related samples t-tests were used to compare concurrent task trials with appropriate control trials. All comparisons had 8 degrees of freedom. In the horizontal errors analysis it was demonstrated that visual-sine wave tracking and performing both concurrent tasks had a detrimental effect on performance on the visuo-spatial memory task ($t = 3.32$, $p<.05$ and $t = 4.17$, $p<.01$ respectively). However the effect of articulatory suppression failed to reach significance ($t = 0.16$, $p>.05$). Similarly the vertical errors comparisons showed significant effects of sine wave tracking ($t = 4.01$, $p<.01$) and performing both tasks ($t = 5.22$, $p<.01$) but no reliable effect of articulatory suppression ($t = 0.50$, $p>.05$).

In general, direct comparisons between concurrent task blocks is not valid because there is no means of assessing the comparable difficulty of the different tasks. However this is not the case in the condition with both concurrent tasks when one might expect the effect of performing both tasks concurrently to increment the deficit. Inspection of the means (see Table 3.1.) suggests that this is not the case so independent samples t-tests comparing the eye movements condition with the both tasks condition were two-tailed. Separate comparisons were made for horizontal and vertical errors. Both comparisons had 16 degrees of freedom. Neither analysis was significant ($t = 0.18$, $p>.05$ and $t = 1.55$, $p>.05$ respectively). One-tail tests in the unpredicted direction (i.e. eye movements > both tasks) would also fail to reach significance. Concurrent articulation seems to have no reliable effect, in this experiment, on visuo-spatial processing irrespective of whether it is performed with or without visual sine wave tracking.

3.3.3. Discussion

The results of this experiment are straightforward. Tracking a sine-wave with one's eyes clearly disrupts visuo-spatial memory whereas articulatory suppression does not. The lack of an effect of concurrent articulation highlights two problems. First, the articulation task may not be as 'difficult' as tracking. Furthermore this experiment has little statistical power; perhaps the effect of articulation is very subtle. However these objections can be refuted by examining the results of Experiment 6.1. If one accepts the lack of an effect of articulation at face value until this problem is addressed in Chapter 6 then it can be concluded that the spatial task is useful in that it succeeds in 'decoupling' the loop from the rest of the working memory system in the sense that its deployment is specious in this situation.

Another objection to the acceptance of the null result found with concurrent articulation is that articulation was not continued for long enough. Objections to the use of a visual tracking task can also be raised. Although subjects reported no perceptual problem when performing this task this cannot be offered as objective evidence that there was indeed no perceptual problem.

This raises the question of whether the results of this condition are spurious. To answer this question one must anticipate experiments reported later in this thesis. In particular, Experiments 4.2. and 6.1. demonstrate, respectively, that the effects of visual tracking are confined to the encoding phase of visuo-spatial memory and that sine—wave tracking will also impair memory for auditorily presented non-spatial material.

The next two experiments, and the experiments reported in Chapter 4, employed a modified version of the visuo-spatial memory task. In these experiments the stimuli were presented serially, as opposed to simultaneously, thus trial duration was considerably extended. This facilitated an increase in the duration of concurrent activities.

3.4. General Method for Experiments Using Serial Presentation.

The procedure in general was the same as in Experiment 3.1. However there were some modifications to the basic task and method. The spatial locations used in Experiments 3.2. - 4.7. were presented serially. Thus the cross and warning tone appeared at the beginning of a trial then a square appeared for 1 second. This had 1 location filled. The screen was then blank for 0.5 seconds after which the square reappeared with a different location filled. This procedure was continued until 5 locations had been presented serially. There was never more than 1 location present at any time and total trial duration was 10 seconds (1.5s before the first location, 5 x 1.5s for stimulus presentation and a further second before recall was allowed). All other features of the task were identical to those employed in Experiment 3.1. except where indicated in the specific experiment method sections. The same scoring method and criterion was used.

3.5 Experiment 3.2.

Experiment 3.2. was a replication of Experiment 3.1. with an extended trial duration. The purpose of this experiment was, firstly, to examine the effects of a demanding articulatory suppression task. Secondly, the significant difference between control conditions in the vertical errors analysis of Experiment 3.1. is problematic. Thus Experiment 3.2. also examines this to see if it is artifactual.

3.5.1. Method

3.5.1.1. Subjects

27 Durham University undergraduates were each assigned to one of three groups of nine. Because of recruitment difficulties the subjects from Experiment 3.1. were used. However the stimulus locations employed differed from the earlier study.

3.5.1.2. Procedure

As noted above, this experiment replicated Experiment 3.1. except that the serial presentation and extended trial duration outlined in the general method were employed. The concurrent tasks were also modified accordingly. Ss were told to track the sine wave five times and to count from 300 five times as appropriate. It was indicated that each new tracking and/or counting should begin as soon as the screen cleared. Comparable instructions were given to Ss in the both concurrent tasks condition.

3.5.2. Results

As in Experiment 3.1. planned comparisons were used to compare the control trials. Horizontal and vertical errors were analysed separately. All comparisons had 1 and 24 degrees of freedom. There was no difference between the eye movement and the articulatory suppression control groups ($F=3.35$) and the eye movement and both tasks control groups ($F = 3.44$) and the F value for the articulatory suppression and both tasks comparison was less than unity. The equivalent comparisons for the vertical errors all produced F values of less than 1.

Analysis of variance was then carried out on all the experimental data with type of concurrent task as a between S factor. Again separate analyses were carried out on horizontal and vertical errors. There was a main effect of conditions ($F(2,24) = 6.30$, $p<.01$ in the horizontal errors analysis. A clear effect of treatments was also found ($F(1,24) = 35.12$, $p<.001$ and the interaction was also significant ($F(2,24) = 5.92$, $p<.01$. The vertical errors analysis demonstrated main effects of conditions ($F(2,24) = 4.48$, $p<.025$) and treatments ($F(1,24) = 10.20$, $p<.01$) but the interaction failed to reach significance ($F(2,24)=3.20$, $p>.05$).

Related samples t-tests were used to compare concurrent task trials performance with appropriate control trials. All comparisons had 8 degrees of freedom. Significant memory decrements were found with the eye movements condition ($t = 6.22$, $p<.01$) in the horizontal errors analysis but the effect of articulatory suppression failed to reach significance ($t = 0.50$, $p>.05$). A similar pattern of results was found in the vertical errors analysis with significant decrements produced by eye movements ($t = 2.44$, $p<.05$) and both tasks ($t = 3.43$, $p<.01$) but once again there was no effect of articulatory suppression ($t = 0.22$, $p>.05$). The means and standard deviations are shown in Table 3.2 and represented graphically in Figure 3.3.

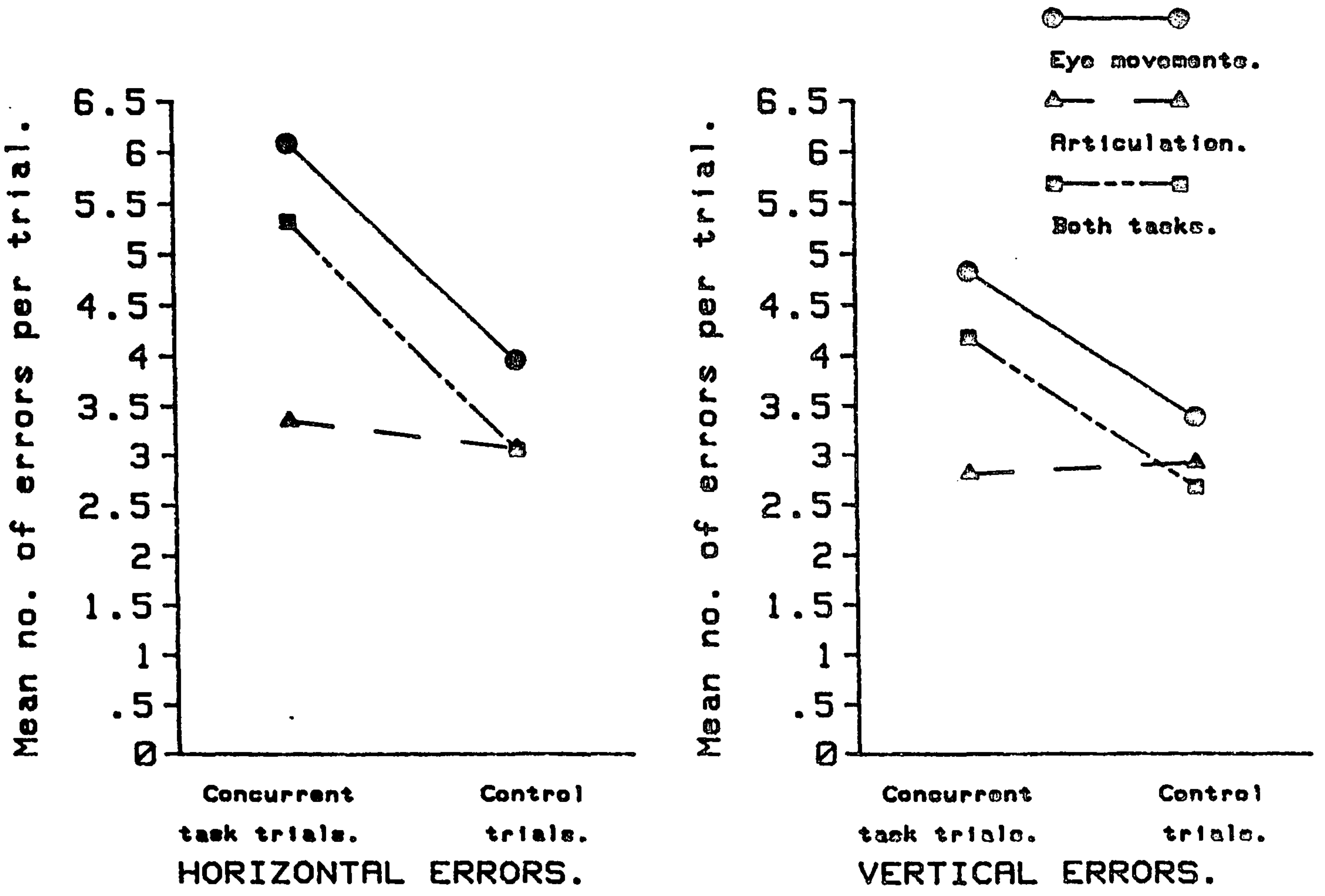
	Control	Concurrent task
EM group	3.96	6.09
	(1.30)	(1.97)
AS group	3.07	3.35
	(1.04)	(1.23)
Both group	3.06	5.32
	(0.67)	(1.11)

Vertical Errors

	Control	Concurrent task
EM group	3.39	4.83
	(0.86)	(1.36)
AS group	2.93	2.81
	(1.55)	(1.17)
Both group	2.68	4.18
	(0.90)	(1.01)

Table 3.2. The effects of concurrent visual sinewave tracking (EM), articulatory suppression (AS) and both tasks on memory for serially presented visuo-spatial locations.

FIGURE 3.3. THE EFFECTS OF CONCURRENT ACTIVITY ON RECALL OF VISUO-SPATIAL INFORMATION PRESENTED SERIALLY.



3.5.3. Discussion

The results of this experiment, in general, replicate the results of Experiment 3.1. It is clear that the prolongation of articulatory suppression does not impair performance on this task whereas visual tracking does.

The possibility of perceptual problems however remains. Perhaps visually tracking a sine wave merely impairs sensory registration of the to-be-remembered locations. Ss report that they have no such perceptual problems but nevertheless it is desirable to demonstrate interference with this task in a manner that clearly rules out perceptual difficulties. This situation is remedied in Experiment 3.3. by using a non-visual tracking task developed by Moar. Moar's (1978) tracking task disrupted topographical memory representation. The next experiment examines the effect of Moar's task on the visuo-spatial memory task employed in Experiment 3.2. It is predicted that this non-visual task will disrupt visuo-spatial representation (Baddeley and Lieberman, 1980).

3.6. Experiment 3.3.

3.6.1. Method

3.6.1.1. Subjects

9 members of the technical staff of Durham University Psychology Department. Ss were run individually.

3.6.1.2. Procedure

This experiment replicated Experiment 3.2. with a non-visual spatial tracking task. The same procedure and materials were used but Ss had to perform a tracking task on a Moar box (see Moar, 1978). The Moar box consisted of a box with an array of 5 x 5 keys (as illustrated in Figure 3.4.). Subjects were required to depress the keys along one column and then reverse along the next column and so on until the trial ended. Subjects had to press every key in the correct pattern at least once on every tracking trial and they were required to backtrack up the last row if they had pressed every key before the end of a trial. The box was concealed from visual inspection. Five minutes practice on the tracking task was given at the beginning of the experiment (and subsequent experiments using this task), before actual practice trials began, to familiarise subjects with the apparatus. The Moar box keys were connected to a remote LED display so that the experimenter could check that subjects performed to criterion. All other aspects of the procedure were identical to those outlined in the General Method (Section 3.4).

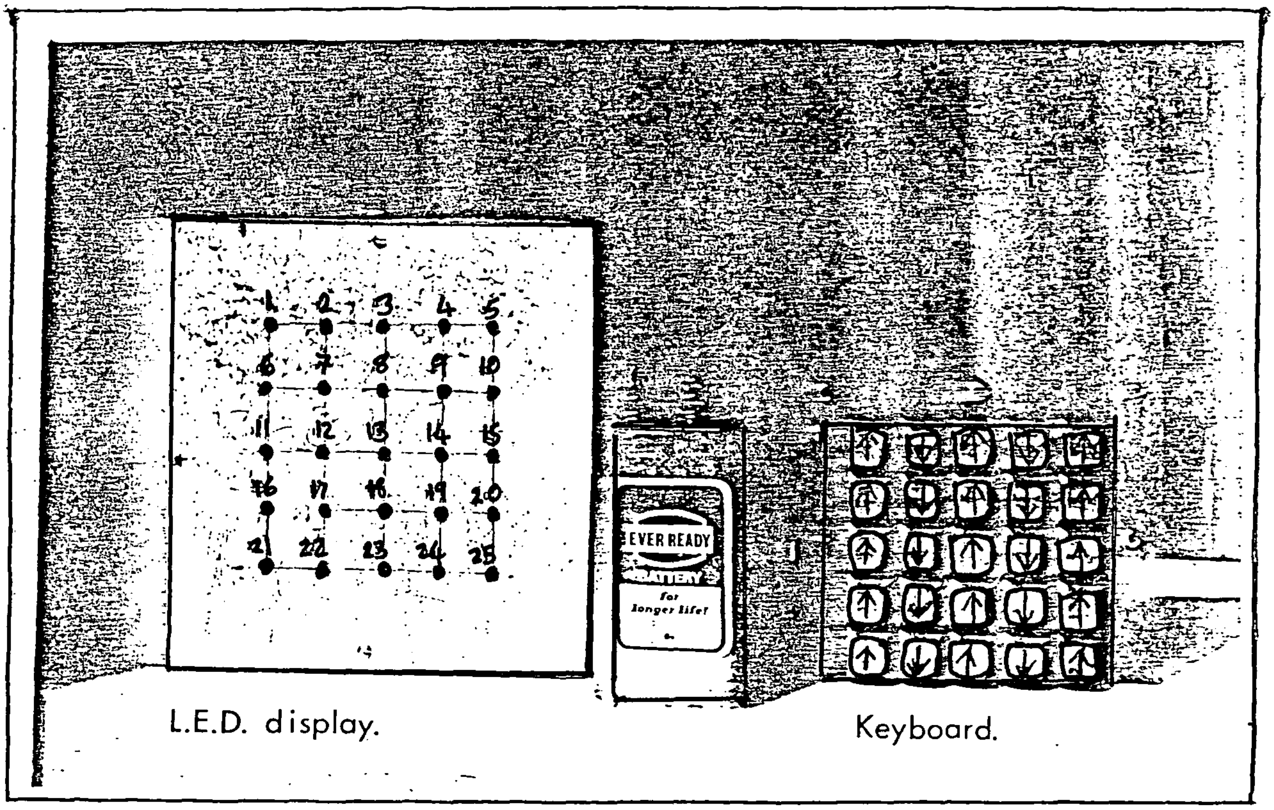


Figure 3.4. The Moar Box. The Moar Box tracking task required the subject to press each key on the keyboard. Subjects began with the bottom left key and then tapped out the pattern indicated by the arrows in the illustration. A 6v battery provided the power necessary to light the appropriate LED display units and thus allowed the experimenter to verify that the subject performed to criterion.

3.6.2. Results

All Ss performed to criterion level on the tracking task. Related samples t-tests were carried out on horizontal and vertical errors. There was a significant effect of tracking on both horizontal ($t(8) = 6.73$, $p < .001$) and vertical errors ($T(8) = 4.64$, $p < .001$). The means and standard deviations are reported in Table 3.3.

Mean no. of errors per trial (standard deviations in brackets).

	Horizontal Errors	Vertical Errors
No concurrent task	2.91 (1.23)	3.06 (1.23)
Moar box tracking	6.07 (1.65)	5.35 (1.38)

Table 3.3. The effect of Moar Box tracking on visuo-spatial memory.

3.6.3. Discussion

This experiment is basically an extra condition to supplement Experiment 3.2.

The sample seems to be comparable because control trial performance was at a level comparable to that found with undergraduates participating in Experiment 3.2.

The basic finding is that a non-visual tracking task impairs performance on the memory task. This supports the findings of Baddeley and Lieberman (1980) that non-visual tracking tasks impair the use of imagery. Furthermore, in this experiment, the disruption cannot be simply assumed to be a perceptual problem. Taken at face value, interpretation of this result seems to be straight forward. However later experiments reported in Chapter's 4 and 6 will suggest that the explanation of tracking effects is likely to be problematic.

3.7. General Discussion

The experiments reported in this chapter were designed to develop a visuo-spatial memory task that could not be verbally recoded but which would be subject to the sort of interference effects that one would expect to occur with visuo-spatial (or purely spatial) representation. Clearly the task introduced in Experiment 3.2. seems to have these properties. This task is examined in more detail in Chapter 4.

A number of questions have not been answered. We are not in a position to comment on the relationship of the visuo-spatial scratch pad to the central executive. It may be that there is no scratch pad. Imaginal representation (if this is what occurs) may simply be a function of the central executive. Alternatively the central executive may be required to load and monitor the scratch pad or perhaps it is the case that the scratch pad is independent of central executive functioning.

For the moment it is sufficient that the articulatory loop has been dissociated. Thus we have a task that does not require an important component of the working memory system and this is consistent with the literature reviewed in Chapter 2. To this extent these experiments have begun the fractionation of the system. It is now necessary to see if the system can be further fractioned, or, if indeed it is the case, that the rest of the system needs to be considered in toto. To this end it is necessary to examine some of the fundamental characteristics of the store e.g. its decay function. The locus of interference also needs to be established and because double dissociations have not been used it is necessary to demonstrate that the articulatory suppression task used can have some effect on memory in a situation where a memory task that is in some way comparable is disrupted. Furthermore the effects of the other concurrent tasks used need to be investigated using a wider range of working memory tasks. The remaining chapters of this thesis examine these factors and present a theory of how an integrated working memory system might operate.

Chapter 4

Identifying the locus of central executive control of visuo-spatial processing

4.1. Summary

The experiments reported in this chapter employ the memory task developed for Experiments 3.2. and 3.3. Experiment 4.1. demonstrates that the memory 'trace' for visuo-spatial material does not decay over at least 20 seconds. The remaining experiments examine the locus of interference with this task. It is concluded that interference can occur at encoding and retrieval. However neither tracking nor a memory load of six consonants is disruptive during maintenance rehearsal. A consonant pre-load is however disruptive and this finding, taken together with the results from the other experiments employing the visuo-spatial memory task, suggests that a consonants pre-load interferes with the deployment of the visuo-spatial scratch pad by occupying the central executive.

4.2. Introduction

The experiments reported in Chapter 3 demonstrated that visual and tactile tracking tasks disrupt visuo-spatial representation. These experiments, however, did not identify the locus of interference. The effects might, for example, be confined to the encoding phase or they might be more global and disrupt representations that have already been formed.

One way to decide between these alternatives would be to move the locus of the interfering activity. One could, for example, require Ss to perform the interfering activity before or after encoding. However because there is no memory load requiring retention in any of the tracking situations one would expect any capacity used by these tasks to be freed after tracking has ceased. Thus the logical approach to take is to introduce interference after encoding of the spatial memory task but before recall.

This raises problems of memory 'trace' decay over time. Any deficit observed might simply be due to the passage of time during tracking. Kroll et al (1970) have suggested that visual representations can be held without degradation for at least 25 seconds. If this is the case then any effects found after the insertion of post encoding interference should be due exclusively to non-temporal factors.

4.3. Experiment 4.1.

Experiment 4.1. sought to establish whether memory for the serial location memory task would decay over a time span of 20 seconds. To introduce interference after encoding it is necessary to delay recall of visuo-spatial information. Experiment 4.1. examines the effects of delaying recall of 0, 5, 10 or 20 seconds on performance on the visuo-spatial task used in Experiments 3.1. and 3.2.

4.3.1. METHOD

4.3.1.1. Subjects: 9 members of the technical staff of Durham University Psychology Department. Some of these Ss also participated in Experiment 3.3. but this experiment was run three months after Experiment 3.3.

4.3.1.2. Procedure: Ss received exactly the same trials as those used in Experiments 3.2. and 3.3. but observed one demonstration trial and then received four practice trials. The scoring method was the same. No concurrent tasks were used. Ss had merely to recall the locations but various delay intervals were introduced between presentation and recall.

This was a completely within-subject design with four randomized blocks of three trials per block. Ss were run individually. The delays used were 0, 5, 10, 20 seconds. During the delay Ss were instructed to look away from the screen and the experimenter said "recall" after the appropriate delay.

4.3.2. Results: Separate one-way repeated measures analysis of variance were performed on the horizontal and vertical errors. There was no significant effect of delay on horizontal errors (F(3,24)<1) or vertical errors (F(3,24)<1). The mean number of errors per trial and standard deviations are shown in Table 4.1.

Mean no. of errors per trial (standard deviation in brackets).

	Recall delay (seconds).			
	0	5	10	20
Horizontal	3.96	3.55	4.07	4.07
Errors	(1.42)	(1.20)	(1.33)	(1.22)
Vertical	2.74	3.59	2.89	3.04
Errors	(2.35)	(1.29)	(0.83)	(1.08)

Table 4.1. The effect of recall delay on visuo-spatial memory.

4.3.3. Discussion

The total duration of a visuo-spatial memory trial presentation was always ten seconds. Experiment 4.1. demonstrated that there was little forgetting over this time course so it is possible to present ten seconds of interfering activity after presentation, rather than concurrent with the visual material, without any confounding effects of forgetting. Experiment 4.2. involved presenting the concurrent activities used in the earlier experiments after presentation of the visuo-spatial memory task.

4.4. Experiment 4.2.

4.4.1. METHOD

4.4.1.1. Subjects: 9 Durham University undergraduates. None of these Ss participated in any of the other experiments in this series.

4.4.1.2. Procedure: In this experiment recall was always delayed for 10 seconds. This 10 second delay interval was filled with a different interference task on each of three of four blocks of trials. The order of condition presentation was randomized for each S. On one block Ss performed the articulatory suppression task used in Experiment 3.2. during the interval. Visual tracking to the same criterion used in Experiment 3.2. was used on another block. A picture of a sine-wave was presented below the VDU in this condition and a video camera recorded the eye movements to verify that the task had been performed. The third condition used the Moar box tracking task employed in Experiment 3.3. (once again this was concealed from visual inspection) and the same criterion was employed. On a fourth block the delay was unfilled. Ss were run individually.

4.4.3. Results: Separate one-way analyses of variance were performed on the horizontal errors. There was no effect of any interference task on horizontal errors ($F(3,24)=1.03$, $p>.05$) or vertical errors ($F(3,24)=1.71$, $p>.05$. The means and standard deviations are shown in Table 4.2.

Mean no. of errors per trial (standard deviations in brackets).

	Type of task performed during delay			
	No task	Articulatory suppression.	Visual tracking.	Moar box tracking.
Horizontal Errors	4.52 (1.10)	4.15 (1.53)	5.08 (1.43)	5.19 (1.46)
Vertical Errors	2.93 (1.02)	3.93 (0.67)	3.85 (1.43)	4.11 (1.78)

Table 4.2. The effects of post-presentation interference on recall of visuo-spatial information.

4.4.4. Discussion: This experiment suggests that the locus of interference is unlikely to be during maintenance rehearsal. The obvious conclusion to be drawn from this is that tracking probably disrupts some aspect of attention but does not occupy the memory store itself.

An alternative explanation is that visuo-spatial information is initially stored in a transient memory store which is disrupted by appropriate concurrent activity initially but if it survives it is transferred to a longer term store. An iconic type representation is unlikely. Haber (1983) has discussed the problems of postulating such a store as functionally relevant. However a number of other considerations militate against such a view.

Serial presentation of locations should disrupt such a store (by masking and requiring a longer term representation). Furthermore, it is difficult to see how a non-visual task (Moar box tracking) could disrupt such a process. The most compelling explanation that remains is that tracking impairs encoding not storage. Thus the use of the central executive or some spatial monitoring device in performing the concurrent tasks seems to be the causal agent implicated in the impairment of visuo-spatial representation.

Two caveats should be introduced here. First, there may be interference effects at retrieval. These experiments have not addressed this possibility. The results of Brooks (1968) suggest that this is the case. Furthermore, the nature of the memory task may also be crucial. This task does not involve extensive transformation of input although some transformation is necessary. Subjects must store the spatial relationships between the stimuli without maintaining the original stimuli magnitudes because the response squares were much smaller than the VDU display. However extensive transformations such as those required by, for example, mental rotation tasks were not required. Thus, the scratch pad may engage in rather simple maintenance rehearsal after encoding. This probably requires little central executive capacity. However tracking may well disrupt more active spatial processing even after initial registration on the scratch pad.

The implication is that articulatory suppression has very little effect because little or no central executive capacity is required to operate the loop in these circumstances. The scratch pad on the other hand requires central executive attentional resources at encoding and retrieval. Once encoding has been achieved it can hold representations without disruption from otherwise interfering tasks provided these tasks do not require the scratch pad.

Thus the effect of concurrent activities like the tracking tasks are attentional in nature. Indeed when we consider general effects of concurrent activity we may simply be referring to the distracting effects of 'splitting' attention. This view is in accord with that of Phillips and Christie (1977a).

If it is the case that the scratch pad requires central executive resources during encoding and retrieval then a verbal memory load approaching digit span should disrupt encoding because this load should occupy a significant amount of central capacity. Baddeley and Hitch (1974) demonstrated that a near-span load slows verbal reasoning and they argued that this is because central capacity is reduced by holding a six figure number. If the scratch pad operates in isolation from the central executive or requires a separate control process to that used for verbal reasoning then the verbal load should have no effect.

It is clear from Experiments 3.1. and 3.2. that the articulatory loop is not necessary to process spatial information but a verbal load of six consonants should overload the loop and thus require either general or verbal memory capacity. Furthermore if it is the case that the role of the executive is largely confined to the encoding phase as indicated by the last experiment then a verbal load presented after spatial encoding should be ineffectual in disrupting representation unless it interferes with retrieval processes. Thus the following three experiments examine this issue.

4.5. Experiment 4.3.

Experiment 4.3. examines the effect of a verbal preload on visuo-spatial memory encoding. The effect of this load on retrieval is also examined by requiring consonant recall first on one block and spatial location recall first on another block.

4.5.1. METHOD

4.5.1.1. Subjects: 9 Durham University undergraduates. None of these subjects participated in other experiments in this series.

4.5.1.2. Procedure: The memory trials used in Experiments 3.2.-4.2. were used. There were additional practice trials. Ss observed one demonstration trial and then had a block of 4 practice trials each with a verbal pre-load.

Before each spatial memory presentation Ss were auditorily presented with 6 consonants at one per second on two blocks of four trials. The consonants were random selections of six consonants from a population of 12 (B,F, G,H,J,K,L,Q,R,V,Y,Z.) without replacement on each trial. They also received a block of four trials with no verbal memory pre-load. The ordering of these blocks was randomised for each subject.

On appropriate blocks, the verbal memory load was presented and then one second after the final consonant the spatial memory trial was presented. Immediately after the tone indicating that the final spatial location had been presented Ss were required to recall the consonants first and then the locations and vice versa on another block. Ss were tested individually.

4.5.2. Results.

4.5.2.1. Recall of Consonants. The mean number of consonants correctly recalled in the appropriate serial order was 4.50 (s.d.= 0.94) when the letters were recalled first and 4.69 (s.d.= 1.02) when the spatial locations were recalled first. This difference was not statistically reliable ($t(8)=0.57$, $p>.05$).

4.5.2.2. Recall of Spatial Locations. Separate one-way, repeated measures analysis of variance were carried out on horizontal and vertical errors. The horizontal errors analysis was significant ($F(2,16)=6.87$, $p<.01$). Related samples t-tests showed that there were significantly more errors in the recall of letters first condition compared to the no verbal memory load condition ($t(8)=3.35$, $p<.01$) but the comparison of location-first-recall and the no-verbal-memory-load condition failed to reach significance ($t(8)=1.69$, $p>.05$). There was no difference in spatial location recall between the letters-first and locations-first recall ($t(8)=2.64$, $p>.05$).

The vertical errors analysis was also significant (F(2,16)=9.00, p<.01). t-tests showed that the recall of letters first comparison with no verbal memory load was highly significant (t(8)=5.80, p<.001) but the recall of locations first comparison with no verbal memory load was non-significant (t(8)=0.48, p>.05). Recalling letters before locations had a marked effect (t(8)=3.14, p<.025). The means and standard deviations for the spatial location error scores are shown in Table 4.3.

Horizontal Errors.

Mean no. of errors per trial,
(standard deviations in brackets)

No memory load.	Letters first.	Locations first.
3.11 (1.16)	4.75 (1.02)	3.97 (0.97)

Vertical Errors.

Mean no. of errors per trial;
(standard deviations in brackets)

No memory load.	Letters first.	Locations first.
2.47 (0.90)	4.50 (0.77)	2.78 (1.34)

Table 4.3. Errors of spatial location recall with verbal preload.

4.5.3. Discussion

Although a verbal preload clearly has an effect on spatial memory performance the magnitude of this effect is quite small compared to the effect of tracking. Presumably some of the verbal load can be held in the articulatory loop so that only a small part of the load will interfere with spatial encoding.

The results are somewhat ambiguous. Horizontal errors are largely attributable to recalling the letters first. This result is counter intuitive. One would expect that when S is relieved of the verbal load (by recalling it first) performance should be better on the spatial task than when S has to hold the verbal load while recalling the spatial material. This suggests an effect, albeit rather subtle, at retrieval rather than at encoding. The vertical errors analysis also reveals a similar trend but further emphasises the effect of recalling letters first.

There is a general trend throughout most of the conditions in this and the earlier experiments using serial presentation of spatial material for there to be less vertical than horizontal error. The experiments reported here suggest no explanation for this. Possible explanations of this effect will be discussed in Chapter 8 but it is clearly a problem that requires the proverbial further research.

4.6. Experiment 4.4.

Experiment 4.4. replicates Experiment 4.3. but the verbal load is presented after the spatial memory material. This experiment examines specifically the effect of a verbal load on retrieval because the spatial material has already been encoded (the low error rates found in earlier experiments especially Experiment 3.1. show that any necessary consolidation occurs rapidly and Experiment 4.1. demonstrates that the 'trace' is not vulnerable to forgetting).

4.6.1. METHOD

4.6.1.1. Subjects: 9 Durham University undergraduates. None of these subjects participated in earlier experiments.

4.6.1.2. Procedure: All the materials were the same as those used in Experiment 4.3. The experimental design was identical except that the spatial task preceded the auditorily presented consonant load which was presented 1 second after the tone indicating that all the spatial locations had been presented. Once again condition presentation order was randomised for each subject.

4.6.2. Results

4.6.2.1. Recall of Consonants: The mean number of consonants correctly recalled in the appropriate serial order was 5.22 (s.d.=0.74) when the letters were recalled first and 4.00

(s.d.=0.96) when the spatial locations were recalled first. This difference was statistically reliable (t(8)=5.92, p<.01).

Horizontal Errors.

Mean no. of errors per trial.
(standard deviations in brackets)

No memory load.	Letters recalled first.	Locations recalled first.
3.92 (1.63)	4.39 (1.65)	3.92 (0.74)

Vertical Errors.

Mean no. of errors per trial.
(standard deviations in brackets)

No memory load.	Letters recalled first.	Locations recalled first.
3.40 (1.08)	3.83 (1.22)	3.86 (1.43)

Table 4.4. Errors of spatial location recall with verbal postload.

4.6.2.2. Recall of Spatial Locations: Separate one way, repeated measures analysis of variance were carried out on horizontal and vertical errors. Both tests had 2 and 16 degrees of freedom. For the horizontal analysis the computed value of F was less than 1 and the vertical errors value was also non-significant (F=2.74, p>.05). Table 4.4. presents the mean number of errors and the standard deviations.

4.6.3. Discussion: This experiment demonstrates that there is a tendency to lose some of the consonants when the spatial information has to be recalled first. This was not the case in Experiment 4.3. The obvious explanation is that this occurs during the recall of the spatial material but this is not the case when the consonants are presented as a preload. It is clearly not the case that this is an effect produced at encoding because overall recall is slightly higher in this experiment than in the preload experiment. Indeed there is a clear 'ceiling effect' in this study. A more likely explanation is that Ss performing the task as a preload adopt a different rehearsal strategy.

In Experiment 4.3. it would be advantageous to rapidly consolidate any representation of the verbal material before a heavy spatial processing load develops. In Experiment 4.4. immediate recall of the verbal material is possible on the consonants recalled first block and this probably accounts for the ceiling effect. However recalling spatial locations first may reduce rehearsal of verbal material for a few seconds (typically the time taken to recall the spatial material). In the previous experiment a preload might well receive enough rehearsal before the spatial load is presented to make the 'trace' less vulnerable. This is speculation. The next experiment used the verbal load concurrently and the results will clarify the situation.

The results of the spatial memory analysis are relatively clear cut. A verbal memory load presented after the spatial memory material has no reliable effect on performance. An experiment with greater power might well detect some subtle effects but the means suggest that there is little interference at retrieval when recalling location information before or after the verbal information. Experiment 4.2. demonstrated that spatial location representations are resistant to degradation after encoding even when tasks having marked effects when presented concurrently (e.g. Moar box tracking) are used. This experiment replicates this finding.

4.7. Experiment 4.5.

Verbal loads have only a marginally disruptive effect on visuo-spatial memory and this only occurs when the verbal load is presented first. However one might expect some interference when the two tasks are presented concurrently. Experiment 4.5. examines this possibility.

4.7.1. METHOD

4.7.1.1. Subjects: 9 Durham University undergraduates. None of these Ss had participated in any of the earlier experiments.

4.7.1.2. Procedure: The procedure was, in general, the same as in the earlier experiments reported in this chapter. However only 5 consonants were used and these were once again presented auditorily but also concurrently with the locations so that each time S observed a location he/she heard a consonant. Again the order of presentation of the three conditions was randomised for each S (no consonants presented, recall of consonants first, recall of locations first).

4.7.2. Results.

4.7.2.1. Recall of Consonants: The mean number of consonants correctly recalled in the appropriate serial order was 4.61 (s.d.=0.59) when the letters were recalled first and 4.44 (s.d.=0.72) when the spatial locations were recalled first. This difference was not statistically reliable (t(8)=0.71, p>.05).

4.7.2.2. Recall of Spatial Locations: Separate one way, repeated measures analyses of variance were carried out on horizontal and vertical errors. Both tests had 2 and 16 degrees of freedom. The horizontal errors analysis was significant (F=3.95, p<.05) and related samples t-tests revealed that recalling letters first had a significant, detrimental effect on performance compared to recalling locations only (t(8)=4.58, p<.01) but recalling locations first did not produce a reliable effect (t(8)=2.20, p>.05). The comparison of letters first recall with locations first recall also failed to reach significance ((t8)=0.39, p>.05).

A similar pattern of results was forthcoming from the vertical errors analysis. The analysis of variance was significant (F=4.27, p<.05) as was the comparison of locations-only recall with letters first recall (t(8)=3.46, p<.01). The locations-only recall with locations-recall first failed to reach significance (t(8)=1.63, p>.05) as did the recall order comparison (t(8)=0.48, p>.05). The mean number of errors per trial and standard deviations are reported in Table 4.5.

Horizontal Errors

Mean no. of errors per trial.
(standard deviations in brackets)

No concurrent verbal load.	Letters recalled first.	Locations recalled first.
3.36 (0.89)	4.97 (1.35)	4.67 (1.80)

Mean no. of errors per trial
(standard deviations in brackets)

No concurrent verbal load.	Letters recalled first.	Locations recalled first.
3.06 (1.98)	4.36 (1.21)	4.30 (1.49)

Table 4.5. Errors of spatial location recall with a concurrent verbal load.

4.7.3. Discussion: Concurrent verbal encoding has a disruptive effect on visuo-spatial encoding. The absence of a marked effect of recall order suggests that the retrieval effects found in the previous two experiments are due to the availability of rehearsal strategies that are not possible or ineffective when the verbal load is presented concurrently. Another possibility is that the reduction of the verbal load in this experiment from 6 to 5 removes retrieval effects. The load reduction was necessary to match the number of locations presented to the number of consonants presented. This explanation, however, is unlikely as the mean number of consonants recalled in this experiment is comparable to those reported in the two previous experiments.

The final two experiments in this chapter examine specifically the possibility of strategy manipulation. The verbal load experiments show clearly that there is a trade off, albeit a small one, between processing and maintaining verbal and visuo-spatial information. In particular it may be possible to adopt a mode of preferential encoding and retrieval of verbal or visuo-spatial material. The experimental designs used in Experiment 4.3. and 4.4. are particularly suitable for separating out voluntary strategy use.

With a verbal preload Ss may have the option of committing a large amount of central executive capacity to maintaining the consonant load or to commit some of this capacity to encoding the visuo-spatial material at the expense of maintenance rehearsal of the verbal load. However when the visuo-spatial material acts as a preload to the verbal material (as in Experiment 4.4.) then this should not be the case as it has been demonstrated that spatial encoding is rapid and not vulnerable to subsequent decay.

No attempt was made to replicate Experiment 4.5. as a concurrent verbal load has only a small effect and did not allow Ss to clearly separate, temporally, the two tasks and thus prevented the development of a simple strategy of consolidating one type of material before the other. Strategies developed in Experiment 4.5. would not be separable into encoding and retrieval strategies relatively unambiguously.

If one asked Ss to concentrate on verbal or visual material in the concurrent presentation experiment then three basic options would be open to the subjects:-

[1]. To ignore one modality.
[2]. To 'time share' between the rehearsal of the tasks.
[3]. To use parallel processing.

The most likely strategies to be adopted would be [2] and [3] (because Ss were told that they should perform as well as possible on both tasks and the results of Experiment 4.5. suggest that recall of the visuo-spatial material is still quite accurate even when there is a ceiling effect on verbal memory performance; thus there is no need to adopt strategy [1]).

Of the two remaining strategies [3] is the most likely to be adopted. Time sharing is unlikely to be necessary until quite late in the time course of a trial because the memory load accumulates throughout the trial (Increasing from 1 location and 1 consonant at the beginning of a trial to 5 locations and 5 consonants by the end of a trial; this of course is true to a lesser extent in Experiments 4.3. and 4.4. also). One might expect that strategy changes would be particularly likely to occur over the course of such a trial and a heavy emphasis would be placed on encoding and retrieval of verbal information (which is more vulnerable to decay). Thus there seems to be little point in attempting to manipulate the strategic use of resources in this experiment (unless this was done systematically with various loads).

4.8. Experiment 4.6

It was argued in the discussion of Experiment 4.3. that retrieval strategy was particularly important. However the results of Experiment 4.4. suggest that presenting a verbal load after visuo-spatial encoding results in some loss of verbal information during the retrieval of visuo-spatial information. This is reflected in an inability to immediately recall a verbal load that was vulnerable because it had not been at least partially consolidated before the visuo-spatial load was presented. Thus both of these tasks could be handled in different ways by Ss if either verbal memory performance or visuo-spatial memory performance was stressed. Therefore Experiments 4.3. and 4.4. are replicated with instructional biases in Experiments 4.6. and 4.7. respectively.

4.8.1. METHOD

4.8.1.1. Subjects: 12 Durham University undergraduates were recruited to take part in this experiment. None of them had participated in any of the earlier experiments.

4.8.1.2. Procedure: This experiment was similar to Experiment 4.3. It differed in that there was a consonant load (6 consonants) on all 12 experimental trials (and four practice trials). Trials were divided into four blocks of three trials.

On two blocks Ss recalled the consonants first and then the spatial locations. The recall order was reversed for the other two blocks.

For half the experiment the emphasis was placed on recalling the spatial information "at all costs" and the emphasis was switched on the other half of the experiment to recalling the consonants at all costs. Ss were run individually and the instruction presentation order was counter-balanced.

Thus in the spatial bias condition Ss were told that they should be as accurate as possible in encoding and recalling the spatial information. They were also told that they should recall as many of the consonants as possible but if there was any conflict between encoding both then the spatial information should be given priority. The bias was reversed on the other six trials.

4.8.2. Results.

4.8.2.1. Recall of Consonants: A repeated measures, 2 factors, analysis of variance was performed on the data with Instructional bias and Recall order as the two factors.

There was no effect of instructional bias (F(1,11)=1.13, p>.05) or order of recall (F(1,11)=1.39, p>.05) and there was no interaction (F(1,11)=3.92, p>.05).

Serial recall of consonants.

Mean no. correct per trial (standard deviations in brackets).

Spatial Bias.		Verbal Bias.	
Recall Order.			
Letters 1st	Locations 1st	Letters 1st	Locations 1st
3.78 (0.67)	4.42 (1.18)	4.47 (1.64)	4.53 (1.11)

Horizontal Spatial errors.

Mean no. of errors per trial
(standard deviations in brackets).

Spatial Bias.		Verbal Bias.	
Recall Order.			
Letters 1st	Locations 1st	Letters 1st	Locations 1st
3.92 (1.62)	4.17 (1.63)	5.61 (1.98)	3.14 (1.39)

Vertical Spatial errors.

Mean no. of errors per trial
(standard deviations in brackets).

Spatial Bias.		Verbal Bias.	
Recall Order.			
Letters 1st	Locations 1st	Letters 1st	Locations 1st
4.36 (1.75)	2.92 (1.03)	4.00 (1.63)	3.39 (1.98)

Table 4.6. Errors of spatial location recall with verbal preload and strategy manipulation.

4.8.2.2. Recall of Spatial Locations: Separate repeated measures, 2 factors, analyses of variance were performed on horizontal and vertical errors with Instructional Bias and Recall Order as the 2 factors.

In the horizontal errors analysis there was no main effect of instructional bias (F(1,11)>1) but a significant main effect of recall order was found (F(1,11)=12.78, p<.01) and the interaction was also significant (F(1,11)=10.52, p<.01).

Recalling locations first had no effect with instructions to preferentially encode visuo-spatial information (t(11)=0.62, p>.05) but instructions to preferentially encode the consonants resulted in greater horizontal errors when the visuo-spatial information was recalled after the consonants (t(11)=3.99, p<.01).

In the vertical errors analysis there was no main effect of recall order (F(1,11)=8.91, p<.025) and no interaction (F(1,11)<1).

With a bias toward encoding the visuo-spatial memory task recalling the locations first had a marked effect (t(11)=3.02, p<.025) but no such effect was found on this type of trial where Ss were required to preferentially encode the consonants (t(11)=0.61, p>.05). The means and standard deviations of each recall order for consonant recall and spatial location recall are shown in Table 4.6.

4.8.3. Discussion: The serial recall of consonants is not affected by instructional bias in this experiment and is at a level comparable to that found in Experiment 4.3.

There is, however, some subtle and inconsistent effects on visuo-spatial memory performance. In the horizontal errors analysis it is clear that a bias towards processing the consonant load preferentially results in an increase in location memory errors but only when the consonant preload is recalled first. If the means of the appropriate conditions in Experiments 4.3. and 4.6. are compared (these are retabulated in Table 4.7) then it can be seen that this is due to an increase in errors in Experiment 4.6. when letters are recalled first (as opposed to a reduction when locations are recalled first).

HORIZONTAL ERRORS

No Bias.		Spatial Bias.		Verbal Bias.	
Recall Order.					
Letters first.	Locations first.	Letters first.	Locations first.	Letters first.	Locations first.
4.75	3.97	3.92	4.17	5.61	3.14

VERTICAL ERRORS

No Bias.		Spatial Bias.		Verbal Bias.	
Recall Order.					
Letters first.	Locations first.	Letters first.	Locations first.	Letters first.	Locations first.
4.50	2.78	4.36	2.92	4.00	3.39

Table 4.7. Visuo-spatial memory errors from experiments 4.3. and 4.6. (conditions from Experiment 4.3. are designated as no bias).

This effect is not present in the vertical errors analysis. In this analysis there is an effect of preferentially recalling visuo-spatial information. This replicates the results of Experiment 4.3. Of greater interest is the lack of an effect of the verbal bias. In this condition the results of Experiment 4.3. are not replicated. In the earlier experiment a significant difference was found with less statistical power. The locus of the effect here, then, (Experiment 4.6.) seems to be due to an increase in visuo-spatial errors with a verbal bias when locations are recalled first but a reduction in errors when letters are recalled first.

The effects found in Experiment 4.6. are complex and not clear cut. Only one generality is possible and that is that the instructions to preferentially process visuo-spatial information are ineffective.

It is the case that Ss either do not comply with instructions because the instruction manipulation was not sufficiently emphasised to S or they are unable to comply with these instructions (perhaps because Ss do not have appropriate metamemorial skills in experiments of relatively brief duration). Ss were certainly aware of the instructional bias as it was reiterated before each trial. The obvious conclusion is that this is an insensitive manipulation at least in the short term.

In the horizontal errors analysis the effect of verbal bias is intuitively plausible. When everything possible is loaded in favour of verbal processing (biased instructions and recall of consonants first) a clear visuo-spatial memory deficit is found and this seems to be largely the result of a retrieval strategy.

The vertical errors analysis however presents a more complex picture. Again comparing the means with those found in Experiment 4.3. there is only a very small difference between no bias instructions and verbal bias instructions thus the most parsimonious explanation seems to be that Ss in these experiments use a verbal processing bias and instructions to use a spatial processing bias does not abort such a bias but reduces it without a beneficial effect on visuo-spatial processing.

4.9. Experiment 4.7.

The final experiment in this chapter replicates Experiment 4.4. with instructional bias. In that experiment a verbal load presented after the visuo-spatial task had no effect on visuo-spatial processing but recalling the locations first impaired the serial recall of consonants. Experiment 4.7. examines whether instructional bias will modify these effects.

4.9.1. METHOD

4.9.1.1. Subjects: 12 Durham University undergraduates volunteered for this experiment. None of these Ss had participated in any of the earlier experiments.

4.9.1.2. Procedure: The procedure was exactly similar to that used in Experiment 4.6. except that the consonant load was presented after the visuo-spatial memory task. In all respects, except for the instructional bias and the lack of trials without a verbal memory load, this experiment was a replication of Experiment 4.4.

4.9.2. Results.

4.9.2.1. Recall of Consonants: A repeated measures, 2 factor, analysis of variance was performed on the data with Instructional bias and Recall order as the two factors. There was no effect of instructional bias $(F(1,11<)1)$ or order of recall $(F(1,11)=2.83, p>.05)$ and there was no interaction $(F(1,11)<1)$.

4.9.2.2. Recall of Spatial Locations: Separate repeated measures, 2 factors, analyses of variance were performed on horizontal and vertical errors with Instructional bias and Recall order as the two factors.

In the horizontal errors analysis there was no main effect of instructions $(F(1,11)=2.94, p>.05)$ or order of recall $(F(1,11)<1)$ and no interaction $(F(1,11)<1)$. All comparisons in the vertical errors analysis had 1 and 11 degrees of freedom and all computer F values were less than 1 except for the interaction $(F=3.02)$ which failed to reach significance $(p>.05)$. The means and standard deviations are reported in Table 4.8.

Serial recall of consonants.

Mean no. correct per trial (standard deviations in brackets).

Spatial Bias.		Verbal Bias.	
Letters 1st	Locations 1st	Letters 1st	Locations 1st
4.78 (0.78)	4.50 (1.01)	5.06 (0.84)	4.53 (0.89)

Horizontal Spatial errors.

Mean no. of errors per trial
(standard deviations in brackets).

Recall Order.

Spatial Bias.		Verbal Bias.	
Letters 1st	Locations 1st	Letters 1st	Locations 1st
3.33 (1.48)	3.00 (1.06)	3.89 (1.06)	3.78 (2.03)

Vertical Spatial errors.

Mean no. of errors per trial
(standard deviations in brackets).

Recall Order.

Spatial Bias.		Verbal Bias.	
Letters 1st	Locations 1st	Letters 1st	Locations 1st
3.83 (1.57)	3.06 (1.16)	3.50 (1.56)	4.00 (1.57)

Table 4.8. Errors of spatial location recall with verbal postload and strategy manipulation.

4.9.3. Discussion: The results of this experiment replicate the finding in Experiment 4.4. that a verbal load presented after the visuo-spatial task does not significantly impair accuracy of visuo-spatial memory recall. Instructional bias clearly has no effect in this experiment except perhaps to remove the subtle difference in serial recall of consonants performance found in Experiment 4.4.

It would seem that the development of a verbal processing strategy is not beneficial in this experiment (perhaps because performance on the verbal task approaches a 'ceiling') because this experiment does not seriously overload the memory system. The temporal location within a trial of the verbal load is the crucial factor in the efficacy of particular strategies. It is assumed that the central executive is responsible for effective development and execution of strategies and, if this is the case, then these experiments demonstrate that central executive attentional capacity is crucial to efficient memory performance especially at the encoding and retrieval stage but is less important for the maintenance of visuo-spatial material than for a verbal load.

Verbal and visuo-spatial processing seem to be distinct modes of representation that require common central executive resources. The central executive is crucially important at encoding and retrieval and the results of these experiments are consistent with the view that the executive offloads memory loads into appropriate slave systems once it has encoded the information. Thus visuo-spatial representations and representations of verbal material seem to require central executive capacity initially and at retrieval but the slave systems themselves do not make heavy demands on central capacity during maintenance rehearsal.

One would expect maintenance rehearsal to be disrupted only if the slave system deployed were given additional tasks to perform. Tracking does not seem to require the visuo-spatial scratch pad but does impair off-loading on to the scratch pad. Articulatory suppression is another matter altogether. This task seems to be disruptive by 'filling' the loop rather than by using significant amounts of central capacity. Thus the lack of an effect of articulatory suppression on visuo-spatial processing is compelling evidence for separating the slave systems into functionally specific devices.

The strategy manipulation experiments suggest that subjects give priority to processing verbal information and this may reflect a cognitive style that is too deeply ingrained to be overcome in brief experiments. The Kearins (1981) study, discussed in Chapter 3, provided compelling evidence for culturally based biases towards preferred modes of processing even when these are inappropriate. Thus the failure of Experiments 4.6 and 4.7. to induce Ss to adopt a spatial processing bias may arise as a result of conflict with Ss preferred cognitive style rather than as an effect reflecting the structure of the processor(s). A cross cultural replication of these experiments would be necessary to establish or refute this claim.

A picture emerges of a system that strategically controls the resources available to it and reacts flexibility to changing demands on its capacity. A verbal preload requires a lot of central capacity initially and some of this must be 'dumped' into the articulatory loop if the central executive is to process visuo-spatial material. The system seems to do this quite effectively before visuo-spatial encoding requires central capacity. However disruption of visuo-spatial representation can occur at retrieval following the retrieval of consonants.

It was pointed out that one would expect that recalling the consonants first should free central capacity for recalling the locations but it is the act of recalling consonants that produces the small but reliable deficit in spatial performance. The obvious explanation of this is that the central executive is required to maintain visuo-spatial representations and the recall of verbal information disrupts this. The effects of writing down the consonants might, for example, be analogous to the disruption observed with pointing in Brooks (1968) study. If this were the case then Moar box tracking after spatial encoding should also be disruptive and this is clearly not the case (Experiment 4.2.). Another possibility is that retrieval of verbal material expends attentional effort (Kahneman, 1973) and depletes central resources before recall of the visuo-spatial material. This explanation is also untenable because one would expect to find a similar effect when the verbal load is presented after the spatial load.

It was argued in the discussion section of Experiment 4.4 (4.6.3.) that rapid consolidation of the verbal material would be advantageous because a spatial load was imminent and verbal recall delayed considerably when the consonants were presented before the spatial load. This might well 'prime' the system to verbal processing with no effect on spatial encoding but result in a carry-over effect expressed at retrieval so that the system is still primed to recall verbal material (which is recalled rapidly) when spatial recall is required. This priming would have to be activated by verbal recall to explain these results rather than being solely contingent on priming associated with encoding verbal material first. Post hoc explanations of this kind are obviously unsatisfactory and speculative but these results are counter-intuitive and replicated in Experiment 4.6. at least in the condition with verbal bias instructions.

Instructions to use a spatial bias seem to tax the metamemorial skills of the subjects and thereby produce confusing results. Perhaps the system could be primed to process spatial information but requires a considerable change in Ss habitual cognitive style.

Hellige et al (1979) have shown priming effects for the right visual field with verbal preloads but a corresponding priming effect in the left visual field has so far proved elusive (Lambert, 1981). This is consistent with the findings of Experiments 4.3. and 4.6. but does not provide strong grounds for asserting that priming occurs in the verbal processing domain in these experiments.

4.10. Conclusion

In summary, it has been shown that the visuo-spatial scratch pad requires central executive resources at encoding and its deployment is restricted by concurrent tracking and verbal memory loads although the effects of a verbal memory load are complex and of a small magnitude. Furthermore maintenance rehearsal of visuo-spatial representations does not seem to require a heavy central executive commitment nor are these representations subject to decay over at least 20 seconds.

Experiments 4.6. and 4.7. suggest that subjects cannot develop a strategy of processing visuo-spatial information rather than verbal information. A more longitudinal study may show this conclusion to be false. Chapter 5 presents evidence that dual coding (Paivio, 1971) occurs and that this involves the assembly of simple working memory constellations. This concept is developed more fully in Chapter 7. The experiments in Chapter 5 examine the effects of concurrent tasks on two highly modified versions of the visuo-spatial task introduced in Experiment 3.1. These tasks were developed to be verbally recodable and they should, therefore, be subject to a wider range of interference effects than non-verbal tasks. In particular, it is hypothesised that articulatory suppression will produce memory performance decrements with the modified tasks. A study is also included that examines whether visuo-spatial encoding can be avoided by specifically instructing subjects to form verbal representations.

Chapter 5.

Integrating the Articulatory Loop and the Visuo-spatial Scratch Pad in Visuo-spatial Processing.

5.1. Summary

Three experiments are reported. The results of these studies suggest that subjects use 'dual-coding' which involves the deployment of simple working memory constellations to perform tasks that have both verbal and visuo-spatial components. Such dual-coding is subject to a wider range of interference effects than encoding within a particular processing domain (e.g. 'the verbal domain' or 'the spatial domain'). Thus while Paivio has contended that dual-coding leads to better performance it should be noted that this is probably only the case when the central executive is not preoccupied.

5.2. Introduction.

Paivio (1971) argued that many of the stimuli used in memory experiments could be encoded both verbally and imaginally. His 'dual encoding' hypothesis suggested that dual representation would lead to better recall than either imaginal or verbal representation. Such dual representation, in short-term memory, would involve the assembly of a constellation consisting of the articulatory loop, the scratch pad and the central executive. However highly verbal material would probably not require the scratch pad unless the subject chose to form images and it was demonstrated in Chapter 3 that spatial information can be encoded without using the loop. Thus it would seem that imaginal representations do not require that a verbal representation is formed also. These representations may well be formed in parallel.

It appears that the scratch pad is used to encode spatial information but considerable care is necessary to prevent verbal recoding. The experiments reported in Chapter 3 involved precautions to prevent this. Experiments 5.1 - 5.3 employ stimulus materials that are not constrained in this way in an attempt to encourage verbal recoding of nominally spatial information. Indeed Experiment 6.3. has demand characteristics that make both verbal and spatial properties of the stimuli very salient.

These experiments attempt to encourage the deployment of simple constellations which should be subject to interference from both spatial and verbal tasks. For this to be interesting the primary memory tasks, however, should resemble the tasks used in the earlier experiments because a double dissociation was not obtained in those experiments and it is also desirable to identify the conditions under which verbal recoding will occur.

5.3. Experiment 5.1

Experiment 5.1. requires subject to encode spatial locations that are presented in grids. These grid locations can be accurately specified by verbal descriptions and the materials are present for a sufficient duration to facilitate this.

5.3.1. METHOD

5.3.1.1. Subjects. 48 Durham University Undergraduates participated in this experiment during 1st year practical classes. Some of these subjects had also participated in Experiment 3.1. and Experiment 3.2. Experiment 5.1 was run approximately three months before these experiments.

5.3.1.2. Materials. A series of 4 x 4 grids were prepared, photographed and mounted on slides. These were subsequently video taped in a manner analogous to the method employed in Experiment 3.1. Half of these slides had a large dot assigned randomly to six of the locations. The other slides had eight randomly assigned dots.

5.3.1.3. Procedure. Subjects observed 16 4 x 4 grids (after two practice trials with the appropriate concurrent task), eight with 6 locations filled and eight with 8 locations filled. The grids were visible for 10 seconds (and preceded by a warning tone) and subjects were allowed 20 seconds to indicate the dot locations on a recall sheet of blank grids (a pilot study indicated that this was a more than adequate recall period). It was emphasised to subjects that they must make the appropriate number of responses i.e. six on 6 locations filled trials and eight on 8 locations filled trials. Within a trial all locations were presented simultaneously.

This experiment had two between-subject conditions. Half the subjects were instructed to use articulatory suppression on half of the trials. The remaining subjects were run on a different day and had to perform a visual tracking task on half the trials. 6 and 8 locations trials were pseudo-randomised i.e. within any block of four trials two of them had 6 locations filled and two had 8 locations filled. Each block was designated, on the recall sheet, as either "Control" or "Task" with half the subjects in each group receiving the order control/task/control/task and the other half receiving task/control/task/control instructions.

After each block of trials the subjects were reminded that they should change conditions and they indicated to assistants present that they understood this. Furthermore the experimenter indicated before each trial commenced the number of stimuli that would be presented and this was also indicated on the recall sheet. All subjects observed exactly the same trials in the same order.

5.3.1.3.1. Articulatory Suppression. On the articulatory suppression trials subjects were requested to "count under your breath" rapidly while performing the memory task. Counting commenced 1 second before the presentation of the grid and continued for 0.5 seconds afterwards. The experimenter emphasised the importance of complying with the instructions to count and subjects were given practice doing this aloud until a count of at least 20 was achieved. Subjects were not told to count to 20. They were told to count throughout the appropriate trials and the practice period was merely used to indicate the required rate.

5.3.1.3.2. Visual Tracking. Two horizontal arrays of dots presented above and below the grid were used as an outline of a sine wave (in the configuration shown in Figure 3.1.). Subjects were required to track this at an even pace with their eye movements (up/down in a left to right direction) throughout the appropriate trial presentations. They were given practice at doing this (by following the Experimenter's finger as in Experiment 3.1) until all subjects reported that they had achieved a suitable tempo to complete this 3 times within a trial. They began this 1 second before the grid was presented and continued for 0.5 seconds after presentation (a total of 11.5 seconds). It was stressed that they should continue to do this to the end of the trial even if they had done it 3 times. All subjects reported that this did not prevent them from perceiving the grid.

Subjects were not told the purpose of the experiment until it was over. The visual angle of the displays was not controlled nor was there any objective measurement of concurrent activity performance. This was not possible with large group presentation.

5.3.1.4. Scoring. The number of locations correctly recalled each on trial were transformed into percentage correct values.

5.3.2. Results. Inspection of the means of the control conditions performance (see Table 5.1) indicated that a ceiling effect may be present for both 6 and 8 locations trials thus comparisons between these trials may not be meaningful. Separate analyses of variance were therefore carried out on the 6 locations filled and the 8 locations filled data with type of concurrent task and control trials as a between subject factor. Control v Task performance was a within subject factor.

Mean % of locations correctly recalled (s.d. in brackets).			
6 locations filled trials.		8 locations filled trails.	
Control.	Concurrent task.	Control.	Concurrent task.
Articulatory Suppression Condition		Articulatory Suppression Condition	
92.19	86.50	93.36	80.51
(7.61)	(7.90)	(7.22)	(9.49)
Tracking Condition		Tracking Condition	
90.97	73.09	89.20	72.79
(10.97)	(16.25)	(9.97)	(16.68)

Table 5.1. The effect of concurrent activity on memory for 6 and 8 locations in a 4 x 4 grid.

The control trials of the two groups were compared using independent samples t-tests (46 degrees of freedom) with separate analyses for 6 and 8 locations. For 6 locations filled $t=0.45$, $p>.05$ and for 8 locations filled $t=1.66$, $p>.05$. Thus the two groups did not differ on control trial performance

Analysis of variance on the 6 locations data demonstrated main effects of conditions (the between subject factor - $F(1,46) = 7.05$, $p<.025$) and concurrent activity ($F(1,46) = 47.38$, $p<.001$). The interaction was also significant ($F(1,46) = 12.69$, $p<.001$).

These results indicate that with 6 locations filled subjects do not differ on control trial performance but both concurrent tasks produce a decrement and this decrement is greater with tracking than with articulatory suppression.

With 8 locations filled there were main effects of condition ($F(1,46) = 4.70$, $p<.05$) and concurrent tasks ($F(1,46 = 64.89$, $p<.0001$) but no interaction ($F(1,46)<1$). The results of this analysis largely replicates the previous analysis except that articulation and tracking produce similar performance decrements. The mean % correctly recalled are presented in Table 5.1.

5.3.3. Discussion. These results clearly suggest that verbal recoding is attempted by the subjects in this experiment. Given the results of Experiments 3.1 and 3.2 there is no reason to expect that articulatory suppression should have an effect unless this was the case.

The grid can be used to generate verbal descriptions. One could, for example, label the locations numerically. A 4 x 4 grid can be given values of 1-16 with each number identifying a location. In the earlier experiments such a strategy would have led to accurate performance only if one numbered from 1-81. This is an unlikely strategy because such a description would take some time to generate; it would be subject to the effects of articulatory suppression and the subject would need to know that 81 locations were used.

Using grids, it seems that 'dual coding' does occur and this might lead to better memory performance but it is also the case that such representations are subject to a wider range of interference effects.

5.4. Experiment 5.2

If dual coding is not obligatory then it should be possible to use a strategy that will not be subject to a specific type of interference. Experiment 5.2 replicated the visual tracking condition used in Experiment 5.1 but subjects were given instructions to use strategies specified by the experimenter. If the mnemonic specified by the experimenter was effective then one would expect that instructions to verbally encode material should result in less errors with tracking than with instructions to imaginally encode the locations. However this would only be true if dual-coding was parallel. If, initially, spatial encoding is necessary then tracking should pre-empt verbal recoding.

5.4.1. METHOD

5.4.1.1. Subjects. 60 Durham University Undergraduates participated in this experiment during 1st year practical classes. This experiment was run one year after Experiment 5.1 thus none of the subjects in this experiment participated in the earlier experiment.

5.4.1.2. Materials. The materials were identical to those used Experiment 6.1.

5.4.1.3. Procedure. Subjects were divided into three groups of twenty (in practice they were three separate practical classes). The smallest class had 20 members. Subjects were dropped at random from the other two groups to produce equal sample sizes. (The largest group had 24 members).

All subjects received exactly the same trials as those used in Experiment 5.1. but only one concurrent task was used. All subjects performed the visual tracking task on half the trials Thus half the subjects within a group received blocks of 4 trials (2 with 8 locations filled; 2 with 6 locations filled) in the order - control/tracking/control/tracking and half received the order - tracking/control/tracking/control.

Three groups were used because each group received different instructions. The group run on the first day of the experiment received no instructions about the type of encoding strategy that they should use. The second group received instructions to verbally encode the material while the third group were told to form visual images of the material.

5.4.1.3.1. Verbal Encoding Instructions. Subjects were told that a major problem in memory research is that subjects tend to remember things in rather idiosyncratic ways. To overcome this, they were told, it is necessary for everyone to use the same method of memorisation and it was stressed that the only way to do this was for them to be instructed in the use of a specific memory technique. These instructions were also given to the imaginal encoding group.

The technique employed was to require the subjects to remember the vertical columns as columns 1-4. Each of these, it was argued, has four possible values so that the top right location in the grid, for example, can be remembered as 1;4. Slides were shown of grids and they practised naming them in this way. Furthermore they were required to respond by placing the correct number in the appropriate position in the horizontal plane e.g. a 4 in the last position in the top row to represent the top right hand corner (in all other conditions and in the previous experiment subjects had responded with crosses). Tracking instructions etc. were also given in the same manner as in Experiment 5.1.

5.4.1.3.2. Imaginal Encoding Instructions. In this condition subjects were given a brief lecture on 'Gestalt

Psychology'. They were told that a good way of memorising some things was to form an image of them. It was stressed that such an image should be a pattern not a series of separate images. Slides were shown of grids and each of these was then replaced by an identical slide without a grid but with the pattern formed by the locations still present. They were told that the shape created by the dot pattern could be memorised as a single pattern. Gestaltists, it was argued, suggested that the integrated whole was more than the mere sum of the parts and that this was particularly true of images (at the end of the practical they were told that there were other reasons why a pattern might be more memorable). It was stressed that verbal encoding was not a good way to perform this task because we wished to examine memory for 'pictures in the head'. Subjects responded by indicating the locations presented in the grids using crosses. Subjects drew several of these demonstration patterns on blank paper before the experiment began. They were also given instructions on tracking etc.

In both the instructional bias conditions the instructions were presented rather informally i.e. subjects were encouraged to ask questions while the experimenter was instructing them and no technical terms were used. More elaborate explanations were provided at debriefing (largely to give a more balanced account of psychological thought on encoding strategies). The same scoring method as in Experiment 5.1 was used. If an incorrect number was placed in the correct location this was scored as an error.

5.4.2. Results. Separate analyses of variance were performed on the 6 and 8 locations data with concurrent task as a within subject factor and type of instruction as a between subject factor. The mean % correctly recalled are presented in Table 5.2.

Mean % of locations correctly recalled (s.d. in brackets).			
6 locations filled.		8 locations filled.	
No tracking.	Tracking.	No Tracking.	Tracking.
	NO BIAS		
90.62	71.87	89.53	70.32
(11.38)	(17.51)	(10.79)	(16.95)
	VERBAL BIAS		
92.08	76.25	88.28	76.10
(6.74)	(10.57)	(10.43)	(10.73)
	IMAGERY BIAS		
90.21	72.29	85.32	73.44
(9.10)	(19.04)	(9.30)	(12.56)

Table 5.2. The effect of instructional bias on recall of location information in a 4 x 4 grid.

There was no significant effect of instruction in either analysis (F(2,57)<1). In the 6 locations analysis there was a massive effect of concurrent activity (F(1,57) = 67.59, p<.0001) but no interaction (F(2,57)<1). A similar massive effect of tracking was found in the 8 locations analysis

$(F(1,57) = 53.70, p<.0001)$ and again there was no interaction $(F(2,57) = 2.97, p>.05)$.

5.4.3. Discussion.

The effect of visual tracking on memory for locations was replicated in this experiment. However the introduction of an instructional bias had no observable effect. Attempts to induce preferential encoding in Experiments 4.6. and 4.7. also proved fruitless.

Clearly one can improve 'memory' performance. Guides to "Improve your memory" usually offer a range of mnemonic devices which lead to improved organisation and a number of expert mnemonists have revealed their encoding strategies (see Neisser, 1982). Furthermore there is evidence that it is possible to teach memory skills to children and the mentally retarded (see Chapter 7).

Why, then, have these experiments failed to demonstrate improved performance with instruction? The possibility that the subjects simply lack appropriate metacognitive skills or tend to ignore the experimenters instructions have already been discussed. However a number of other possibilities are also tenable.

Most mnemonic devices are designed for remembering verbal material (even the method of loci to some extent) and it is possible that verbal material is more easily reorganised and conceptually richer than spatial material.

This explanation is unlikely because it has been demonstrated (by the effect of articulatory suppression) that the location information is recoded. With control performance at ceiling, even with eight locations to remember, one would expect no effect of instruction but one might expect that instructional bias would improve performance with concurrent tracking especially when a verbal bias was used. One can argue, of course, that representation, initially requires the scratch pad before verbal recoding can commence and that the tracking impairs this initial representation. This explanation is plausible and needs to be considered in conjunction with another possibility. It was argued that central executive monitoring is essential to the use of slave systems. If the executive is occupied with tracking then it cannot oversee control processes. It is therefore not possible for the subjects to adopt a processing bias with concurrent tracking.

It is unfortunate, then, that control performance was at ceiling because instructional bias might only be effective on control trials. This ceiling effect was largely unavoidable. Eight locations provides the maximum memory load in a 4 x 4 grid (with more locations filled the subjects merely remember the lesser number of unfilled locations) and larger grids might not be verbally recoded.

One criticism of this experiment might be that the subjects cannot perceive the grids properly while tracking. This possibility was discussed in Chapter 3. The tracking task used in these experiments (5.1. - 5.3.) was easier (it was slower and less tracking was required) and the whole memory array was presented for the full ten seconds. Postgraduates used in a pilot study involving a wide range of visually presented materials (including those used in these experiments) reported that they experienced no perceptual impairment with this rate of tracking but some commented that rehearsal was difficult.

It is interesting to note that one subject in this experiment scored 100% on all trials. He was in the no instructional bias condition. The explanation he offered (which he volunteered without questioning by the experimenter) was that he merely recoded the locations into a binary code. He informed the experimenter that he could read morse code and that he had used this ability to tackle the problem. This of course is merely an informal demonstration of how one might overcome the effects of concurrent activity if one has a well learned mnemonic. Clearly individuals with such skills could contribute useful data, in the form of case studies, which might well shed some light on the flexibility of working memory. Unfortunately this student was unwilling to participate in further studies not required by course regulations thus this observation may be based on suspect data.

Experiments 5.1. and 5.2. demonstrate two points. Spatial information can be verbally recoded but only under certain circumstances (c.f. with the conditions described in Chapter 3) and it is difficult to form such representations while tracking.

5.5. Experiment 5.3

It has already been noted (Chapter 2) that tracking has general effects on memory performance. Thus it may not be an appropriate source of interference for a spatial memory task. However, it does seem to be the case that it has a specific effect on spatial processing in addition to its more general effects on cognitive processes. The final experiment in this chapter examines this by using materials which are highly verbal (consonants) but these are presented either left to right across the middle of a square (so that only the serial order and identity of the consonants is salient) or in eight locations in a 4 x 4 grid. This experiment 'bridges the gap' between the earlier experiments in this chapter which were ostensibly spatial in nature and the experiments to be reported in Chapter 6 which require only serial recall.

5.5.1. METHOD

5.5.1.1. Subjects. 39 Durham University undergraduates participated in this experiment during practical classes. This experiment was run one week after experiment 5.1 and subjects received a different concurrent task to the one that they had received the previous week. 13 subjects were assigned to each condition.

5.5.1.2. Materials and Procedure. All trials involved the presentation of eight lower case consonants (b f g h j k r z) randomised by serial position on half the trials. After two demonstration and two practice trials presented on television on monitors, subjects observed 16 experimental trials with a presentation duration of 10 seconds and a 20 second recall interval. Subjects were required to always make eight responses and they were provided with a list of the eight consonants. The same eight consonants were presented on every trial.

Eight of the experimental trials consisted of the simultaneous presentation of the eight consonants in random serial order, left to right , across the centre of a square in the horizontal place. These trials were randomly mixed with 8 trials in which the eight consonants were presented randomly in eight of the sixteen locations of a 4 x 4 grid which was the same size as the square used on serial recall trials. Subjects were required to serially recall the consonants or, where appropriate, to recall the consonants in the correct locations in blank 4 x 4 grids.

In addition concurrent tasks were introduced as a between subject factor. Thus one group of subjects tracked a visual sine-wave in a manner exactly similar to the tracking task used in Experiments 5.1. and 5.2. Another group, the control group, had no concurrent task and the third group were instructed to perform the articulatory suppression task employed in Experiment 5.1.

5.5.2. Results.

The means and standard deviations for the serial recall data are presented in Table 5.3. The mean number of consonants correctly recalled in the appropriate grid locations, with standard deviations in parentheses, was 37.23 (9.08) in the control condition, 26.46 (4.74) with articulatory suppression and 19.69 (8.58) with tracking. Separate analyses of variance were carried out on serially and spatially presented material.

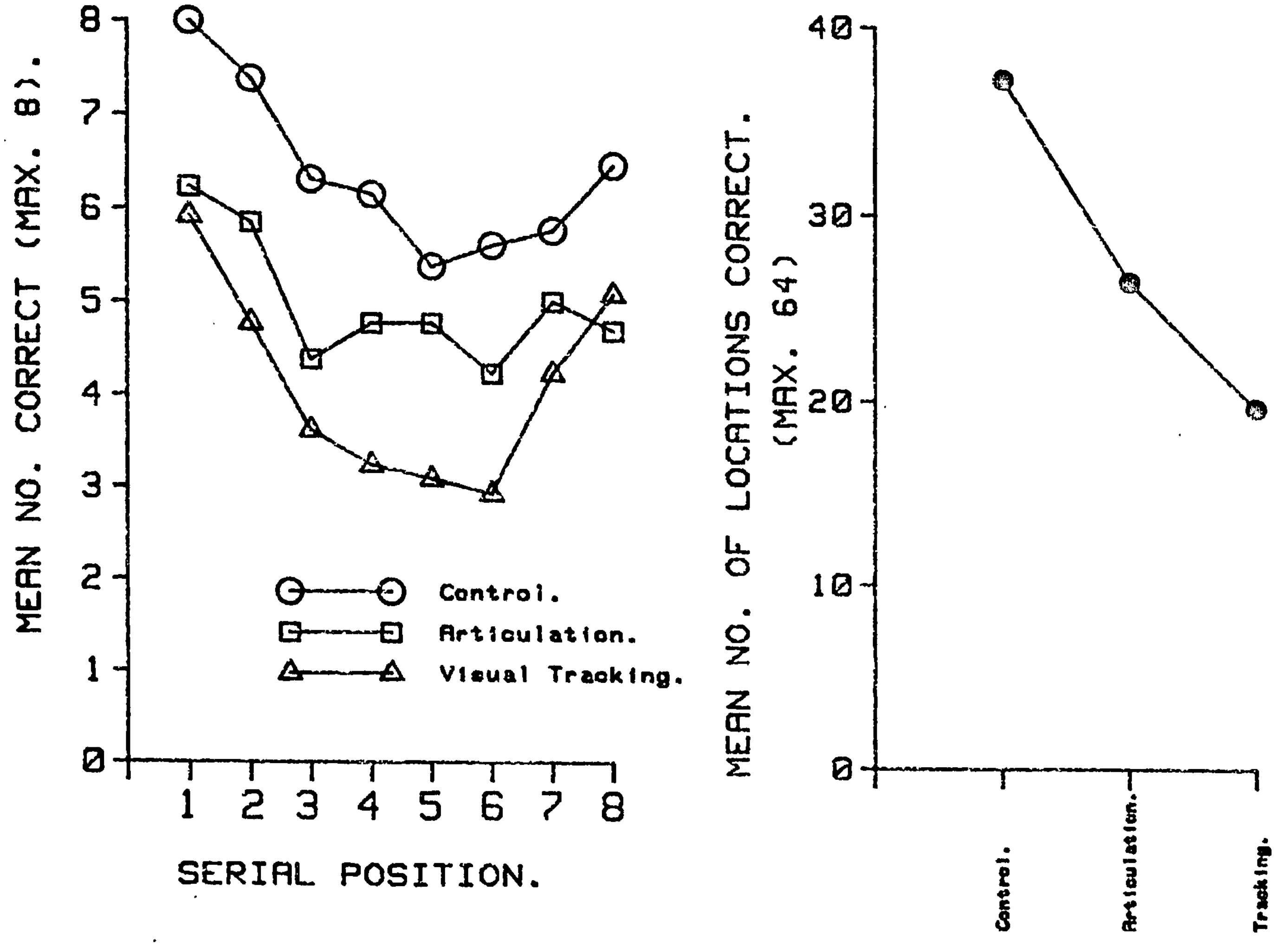
	Serial Position							
	1	2	3	4	5	6	7	8
Control condition	8.00 (0.0)	7.33 (0.65)	6.33 (1.44)	6.42 (1.77)	5.50 (1.61)	5.58 (1.66)	5.83 (1.24)	6.50 (1.13)
Articulatory suppression	6.23 (1.88)	5.85 (1.82)	4.38 (1.89)	4.77 (1.09)	4.77 (1.79)	4.23 (1.74)	5.00 (2.94)	4.69 (1.75)
Visual tracking	5.92 (2.06)	4.77 (2.28)	3.61 (1.56)	3.23 (1.54)	3.08 (1.50)	2.92 (1.55)	4.23 (1.54)	5.08 (1.75)

Table 5.3. The mean number correct for serial recall trials (max. = 8, n = 13 for each condition, standard deviations are shown in brackets).

A one-way analysis of variance (between-subjects) revealed a significant effect of concurrent task on number of correct letters assigned to correct locations ($F(2,36) = 17.09$, $p<.001$). An independent t-test comparing trials with articulatory suppression and sine wave tracking revealed a significantly greater decrement resulting from sine-wave tracking (t,24 d.f. $= 2.39$, $p<.05$).

For serial recall trials analysis serial position was blocked (positions 1-4 and 5-8) as a within subject factor with concurrent task as a between subject factor. There was a large main effect of concurrent task (F(2,36) = 13.69, p<.001) and serial position (F(1,39) = 11.85, p<.001) but the serial position x concurrent task interaction failed to reach significance (F(2,39) = < 1). t-tests revealed that there was no difference between articulatory suppression and sine-wave tracking at positions 1-4 (t, 24 d.f. = 1.53, p>.05) and positions 5-8 (t, 24 d.f. = 1.16, p>.05). All comparisons of appropriate control trials with concurrent task trials were significant (the comparison of positions 5-8 for articulatory suppression and control trials was significant at the 5% level. All other comparisons were significant at the 1% level). The data for spatial and serial recall are plotted in Figure 5.1.

FIGURE 5.1. THE EFFECT OF CONCURRENT ACTIVITY ON SERIAL AND LOCATIONAL RECALL OF VISUALLY PRESENTED CONSONANTS.



5.5.3. Discussion.

It was hoped that a double dissociation would be obtained i.e. that articulatory suppression would have a greater effect than tracking on serial recall and that the converse would be true with locational recall. Clearly, however, there is a greater effect of tracking on the more spatial task. Whether this is due to a specific effect of tracking on spatial processing or simply a result of tracking specifically impairing very difficult cognitive tasks is not clear. This issue is tackled in Chapter 6 when the effects of tracking on a range of memory tasks is examined.

Some simple generalisations are possible. Performance on this grid task is very poor. This suggests that verbal recoding has been attempted as purely visuo-spatial representation, in the control condition, should require little encoding time (Avon and Phillips, 1980) and memory for eight locations does not seriously overload the system (Experiment 5.1.). One could of course argue that imaginal representation of quite complex shapes (lower case letters) requires a large amount of scratch pad capacity.

However if a purely visuo-spatial representation were maintained it is difficult to see why there should be an effect of articulatory suppression given the results of Experiment 3.2. The effect of articulatory suppression is compelling evidence that at least some verbal recoding takes place and, furthermore, that there is less effective recoding with grid presentation than with a simple horizontal string of consonants (given that tracking and articulation are equally disruptive with the latter type of presentation).

5.6. General Discussion.

It appears then, to recap, that the tasks employed in Experiments 5.1 - 5.3 require a working memory constellation consisting of the central executive, the articulatory loop and the visuo-spatial scratch pad. However, it has not been demonstrated that tracking tasks interfere specifically with spatial processing although this has been asserted in the literature (e.g. by Oakhill and Johnson-Laird, 1984). Before one can postulate the necessity for a scratch pad the above assertion must be demonstrated empirically. An alternative explanation is that visuo-spatial encoding takes place in the central executive store.

If this is the case then it is clear from Experiment 4.2. that maintenance rehearsal of such material is not a function of the executive. Thus there is a prima facie case for postulating a scratch pad but this case is weakened by the failure to clearly show a specific effect of tracking on visuo-spatial representations.

The model of working memory to be outlined in Chapter 7 postulates that the slave systems are tightly coupled to the executive during encoding thus it should be difficult to 'corner' a slave system operating independently. Given that there is likely to be this difficulty, as one would expect with a functionally integrated system, the experiments in Chapter 6 attempt to interfere with the critical processing phase i.e. the component of processing concerned with transfer to the scratch pad.

Chapter 6.

Integrating the Articulatory Loop and the Visuo-spatial Scratch Pad in Verbal Processing.

6.1. Summary

Three experiments are reported. Experiment 6.1. examines the effects of visual and Moar box tracking on serial recall of auditorily presented consonants. The tracking tasks produced deficits comparable to those found with concurrent articulation. This experiment was replicated in the visual modality. No effect of tracking was found. However in Experiment 6.3. tracking was found to specifically disrupt memory for the 'recency' items when items were presented visually with visuo-spatial grouping. These results suggest that 'tracking' requires central executive resources and this limits the control processes available for performing the primary task. Furthermore, tracking disrupts a spatial monitoring device that is coupled to spatial working memory.

6.2. Introduction

The purpose of this chapter is two-fold. The first experiment examines the effects of the interference tasks used in the earlier experiments on a 'traditional' memory task. The task used is auditory presentation of consonants with subsequent serial recall. If the effects of tracking are not 'general' i.e. if the interference is purely specific to visuo-spatial processing then there should be little or no interference with this task which is neither visual not highly spatial. Secondly, if there is an effect of tracking, this experiment should allow a comparison of the degree of general interference relative to the specific interference of articulatory suppression. This would reinforce the findings of Experiment 5.1. which suggests that the articulatory suppression task employed did not simply fail to have an effect in the experiments reported in Chapter 3 because it was 'easier' than the tracking tasks. An effect of visual tracking would also further support the contention that tracking a visually presented sine-wave does not merely created perceptual problems.

The last two experiments address the problem of selectively interfering with the functioning of the scratch pad without confounding this with central executive control impairment.

6.3. Experiment 6.1.

6.3.1. METHOD

6.3.1.1. Subjects. 9 Durham University undergraduates volunteered to participate in this experiment.

6.3.1.2. Materials and Procedure

34 lists of 9 consonants were prepared by randomly selecting, without replacement within a list, from a population of 12 consonants (BFGHJKLQRVYZ).

These lists were recorded onto audio tape at a rate of 1 per second. Each list was preceded by a tone 1 second before the first consonant. Another tone was also heard 0.5 seconds after the presentation of the final consonant. The first two lists were used as demonstration examples and the remainder were blocked into four blocks of 8 lists with the first two of each block being used as practice trials.

The conditions were Visual Sinewave Tracking, Moar Box tracking, Articulatory Suppression and Control. The presentation order of these conditions was randomised in blocks for each subject. Subjects were run individually. This was a completely within-subject design. In the control condition subjects had no interference activity. Articulatory suppression consisted of silently counting from 300 upwards and the same tracking criterion as that employed in Experiment 3.3 was used in the Moar Box Tracking condition. The Moar box was concealed from visual inspection.

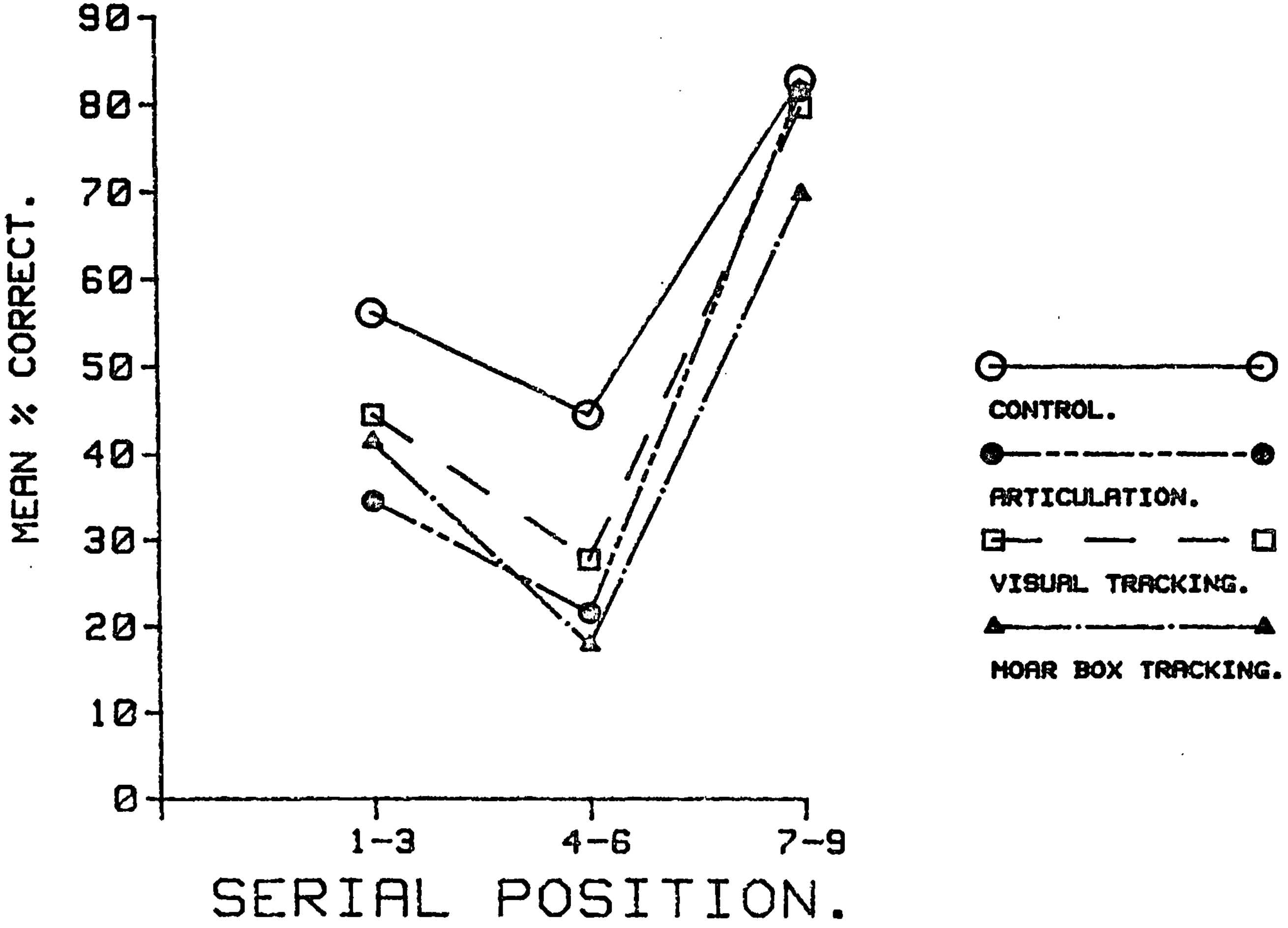
The visual sine-wave tracking task was modified. As subjects did not have to attend to any other visual source the sine-wave was presented on a B.B.C. B microcomputer. The computer plotted this on a V.D.U. It created 3 peaks and then cleared the screen before beginning again at the origin on the left of the screen. The tempo was such that it did this 3 times during a trial. Subjects rested their heads on a chin rest during trials to facilitate video tape recording of their eye movements. The audio tape recorder output was also recorded onto the video tape to indicate when trials were in progress. The sine-wave subtended a visual angle of approximately 5 degrees in the horizontal plane.

All concurrent task conditions were practiced to criterion before the experiment began and subjects were required to serially recall the consonants. The only recall constraint was that they should assign the consonants to their correct serial position (so, for example, they were not prevented from recalling the last item first). Subjects were given a list of the 12 consonants used in this experiment but were told not to refer to this except during recall. The subjects indicated when they were ready for the next list.

6.3.2. Results.

The data was transformed into mean percentage correct scores and collapsed into 3 serial position blocks (1-3, 4-6 and 7-9). The data from each of these three serial position blocks was then subjected to one-way analysis of variance with condition as a within subject factor. These serial positions blocks were analysed separately because such an analysis is crucial in Experiments 6.2. and 6.3. which are, in some ways, formally equivalent to this experiment. The means and standard deviations of the data are shown in Table 6.1. and plotted in Figure 6.1.

FIGURE 5.1. THE EFFECTS OF CONCURRENT ACTIVITY ON SERIAL RECALL OF AUDITORILY PRESENTED CONSONANTS.



Mean % correct (s.d. in brackets).

	CONDITION			
Serial Position	Control	Visual Tracking	Moar Box Tracking	Articulation
1-3	56.17 (18.52)	44.44 (18.43)	41.36 (18.24)	34.57 (21.83)
4-6	44.45 (14.16)	27.78 (11.78)	17.90 (11.38)	21.60 (9.40)
7-9	82.72 (18.10)	79.63 (11.11)	69.75 (18.45)	81.48 (18.63)

Table 6.1. The effects of concurrent activity on serial recall of auditorily presented consonants.

6.3.2.1. Serial Position block 1-3.

The analysis of variance was significant (F(3,24) = 2.61, p<.05). This indicates that there is an effect of concurrent activity. Related samples t-tests were used to compare each concurrent task condition with the control trials. All comparisons had 8 degrees of freedom. There was a significant effect of articulatory suppression (t = 3.28, p<.025) and Moar Box tracking (t = 2.31, p<.05) but the effect of visual sine-wave tracking failed to reach significance (t = 1.29, p>.05). A further t-test indicated that there was no significant difference in performance between the Moar box tracking and articulatory suppression conditions (t = 0.91, p>.05).

6.3.2.2. Serial Position Block 4-6.

This analysis of variance was also significant ($F(3,24) = 10.69$, $p<.001$). Post hoc analysis revealed significant effects of articulatory suppression ($t = 4.14$, $p<.01$), Moar Box tracking ($t = 5.88$, $p<.001$) and visual sine-wave tracking ($t = 3.40$, $p<.01$).

6.3.2.3. Serial Position Block 7-9.

This analysis of variance failed to reach significance ($F(3,24) = 2.12$, $p>.05$).

6.3.3.6. Discussion.

It is clear from these results that tracking, especially Moar box tracking, has a profound effect on the serial encoding of auditorily presented consonants. Articulatory suppression also severely impairs performance. Interestingly, however, there is no reliable effect of concurrent activity on the recency portion of the recall curve(Richardson and Baddeley, 1975).

The effects of tracking at other serial positions suggests that executive control is necessary to maintain or, perhaps, to elaborate on the initial encoding which, in the first instance, seems to be quasi-perceptual. Furthermore the lack of an effect of articulatory suppression on recency suggests that the articulatory loop is not the mechanism responsible for the recency effect. One would expect that the loop would be used as a rapid output buffer given that its known properties make it ideal for such a purpose. (Morris and Jones, in press). It may be however that an alternative acoustic store is used. Crowder and Morton (1969) have postulated a Pre-categorical Acoustic Store (P.A.S.) that holds at least one item 'echoically' thus privileging a final item that is nevertheless subject to acoustic masking (see Frankish 1976 for an extensive review). If a similar store were operating in this experiment, however, it would have to hold more than one item.

However the main finding of this experiment was that the tracking tasks do indeed require executive resources and that they do not interfere with the recency portion of the recall curve. This suggests that 'recency', in this instance, is the product of an acoustic store that does not require executive monitoring unless, perhaps, the representation must be maintained for some time.

Is there a comparable visual store? The final two experiments examine the possibility that the visuo-spatial scratch pad under certain circumstances, can be used in an analogous way and that it too can operate independently of the executive. If this is the case then the scratch pad can hold verbal material by maintaining its morphological structure much as the loop can hold an articulated account of spatial information.

6.4. Experiment 6.2.

The next experiment is a replication of Experiment 6.1. in the visual modality. The visual sine-wave tracking condition was dropped from this experiment and Experiment 6.3. because it is clear that there would be perceptual problems with these tasks.

6.4.1. METHOD

6.4.1.1. Subjects. 9 Durham University undergraduates participated in this study. None of these subjects participated in Experiment 6.1.

6.4.1.2. Materials and Procedure.

24 lists of nine consonants were randomly selected from the 34 lists generated for Experiment 6.1. The lists were presented visually using a Sony V.T.R. The first 3 lists were practice trials and the remaining 21 lists were blocked into 3 blocks of 7 trials. On one block subjects performed the articulatory suppression task used in the last experiment. Another block was designated as the Moar Box tracking condition and the third block was the control condition. Moar box tracking was to the same criterion used previously. Subjects were run individually and condition order was randomised for each subject. As in the previous experiment training in the tasks was given and recall was constrained in an identical manner. Once again subjects had a list of the 12 consonants to refer to during recall.

The letters were presented on a V.D.U at the centre of the screen. Each letter was approximately 1/2 inches in height and the screen was located about 1 metre in front of the subject. The video tape recording was created by running a program on a B.B.C. micro-computer with a monochromatic video camera mounted in front of it. The consonants were presented at a rate of one per second and were preceded, on each trial, by a row of 'x's across the screen. This row of 'x's was accompanied by a tone indicating that a trial was beginning. No visual signal was given at the end of a trial to avoid masking but an auditory signal was presented. The consonants were upper case, all presented in the same location, and they each had a duration of 0.5 seconds with an interstimulus interval of a further 0.5 seconds.

Mean % correct (s.d. in brackets).

Serial Position	Control	Tracking	Articulation
1-3	50.80 (27.04)	51.85 (28.22)	36.51 (19.76)
4-6	38.10 (26.73)	33.86 (29.20)	10.05 (6.92)
7-9	55.03 (36.20)	39.68 (26.51)	29.30 (29.30)

Table 6.2. The effects of concurrent activity on the serial recall of visually presented consonants.

6.4.2. Results.

The data were transformed into mean percent correct scores and separate, repeated measures, analyses of variance were carried out on each serial position block. The means and standard deviations of the % correct scores are shown in Table 6.2. and plotted in Figure 6.2.

6.4.2.1. Serial Positions 1-3.

This analysis failed to reach significance ($F(2,16) = 2.48$, $p>.05$)

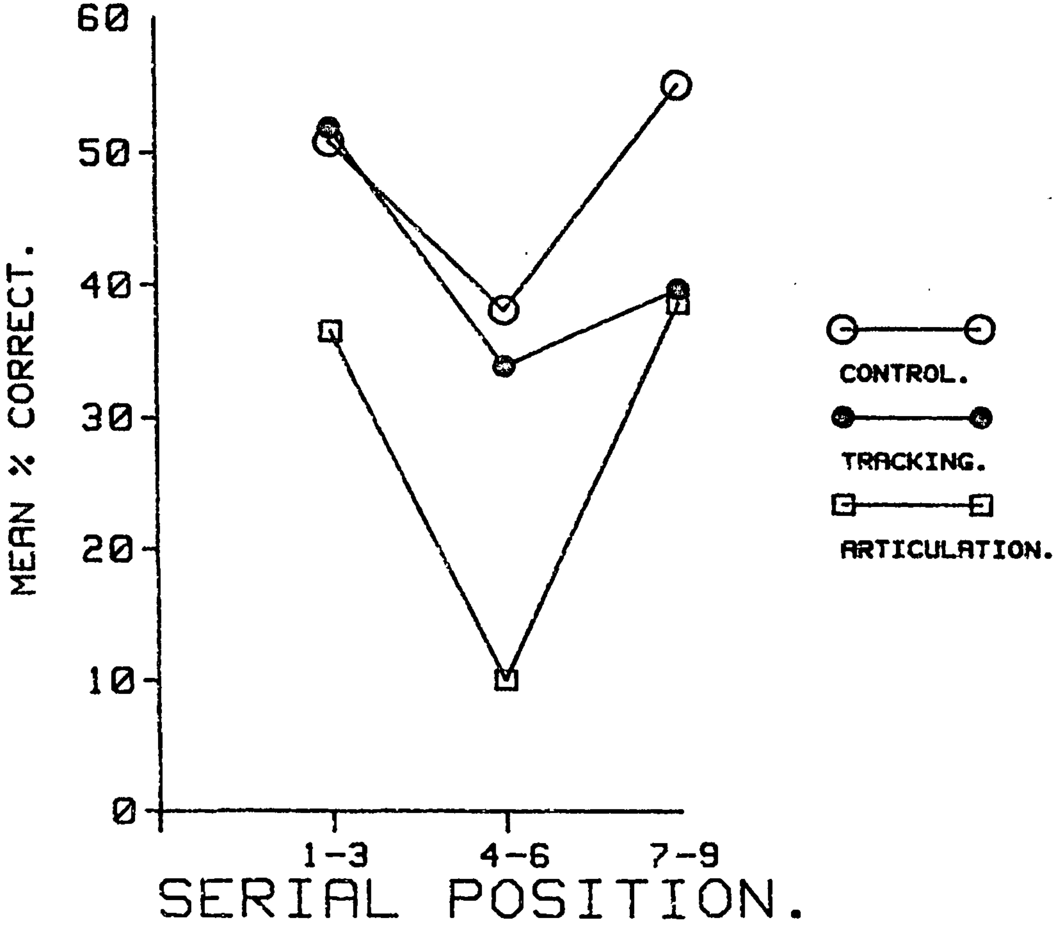
6.4.2.2. Serial Positions 4-6.

This analysis was significant at the 1% level ($F(2,16) = 8.71$). Related samples t-tests revealed that concurrent tracking did not impair performance relative to the control condition ($t(8) = 0.83$, $p>.05$) but articulatory suppression had a large effect ($t(8) = 3.62$, $p<.01$).

6.4.2.3. Serial Positions 7-9.

This analysis failed to reach significance ($F(2,16) = 2.67$, $p>.05$). This is surprising if one inspects Figure 6.2. However if one examines the standard deviations in Table 6.2. it is clear that there is massive variation in this data.

FIGURE 6.2. THE EFFECTS OF CONCURRENT ACTIVITY ON SERIAL RECALL OF VISUALLY PRESENTED CONSONANTS.



6.4.3. Discussion.

The results of this experiment are very different from those reported for Experiment 6.1. There is no effect of tracking and articulatory suppression only produces a decrement in the middle of the serial recall curve. Unless this result is artifactual then the data suggest that the effects of tracking may not be due purely to interference with visuo-spatial processing. However there are no general effects either. Tracking seems to interfere with control processes necessary to the processing of auditorily presented consonants but not to visually presented consonants.

This finding is counter-intuitive. There is no obvious reason why tracking should have an effect on memory for auditorily presented consonants but little effect on visually presented consonants. Indeed one would expect tracking to either interfere with both modalities (general interference) or selectively with the visual modality (by suppressing 'visualisation').

The large effect of articulatory suppression is consistent with Baddeley's contention that visually presented verbal material is phonemically recoded (Baddeley, Thomson and Buchanan, 1975). The results of Experiments 6.1. and 6.2. suggest that the visuo-spatial scratch pad is not deployed and that the articulatory loop is not responsible for the recency effect.

6.5. Experiment 6.3.

In an attempt to further investigate the effects of tracking on memory for visually presented material Experiment 6.2. was replicated with two changes. The consonants were presented at 3 different locations and these locations were either predictable or chosen at random. Thus on half the trials subjects knew where the next stimulus would appear and on the remaining trials three possible locations had to be monitored.

Experiment 5.3. demonstrated that the executive and probably the scratch pad were utilised when encoding the spatial location of consonants. This experiment examines the role of the scratch pad in using spatial information that does not have to be recalled. Indeed with random location presentation and temporal, serial recall encoding the spatial information would be detrimental to memory performance because the temporal and spatial properties of the display are not highly correlated. This is not the case with 'predictable' presentation.

Given the lack of an effect of any concurrent activity at serial positions 7-9 it seems unlikely that the executive is responsible for 'recency' effects. Recency, in these studies, seems to result from the use of retrieval strategies that are dependent on short-lived representations on sensory 'scratch pad type' stores that need little executive monitoring.

If the visuo-spatial scratch pad can be used in this way then the last three items should be well recalled in the predictable condition and subject to large interference effects in the random presentation condition (where they will be subjected to 'over writing'). Finally tracking should, in this experiment, have an effect on the recency portion of the curve because it has been argued (Chapter 3) that it interferes with the deployment of the scratch pad.

6.5.1. METHOD

6.5.1.1. Subjects. 10 Durham University undergraduates volunteered for this experiment. None of these subjects participated in Experiments 6.1. or 6.2.

6.5.1.2. Method and Procedure. This experiment was very similar to Experiment 6.2. but differed in a number of respects.

The number of trials (including practice trials) was increased to 36. Half of these trials were presented spatially grouped. This entailed presenting serial positions 1, 4 and 7 offset to the left of centre and serial positions 3, 6 and 9 offset to the right of centre so that presentation was left-centre-right, left-centre-right, left-centre-right. The relevant area of the display (the area in which consonants appeared) subtended a visual angle of approximately 5 degrees. The other 18 trials involved the presentation of consonants in the same three locations but the location of any given consonant was random (this randomisation was created by the computer) thus on half the trials the location of a consonant was predictable and on the other 18 trials the subject had to attend to all 3 locations to detect the stimulus. This was a completely within-subject design.

The duration of a stimulus was 0.5 seconds and the inter-stimulus interval (onset to onset) was 1 second. Trials were blocked so that 5 subjects received 18 predictable trials first and 5 subjects received 18 random trials first. Within these 2 blocks the trials were further randomised, for each subject, into 3 blocks of 6 trials (the first two trials of each of these blocks being designated practice trials). One block of trials in each condition (predictable/random) was designated as the control block. Subjects simply recalled the sequence by identifying the consonants in their correct temporal order. The other two blocks in each condition involved articulatory suppression and Moar box tracking. The concurrent activities were performed to the same criteria as those employed in Experiment 6.2. The concurrent activities were practiced before the experimental session commenced.

Stimuli were recorded on video tape and presented on a monochromatic V.D.U. The video tape was prepared by filming the display of a Hewlett-Packard 9816 micro-computer which was used to create the appropriate stimulus materials. The tapes subsequently had tones dubbed onto them at appropriate points to indicate the beginning and end of each trial. In all other respects the materials and procedure were identical to Experiment 6.1. Subjects were tested individually.

6.5.2. Results.

The data was collapsed into three serial position blocks (as in Experiments 6.1. and 6.2.) and a separate, repeated measures, analysis of variance was performed on each of the three blocks. There were two within subject factors - spatial predictability and concurrent task. Post hoc comparisons examined the effect of concurrent activities within each level of predictability. The means and standard deviations for mean % correct are presented in Table 6.3. and plotted in Figure 6.3.

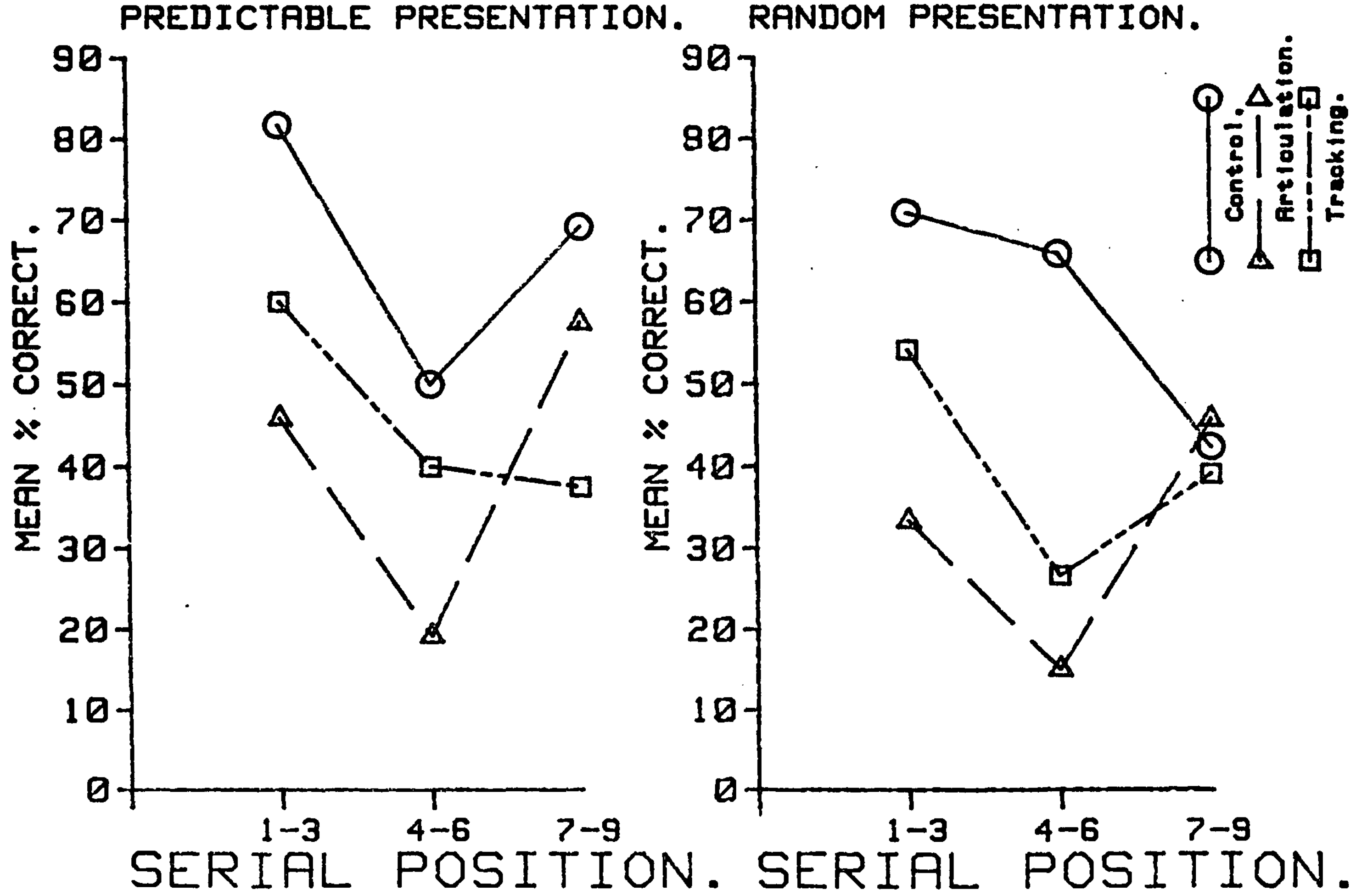
Mean % correct (s.d. in brackets).

Predictable presentation

Serial Position	Control	Tracking	Articulation
	Predictive Presentation		
1-3	81.67 (12.30)	60.01 (22.16)	45.83 (24.61)
4-6	50.00 (25.76)	40.00 (27.44)	19.17 (12.45)
7-9	69.17 (32.17)	37.50 (29.46)	57.50 (25.59)
	Random presentation		
1-3	63.33 (27.27)	54.17 (27.85)	33.33 (28.33)
4-6	65.83 (19.42)	26.67 (17.48)	15.00 (12.91)
7-9	42.50 (29.77)	39.17 (23.26)	45.83 (22.31)

Table 6.3. The effects of concurrent activity on serial recall of consonants presented visually in predictable and random locations.

FIGURE 6.3. THE EFFECTS OF CONCURRENT ACTIVITY ON SERIAL RECALL OF CONSONANTS PRESENTED VISUALLY IN PREDICTABLE AND RANDOM LOCATIONS.



PREDICTABLE PRESENTATION. RANDOM PRESENTATION.

6.5.2.1. Serial Positions 1-3.

A main effect of predictability was found ($F(1,9) = 7.32$, $p<.025$). There was also a main effect of concurrent activity ($F(2,18) = 17.18$, $p<.001$) but the interaction failed to reach significance ($F(2,18)<1$).

6.5.2.2. Serial Positions 4-6.

There was no main effect of predictability for positions 4-6 ($F(1,9)<1$) but again there was a large effect of concurrent activity ($F(2,18) = 31.37$, $p<.001$) and a significant predictability x concurrent task interaction ($F(2,18) = 4.05$, $p>.05$). On predictable trials there was no significant effect of tracking ($t(9) = 1.71$, $p>.05$) but articulatory suppression produced a decrement ($t(9) = 4.13$, $p<.01$). Post hoc analysis of the random presentation trials revealed a large effect of tracking ($t(9) = 7.87$, $p<.001$) and articulatory suppression ($t(9) = 6.54$, $p<.001$).

6.5.2.3. Serial Positions 7-9.

There was no main effect of predictability ($F(1,9) = 2,15$, $p>.05$) but the concurrent tasks produced a large main effect

(F(2,18) = 7.48, p<.01) and the predictability x concurrent task interaction was significant (F(2,18) = 3.66, p<.05). On predictable trials there was a large effect of tracking (t(9) = 4.59, p<.01) but little effect of articulatory suppression (t(9) = 1.68, p>.05). Tracking had little effect on random presentation trials (t(9) = 0.48, p>.05) and this was also the case with articulatory suppression (t(9) = -0.38, p>.05). If the effect of randomisation was to 'overwrite' locations previously presented then one would expect that serial position 9 on control trials would not be overwritten and, therefore, recall of this position should be better than performance at positions 7 and 8. A t-test comparing control trial performance in the random presentation condition using serial positions 8 and 9 was not significant (t(9) = 1.83, p>.05) and a similar comparison of positions 7 and 9 also failed to reach significance (t(9) = 0.88, p>.05). A comparison of serial positions 8 and 9 on control trials with predictable presentation revealed no difference in performance level (t(9) = 0.55, p>.05). The latter comparison was carried out to examine performance decrement when there was no possibility of 'over-writing'.

In addition, a comparison was made between random presentation performance at position 9 with and without tracking. This proved to be non-significant (t(9) = 1.63, p>.05). The same comparison was also carried out on position 9 data from the predictable presentation condition. This comparison was significant (t(9) = 4.00, p<.01). The implications of these tests will be examined in the discussion.

6.5.3. Discussion.

Random location presentation produced a main effect at positions 1-3 but its effects were modified by concurrent activities at the other positions and this is reflected in the interactions. There is a general deficit across all serial positions in the control condition with random location presentation. This is to be expected because random presentation results in a mismatch between spatial encoding and the temporal encoding required for serial recall. Thus random presentation is, in a very real sense, a more difficult condition than predictable presentation. Indeed spatial grouping results in better recall than presentation in only one location. The control condition means in Experiment 6.2. are much lower than in this experiment. It may be the case, then, that spatial grouping increases the discriminability of the stimuli. If locations are 'over-written' or 'masked' one would expect this. An alternative explanation, however, is that 'grouping' per se is helpful. Ryan (1969) found that temporal grouping with auditory presentation, improved performance and the present author has replicated this finding with visual presentation. (Morris and Jones, in press).

However the analysis of serial positions 4-6 suggests that the effect is complex. There is no evidence of a specific masking effect. With predictable presentation there is no effect of tracking but a marked effect of articulation which suggests a phonemic recoding strategy which was also demonstrated in the earlier experiments in this chapter.

Tracking does have an effect, however, when random location presentation is used. This suggests a spatial monitoring problem that occurs subsequent to encoding the primary items. These complex effects are clearly in need of further examination. They probably reflect the use of a range of control processes which are more easily disrupted as the memory load increases.

However of greater interest, with respect to the hypotheses postulated here, is the analysis of the recency portion of the serial recall curve. The analysis of positions 7-9 showed no main effect of predictability but there was a large effect of tracking. The lack of an effect of articulatory suppression replicates the findings of Experiment 6.2. but clearly tracking has an effect that is specific to spatially grouped stimuli. The effect is marked and the earlier experiments have shown that tracking always has an effect when it is performed concurrently with a visuo-spatial task (see especially Chapter's 3 and 4). Furthermore these results resemble those found in Experiments 6.1. and 6.2. where it was demonstrated that tracking has little effect with auditory presentation (Experiment 6.1.) or visual presentation in one location (Experiment 6.2). The effects of tracking at earlier serial positions with auditory presentation but not with visual presentation suggests that we do not have a good understanding of the range of interference effects produced by tracking.

However the results presented here suggest that the effects are attentional in nature, are confined to encoding, at least with presentation of highly visuo-spatial material, and this experiment indicates that tracking has a very specific effect on recency for visuo-spatially discriminable materials.

The random presentation analysis reveals some very interesting results at serial positions 7-9. Tracking has no effect almost certainly because random presentation has had a devastating effect on recency in all conditions. It is not simply the case that the effect of tracking and random presentation are additive, i.e. they affect the same processing stage, although there is clearly no floor effect here. This suggests that there are memory components/strategies that are not vulnerable to tracking effects but which are not capable of creating a recency effect.

The above mentioned considerations indicate that it would be parsimonious to assume that the same store(s) deployed in the experiments described in Chapter 3 was also used in this experiment. Furthermore the lack of an effect of any interference task at serial positions 7-9 in any of the other serial recall experiments suggests that the executive is not responsible for recency. General effects of tracking can therefore be ruled out (because we would certainly expect any general effects to be operating in Experiment 6.1.) and a specific effect of tracking on spatial monitoring is indicated. It may be the case,of course, that the burden of holding six consonants (serial positions 1-6) impairs spatial monitoring. This certainly seems to be the case, to a small extent, in many of the experiments reported in Chapter 4.

The analysis of positions 7-9 by individual serial position indicates that the effect of randomised presentation is not due to overwriting of some quasi-perceptual representation. Such overwriting would 'privilege' position 9 on control trials. Tracking does 'knock out' this position; this is clear from the analysis of position 9 in the predictable presentation analysis so it would seem that locational uncertainty or an artifact associated with this, is responsible. One problem with using random locations is that there is always a concurrent task - the necessity to scan the display with one's eye movements. One would not expect this to have a marked effect on this last position but the possibility cannot be ruled out given the results of earlier experiments.

If one accepts that the memory task used in Experiment 6.3. is a considerable departure from more 'traditional' serial recall paradigms and is therefore in need of more systematic investigation then some tentative generalities can be made.

The scratch pad is a good candidate for a slave system that can be deployed, but not necessarily by the subjects own volition, to process verbally recodable visuo-spatial information. Such a system would probably be under volitional control, to some extent, when coupled to the central executive. However this recency effect is clearly sensitive to interference which suggests that it is either <u>initially</u> encoded in a store that is very vulnerable to such interference or, given the lack of an effect on visuo-spatial representation of Moar Box tracking in Experiment 4.2., the store is a way-station preceding a longer-term store. These experiments cannot discriminate between these two hypotheses.

It was argued earlier that tracking prevents central executive deployment of the scratch pad. One would expect that if the central executive is not involved in the production of a visuo-spatial recency effect that there would be no effect of tracking on this recency. It is clear, however, from this experiment that tracking does impair this recency. This seems to indicate that tracking impairs spatial monitoring of the external environment and that this monitoring is not a function of the executive. One possible conclusion is that for the recency effect to occur the system must use a monitoring device that is essential to the performance of the tracking task but is not in isolation adequate to perform the tracking task. It was argued in Chapter 2 (page 15) that even a simple tracking task might involve cognitive processes that we are not in a position to specify. The results of this experiment suggest that this is the case. Taken as a whole these experiments indicate that there is a spatial monitoring system that 'scans' the external environment without necessarily requiring executive monitoring. In evolutionary terms such a system would be advantageous to an organism that engaged in complex verbal processing while, for example, it was in motion.

6.6. General Discussion.

The experiments reported in this chapter raise more questions than they answer. Ideally a much longer series of experiments would be necessary to address the admittedly rather speculative conclusions that have been reached. However the central theme of this thesis is that working memory is a complex, flexible system and it therefore seems more appropriate to superficially sample its operations than to attempt to systematically examine a very narrow band of its capabilities.

An attempt has been made to provoke interest in some of the system's capabilities and limitations and such an approach, by its very nature, leads to many 'loose-ends'. This thesis has no logical termination. These experiments simply represent the amount of work that can be done within imposed time constraints. The penultimate chapter provides a theoretical discussion of these findings in terms of a working memory constellation model. Chapter 8 presents an overview of this work and some speculations of the future of working memory research.

Chapter 7

Working Memory Constellations.

7.1. Summary

This chapter is highly speculative. It is argued that memory theorists have tended to underestimate the flexibility of the memory system. A model that attempts to outline, in a rudimentary form, how a more flexible system might be depicted is presented.

7.2. Introduction

If working memory is a system involved in processing information in real time, i.e. a system that handles the current cognitive load in the specious present (James, 1890), then it should account for all 'thinking' (or all conscious thought). Obviously no model can be this adequate. A compromise is necessary. The working memory model should be capable of reflecting the adaptability of human cognition to coping with the specious present i.e. it should not be specified in such a way that it underestimates the flexibility of short-term memory.

Baddeley (1982a) commented on working memory that its "flexibility allows one to capture much ... of the richness of the remarkable cognitive skills that we all display" (page 169). If one accepts the basic tenet of the theory of evolution that the successful organism is highly adapted to the ecological niche in which it lives then it is clear that a crucial adaptation is its information processing efficiency especially if the environment is highly labile. An adequate human working memory model must reflect this remarkable range of cognitive activities that are carried out in day to day living. Also it should be modelled in such a way that its mode of processing can be switched rapidly.

7.3. The Flexibility of Human Memory

When one considers the vast number of strategies that can be postulated to solve complex cognitive problems it becomes clear that a major problem for experimental design in memory experiments is constraining the strategies that subjects can adopt. The spatial memory task used in Experiments 3.2.-4.7., for example, was highly artificial and was specifically designed in this way to avoid verbal recoding. While it is desirable to emphasise the flexibility of human memory it is also necessary to identify specific memory structures, thus, ideographic and nomothetic studies need to be pursued in parallel if we are to give a useful account of short-term memory processing. However, Neale and Liebert (1973) caution that one must not sacrifice internal validity for external vadildity i.e. that one should not reject data that is not obviously ecologically valid because the initial construction of a useful theory is usually generated from tightly constrained laboratory paradigms. Rather, one should test the generality of a theory in a less constrained environment after it has been well mapped out in the laboratory. Bearing this in mind the following discussion examines the performance of the system under adverse circumstances.

Such performances are particularly striking when patients show some degree of recovery from brain injuries that initially seriously, and quite globally, cripple the memory system. Such recovery is often reflected in the use of intact memory structures to process information previously handled by the damaged areas. Although evidence of this adaptation is sparse, and the recovery far from complete, it could have far reaching consequences for the amelioration of memory problems if we had a better understanding of the range of memory structures available and their processing capabilities and limitations. Such an understanding might well lead to improvements in the educability of the mentally retarded and the 'normal'. However the evidence accumulated so far is not promising. It remains to be seen whether memory theorists can provide insights that are superior, in practice, to the intuitions of the layman.

Geschwind, in an interview with Gilling and Brightwell (1982), speculated that some aphasics have brain damage that prevents correct repetition because the patient cannot transfer the heard word from Wernicke's area forward to Broca's area. The damage, he argues, includes pathways between these two areas and so information processing must be re-routed. He argues that "For example, somebody being given a word like "tree" might transfer it from the left hemisphere over to the right hemisphere where it might arouse an association. Then he might pass that association forward to another location in the right hemisphere and some how use a long detour to get to the speech area in the left hemisphere. But by then the word would be in a non-verbal form: it might be a visual memory, for example, and what might be spoken could be a word like 'orchard'. That could occur regardless of whether the word had originally been read or heard, or even if it was a picture or something that the patient had held in his hand" (page 67). This hypothesis is clearly in need of further investigation. However it has long been recognised that 'split-brain' patients (patients who have had their corpus callosum severed) function remarkably well and some ingenuity is required in the laboratory to detect some of the subtler deficits that result from this operation (Gazzaniga, 1967). One explanation of this is that information from one hemisphere is transmitted to the other by cueing. Gazzaniga provides an example of this. "If a red light was flashed and the patient by chance guessed red, (when red was presented) he would stick with that answer. If the flashed light was red and the patient by chance guessed green, he would frown, shake his head and then say "Oh no, I meant red". What was happening was that the right hemisphere saw the red light and heard the left hemisphere make the guess green. Knowing that the answer was wrong, the right hemisphere precipitated a frown and a shake of the head, which in turn cued in the left hemisphere to the fact that the answer was wrong ..." (page 170). However although cutting the corpus callosum and the other commissures isolates the two hemispheres there are still intact connections between 'lower' brain areas which have connections to cortical areas thus the hemispheres are not completely isolated. The point is, however, that when a particular strategy of information processing is not available to a patient he or she will often discover an alternative, albeit less efficient, strategy. One cannot assume that apparent recovery is necessarily due to the relocation of function (Geschwind, 1979).

One would however expect that the strategies available to someone with an intact brain would probably be more diverse than those available to a brain damaged population. Thus if a particular brain structure cannot be engaged in cognitive processing then alternative structures, where ever possible, will be used although it may take some time to develop a new strategy. If this is accepted then it follows that it would be unwise to simply specify that a particular cognitive activity requires the use of a specific memory structure. Appropriate interference may demonstrate that subjects tend to use a particular constellation of processors but they are not necessarily obliged to.

It was noted above that this might have consequences for the rehabilitation of the mentally retarded. It might be possible to train those with specific brain injuries to use their remaining capacity in ways that would circumvent some of these limitations and functional retardation, possibly caused by impoverished social conditions, might be reduced by specifically teaching new control processes (strategies).

7.4. Can Memory Be Educated?

Miller (1984) suggests that teaching imagery mnemonics to brain damaged patients can improve verbal memory performance at least in the short-term but it is not clear whether this is due to the use of specific memory structures or simply to the greater duration of the study period in the mnemonic conditions. Furthermore this enhancement was not forthcoming with severe amnesics and Miller concludes, pessimistically, that the enhancements obtained are probably of an insufficient magnitude to be clinically significant.

Attempts to teach mildly retarded children to use effective rehearsal strategies have been more successful. Campione and Brown (1978) trained their subjects, in one condition, to rehearse pictures that they had previously named correctly. Performance was better for children who had been taught to group rehearse the items and this increment generalised, without further instruction, to prose learning. Belmont, Butterfield and Borkowski (1978) found that strategy generalisation in adolescent retards only persisted with extensive training. These results suggest that at least some retarded children can be trained to use their working memory capacity more effectively and that this could have practical benefits because these children have sufficient insight to generalise these skills to memory tasks other than the initial training task.

Thus it can be argued that poor digit span, for example, in retarded populations may be due, in part, to their failure to realise that they can deploy useful memory structures or control processes, rather than to reduced memory capacity exclusively. That such training tends to fail with severely brain damaged patients and profoundly retarded children may be due to structural damage to the memory system and/or a number of other problems which arise with any serious impairment (attentional and motivational problems, severe communication problems, the need for regular medication etc.).

If poor strategic deployment of short-term memory stores is a major reason for poor performance in the retarded then one would expect that if young children show a similar lack of insight into their available options then it should be possible to teach them appropriate metamemorial skills provided that appropriate memory structures have developed and suitable mnemonic devices can be found.

It is clear that performance on most memory tasks increases as children develop (Kail, 1979). Two explanations of this effect seem plausible. The capacity of a memory store may increase developmentally and/or children may gain increasing insight into the control processes available and form more realistic ideas about their memory capabilities (meta-memory). Hitch and Halliday (1983) have argued that the articulatory loop, and possibly the scratch pad, are used at an early age although articulation is rather slow in young children (Nicholson, 1981). Thus short-term memory seems to be structurally differentiated at an early age. The question that remains is whether or not young children do use, or can be taught to use, control processes that will result in the efficient use of available memory structures. If structural limitations do not result in a very small working memory capacity then children should benefit from mnemonic instructions at least in the short-term if they can comply with the task demands. Whether any improvement observed is due to the development of greater capacity or more efficient use of available capacity is difficult to decide but the latter explanation is more likely if improvement occurs very rapidly.

Flavell, Beach and Chinsky (1966) presented an array of pictured objects to 5, 7 and 10 year olds. The children wore a 'space helmet' during a 15 second delay and recall. The helmet obscured the object array and allowed a trained lip-reader to observe their covert articulation. Performance improved with age as did sub-vocal rehearsal. Keeney, Cannizzo and Flavel (1967) found that in the 6-7 year age bracket poor rehearsers performed less well than good rehearsers but a rehearsal training period resulted in parity of performance. However withdrawal of prompting led to a performance deficit in most of the poor rehearsers. Kennedy and Miller (1976) replicated this finding using 5-7 year olds but found that if it was pointed out to subjects, repeatedly, that whispering the names of the items improved memory then the strategy use was transferred to other related problems. These results suggest that the flexibility of the working memory system increases, at least for some processes, with the acquisition of metamemorial skills rather than as a result of structural changes in the memory system. Given that one has an intact working memory system, memory performance in a wide range of circumstances is likely to vary as a function of control process deployment and structural limitations rather than as simply at total capacity limitation function. Cognitive failure may be ameliorated under certain circumstances. Furthermore failure to ameliorate its consequences may be as much the result of the psychologists lack of insight into the range of memory control processes available as to the subjects deficiencies in meta-memorial skills. This is clearly an area worthy of further investigation.

Models of memory that depict short-term memory as an inflexible, very limited capacity system have tended to do so, to some extent, because they have generated experimental paradigms that tend not to tap the range of control processes and memory structures that are available to subjects. An attempt to do just this may be over ambitious but it is a desirable end.

Indeed psychometricians have postulated a cognitive flexibility/rigidity dimension (Guilford, 1967) and a study by Cosden, Ellis and Feeney (1979) demonstrated that performance on tests of flexibility correlated with memory performance on a task requiring the development of a non-obvious 'chunking' strategy. It has also been noted earlier that there are cross-cultural differences in the strategies adopted (Kearins, 1981).

It is also instructive here to note that the case history approach has produced a large body of literature on the different strategies used by expert mnemonists (most notably Luria's 1968, S). Most of these are documented in Neisser (1982).

The purpose of this brief review has been to demonstrate that human memory operates by using a diverse range of strategies and that, within a working framework, these control processes must operate via a considerable number of memory structures. If working memory has only a single short-term store then interference tasks that disrupt this store would present insurmountable problems for the system. Control processes, at least in the well practiced adult, are generated to overcome interference. Clearly this requires that subjects develop expectancies about what will occur next in order to cope with the current and future cognitive loads. In the short-term quite novel situations may overtax the metamemorial skills of the subject (and continue to do so for some subjects).

One way to tackle this question empirically might be to provide feedback to subjects after each memory trial. Feedback is recognised as an integral part of most learning (Miller, Galanter and Pribram, 1960). We know intuitively that up to a certain point immediate feedback will improve memorial performance. Thus it would be interesting to study individual differences in and the development of the ability to benefit from feedback. For example, a line of Shakespeare may be learned as a 'chunk' with two of the words incorrect. With feedback gained by looking at the play again this could be corrected without learning the whole chunk again. More importantly, however, it would give a measure of just how useful the current strategy being used was - we should be able to monitor our acquisition strategy as well as the contents of memory.

Most models of human memory examine the kinds of errors made by subjects in order that the types of processing underlying acquisition and retrieval may be illuminated. However, these studies usually place the subject in an unusual position - much as examinations do. The best way to improve ones own memory performance seems to be by checking how well we have just acquired some knowledge (as in the Shakespeare example) and by noting the sorts of errors that we have been making.

Memory experiments, in general, encourage persistent errors by denying the subject feedback after each trial and there may be, therefore, an assumption that certain types of errors are indicative of the nature of the processors subjects are compelled to use when in fact such persistent errors may simply be an artifact of keeping subjects 'in the dark'. If this proves to be the case then the types of limitations we assume to exist in memory may be unrealistic.

Certainly it can be argued that subjects meta-memorial knowledge is such that they are quite accurate in their assessment of their performance level and they therefore receive intrinsic feedback. But do they know the nature of their errors? For example, we know that phonemic confusions occur but can we train, by using trial by trial feedback, subjects to fail to make these errors? If we can then are there situations where this training is ineffective? For example, we may find that subjects can bypass some phonemic coder if they are informed that phonemic errors are occurring. On the other hand it may be the case that phonemic encoding is an integral part of the acquisition/retrieval process for certain memory operations, in which case feedback should prove ineffective. The use of feedback may indicate which processes are essential to memorial performance and which are optional for a given memory task. It was noted in Chapter 2, for example, that the use of the articulatory loop seems to be optional in some circumstances, most notably when presentation is visual.

The pathological and developmental literature certainly suggests that the study of encoding strategies will continue to be fruitful provided that we are sufficiently astute to identify the sorts of instruction and feedback that may be useful to subjects. A major problem, however, might be that alternative strategies adopted by subjects might well be sub-optimal and careful scrutiny of the resulting pattern and nature of errors would be necessary.

7.5. Priming Human Memory

Poulton (1973) and Greenwald (1976) have argued for more careful consideration by the researcher of the wisdom of using within-subject designs because of the problem of carry-over effects. Carry-over effects presumably occur for a number of reasons, for example, proactive inhibition effects, fatigue etc., and there is likely also to be an effect of cognitive set. The system is 'locked in' to a particular processing strategy and this is likely to continue when the trial type changes. It is desirable to introduce rests between blocks of trials unless one wishes to introduce carry-over effects specifically. All the experiments reported in this thesis had rest periods and instruction prompts between blocks to overcome this. However the experiments involving consonant preloads, concurrent loads and postloads (Chapter 4) may have introduced carry-over effects unavoidably because of the necessity of recalling a verbal load and a spatial load in close temporal proximity. Thus it was argued that a verbal preload that was encoded before a large visuo-spatial memory load accumulated rapidly might well prime the system to process verbally with an additional increment in this direction when verbal retrieval preceded spatial retrieval. This might well reflect an induced executive bias towards verbal processing that carried over into the spatial material retrieval phase. If this is the case then the effect is subtle. Hellige and Cox (1976) found that 'easy' memory loads (2 or 4 nouns) improved visual recognition of words but holding 6 nouns produced a deficit. This suggests that sub-capacity loads may 'prime' appropriate processors while heavier loads impair performance by overloading the system. In Experiments 4.6. and 4.7. instructional bias was used to 'prime' the system. This was largely ineffective. However the task demands may be effective in priming the system. The experiments reported, however, do not address the issue of priming sufficiently systematically to allow this inference.

A complex processing system would usually function more efficiently with a priming capability and such a capability would lead to a short duration carry-over effect to the next experimental condition. Thus in Norman and Bobrow's (1975) terminology the system may be controlled by both data-driven processes (e.g. current sensory input) and memory-driven processes. Priming would occur firstly because the system is not sufficiently labile to almost instantaneously change its mode of processing and secondly because expectancies lead the executive to assemble working memory constellations in anticipation of a particular type of task. The assembly stage should result in a larger priming effect than the dismantling stage i.e. that preparation for a new task should take longer than recovery from performance of the previous task. The lack of an effect of instructions in Experiments 4.6. and 4.7. and the low verbal load priming effect found by Hellige suggest that data-driven processing is important in constellation construction. This is consistent with a system that must adapt to unexpected changes as well as predicted changes. The unexpected is likely to be highly significant and to present itself to the senses rather than being internally generated.

The evidence for these assertions is clearly flimsy. However a system that is primed in this way would be subject to state-dependent learning (Eich, 1980). Furthermore Rabbitt (1981) has shown that elderly subjects tend to treat random perturbations in a self paced choice response task involving signals with different occurrence probabilities as 'real' shifts. This is compatible with the idea that they may fail to maintain a primed state. Alternatively they may demonstrate more rapid memory decay. However short-term memory decay is usually considered to be a consequence of failure to rehearse. Thus the elderly may develop strategies that are simpler than those used by the young and they may fail to maintain their rehearsal strategy. Crucial evidence for priming effects of course requires improved performance with a heavier cognitive load. The Hellige and Cox study meets this criterion but clearly a similar finding would have to be obtained across a variety of memory tasks. It is only possible at this time to assert that it makes sense to have a primable system and this leads to the assumption that, paradoxically, a concurrent load can lead to better performance than in a condition with no concurrent load (cf. the effects of 'under-arousal' on performance).

The next section explicitly states how a tentative model of working memory with numerous components might operate. This outline is necessarily speculative because of the dearth of relevant experimental evidence. However it is hoped that these speculations should at least be subject to empirical verification or refutation. Chapter 8 outlines how such empirical testing might proceed.

7.6. Working Memory Constellations.

Figure 7.1. shows a flow-chart outlining how the working memory system might operate. Only two slave systems are specified but other slaves could be indicated. There has been little investigation of these other slave systems but at

least two other stores (or possibly control processes) have been suggested by Klapp, Marshburn and Lester (1983) and Reisberg, Rappaport and O'Shaughnessy (1984). These will be discussed in detail later.

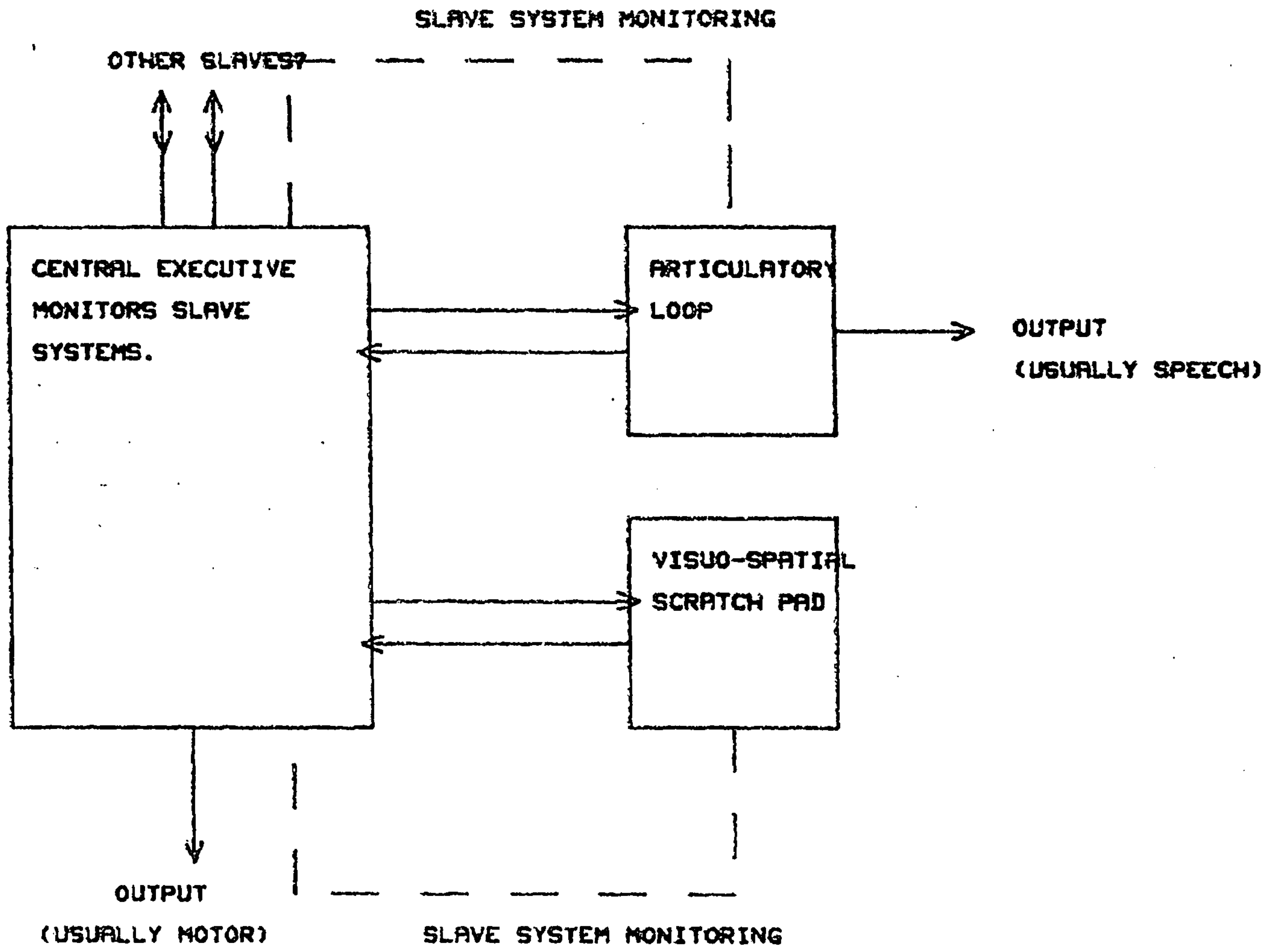


FIGURE 7.1. A SIMPLE WORKING MEMORY CONSTELLATION.

The experiments reported in Chapter 4 demonstrated that the effects of tracking are largely confined to the encoding phase. This suggest that the executive has to be linked to the scratch pad during encoding and that it cannot monitor the use of the scratch pad effectively when it must also 'attend' to a tracking task. An alternative explanation is that the material is encoded in the central store and then offloaded onto the scratch pad. However the small magnitude of the deficit created by holding six consonants in working memory suggests that information is off-loaded rapidly onto the scratch pad and that the effect of tracking is to interfere with this. Thus the flowchart shows executive monitoring of the scratch pads contents. Monitoring is assumed to be minimal during maintenance rehearsal. Tracking is assumed to have a general effect rather than an effect confined to only spatial information processing. This was demonstrated in Chapter 6.

A similar monitoring of the loop is also shown. Tracking may impair access to this also, provided that the loop does need to be monitored. It is assumed, in this model, that significant monitoring only occurs, generally, when the contents of the loop are to be recalled (which is not usually the case with articulatory suppression). Experiments 3.1. and 3.2. demonstrated that tracking and articulatory suppression performed together do not increment the deficit produced by tracking. This probably reflects a reduction in tracking because articulatory suppression has little effect on visuo-spatial memory. If this is the case then the executive does seem to need to monitor during counting (although this may not be the case with other forms of suppression e.g. articulating "blah" unless articulation to a predetermined criterion is required). When subjects were required to track a visual sine-wave for ten second periods while counting aloud they counted more slowly than when they were not required to track (this is an informal demonstration as the data on eye movement performance was erased, accidentally, before it was closely scrutinised). However this may be due to synchronisation of eye movements with tracking e.g. subjects may count their gross eye movements.

Returning to visuo-spatial encoding, it is the case that occupying the executive's monitoring capacity after visuo-spatial information has been off-loaded onto the scratch pad does not degrade visuo-spatial representation (Experiment 4.2.). This suggests that the executive does not have to closely monitor maintenance rehearsal but is intimately involved in the control processes deployed at encoding. Similarly loading up its capacity with consonants after visuo-spatial encoding does not result in a significant decrement (Experiments 4.4. and 4.7.). Nor does counting require sufficient executive monitoring to impair visuo-spatial encoding. The tracking task, however, seems to require most of its monitoring capacity. Unfortunately Experiment 3.2. did not include objective measurement of tracking performance. The visuo-spatial memory task seems to have required only a modest amount of monitoring because even with Moar box tracking (the most effective interference task used) performance was still above chance level.

There is a strong case for postulating a role for the central executive in elaborate rehearsal which probably requires the use of the central memory store. The executive can then off-load this material onto the slave systems while it performs other mental operations.

An interlingua (see Chapter 1) is also required. Most information is multifaceted conceptually and if a synthesis of, for example, verbal and spatial properties is to be achieved then some common representational language needs to be used. Given the functional specificity of the slaves such representations probably reside in the central store. Thus such syntheses require the slave system's contents to be output to the executive system.

A working memory constellation is a complex processing assembly consisting of a number of slave systems which are monitored by the executive's attentional device during elaborate rehearsal and these slaves output their contents into the general capacity store during processing stages that require multifaceted representation. The purpose of the slave systems is to hold information temporarily, and probably quite 'passively', while the executive's capacity is committed to complex information processing. This releases attentional capacity and the central store once slaves have been loaded.

Constellations differ from domains (see Baddeley, 1982b) in two respects. Constellations may involve a diverse range of processors being activated whereas domains, in this model, consist of assemblies that may usually be activated together (for example, 'verbal' processors) and it may be difficult not to activate some of these when the system is appropriately primed. Thus the Evans and Brooks (1981) study (discussed in Chapter 2) showed improved performance under articulatory suppression. This was probably because this prevented the use of the loop, which in this instance would slow response, and thus it would seem, given this result, that subjects did use an inappropriate slave unless prevented from doing so. The second difference between a constellation and a domain is that constellations are subject to a much wider range of interference than domains. Thus a constellation's processing may be seriously disrupted by tracking and articulatory suppression whereas the spatial domain does not seem to be vulnerable to articulatory suppression. Whether or not it is useful to make such a distinction remains to be seen. It seems likely that constellation construction also involves widespread activation of domains so that, for example, subjects given a verbally recodable spatial task may not be able to avoid the effects of articulatory suppression (see Chapter 5 for more on this). The experiments reported in Chapters 5 and 6 used materials that were subject to 'dual coding' (verbal and spatial) hence they involved the use of simple constellations and diverse secondary tasks produced memory deficits. However the tasks used in the experiments reported in

Chapters 3 and 4 were not vulnerable to interference from articulatory suppression.

Given that this model postulates that quite complex processing assemblies can be constructed we need to consider what other slave systems are available to the executive. Evidence for the existence of other processors is sparse but this may be largely due to lack of research. Relevant studies are reviewed below.

The possibility that there may be more than one phonological store and, perhaps, an acoustic imagery system was discussed in Chapter 2. It was also argued in that chapter that the spatial domain may also have a number of components that can be fractionated. However, as was noted earlier in this section, there is also some evidence that other functionally separable stores also exist.

Indeed it is likely that a flexible memory store must have many stores that have not been identified because there is not an obviously finite number of mental operations that an individual can perform and until it is demonstrated empirically that two or more control processes do employ the same memory structure it would be unwise to assert this given that some components of the system have already been fractionated. However parsimony dictates that stores should not be postulated ad hoc. One should only postulate a new addition to the model when the existing model cannot handle new data. This is discussed further in the final chapter.

One such new component was suggested by Klapp et al (1983) who rejected the idea that working memory has a general processing store (the common resources hypothesis) which is used to perform most mental operations. For Klapp working memory is a complex multi-store system that is not filled by a digit-span load. In support of this contention they demonstrate that whereas temporal grouping at presentation improves serial recall of digits this has no effect on a missing digit identification task (in which, for example, the digits 1-8 may be presented in random order with one of the digits deleted; the subject must then identify the missing digit). The implication is that serial recall and missing digit identification require different processes. Furthermore there is no effect, of a comparable magnitude, on the missing digit span task of articulatory suppression. Klapp demonstrates that it is the case that a digit-span load only interferes with a reasoning task during digit rehearsal but not digit retention because a brief digit rehearsal period before presentation of the reasoning task removes the detrimental effect of the load.

Klapp concludes that the working memory system can operate while holding a digit span load thus digit span is not a good measure of working memory capacity. Furthermore he suggests that the missing digit tasks require the use of unidentified working memory components. He concludes "that the missing digit task must be, at least in part, based on some system of memory that is distinct from either the residual (the general processor) or the auditory component (the articulatory loop) of memory span" (page 251).

Klapp's distinction between rehearsal and retention is consistent with the view expressed here that heavy central executive resource demands are only made at encoding but not during maintenance rehearsal. His results indicate that a general purpose store model may be untenable. However Baddeley never claimed that such a store was feasible; for Baddeley it merely represents our residual ignorance and this is to be 'chipped' away gradually. Klapp has detached another shard and he rightly concludes that "the move to a more complex theory seems clearly required by the data" (page 262).

Indeed if one looks at the tables of means from many working memory studies (for example those for the reasoning studies in Baddeley and Hitch; 1974) and those presented in Chapter 4 of this thesis) it is remarkable just how small the deficits produced by digit span loads are. Given that a digit-span load, by definition, fills some store(s) the subtle nature of its interference indicates that working memory has plenty of 'space' left somewhere. That most interference seems to occur during encoding suggests that the major limitation of working memory is its ability to <u>allocate</u> and <u>monitor</u> control processes. A heavy verbal preload may do this.

It was argued by Riesberg et al (1984) that there are no limitations on the working memory constellations that can be created. They suggest that "memory tricks ... are important components of the working memory system" (page 203) and they attempted to demonstrate this by instructing subjects in the use of a mnemonic which, they argue, involves "creating a temporary memory component by taking an activity that is not intrinsically memorial and temporarily recruiting that activity for short-term storage" (page 204). This, says Reisberg, is what happens when we use the articulatory loop.

Reisberg taught his subjects to use their fingers as an analogue to the articulatory loop. The eight fingers were designated values of 1-10 (with five and six deleted) and subjects were told to rehearse subsequently presented digits by tapping their fingers in the appropriate order. Using this mnemonic increased memory span. Subjects had normal memory span plus an increment created by the motor rehearsal with fingers. With practice this increment was about 50%. The increment could be removed by interfering with the 'finger loop'. This was achieved by requiring subjects to 'drum' their fingers. However recall after doing arithmetic was no better when subjects could use their finger loop than it was when drumming. This suggests that this 'loop', at least initially, requires some executive 'supervision'.

Reisberg concludes that .. "The tricks of finger rehearsal and articulatory rehearsal are in fact quite similar. Both are strategic activities employing repetitive sequencing of coded material, so that the coded material is stored. Both require minimal conscious effort, so that the activity does not disrupt other ongoing mental operations. Given these parallels however, it is worth underscoring the two clear advantages of articulatory rehearsal. First, articulation is enormously well practiced. Second, language provides a particularly rich coding scheme for this loop" (pages 217-218).

His model of working memory is in agreement with the model outlined here ... "The properties of working memory would not be fixed, but would depend on the constituents of working memory that a subject chooses to employ in accomplishing a given task. But, beyond this, what constituents would be available, and thus what properties working memory could reveal, would then be an accident of the individuals learning history, so that, in a strong sense, working memory would have no fixed properties" (page 219).

There are strong indications that future research will show working memory to be a complex system whose complexity will be limited by the ingenuity of the subject and the experimenter. Such a model could become unwieldy but it is likely that executive monitoring capacity will limit the size of constellation assemblies that can be constructed.

The maximum assembly size is a crucial question if we are to consider the system as a limited capacity device. Another important problem is the relationship between working memory and long-term memory. At the moment an unspecified link is merely acknowledged but ultimately the relationship between these two systems will prove crucial to a basic understanding of memory processes.

7.7. Conclusion

A complex, flexible working memory system, is necessary for any organism that lives in a complex, changing environment. The organism must be able to rapidly process, and compare with long-term representations, a large variety of inputs if it is to extract salient information from sensory input.

It is argued here that a working memory system that is capable of responding to a changing environment must be able to rapidly activate, or assemble, a diverse range of processors. Reisberg et al (1984) argue that working memory operates by using available neural mechanisms as storage devices and that these mechanisms need not be mechanisms that one would consider to be intrinsically memorial in nature. If this proves to be the case, and this needs further investigation, then working memory is likely to be specified largely by the demand characteristics of the situation.

Cognitive deficits resulting from organic damage would be viewed as arising from the unavailability of appropriate 'hardware' for carrying out particular control processes. This would suggest that alternative hardware or structures could be deployed to overcome or ameliorate such cognitive deficits. Attempts to do this have not been very successful. While Reisberg may be right that many neural mechanisms may be co-opted into acting as temporary storage devices it is probably also the case that some neural mechanisms are intrinsically memorial (e.g. face recognition mechanisms?).

Thus one should be cautious in assigning a memorial function to a mechanism on a purely ad hoc basis, and, one should probably make a distinction between these structures because an intrinsic memory store is likely to be a much more efficient device than an extrinsic memory store because of its functional specificity.

Working memory has been seen as a relatively simple system because the task demands of most experiments have required relatively simple assemblies or many aspects of the tasks have been controlled across conditions so that the experiments do not address the role of most of the processors deployed. This is obviously a sensible way to do research if one is trying to fractionate the system or examine the role of a specific component. However this approach will not elucidate the function of the system in most real life situations. Our experimental sophistication is such that we cannot rigorously examine the roles of components in a complex constellation. However it is possible to examine simple constellations.

The experiments reported in Chapters 5 and 6 attempted to do this by showing how a constellation consisting of the executive, the articulatory loop and the scratch pad can be used to perform quite diverse memory tasks. These tasks have no obvious ecological validity but are nevertheless useful in that they demonstrate that the system can be integrated, and, that this is not always beneficial or avoidable (at least in the short-term).

This chapter was intentionally speculative. It's purpose was to be provocative because it is clear that there is a large body of evidence, some of which was reviewed here, that is inconsistent with rather simple formulations of short-term memory processing. Cognitive psychology, unlike physics, for example, does not have accepted laws (it has no paradigm in the 'Kuhnian' sense) and it is not therefore wise to expound concrete theories.

Chapter 8 presents an overview of the thesis and further speculations. However, it is recognised that the empirical studies presented in this thesis do not present adequate support for the model outlined in the present chapter. The final chapter offers some suggestions for future research that may make this model testable empirically.

Chapter 8.

Speculations and Conclusions

8.1. Summary

A considerable body of evidence has been presented that suggests that single trace theories of memory are untenable. Indeed it has been demonstrated that dichotamous models are also inadequate. The central themes of this thesis have been reiterated throughout i.e. that working memory is a multifaceted flexible system and that our understanding of this system is in its infancy.

8.2. Introduction

The following six sections elaborate on the arguments presented in each Chapter and the remaining sections discuss the implications of these arguments for memory research.

8.3. Evidence for a multiprocess model of short-term memory.

The idea of a unitary memory system is largely an invention of 'experimental psychologists' (most of which are now usually referred to as cognitive psychologists). William James did not subscribe to this view and it was implicit, in the early psychometric literature that 'thinking' involved diverse processes. Neurologists at the beginning of the century also observed that brain lesions produced a range of quite distinct memory impairments. St. Augustine (1955) observed that 'memories' can be stored as 'images' (or eikon's, Aristotle, 1972) but he conceded that other representations were possible. So it is clear that the idea that 'memory' is not a single faculty is an old one.

The main thrust of the argument presented in Chapter 1 was that there has long been resistance to the idea that one simply has <u>a</u> memory. In a sense, the computer analogy, has encouraged the unitary view. The memory store of a computer does indeed have a Pylyshyn type interlingua. It remains to be seen whether or not this is a good analogy to long-term memory but it is clear that it does not adequately represent short-term memory processing. Indeed it was pointed out that modern micro-computers can use a range of peripheral devices which draw on the computers data base and depend on their physical structure and software commands to perform operations in real time. The computer's memory is not sufficient to specify these operations. The nature of the peripheral devices is crucial also. If the human short-term memory system were indeed unitary then one would expect that its limitations would be a function purely of the total amount of information displayed on all the peripheral devices (slaves etc.) currently activated. The particular devices being used would be irrelevant. However it was demonstrated, for example, that articulatory suppression does not impair visuo-spatial representation whereas tracking does (Experiment 3.2.) and both articulation and tracking have comparable effects on some other memory tasks.

There is, then, convergent evidence for the view that short-term memory has some components that do not compete for general resources although there may be competition for attentional monitoring. Armed with this evidence it became possible to start mapping out a complex processing system more capable of reflecting the complexity of human cognitive processing. Perhaps the greatest danger of such modelling is that it will become too complex for us to examine with the experimental techniques currently available. This is a very real danger and is a severely limiting factor in working memory research.

8.4. Working Memory: The Current State of the Art.

Research into working memory has, as was noted above, been severely restricted by the limitations of research techniques currently available. Nevertheless the model has proved to be remarkably useful in advancing our understanding of cognitive processes. If one compares the working memory literature from 1974-1985 with the relevant literature from the 60's it is clear that this model has gone some way towards a unification of quite disparate areas of psychology.

This unification is in its infancy. It is probably the case that the lack of adequate research techniques available to memory researchers was a major impetus in developing an interest in collecting convergent evidence. It is difficult to imagine, for example, how one could develop an interference task that would selectively interfere with shape but not location representation. Undoubtedly one could probably come up with some crude source of interference but neuropsychological studies have demonstrated the existence of independent structures for these processes quite elegantly. Without this neuropsychological evidence one wonders whether this distinction would have been postulated.

If the research techniques developed by experimental psychologists are inadequate one might well feel that psychology should leave the study of cognitive structures to the neuropsychologist. However it should be born in mind that many of the diagnostic tests used by neurologists have been borrowed from cognitive psychology (and psychometrics) or are at least based on such tests. Furthermore psychology has provided a vast range of norms for various cognitive processes (verbal memory capacity, 'spatial ability', memory scan rates etc.) and has also, in many cases, identified theoretical entities useful to neuroscience. The idea of working memory, for example, has emphasised the significance of a number of mechanistic processes for 'normal' cognitive performance. It can be argued that the subject matter of cognitive psychology is behaviour (but methodological behaviourism rather than radical behaviourism) and this is precisely the data base used by neuropsychologists. Thus, although a neuroanatomist may be interested in a different level of reduction to the psychologist (because the actual location of a lesion is of less concern to the psychologist than the behavioural consequences of the lesion) the neuropsychologist is merely using a different population (brain damaged patients) to address the same problems as the cognitive psychologist. If one peruses the contents section of a standard work on neuropsychology (I used Walsh, 1977) then sections on memory, dichotic listening etc. can be observed within chapters on various brain areas. It is the case, then, that cognitive and neuropsychology are complimentary. Indeed if working memory does operate by forming constellations then one would expect that the 'tools' available to cognitive psychologists would be inadequate because an integrated system would 'resist' fractionation. However its <u>physical structure</u> would remain vulnerable. Thus lesion studies should be able to fractionate the system with measurable behavioural consequences resulting.

The ethical limitations to this sort of research do not need to be reiterated here. However there are two other important drawbacks to neuropsychological studies. The first drawback was pointed out earlier in this thesis. This is the problem of 'spiralling reductionism'. Is there a point at which further fractionation of the system is not useful? If the integrated functioning of the system is emphasised then at what point does fractionation result in a component that is merely of purely biological interest? I think that this question answers itself. If a lesion has no measurable behavioural consequences then it is not the concern of contemporary psychology. If it does have detectable behavioural consequences then ultimately it should be explained by an adequate theory. This explanation may be purely cognitive if neurological deficits cannot be detected (functional disorders). If organic pathology is detected then the behavioural measures will have consequences for cognitive theories of 'normal functioning'. Equally importantly cognitive psychology should provide a theoretical framework which clinicians can use to decide which diagnostic procedures to adopt. The structures postulated by the working memory model go some way in providing such a framework and constrain endless reductionism. There is nothing inherently wrong with reductionism but it can lead to a theoretical 'nihilism'. The great advantage of a good theory is that it indicates which lines of future research may increase our understanding of a particular phenomenon. This is also important clinically as it may suggest treatment strategies also.

The second drawback to using neuropsychological studies is that it is difficult to make inferences about normal functioning from pathological populations. In many cases the victims of pathological disorders may not be typical of normal populations even before they exhibit the disorder. Comparisons, then, should be made with caution.

If 'working memory' has only one outstanding virtue as a research framework it is its usefulness as a theory that directs research endeavours of a disparate nature to a common goal i.e. the explanation of 'thinking'. The literature review presented in Chapter 2 reflects this trend.

It was shown that the working memory model may have a role to play in the explanation of prose comprehension, mental arithmetic performance, reading, many aspects of language processing and topographical orientation. Given that it is difficult to adequately theorise about even such mundane aspects of cognitive processing, and that 'working memory' has not 'delivered the goods' in the sense that this theory, too, has not adequately explained these phenomena, it is nevertheless impressive that the theory has addressed all these problems in an empirically testable manner.

The current 'state of the art', at the time of writing, is reflected in the literature presented in Chapter 2. We do not have a clear understanding of the role of the central executive. This will only be clarified when we have tackled the nature of the attentional component. It is not possible at this time to rule out the possibility that there may be a central, general short-term store. All representations may be held in functional specific stores but it seems unlikely and the dictates of parsimony suggest that it would be unwise to discard the central processor.

In summary, the current state of the art is such that we have strong indications that working memory is a useful model for investigating a wide range of cognitive activities but these indications also suggest that the model will need some elaborate modifications that will result in a loss of the structural simplicity that originally made the model so attractive.

8.5. The Visuo-spatial Scratch Pad.

This component has not been as extensively explored as the articulatory loop, Only four published studies (Baddeley et al, 1975; Baddeley and Lieberman, 1980; Logie, 1986; Oakhill and Johnson-Laird, 1984) have specifically addressed this aspect of the system. There is however a large body of relevant literature, notably the work of Brooks and Phillips.

Chapter 3 was concerned with separating the scratch pad from the articulatory loop. Using a highly 'artificial' memory task this proved to be remarkably easy. This, however, suggests that the loop can function independently of the central processor. It does not necessarily follow that the scratch pad can also function separately. Indeed later experiments suggested that central executive monitoring is usually necessary if visuo-spatial representations are to be formed.

Experiment 3.3 demonstrated that interference with visuo-spatial representation does not have to involve a task possessing visual properties. This supports the contention of Baddeley and Lieberman (1980) that the scratch pad is 'spatial' rather than 'visuo-spatial'. Moar box tracking does not occupy the visual system. Of course one could argue that subjects generate a visual image of the Moar box to facilitate tracking but there is no prima facie case for this assertion. Baddeley and Lieberman (1980) demonstrated that a visual non-spatial task does not have a specific effect on visuo-spatial processing thus it seems that tracking interferes with spatial representation by either occupying the scratch pad, the central memory store or some monitoring device. There is no reason to assume that tracking has a significant memory component thus the latter explanation seems to be the most plausible especially in view of the results obtained in Experiment 4.2.

This spatial monitoring is easily disrupted. Tracking a sine-wave with one's eye movements is sufficient to disrupt such representations without creating perceptual problems. One could of course argue that eye movements are used as a rehearsal mechanism so that the motor activities of the fixations are remembered. Reisberg's 'finger loop' seems to operate in an analogous manner.

However there is more to visual tracking than this. Such tracking also disrupts performance on memory tasks that do not have a visuo-spatial component.

The main purpose of Chapter 3 was to develop a memory task that required visuo-spatial representation but little or no verbal processing. The task used in Experiments 3.2. and 3.3. has such properties. This task was explored in detail in Chapter 4 where the relationship between the scratch pad and the central executive was explored.

8.6 Executive control of the Scratch Pad.

The experiments employing verbal loads with the spatial memory task developed for Experiment 3.2. provide convincing evidence that the scratch pad is monitored by the central executive. The relationship of the executive to the scratch pad, however, is complex and far from clear. When a verbal load is effective (i.e. when it is a preload or a concurrent load) its effects are small. This suggests that competition between the two tasks for common resources is small. Also, given the findings of recent studies, notably that of Klapp et al (1983), there is some doubt about the validity of asserting that a 'memory span' load does indeed fill some central store. However it does seem to be the case that encoding and maintenance of such a load does interfere with spatial encoding. The rather complex findings forthcoming from Experiments 4.3. - 4.7.

suggest that considerable 'effort' is required to hold six consonants while no such 'effort' (or an effort of a lesser magnitude) is required for the maintenance rehearsal of the spatial information. The situation is further complicated by the likelihood of different strategy deployment in different experiments. Subjects seem to be more flexible in deploying their verbal processing capabilities (and they may have a wider range of verbal processing strategies then spatial processing strategies available to them).

The studies involving an instructional bias were also disappointing. If one accepts that the failure to find an effect here was not due to inadequacy of instructions then it would seem that the task demands are largely responsible for the deployment of control processes i.e. that the situational factors compel the use of particular constellations, at least initially, and part of the learning process may well involve overcoming the tendency to deploy inappropriate constellations. It was argued in Chapter 7 that a system that can respond to sudden changes in the nature of input would have 'survival' value. Such a system would be primed by input even against the organisms violition. Whereas this might well be detrimental to the organism in some situations it would usually be advantageous in the short-term. Such a mechanism would override violition in the interests of immediate survival and thus fall back on well-learned 'plans' rather than constellations of a novel nature. Thus the response to a fire, for example, might well be panic unless the organism can access a well-learned contingency plan for such an emergency that would not require much 'conscious' executive monitoring. This is clearly speculation but if it is the case then we would expect this initial priming to contaminate laboratory memory tasks as well as real-life situations. Responding to instructions to process information in a novel way might well involve overcoming priming of habitually used constellations.

It was also observed in Chapter 4 that there was a subtle tendency for spatial recall to be better in the vertical plane than in the horizontal plane. This is unlikely to be a perceptual problem. An initial exploratory study of the spatial task (not formally reported here) involved a condition in which subjects merely copied the display. Accuracy was virtually 100% for both vertical and horizontal plane performance. This replicates the findings of Taylor (1961).

The difference seems to be the result of the memorisation process (unless one wishes to argue that the ceiling effect found in the copying study conceals any perceptual problems; however this 'ceiling' was still present when trials involved up to 8 locations). No satisfactory explanation of this phenomenon is available. It may be that the scratch pad does not map the external world accurately but distorts the horizontal plane more than the vertical plane. Why it should do this is a mystery. Fanciful post hoc explanations could probably explain this but I suspect one could also produce a range of equally fanciful explanations that would predict greater vertical distortion (e.g. asymmetrical retinal fields, a number of perceptual after-effects and possibly, the effects of normally reading left to right in the horizontal plane). The present author does not feel, given the small magnitude of the effect, that this is a worthy topic for further research at this time.

Chapter 4 demonstrated that sources of information with no apparent spatial properties can interfere with spatial representation. This was interpreted as a competition for executive monitoring resources. It is implicit in this argument that articulatory suppression does not compete for these monitoring facilities (although under other circumstances use of the loop might do so) and it is clear from the experiments reported in Chapter 6 that Moar box tracking has complex effects that include interference with spatial monitoring (and more general monitoring).

8.7. Working Memory Constellations.

The model outlined in Chapter 7 makes many assumptions that have not been validated empirically.

Rather it is based on 'thought experiments' or 'imaginary experiments' an approach advocated by Einstein (1951). Einstein (1933) comments, with respect to Quantum Mechanics, "I think that theory cannot be fabricated out of the results of observation, but that it can only be invented" (page 458). However whereas some aspects of modern physics do seem to defy empirical investigation they nevertheless logically entail certain conclusions that are derived from known properties of matter and energy. Psychological speculations are not based on a widely accepted theoretical body of knowledge and to proceed with 'imaginary experiments' would be inadmissible. However the attempt here differs somewhat from the endeavours of those concerned with largely meta-physical problems (i.e. cosmologists etc). The thought experiment is an endeavour more akin to an Artificial Intelligence simulation. It is intended that the memory system outlined here should have empirical consequences. These consequences should be observable from laboratory studies, clinical situations etc. and, most importantly, the model should have internal consistency. Einstein may be right in his observations on theorising in modern physics but with respect to Psychology one would be less inclined to take Einstein literally. My interpretation of Einstein is that his standpoint would entail that he argued that 'observation' would never verify, totally, the richness of theory because observational methods (measuring devices) are impoverished and can not reflect the complexity of nature.

The concept of a working memory constellation is a theoretical construct that was developed not to generate a specific series of experiments but to reflect the complexity and flexibility of cognitive processes. The nature of the components is a matter for empirical investigation as is the system's modus operandi. However, ultimately, whether this approach is useful in advancing the study of cognition depends on our experimental ingenuity, the testability of its predictions, the current scientific 'zeitgeist' and, most importantly, whether it does reflect how short-term memory operates.

We do not have a good understanding of the nature of memory. It's biochemistry is not well understood which is hardly surprising given that chemically the brain's complexity presents research problems that are probably intractible. Perusal of two fairly recent texts, a symposium (Littauer et al, 1980) and a text book on molecular neurobiology (McGreer et al, 1978) suggests that we are a longway from unify the experimental evidence that has been forthcoming even though this body of evidence is enormous. It could even be argued that we have no clearer theoretical understanding of the nature of the memory system than Ebbinghaus had (see for example Neisser, 1978). However the scientific study of memory has advanced descriptively. The complexity of the phenomenon has undoubtedly impeded theoretical advances. The current emphasis on examining practical aspects of memory (e.g. the Gruneberg, Morris and Sykes, 1978 symposium) and a more interdisciplinary approach to memory may change this trend. So far an interdisciplinary approach has been disappointing (see for example section 7.3. of this thesis) but it does seem to be an approach that may prove fruitful.

The argument here is that theoretical advances in the study of memory may require that we go beyond the evidence in theorising. I think that the model postulated by Baddeley and Hitch (1974) did just this. As a result it stimulated further research and the model subsequently became more complex, and more confusing, but this surely reflects the reality of 'memory' more so than earlier rather arid memory models (e.g. associationist models) that simply failed to address many aspects of memory. Such a model may overcome the criticism of Neisser (1978) that "We have established firm empirical generalisations, but most of them are so obvious that every ten-year old knows them anyway" (page 12).

The elaboration of the model offered here was heavily influenced, in the later stages of its formulation, by the Reisberg et al (1984) paper, which was discussed in Chapter 7. The term working memory constellation was derived from this source. It is likely that there are cognitive structures that are intrinsically memorial in nature (i.e. that there are structures that have evolved into memory processors) but Reisberg's point that other structures can be employed as quasi-memory structures is important. It is unlikely for example, that the visuo-spatial scratch pad serves some other purpose than spatial processing and whereas it may be the case that the articulatory component of the articulatory loop may well result from the need to possess a speech apparatus; the phonological and/or acoustic components are likely to be purely memory structures. One should perhaps consider quasi-memorial structures to be addenda to structures that are intrinsically memorial.

The central argument is that complex cognitive processing requires complex assemblies of processors. Some speculations on how these assemblies might be constructed have been presented. In particular it was suggested that the central executive is essential for elaborate rehearsal but not maintenance rehearsal; that the assembly of a constellation takes time and that 'priming' probably occurs i.e. that assembly is largely data driven.

It was also suggested that it takes time to dismantle constellations thus 'carry over effects' occur. In particular with respect to Experiment 4.3. it could be argued that a verbal preload primed the system to verbal processing (which seems to require more resources than spatial processing) and that recalling the consonants first left some verbal output device operative and thus disrupted spatial recall. This would entail developing a different explanation of the results of Experiment 4.4. (the post load experiment). Here one would have to argue that the initial encoding of spatial information was better and thus overcame the effects of an operative verbal output mode. However the major emphasis was placed on the limited monitoring resources of the executive particularly at encoding. While it is the case that these features of the model are speculative they do have empirically testable consequences.

8.7.1. Some Speculations on the Central Executive

The attentional component of the executive system is likely to present the most intractible research problem. Kahneman's (1973) model (outlined in Chapter 1) postulates a limited capacity system analogous to an electricity generating system with a governor mechanism that controls fuel injection into the system as a response to negative feedback. This analogy however does not explain why repetitive tasks are subject to practice effects. Logan (1979) suggested that working memory employs 'plans' that can be stored in long-term memory and accessed at appropriate times. Thus attentional monitoring demands are initially great but decrease when a plan has been established. This is analogous to Allport's (1980) PS system. However Allport attempted to abolish the need for a central executive component by arguing that activation of a plan merely requires that its "condition is satisfied by the database" (page 34). A critique of this view was presented in section 2.4. A central executive is required to create a plan. It may well be the case that reactivation of a plan does not need to be mediated by an executive and thus 'practice does make perfect'. On the negative side, reactivation of a plan without executive control can lead to actions that are inappropriate (e.g. taking the train home when one has driven to work for the first time). A major function of the executive seems to be to prevent perseveration when it is inappropriate. Such flexibility is costly, but necessary, in a limited capacity system. If slave systems also demand attentional monitoring then this would restrict flexibility but, paradoxically, reduce reflexivity.

To summarise, the executive is the component of the system that prevents memory from being purely reflexive. However such flexibility makes heavy demands on a limited capacity system so that complex processing can only occur by trading flexibility against reflexive response. Skill acquisition requires heavy expenditure of cognitive resources, in the short term, and plans generated are subsequently stored. Such plans are 'streamlined' as skill develops and thus require less working memory capacity when they are retrieved. These plans run with little executive control and employ slave systems and some central capacity. However some executive monitoring is necessary if performance is not to become 'robot-like'. Such 'robot-like' reflexive performance leads to 'absent mindedness' (see Reason, 1984). Thus although 'peeking' at satellite processors may seem to defeat the purpose of possessing such devices the sacrifice is likely to be beneficial in a labile environment where absentmindedness may have severe consequences. Furthermore, such 'peeking' may not require a significant amount of attentional capacity unless an elaborate working memory constellation has been assembled.

8.7.2. Empirical Investigation of Working Memory Constellations.

The following sub-sections offer some suggestions for future research. In particular, they 'spell out' the kinds of experiments that might be carried out to examine the validity of the hypotheses that have been developed in this thesis.

8.7.2.1. Elaborate rehearsal.

Elaborate rehearsal can be considered to be rehearsal that involves attempting to retain something in memory by expanding on the original physical characteristics inherent in the stimulus. For example, one might "chunk" items semantically so that the words "larch" "oak" and "birch" might be encoded with a 'tag' "trees" to improve recall. Thus remembering that they are all trees would cue subsequent recall of all members of the triplet of words. It is usually the case, for example, that recognition memory is better than free recall. In this instance if the experimenter required free recall then the subject could impose recognition type conditions by generating from semantic memory exemplars of the category "trees". Alternatively the subject might form an image of an oak thereby having a 'picture' of the tree as well as some other representation of the word "oak". The important point about elaborate rehearsal is that it is not passive in the sense that the subject imposes a preferred mode of representation on the stimulus by drawing on his or her metamemorial skills and semantic memory. Maintenance rehearsal on the other hand may simply involve rote rehearsal in an attempt to simply continually refresh the memory trace held within a slave system. In the formulation of Craik and Lockhart (1972) elaboration involves 'deeper processing' but deeper processing involves bringing more elaborate control processes to bear on the problem and this involves greater use of executive resources.

Within a working memory framework maintenance rehearsal, for example, in the articulatory loop can be carried out using very limited executive resources while more elaborate rehearsal is ongoing. Furthermore this slave system (and others) can be used to hold material that has been elaborated. Thus the loop might hold a partial solution to a mental arithmetic problem while further arithmetic operations are performed on another stage in the problem (Hunter, 1979). If 'slaves' are to be useful then they must act as holding stores for information that does not, for the time being, require further elaboration. The executive expends most of the capacity that it directs to a slave system at the input and retrieval stages. If it must also expend a large amount of its capacity during maintenance rehearsal then there would be little advantage in postulating slave systems. Tracking requires a lot of executive capacity and it is therefore difficult to encode spatial information while performing this activity (Experiment 3.3.) but little or no interference occurs after encoding (Experiment 4.2.)

It is clear that the non-verbal spatial memory task involves some elaborate rehearsal because the relationship of the filled locations to each other must be encoded. This involves some abstraction of spatial properties because a size transformation must be made (the size of the V.D.U. used to present the materials was of a much greater order of magnitude than the response box on the recall sheet). This transform is unlikely to occur at retrieval. We do not know what size 'screen' the scratch pad has but there is evidence that the real magnitude of large objects is not represented (see for example Kosslyn, 1975) although the relative magnitudes of its components may be conserved.

The interference with the spatial memory task might well occur during the preparation of the representation for entry onto the scratch pad. This hypothesis generates a number of further experiments that would test this prediction. One might, for example, use geometrically symmetrical arrangements and random arrays thereby manipulating the 'Pragnanz' of the array (see Koffka, 1935, page 110). Thus it would be predicted that tracking would have a greater effect on random arrays and, crucially, it would still have no effect after encoding.

Another prediction forthcoming from this hypothesis is that loading the scratch pad with spatial information should not reduce tracking performance unless some transform were required while tracking. Thus, for example, if a configuration that had been encoded prior to tracking had to be matched to an array presented while tracking one would predict that greater matching disparity would cause greater tracking impairment. The 'mental rotation' paradigm could be used for the matching task. The latter experiment is likely to be more crucial because highly symmetrical patterns may be verbally recodable although this problem should be surmountable with large arrays. One would also predict, intuitively, that random patterns would take longer to encode.

Within the verbal domain one would predict that preloads that would not 'overflow' the loop would not impair elaboration that did not require the loops capacity also (see Baddeley and Hitch, 1974).

8.7.2.2. Assembly and Priming.

Extensive, difficult tracking before trial presentation and during presentation should cause a greater performance decrement on a spatial memory task than tracking during presentation only. If tracking impairs the assembly of working memory constellations then pretrial tracking should impair priming. One might also envisage a subtle effect of unpredictability of trial type also if trial presentation was brief.

8.7.2.3. Dismantling Constellations.

If the contention of this thesis that a flexible working memory system must be able to rapidly switch from one mode of processing to another is valid then constellations should be dismantled rapidly. One would expect however that this process would be slowed in instances where it is not clear that the current assembly will not continue to be useful. Furthermore it is predicted that complex assemblies would be dismantled more quickly than simpler assemblies because they are harder to maintain. If the latter contention is true then slave system monitoring should require a significant amount of central capacity when large constellations are in existence because this model predicts that little monitoring of the contents of slaves is necessary but 'attention' is required to hold together the constellation.

This would be difficult to test empirically but dual task experiments like Experiment 4.3. (the verbal preload experiment) with systematic manipulation of order of recall (location 1st etc.) compared with probed recall (a signal at retrieval indicating whether locations or consonants are to be recalled first) may throw some light on this aspect of the theory.

8.7.2.4. Executive Monitoring

The attentional capacity of the system is crucial. In Chapter 2 an analogy was made with a manager overseeing a factory floor space. If this 'manager' was distracted one would expect that new commands (control processes) could not be issued and any ongoing work requiring attention would be disrupted. However in any reasonably well organised factory one would not expect all production to grind to a halt. Routine aspects of production would continue. Similarly executive distraction should largely affect elaborative processing but have little or no effect on maintenance rehearsal.

Everyday experience conflicts with this argument. It requires very little distraction to make one forget a telephone number that is being rote rehearsed. Presumably this is because the number overflows the loop and must therefore be continually fed through the loop from the central store. A three digit number, for example, would not overflow the loop and would therefore be less subject to distraction unless the distractor impinged on the loop (e.g. 'unattended speech [Salame and Baddeley, 1982]).

Large memory loads not only fill the central store but require a large part of the executive's attentional capacity also. Some cognitive tasks have very high attentional demands e.g. shadowing prose. Such attentional tasks should disrupt the deployment of slaves but have little effect after encoding unless their performance requires the use of a specific slave system. One might consider, for example, that an imaginary walk down a well known corridor with a requirement to count the doors would be a useful task for 'knocking out' both the articulatory loop and the scratch pad. Unfortunately it would also use up some of the attentional resources of the executive.

Such a task when compared with a shadowing task matched for difficulty on a verbal memory test might prove useful in disrupting the visuo-spatial scratch pad during maintenance rehearsal. It is necessary to show that disruption can occur after the encoding phase otherwise the lack of an effect of interference tasks on visuo-spatial representation can be explained by the simple generalisation that the spatial information has entered long-term memory. Such a disruptive effect would suggest that the resilience of visuo-spatial representation to tracking, after encoding, is indeed due to the lack of an effect of monitoring disruption on a working memory component during maintenance rehearsal. The imagery task should require the memory capacity of the scratch pad (which is finite while presumably long-term memory, in practice, is not) while tracking does not. Unfortunately this experiment has not yet been carried out.

The lack of an effect of tracking after encoding (Experiment 4.2.) might well be explained in terms of registration in long-term memory. This explanation would be functionally isomorphic with the maintenance rehearsal explanation. However, given that we know very little about long-term memory, a re-registration explanation does not really say very much. It entails that we cannot interfere with the representation during storage and this seems unlikely.

8.8. Simple Working Memory Constellations.

Simple working memory constellations consist of assemblies comprising the central processor and one or two slave systems. For example, it was hypothesised that the memory tasks used in Experiments 5.1., 5.2., 5.3. and 6.3. used assemblies consisting of the executive and the scratch pad and articulatory loop while the experiments reported in Chapters 3 and 4 required the executive and the scratch pad and the remaining experiments required the executive and the loop.

Unfortunately an interference task that only interferes with the scratch pad (but not the executive) has not been found. However a recent paper by Logie (1986) employed an 'unattended' picture task which may go some way towards overcoming this problem. Baddeley (1981) has commented that such a task would be a major asset. What we need is an equivalent to articulatory suppression. Undoubtedly one could load up the scratch pad with spatial information but unfortunately 'spatial' is a rather abstract concept that is not related to a particular sense modality whereas articulation is in a sense intimately related to the auditory modality. Assuming that one would normally load the scratch pad with visuo-spatial information it would be necessary then to introduce a memory task (not a tracking task as this requires executive resources also) that was spatial but not visual. Such tasks would not be difficult to develop but it would be difficult to tap the retrieval process because response is usually visual (e.g. drawing shapes or pointing) and the conflict might well be visual rather than visuo-spatial.

A more interesting approach to take might be to consider the scratch pad as a part of an executive/scratch pad complex. Thus the best strategy, the one adopted in Chapter 4, would be to interfere with the executive component rather than the scratch pad itself. Thus, for example, the results of Experiment 4.2. (with interference tasks presented after spatial encoding) suggest that the scratch pad, in isolation, is only used for maintenance rehearsal. Such an experiment could be replicated with increasing spatial loads until significant performance deficits occurred. This would give a rough idea of just how much maintenance rehearsal can occur on the scratch pad.

Generally the results of the experiments reported in Chapters 5 and 6 are rather noisy and ambiguous. This is probably largely due to our poor understanding of the task demands of these dual task situations. Attempts to induce particular processing strategies (Experiment 5.2.) failed and Experiments 6.1. - 6.3. produced complex results that certainly require further investigation.

However Experiment 5.1. clearly demonstrated that dual coding occurs and this is reflected in the deployment of more than one memory structure. Spatial information processing does not require an articulatory loop but this is added to the assembly when it can be used. This additional construct does not seem to be under violitional control at least in the short-term (otherwise one would not expect articulatory suppression to ever produce a performance increment (Evans and Brooks, 1981) and subjects would not attempt verbal recoding of spatial material with articulatory suppression) and this may be the result of poor insight into the range of strategies available.

No attempt has been made to examine complex working memory constellations. Indeed we do not know if such constructions are possible. However given the complexity of the environment it seems likely that such constructions are possible and that the major limiting factor on such constructions is the executives ability to maintain such edifices.

For the moment it would probably be more wise to tackle the problems arising from the study of simple constellations. A brief perusal of the literature suggests that there are still many grey areas to be examined. Indeed the study of complex constellations might well be tackled better within the domain of applied psychology. The 'real world' provides many complex situations that should provide clues to the nature of complex cognitive functioning. I would argue that for the study of working memory to be really fruitful the 'British tradition' of not clearly separating purely academic research from applied research should be followed.

8.9. Possible Future Trends In Working Memory Research.

The working memory model's main strength lies in its potential for explaining cognition in 'everyday life'. However it has already been noted that as the model is applied to an increasing range of activities it has tended to increase in complexity itself.

Some recent applications of the theory do look promising. Wilson, Brooks and Phillips (personal communication, 1984), at the University of Stirling, have recently commenced a project that examines visual working memory in a population of patients with closed head injuries. This approach should not only result in the further fractionation of the scratch pad but may well prove significant in the diagnosis of the location and extend of closed head injuries.

Hitch (1983) has reviewed the literature on working memory in animals. Examining working memory in animals is of course a very different endeavour to looking at human working memory. It was argued in Chapter 1 that other organisms do not seem to have a communications system that is as flexible and elaborate as human language. Nevertheless if one accepts the basic tenets of the theory of evolution then one would expect organisms to have a working memory system that reflects the needs of the organism that is well adapted to survival in its ecological niche. Darwin (1859) commented that " ... the mental qualities of our domestic animals vary, and ... the variations are inherited"(page 262). Darwin is loathe to assign consciousness to other species but he considers their 'instinctive' behaviour to have resulted from the pressures of natural selection. A more recent literature has sought to demonstrate under laboratory conditions that organisms are particularly good at learning discriminations that are appropriate to their ecological niche (see for example Bitterman, 1975). One might expect that highly mobile organisms which do not display highly stereotypic behaviour (i.e., organisms that clearly learn new contingencies introduced into the environment) would have quite complex working memory systems. Olton (1977), for example, has shown that rats can remember the spatial location of depleted food stores.

One should be very cautious in making inter-species comparisons. Nevertheless one might consider that other species might have more 'primitive' working memory systems i.e. that they might have systems that do not process verbal information but do process spatial information. Current research suggests that the hippocampus is involved in spatial memory processing in humans and other species (this was discussed briefly in Chapter 3) and while it is not suggested that comparative studies should be carried out it is likely that findings from animal studies might provide some clues as to the sorts of questions we should be asking about human spatial memory.

The verbal processing domain may well have evolved by adaptation of acoustic type memory stores. If this is the case then animal studies should not be neglected. Similarly spatial processing may have an evolutionary history and it is possible that our species may not have the most sophisticated spatial processing domain. These are points worth considering if an ethological approach to working memory is not to be ruled out.

Given, however, that any comparative study between species is likely to be limited it might be more fruitful to look at cross-cultural aspects of memory. This has been mentioned at various points in this thesis. One would hope that future working memory research would encompass this approach as well as studies of individual differences within societies. Developmental studies in working memory also seem to be proliferating (see, for example, Hitch and Halliday, 1983).

In summary if a flexible working memory model is to be developed then a highly interdisciplinary approach will be necessary. One can only hope that the initial indications of such an approach will continue to develop and broaden the scope of memory research. Without broadening our horizons it is unlikely that we will ever achieve a theoretical sophistication beyond that achieved by Ebbinghaus.

8.10. Obstacles.

In reality research endeavours are restricted. There is a mismatch between what needs to be examined and what will be examined. The above suggestions would require a research program that is unlikely to develop. Besides the obvious financial limitations on research there are other obstacles to developing an adequate account of working memory.

The limitations of the research techniques that we currently possess have already been discussed. There is no reason to suppose however, that better techniques would not be developed in response to new theoretical developments. Necessity may well be the mother of invention but new theories have been known to sire a few innovative research techniques also. A much greater problem that has always plagued psychology is the lack of a 'paradigm' (Kuhn, 1970) i.e. a body of theory that is accepted by a general consensus of opinion. Memory theories tend to have brief life spans and several tend to exist concurrently. This fragmentation undoubtedly reflects healthy scepticism about the validity of theories but it has not led to a better understanding of the problems because the same old theories keep emerging in new guises. Associationist theories, for example, have a long history (see, for example, James, 1890; Watson, 1930; McDougall, 1947; Eich, 1982). These theories differ in the language used to describe them and in the weight placed on the role of association formation in memory. Association is undoubtedly an important aspect of memory and the treatment of this by Eich is much more sophisticated than the account given by James. Furthermore Eich does address the problem of how associations might be formed by developing a functional model whereas James was not in a position to offer more than some vague, speculative 'physiologisms'. One is tempted however to conclude that a holographic model is merely a reflection of the current zeitgeist which is replacing, to some extent, earlier analogies derived from technological innovations (e.g. telephone exchanges, computers etc.). Indeed correspondence to the Bulletin of the British Psychological Society (December, 1979) included a facetious letter suggesting an award for the first model of human behaviour using silicone chip technology.

Psychological theorising has always relied on analogy to the physical world and this has undoubtedly been a useful heuristic but the heuristic value of an analogy is severely reduced when it is taken too literally. It was argued in section 8.3. that the computer analogy is limited and an overly literal reliance on such an analogy is likely to result in models of 'micro's' not memories. This sort of thing is often a danger when functional models are developed.

Most of the criticisms offered in this section apply to the model of working memory outlined here. It is hoped, however, that a convergent approach to working memory research (drawing on neuropsychology, developmental psychology etc.) will result in a model that is not 'paradigm bound' (i.e. not the property of a group of individuals all working from the same perspective with the same ideas on how to do 'research').

8.11. Overview

Working memory is seen as a flexible system strategically controlled by a central executive with a diverse set of resources at its disposal which it can use in isolation or combination depending on the nature of the task confronting the subject.

This thesis has outlined some of the ways in which the executive can deploy the scratch pad in isolation and in conjunction with the articulatory loop. It is argued that multifaceted tasks require a complex multifaceted system. Given the diversity of human cognitive skills, it is argued that a general resources working memory model without functionally specific sub-systems could not adequately account for the flexibility of human cognitive processing.

Combinations of sub-systems working in unison are designated working memory constellations and they are assembled and maintained by a central executive system comprising a central store in which elaborate rehearsal is carried out and an attentional monitoring device(s).

This complex system is responsible for processing in real time and is linked to long term memory in an as yet unspecified manner. Presumably the system has scratch pad type stores for all the sensory modalities (gustation etc.) but these have not been examined in detail yet. This thesis examined memory performance in the auditory and visual modality using a diverse range of memory tasks. It was argued that a working memory model can explain, functionally, how we perform these activities.

REFERENCES

Allport, D.A. Patterns and Actions: Cognitive mechanisms are content-specific. In G. Claxton (ed.) Cognitive Psychology: New Directions. London, Routledge - Kegan Paul, 1980.

Aristotle. De Memoria et Reminiscentia. Trans. Sorabji R. Duckworth, London, 1972.

Atkinson, R.C. and Shiffrin, R.M. Human memory: a proposed system and its control processes. In K.W. Spence and J.T. Spence (eds.). The Psychology of Learning and Motivation: Advances in Research and Theory, vol. 2, 1968, New York, Academic Press.

Augustine St. Confessions. Ed. A.B. Outler, Westminster Press, London, 1955.

Avons, S.E. and Phillips, W.A. Visualization and Memorization as a Function of Display Time and Post stimulus Processing Time: Journal of Experimental Psychology: Human Learning and Memory. 1980, 6, 407-420.

Badal, J. Contribution a l'etude des cecites psychiques. Alexie, agraphic, hemianopsie inferieure trouble du sens d'l'espace. Archives of Opthalmology, 1888, 140, 97-117.

Baddeley, A.D. Short-term memory for word sequences as a function of acoustic, semantic and formal similarity. Quarterly Journal of Experimental Psychology, 1966, 18, 362-365.

Baddeley, A.D. A three-minute reasoning test based on grammatical transformation. Psychonomic Science, 1968, 10, 341-342.

Baddeley, A.D. The Psychology of Memory. New York, Harper Row, 1976.

Baddeley, A.D. The concept of working memory: A view of its current state and probable future development. Cognition, 1981, 10, 17-23.

Baddeley, A.D. Your Memory: A Users Guide. Harmondsworth, Pelican Books, 1982a.

Baddeley, A.D. Domain of Recollection, Psychological Review, 1982b, 89, 702-729.

Baddeley, A.D. Reading and working memory. Bulletin of the British Psychological Society, 1982c, 35, 414-417.

Baddeley, A.D. Working Memory. Philosophical Transactions of the Royal Society, London. 1983, B302, 311-324.

Baddeley, A.D., Grant, S., Wight, E. and Thomson, N. Imagery and Visual Working Memory. In P.M.A. Rabbitt and S. Dornic. (Eds.). Attention and Performance V. Lawrence Erlbaum, Hillsdale, N.J., 1975.

Baddeley, A.D. and Hitch, G.J. Working Memory. In G.H. Bower (Ed.) The Psychology of Learning and Motivation, vol. 8. 1974. New York, Academic Press.

Baddeley, A.D. and Lewis, V. Inner Active Processes in Reading: The Inner Voice, the Inner Ear, and the Inner Eye. In A.M. Lesgold and C.A. Perfetti (Eds.). Interactive processes in reading. Hillsdale, N.J. Erlbaum, 1981.

Baddeley, A.D., Lewis, V. and Vallor, G. Exploring the Articulatory Loop. Quarterly Journal of Experimental Psychology, 1984, 36A, 233-252.

Baddeley, A.D. and Lieberman, K. Spatial Working Memory. In R. Kicherson (Ed.). Attention and Performance VIII, Lawrence Erlbaum, Hillsdale N.J. 1980.

Baddeley, A.D., Thomson, N. and Buchanan, M. Word length and the structure of short-term memory. Journal of Verbal Learning and Verbal Behaviour, 1975, 14, 575-589.

Beatty J. Introduction to Physiological Psychology: Information Processing in the nervous system. Monterey, Brooks/Cole, 1975.

Belmont, J.M., Butterfield, E.C. and Borkowski, J.R. Training retarded people to generalize memorisation methods across memory tasks. In M.M. Gruneberg, P.E. Morris and R.N. Sykes (Eds.). Practical Aspects of Memory, London, Academic Press, 1978.

Benton, A. Visuo-perceptive, Visuo-spatial and Visuo constructive Disorders. In K. Heilman and E. Valenstein (Eds.). Clinical Neuropsychology, New York, Oxford University Press, 1979.

Betts, G.H. The distribution and functions of mental imagery. Teachers College, Columbia, New York, 1909

Bisiach, E. and Luzzatti, C. Unilateral neglect of representational space. Cortex, 1978, 14, 129-133.

Bitterman, M.E. The Comparative Analysis of Learning. Science, 1975, 188, 699-709.

Broadbent, D.E. Perception and Communication. Pergamon Press, London, 1958.

Broadbent, D.E. Decision and Stress, New York, Academic Press, 1971.

Broadbent, D.E. Association Lecture: From the percept to the cognitive structure. In J. Long and A.D. Baddeley (Eds.). Attention and Performance IX. Hillsdale, N.J., Erlbaum. 1981.

Brooks, L.R. The suppression of visualisation in reading. Quarterly Journal of Experimental Psychology, 1967, 19, 289-299.

Brooks, L.R. Spatial and verbal components of the act of recall. Canadian Journal of Psychology, 1968, 22, 349-368.

Bruce, D. The How and Why of Ecological Memory. Journal of Experimental Psychology: General, 1985, 114, 78-90.

Bruning, J.L. and Kintz, B.L. Computational Handbook of Statistics 2nd ed. Scott Foresman, Glenview, Illinois, 1977.

Campione, J.C. and Brown, A.L. Training general meta cognitive skills in retarded children. In M.M. Gruneberg, P.E. Morris and R.N. Sykes (Eds.). Practical Aspects of Memory, London, Academic Press, 1978.

Cattell, R.B. Abilities: Their structure, growth and action. Houghton Mifflin, Boston, 1971.

Cherry, E.C. Some experiments on the recognition of speech with one and with two ears. Journal of the Acoustical Society of America, 1953, 25, 975-979.

Conrad, R. Short-term memory processes in the deal. British Journal of Psychology, 1970, 61, 179-195.

Corkin, S. Tactually-guided maze learning in man. Effect of unilateral cortical excisions and bilateral hippocampal lesions. Neuropsychologia, 1965, 3, 339-351.

Cosden, M.A., Ellis, H.C. and Feeney, D.M. Cognitive Flexibility - Rigidity, Repetition Effects, and Memory. Journal of Research In Personality, 1979, 13, 386-395.

Craik, F.I.M. and Lockhart, R.S. 'Levels of processing: a framework for memory research'. Journal of Verbal Learning and Verbal Behaviour, 1972, 11, 671, 11, 671-684.

Crowder, R.G. and Morton J. Precategorical acoustic storage (PAS). Perception and Psychophysics, 1969, 5, 365-373.

Darwin, C. The Origin of Species by Means of Natural Selection. John Murray, London, 1859. Reprinted by Penguin Books, Harmondsworth, 1968.

Davies, G.M Face Recognition: Issues and Theories. In M.M. Gruneberg, P.E. Morris and R.N. Sykes (Eds.). Practical Aspects of Memory. London, Academic Press, 1978.

Dempster, J.J.B. An investigation into the use of verbal and spatial tests in the selection of boys for grammar and secondary technical schools. Unpublished Ph.D. Thesis, University of London, 1951 (cited in MacFarlane-Smith 1964).

De Renzi, E. Disorders of Space Exploration and Cognition. John Wiley, Chichester, 1982.

De Renzi, E., Faglioni, P. and Previdi, P. Spatial memory and locus of lesion. Cortex, 1977, 13, 424-433.

De Renzi, E. and Nichelli, P. Verbal and non-verbal short-term memory impairment following hemispheric damage. Cortex, 1975, 11, 341-354.

De Soto, C.B., London, M. and Handel, S. Social Reasoning and Spatial Paralogic. Journal of Personality and Social Psychology, 1965, 2, 515-521.

Deutsch, J.A. and Deutsch, D. 'Attention': Some theoretical considerations. Psychological Review, 1963, 70, 80-90.

Dixon, N. Preconscious processing. Chichester, John Wiley, 1981.

Ehrlichman, H. and Barrett, J. Right Hemisphere Specialisation for Mental Imagery. A Review of the Evidence. Brain and Cognition, 1983, 2, 55-76

Eich, J.E. The cue-dependent nature of state-dependent retrieval. Memory and Cognition, 1980, 8, 157-173.

Eich, J.M. A Composite Holographic Associative Recall Model. Psychological Review, 1982, 89, 627-661.

Einstein, A. Letter to Karl Popper 11th September 1935. Reprinted in K.R. Popper. The Logic of Scientific Discovery. Hutchinson, London, 1959. p. 457-464.

Einstein, A. "Autobiographical Notes". In P.A. Schilpp (Ed.). Albert Einstein: Philosopher-Scientist. Open Court Publishing Co., La Salle, 1951.

Ellis, N.C. and Hennelley, R.A. A bilingual word-length effect: implications for intelligence testing and the relative ease of mental calculation in Welsh and English. British Journal of Psychology, 1980, 71, 43-52.

Evans, J.St.B.T. and Brooks, P.G. Competing with Reasoning: A Test of the Working Memory Hypothesis. Current Psychological Research, 1981, 1, 139-147.

Eysenck, M.W. Human Memory: Theory, Research and Individual Differences. Pergamon Press, London, 1977.

Flavell, J.H., Beech, D.R. and Chinsky, J.M. Spontaneous verbal rehearsal in a memory task as a function of age. Child Development, 1966, 37, 283-299.

Frankish, C.R. Organisational Factors in Short-term Memory. Unpublished Ph.D Thesis. University of Cambridge, 1976.

Gainotti, G., Messerli, P. and Tissot, R. Qualitative analysis of unilateral spatial neglect in relation to laterality of cerebral lesions. Journal of Neurology, Neurosurgery and Psychiatry, 1972, 35, 545-550

Galton, F. Inquiries into human faculty and its development. Macmillan, 1883.

Gazzaniga, M.S. The Split Brain in Man. Scientific American, 1967, reprinted in R.C. Atkinson (Ed.). Psychology In Progress, San Francisco, W.M. Freeman, 1971.

Geschwind, N. Specializations of the Human Brain. Scientific American, 1979, 241, P. 158-168.

Gilling, R. and Brightwell, R. The Human Brain. London, Orbis and B.B.C., 1982.

Greenwald, A.G. Within-Subjects Designs: To Use or Not to Use? Psychological Bulletin, 1976, 83, 314-320.

Gruneberg, M.W. The distinction between short-term memory and long-term memory. Bulletin of the British Psychological Society, 1976, 29, 327-333.

Gruneberg, M.M., P.E. Morris and R.N. Sykes (Eds.). Practical Aspects of Memory. Academic Press, London, 1978.

Guilford, J.P. The Nature of Human Intelligence. New York, McGraw-Hill, 1967.

Haber, R.N. The impending demise of the icon: A critique of the concept of iconic storage in visual information processing. The Behavioural and Brain Sciences, 1983, 6, 1-54.

Hardyk, C.D. and Petrinovitch, L.R. Subvocal speech and comprehension level as a function of the difficulty level of reading material. Journal of Verbal Learning and Verbal Behaviour, 1970, 9, 647-652.

Hatano, G. and Osawa, K. Digit memory of grand experts in abacus-derived mental calculation. Cognition, 1983, 15, 95-110.

Haxby, J.V., Lundgreu, S.L. and Morley, G.K. Short-term retention of Verbal Visual Shape and Visuo-spatial location information in normal and amnesic subjects. Neuropsychologia, 1983, 21, 25-33.

Hellige, J.B. and Cox, P.J. Effects of Concurrent Verbal Memory on Recognition of Stimuli from the Left and Right Visual Fields. Journal of Experimental Psychology: Human Perception and Performance, 1976, 2, 210-221

Hellige, J. Cox, P., and Litvac L. Information processing in the cerebral hemispheres: selective hemispheric activation and capacity limitations. Journal of Experimental Psychology: General. 1979, 108, 251-279.

Hitch, G.J. Mental Arithmetic: Short-term storage and information processing in a cognitive skill. In A.M. Lesgold, J.W. Pellegrinor, S.D. Fokkema and R. Glaser (Eds.). Cognitive psychology and instruction. New York, Plenum, 1978.

Hitch, G.J. Developing the concept of working memory. In G. Claxton (ed). Cognitive Psychology: New Directions. London, Routledge, Kegan and Paul, 1980.

Hitch, G.J. Short-term memory processes in humans and animals. In A.R. Mayes (Ed.) Memory in Animals and Humans. Van Nostrand, London, 1983.

Hitch, G.J. Working Memory. Psychological Medicine, 1984, 14, 265-271.

Hitch, G.J. and Baddeley, A.D. Verbal Reasoning and working memory. Quarterly Journal of Experimental Psychology, 1976, 28, 603-621.

Hitch, G.J. and Baddeley, A.D. Working Memory. Open University Course D303, Unit 15. Milton Keynes, Open University Press, 1977.

Hitch, G.J. and Halliday, M.S. Working memory in children. Philosophical Transactions of the Royal Society: London. 1983, B302, 325-340.

Hockey, G.R.J. Effect of Loud Noise on attentional selectivity. Quarterly Journal of Experimental Psychology, 1970, 22, 28-36.

Hunt, E. Mechanics of verbal ability. Psychological Review, 1978, 85, 109-130.

Hunt, E. Intelligence as an information processing concept. British Journal of Psychology. 1980, 71, 449-474.

Hunter, J.M.L. Memory in Everyday Life. In M.M. Gruneberg and P.E. Morris (Eds.). Applied Problems in Memory. London, Academic Press, 1979.

Idzikowski, C. and Baddeley, A.D. Eye movements and imagery. Paper presented to the Experimental Psychology Society, 1984.

James, W. Principles of Psychology. New York, Dover, 1950 (original publication 1890)

James, W. Psychology: briefer course. New York, Holt, 1892.

Jorm, A.F. Specific reading retardation and working memory: A review. British Journal of Psychology, 1983, 74, 311-342.

Kahneman, D. Attention and Effort. New Jersey, Prentice Hall, 1973.

Kail, R. The Development of Memory in Children. San Francisco, W.H. Freeman, 1979.

Kearins, J.M. Visual Spatial Memory in Australian Aboriginal Children of Desert Regions. Cognitive Psychology, 1981, 13, 434-460.

Keeney, T.J., Cannizzo, S.R. and Flavell, J.H. Spontaneous and induced verbal rehearsal in a recall task. Child Development, 1967, 38, 953-966.

Kennedy, B.A. and Miller, D.J. Persistent use of verbal rehearsal as a function of information about its value, Child Development, 1976, 47, 566-569.

Kerr, N.H. The Role of Vision in "Visual Imagery" Experiments: Evidence From the Congenitally Blind. Journal of Experimental Psychology: General. 1983, 112, 265-277.

Klapp, S.T., Marchburn, E.A. and Lester, P.T. Short-Term Memory Does Not Involve the "Working Memory" of Information Processing: The Demise of a Common Assumption. Journal of Experimental Psychology: General. 1983, 112, 240-264

Koffka, K. Principles of Gestalt Psychology. Kegan Paul Trench and Trubner, London, 1935.

Kosslyn, S.M. Information Representation in Visual Images. Cognitive Psychology, 1975, 7, 341-370.

Kosslyn, S.M. and Pomerantz, J.R. Imagery propositions, and the form of internal representations. Cognitive Psychology, 1977, 9, 52-76.

Kroll, N.E.A. Parks T. Parkinson, S.R. Bieber, S.L. and Johnson, A.L. Short-term memory while shadowing: Recall of visually and aurally presented letters. Journal of Experimental Psychology, 1970, 85, 220-224.

Kuhn , T.S. The Structure of Scientific Revolution. 2nd Ed. University of Chicago Press, Chicago, 1970.

Lachman, R., Lachman, J.L. and Butterfield, E.C. Cognitive Psychology and Information Processing. Hillsdale, New Jersey, Lawrence Erlbaum, 1979.

Lambert, A.J. Right hemisphere language processing. Unpublished Ph.D thesis, University of Leicester, 1981.

Lenneberg, E.H. On explaining language. Science, 1969, 164, 635-643.

Littauer, U.Z., Dudai, Y. Silman, I., Teichberg, V.I. and Vogel, Z., (Eds.). Neurotransmitters and their Receptors. John Wiley, Chichester, 1980.

Logan, G.D. On the use of a concurrent memory load to measure attention and automaticity. Journal of Experimental Psychology: Human Perception and Performance, 1979, 5, 189-207.

Logan, G.D. Short-Term Memory Demands of Reaction Time Tasks That Differ in Complexity. Journal of Experimental Psychology: Human Perception and Performance, 1980, 6, 375-389.

Logie, R.H. Visuo-Spatial Processing in Working Memory. Quarterly Journal of Experimental Psychology, 1986, 38A, 229-247.

Lovie, A.D. Attention and behaviourism - fact and fiction. British Journal of Psychology, 1983, 74, 301-310.

Luce, T. Blacks, whites and yellows: they all look alike to me. Psychology Today, 1974, 8, 107-108.

Luria, A.R. The Mind of A Mnemonist. Harmondsworth, Penguin, 1968.

MacFarlane-Smith, I. Spatial Ability. London University of London Press, 1964.

McDougall, W. An Outline of Psychology, 11th Ed. Methuen, London, 1947.

McGeer, P.L., Eccles, J.C. and McGeer, E.R. Molecular Neurobiology of the Mammalian Brain. Plenum New York, 1978.

Meadows, J.C. The Anatomical Basis of Prosopagnosia. Journal of Neurology, Neurosurgery, and Psychiatry, 1974, 37, 489-501.

Miller, E. Recovery and Management of Neuropsychological Impairments. Chichester, Wiley, 1984.

Miller, G.A., Galanter, E. and Pribram, K.H. Plans and the Structure of Behaviour. New York, Holt, Rinehart and Winston., 1960.

Milner, B. Visually-guided maze learning in man: Effects of Bilateral Hippocampal, Bilateral Frontal, and Unilateral Cerebral Lesions. Neuropsychologia, 1965, 3, 317-338.

Milner, B. Brain mechanisms suggested by studies of temporal lobes. In F.L. Darley (Ed.). Brain mechanisms underlying speech and language. New York, Grune and Stratton, 1967.

Milner, B. Visual recognition and recall after right temporal lobe excision in man. Neuropsychologia, 1968, 6, 191-209.

Milner, B. Inter hemispheric differences in the localization of psychological processes in man. British Medical Bulletin, 1971, 27, 272-277.

Milner, B. Hemispheric Specialization, Scope and Limits. In F.O. Schmitt and P.G. Worden (Eds.). The Neurosciences Third Study Program, Massachusetts, M.I.T. Press, 1974.

Milner, B. Clues to the Cerebral Organisation of Memory. In Buser and Rougeul-Buser (Eds.). Cerebral Correlates of Conscious Experience. Elsevier/North-Holland Biomedical Press, 1978.

Moar, I.T. Mental Triangulation and the nature of internal representation of space. Unpublished Ph.D Thesis. University of Cambridge, 1978.

Moray, N. Attention in dichotic listenings: Affective cues and the influence of instructions. Quarterly Journal of Experimental Psychology, 1959, 11, 56-60.

Morris, N. and Jones, D.M. Reporting words from the eye or the ear? To Write or to Speak? Ergonomics, In press.

Neale, J.M. and Liebart, R.M. Science and behaviour: an introduction to methods of research. New Jersey, Prentice Hall, 1973.

Neisser, U. 'The multiplicity of thought'. British Journal of Psychology, 1963, 54, 1-14.

Neisser, U. Cognition and Reality. San Francisco, Freeman, 1976.

Neisser, U. Memory: What are the Important Questions? In M.M. Gruneberg., P.E. Morris and R.N. Sykes (Eds.). Practical Aspects of Memory. Academic Press, London, 1978.

Neisser, U. (Ed.). Memory Observed. San Francisco, W.H. Freeman, 1982.

Nicholson, R. The relationship between memory span and processing speed. In M. Friedman, J.P. Das and N. O'Connor (Eds.). Intelligence and Learning. New York, Plenum, 1981.

Norman, D.A. and Bobrow, D.G. On data limited and resource limited processes. Cognitive Psychology, 1975, 7, 44-64.

Oakhill, J.V. and Johnson-Laird, P.N. Representation of Spatial Descriptions in Working Memory. Current Psychological Research and Reviews, 1984, 3, 52-62.

O'Keefe, J. and Nadel, L. The Hippocampus as a cognitive map. New York, Oxford University Press, 1978.

Olton, D.S. Spatial Memory. Scientific American, 1977, 236, 82-99.

Paivio, A. Imagery and Verbal Processes. New York, Holt, Rinehart and Winston, 1971.

Paivio, A., Yuille, J.C. and Madigan, S. Concreteness, imagery and meaningfulness values for 925 nouns. Journal of Experimental Psychology, 1968, 76 (1, Part 2).

Phillips, W.A. Short-term visual memory. Philosophical Transactions of the Royal Society, London, 1983, B302, 295-309.

Phillips, W.A. and Christie, D.F.M. Components of visual memory. Quarterly Journal of Experimental Psychology, 1977a, 29, 117-133.

Phillips, W.A. and Christie, D.F.M. Interference with visualization. Quarterly Journal of Experimental Psychology, 1977b, 29, 637-650.

Posner, M.I. Chronometric Explorations of Mind. Hillsdale, N.J. Lawrence Erlbaum, 1978.

Poulton, E.C. Unwanted Range Effects From Using Within-Subject Experimental Designs. Psychological Bulletin, 1973, 80, 113-121.

Pylyshyn, Z.W. What the minds eye tells the minds brain: A critique of mental imagery. Psychological Bulletin, 1973, 80, 1-24.

Rabbitt, P.M.A. Cognitive Psychology Needs Models for Changes in Performance with Old Age. In J. Long and A.D. Baddeley (Eds.). Attention and Performance IX, Hillsdale, Lawrence Erlbaum, 1981.

Reason, J. Absent-Mindedness. In Nicholson, J. and Beloff, H. (Eds) Psychology Survey 5, Leicester, The British Psychological Society, 1984.

Reisberg, D., Rappaport, I. and O'Shaughnessy, M. Limits of Working Memory: The Digit Digit-Span. Journal of Experimental Psychology: Learning, Memory and Cognition. 1984, 10, 203-221.

Richardson, J.T.E. Mental Imagery and Human Memory. London, MacMillan, 1980.

Richardson, J.T.E. and Baddeley, A.D. The effect of articulatory suppression in free recall. Journal of Verbal Learning and Verbal Behaviour, 1975, 14, 623-629.

Ryan, J. Grouping and Short-Term Memory: Different means and patterns of grouping. Quarterly Journal of Experimental Psychology, 1969, 21, 137-147.

Salame, P. and Baddeley, A.D. Disruption of short-term memory by unattended speech: implications for the structure of working memory. Journal of Verbal Learning and Verbal Behaviour, 1982, 21, 150-164.

Salthouse, T.A. Using selective interference to investigate spatial memory representations. Memory and Cognition, 1974, 2, 749-757.

Semmes, J., Weinstein, S., Ghent, L. And Teuber, H.L. Correlates of impaired orientation in personal and extrapersonal space. Brain, 1963, 86, 747-772.

System Technical Journal, 1948, 27, 379-423, 623-656.

Shepard, R.N. and Cooper, L. Mental images and their transformations, Cambridge, Massachusetts, M.I.T. Press, 1982.

Shepard, R.N. and Metzler, J. Mental rotation of three dimensional objects. Science, 1971, 171, 701-703.

Sokolov, A.N. Inner Speech and Thought. New York, Plenum, 1972.

Spearman, C. *The nature of 'Intelligence' and the principles of cognition*. London, Macmillan, 1923.

Taylor, M.M. Effect of Anchoring and Distance Perception on the Reproduction of Forms. *Perceptual and Motor Skills*. 1961, *12*, 203-230.

Thurstone, L.L. Primary mental abilities. *Psychometrika Monographs No. 1*., 1938.

Thurstone, L.L. and Jeffrey, T.E. *Flags: A test of Space Thinking*. Chicago, Education Industry Service, 1956.

Treisman, A.M. Monitoring and storage of irrelevant messages in selective attention. *Journal of Verbal Learning and Verbal Behaviour*, 1964, *3* 449-459.

Underwood, B.J. Individual differences as a crucible in Theory Construction. *American Psychologist*, 1975, *30*, 128-134.

Vallar, G. and Baddeley, A.D. Fractionation of working memory: Neuropsychological evidence for a phonological short-term store. *Journal of Verbal Learning and Verbal Behaviour*, 1984, *23*, 151-161.

Walsh, K.W. *Neuropsychology: A clinical approach*. Churchill Livingstone, Edinburgh, 1978.

Warrington, E.K. Neurological disorders of memory. *British Medical Bulletin*, 1971, *27*, 243-247.

Warrington, E.K., Logue, V. and Pratt, R.T.C. The anatomical localisation of selective impairment of auditory verbal short-term memory. *Neuropsychologia*, 1971, *9* 377-387.

Watson, J.B. *Psychology from the stand point of a behaviourist*. Philadelphia, Lippincott, 1919.

Watson, J.B. *Behaviourism. 2nd. Ed*. Phoenix Books, Chicago, 1930.

Yates, F. *The Art of Memory*. Harmondsworth, Penguin, 1966.