

320

VISUALIZATION AND MEMORIZATION

A thesis
submitted in fulfilment
of the requirements of the degree
of
Doctor of Philosophy

S.E. AVONS

University of Stirling

June 1980

DEDICATION

To my parents, for their tolerance and kindness, and
for invaluable encouragement over the years.

Acknowledgments.

Many people in the Department of Psychology at Stirling have made substantial contributions to this thesis by their helpful suggestions, discussions and encouragement. Special mention should be made of our excellent technical staff, particularly Angus Annan, Robert Brodie, Jim Nimmo and John Russell. Thanks to their efforts, special equipment was always ready on time and the computer, somehow, kept running. Bob Lavery instructed me in the preparation of diagrams, and did all the photographic work at short notice. Mrs. Ina Mack gave up her spare time to produce a polished typescript from a rough and almost indecipherable manuscript.

Above all, thanks must go to my supervisor, Bill Phillips, who provided the initial inspiration and the foundation for this work. Many of the ideas arose out of discussions with him, and he should share in the credit. Full responsibility for the faults and demerits rests with the author.

CONTENTS

	Page
Chapter 1. Problems and aims.	
1.1 Introduction	1
1.2 Evidence supporting the functional distinction of short- and long-term visual memory (Literature review)	4
1.3 Summary of evidence and methodologies used	21
1.4 Objectives and overview of this thesis	22
 Chapter 2. General Methods.	 25
2.1 Matrix patterns: construction, advantages and disadvantages	26
2.2 Types of interference	31
2.3 Visual masking: considerations leading to the choice of mask	33
2.4 Apparatus used: displays and timing	35
 Chapter 3. Visualization Capacity.	
3.1 Limitations on visualization and the unitary recency effect in visual memory	38
3.2 Experiment 3a. Measurement of visualization capacity using a recall technique	40
3.3 Spatial restrictions on recency	54
Experiment 3b. Recognition of spatially separated matrix patterns	56
Experiment 3c. Recall of spatially separated stimuli ..	59
3.4 The recency effect as a function of pattern complexity..	61
Experiment 3d. Measurement of the serial position curve for simple patterns using a pattern completion test	62
Experiment 3e. Measurement of the serial position curve using a two-alternative recognition test	70
3.5 Final discussion and conclusions	74
 Chapter 4. The distribution of available information over trials.	

	Page
4.1	The distribution of information and its implications ... 78
4.2	Experiment 4a. The effect of feedback on recall of matrix patterns under STVM and LTVM conditions 80
4.3	Experiment 4b. The effect of distractor similarity on recognition under STVM and LTVM conditions 97
4.4	Final discussion and conclusions 106
Chapter 5. The coding of matrix patterns in STVM and LTVM	
5.1	Theories of coding in visual memory: a discussion and review 107
5.2	The coding of matrix patterns: effects of induced coding strategies..... 112
5.3	The effect of familiar, nameable shapes on STVM and LTVM recognition of matrix patterns: outline of experiments 118
	Experiment 5a. Memory for matrix patterns containing familiar and unfamiliar shapes; blocked conditions 123
	Experiment 5b. Memory for patterns containing familiar and unfamiliar shapes; randomized conditions 134
5.4	Final discussion and conclusions 138
Chapter 6. The effects of stimulus display time on STVM and LTVM	
6.1	Display time effects in visual memory studies; a discussion and review 146
6.2	Implications of display time effects on STVM and LTVM .. 152
6.3	Experiment 6a. The effect of display time on STVM and LTVM 154
6.4	Experiment 6b. The increase of STVM for simple and complex patterns as a function of display time 162
6.5	Final discussion and conclusions 173
Chapter 7. The effects of post-stimulus processing time on LTVM	
7.1	Theoretical and empirical considerations, including a brief review 183
7.2	Experiment 7a. The relative contributions of display time and post-stimulus processing time to long-term recognition 185

	Page
7.3 Discussion and conclusions	200
 Chapter 8. The effects of recognition test duration	
8.1 Possible consequences of restricting test time	205
8.2 Experiment 8a. The effect of short (300 msec) and long (2.0 sec) test pattern exposures on STVM and LTVM..	207
8.3 Experiment 8b. The readout of information from a recognition test pattern under STVM and LTVM conditions.	217
8.4 General discussion and conclusions	227
 Chapter 9. Summary and Conclusions	
9.1 The dissociation of STVM and LTVM: a summary of empirical findings	233
9.2 The nature of visualization: its limited capacity; considered as a control process; coding; relationship to perception	236
9.3 Memorization: coding and post-stimulus processing	240
9.4 The relation between visualization and memorization: rejection of the modal model; recoding; role of STVM descriptions in recognition tests	242
9.5 Information-processing considerations: interpretation in terms of storage, retrieval and coding stages; final synthesis	244
Appendix A	248
Appendix B	251
Appendix C	254
Bibliography	261

ABSTRACT

Previous investigations have suggested that visual memory may involve short-term (STVM) and long-term (LTVM) components. Evidence for this comes from the functional differences between visual memory tested after short, unfilled retention intervals (STVM conditions), and performance measured after any interpolated task with a high mental load (LTVM conditions). The suggestion is that stimulus information is maintained over short, unfilled intervals by visualization, an active, voluntary control process utilizing central resources. Under LTVM conditions interference prevents active maintenance, and the item must be memorized. The aim of this thesis was to provide further evidence on the functional distinction, and the nature of the underlying processes.

A number of experiments were conducted using novel matrix patterns as stimulus materials, and on-line control to allow precise manipulation of timing and other display parameters. The dissociation of STVM and LTVM was reflected in several results: STVM and LTVM (a) have different requirements for display time (b) differ in the consistency of performance over trials (c) they involve different coding processes at acquisition and (d) they show quite different relations between accuracy of performance and mean response time. In contrast to this, varying the exposure of a recognition test probe did not dissociate STVM and LTVM performance, and the provision of feedback and retrieval cues during recall had no clearly interpretable effect.

Visualization is a limited capacity process, insofar as it is restricted to one item or presentation at a time, and can maintain information up to a certain level of complexity. Visualized descriptions are constructed rapidly from short display times, and have general application to this class of novel visual patterns. With other evidence, this suggests that visualization is based on low-level 'figural' descriptions,

specifying stimuli as a spatial arrangement of shapes formed by groupings of the pattern elements. LTVM performance increases slowly and irregularly with display time and there is a wide variation in performance over trials. Higher-level, 'semantic' descriptions contribute to memorization, and these cannot be applied rapidly and consistently to randomly generated abstract patterns.

The results have widespread implications for theories of visual memory. Single-process theories which deny any distinction between short- and long-term memory are ruled out by the data. Other models which (a) consider STVM as an 'activated' part of LTVM or (b) claim the dichotomy arises from simple distinctions in coding or storage or retrieval do not give a complete account of the results. The 'modal' model is also rejected since prolonged visualization of an item after stimulus offset does not lead to an increase in LTVM. To account for this latter finding, it is proposed that visualization and the elaborate encoding processes required for memorization compete for central processing resources.

CHAPTER ONEProblems and Aims1.1 Introduction

Over the past decade, a large amount of evidence has supported the distinction of verbal and visual components in human cognition. The position is now sufficiently clear to state that visual cognition has independent properties, and is not mediated entirely by verbal cognitive processes. Evidence for this view comes from six main sources:

(i) The demonstration of memory for visual presentations which are unfamiliar and difficult to name (reviewed by Goldstein and Chance, 1974).

(ii) Studies of mental imagery and its use in mnemonics (e.g. Paivio, 1975).

(iii) Studies which show that visual representations are acted on in ways similar to the physical manipulation of real objects (reviewed by Shepard and Podgorny, 1978).

(iv) Selective interference studies (e.g. Brooks, 1967, 1968).

(v) Verbal information shows an advantage for temporal order processing, visual information for spatial order processing (e.g. Healy, 1975).

(vi) Hemispheric asymmetries in visual and verbal functions (e.g. Gazzaniga, 1970; Dimond and Beaumont, 1974).

In comparison with the vast number of studies concerned with verbal memory, visual memory received little attention until quite recently. This applies to the particular concern of this thesis, the idea that visual memory involves two distinct components, one a short-term process, the other long-term. The general distinction between long-term and short-term memory is an old one, dating back to James (1890). Interest was revived with the advent of information processing approaches to cognition (e.g.

Broadbent, 1958), and since then a large number of studies have addressed this issue, again using predominantly verbal materials. Extensive recent reviews are provided by Baddeley (1976) and Crowder (1976). A few theorists have rejected the duplex theory on the grounds that the evidence is not completely convincing, and the postulate of two separate memory storage systems is unparsimonious (e.g. Melton, 1963; Gruneberg, 1970; Wicklegren, 1975). Others have adopted the view that memory depends on the degree to which stimuli are processed, and therefore reflects a large number of stages or levels, rather than two discrete components (e.g. Craik and Lockhart, 1972; Postman, 1975).

Despite these objections, there are some advantages for the duplex theory. First, it accounts for the difference between the psychological present and the psychological past, as outlined by William James:

"An object which is recollected, in the proper sense of that term, is one which has been absent from consciousness altogether and now revives anew ... But an object of primary memory is not then brought back; ... its date was never cut off in consciousness from that of the immediately present moment."

(James, 1890, Vol I, p.647).

Secondly, temporary storage is a valuable facility for many kinds of information processing system. One example, particularly relevant to studies of perception and memory is provided by the interpretation of a sequence of items, where the initial interpretation of one element may be modified or altered by a later element in the sequence (Lashley, 1951). In such a case it is clearly advantageous to store the earlier elements in a temporary format which can be easily altered, and will not result in permanent storage of misinterpreted data. In the case of visual memory, the interpretation of a scene involves the integration of information over several fixations (e.g. Loftus, 1972; Gould, 1976), which may be

accomplished by a process involving visual short-term memory. Another example rests on the ability of the cognitive system to generate models of the external world. It has been shown that internal representations can be altered procedurally in ways which mimic the behaviour of real objects in space (e.g. Cooper and Shepard, 1973). The use of a temporary store here allows the internal model to be operated on without changing the long-term representation, while the use of procedures to generate matching representations gives rise to considerable savings in storage space. The widespread use of temporary registers in modern computers also testifies to the advantages of a duplex system. Thus there are considerable advantages in positing a duplex memory system, in accounting for subjective experience, and also in terms of the efficiency of the system. The following section reviews the evidence supporting a two-component theory of visual memory. This discussion will be confined to a critical account of selected evidence which is most relevant to this issue. For the sake of brevity, a number of issues have been omitted:

- (i) Coding in short- and long-term visual memory. This is the concern of Chapter 5, and the relevant findings will be discussed there.
- (ii) The question of incidental versus intentional learning, which is not directly relevant. Most of the studies considered below involve intentional learning.
- (iii) Many visual memory studies have used materials which are themselves intrinsically interesting (e.g. human faces, or game positions), but which have not been extensively used in studies of short- and long-term components in visual memory.
- (iv) Another related issue which is not discussed is that of working memory. This is a useful concept which stresses the practical importance of short-term memory, and its involvement in a number of

memory and performance tasks. Thus visual working memory studies include non-visual materials, such as the learning of word lists by self-generated imagery, and concurrent performance tasks not requiring the retention of information (e.g. Baddeley and Lieberman, 1978). The chief concern of this thesis, however, is the retention of displayed visual information in the absence of concurrent competing tasks. Thus, although the same cognitive functions and neural systems may be involved, these two approaches emphasise different aspects of memory performance.

One final point is that the term 'visual memory' is used to denote memory for materials which cannot easily be described in verbal terms and which requires the specification of some configurations or spatial arrangements. The use of this term does not imply that the processing is primarily 'visual' rather than 'spatial' in nature.

1.2 Evidence Supporting the Functional Distinction of Short- and Long-Term Visual Memory

This section will consider two related problems: the evidence which supports the idea of two distinct components in visual memory, and the empirical methods used to separate these components. Several lines of evidence are relevant, including the decay of visual memory over time, recency effects, the nature of interference, the capacity of visual memory, and some neuropsychological evidence. These will be discussed briefly in turn.

One major difficulty with visual memory studies is the variety of materials used. Most investigations relevant to the dissociation of components have used one of four types: memory for dot positions, line drawings or photographs of single objects, pictures of natural scenes and novel configurations such as Vanderplas figures or random element matrices. These differ widely in terms of complexity, the relative content of shape versus position information, and the meaningfulness of

the materials. In addition, there is evidence for a large verbal component when line drawings or pictures of objects are presented:

(i) When line drawings are used as material in the Brown-Peterson paradigm, the decline in performance as a function of the retention interval is the same as when the names of the objects are presented (Pellegrino, Siegel and Dhawan, 1976). This is not the case when more complex visual materials are compared with verbal descriptions (Reeve and Hall, 1976).

(ii) The serial position curves found with line drawings are similar to those found in verbal memory studies (Cohen, 1972; Madigan, McCabe and Itatani, 1972; Paivio, Rogers and Smythe, 1968; Rowe and Rogers, 1975). Complex visual scenes have quite different serial position curves (Tabachnick and Brotsky, 1976).

(iii) Concurrent auditory shadowing has similar effects on memory for serially presented line drawings and lists of their names (Rowe and Rogers, 1975). In contrast, concurrent shadowing has little detrimental effect on memory for novel visual materials, or complex scenes (Rollins and Thibadeau, 1973; Reeve and Hall, 1976).

Thus it is clear that memory for easily-labelled pictures of common objects is functionally different from that found with more complex scenes, and appears to have a large verbal component. Verbal encoding is further encouraged in many studies by using verbal recall of the object names to test memory (e.g. Cohen, 1972). Because of this, the following discussion will largely avoid evidence based on studies using such materials.

The decline in performance over unfilled intervals.

In tasks involving the recall of spatial position, Posner and Konick (1966) and Salthouse (1975) reported no decline in performance over retention intervals of up to 30 seconds, although considerable loss over similar intervals was reported by Dale (1973). The discrepancy

between these studies may be due to differences in the visual cues available at test.

A number of studies involving the recognition and recall of novel visual patterns have found variable rates of decline in performance. Christie and Phillips (1979) and Yuille and Ternes (1975) found no loss in matrix pattern recall over periods of up to 15 seconds. However, Phillips and Baddeley (1971) found a decline in recognition performance for the same materials over unfilled intervals of about 9 seconds duration, and Cermak (1971) reported a similar loss using free-form stimuli. In contrast, Adamowicz and Hudson (1978) found no decrement in recall or recognition of matrix patterns for periods of up to two minutes. Paivio and Bleasdale (1974) reported a decline in matrix pattern recognition for about 30 seconds after stimulus offset, based on both accuracy and RT measures, and further showed that the apparent rate of decline was a function of the overall difficulty of the retention test. It is not clear whether this is due to changes in the baseline level of performance (i.e. by the creation of floor and ceiling effects) or if it is a reflection of changes in task demands.

These studies show that under some circumstances there is a loss of the information available in visual memory which occurs soon after the stimulus presentation. Other evidence which suggests that visual traces may be lost over short unfilled intervals is provided by the well-known reaction time studies of Posner and his colleagues (Posner, 1969). The time required to classify two letters as the same is faster if they are presented in the same case than if presented in different cases. This RT advantage disappears if the interval between the two stimulus presentations exceeds 1-2 seconds (Posner and Keele, 1967) suggesting that the visual trace used in matching the stimuli is not available after that time. However, alternative explanations have been proposed: the visual trace may be available at longer ISI's, but other representations may be

used in matching (Phillips and Baddeley, 1971), or a visual representation may be internally generated for matching to the probe stimulus (Boies, 1969; Parks and Kroll, 1975). Evidence in support of a short-lived visual representation also comes from studies of naming latency for letters (Eichelman, 1970). The visual code inferred from these studies does not dissipate at a fixed rate; its availability depends on factors such as the use of pure versus mixed conditions (Posner et al., 1969) and the spatial separation of presentation and test stimuli (Walker, 1978). When auditory shadowing or articulatory suppression is used to fill the ISI, the 'physical identity' RT advantage is enhanced at relatively short ISI's (Hiles, 1973), and may persist for up to 8 seconds (Parks, Kroll, Salzberg and Parkinson, 1972).

Thus evidence from several paradigms shows that the decline of visual memory over unfilled intervals does not follow a fixed time course, but varies with the nature of the task. The results cannot be explained in terms of a short-term store with a fixed rate of passive decay, but are accountable in terms of an information store with a decay rate which varies with task demands, or in terms of voluntary control processes which are used to maintain information. A clear prediction from the latter theory is that information should be lost if the retention interval is filled by an attention-demanding task.

Performance decline over filled intervals.

A modified Brown-Peterson paradigm has been used with dot positions and novel patterns as materials. In their studies of memory for a single dot location, Posner and Konick (1966) and Dale (1973) found a progressive decline in recall as the filled retention interval increased up to 30 seconds. Meudell (1972) found a similar decline for the recall of letter positions in a 4x4 matrix. The original interpretation for this kind of result was that passive decay or displacement of

information occurred in the absence of rehearsal. A more recent interpretation (Baddeley, 1976) explains the decline as a failure in temporal discrimination between the current and preceding items. In accord with this explanation, Meudell (1977) found that performance on a task involving the recall of spatial locations was a function of the retention interval of the preceding trial, as well as the current trial.

Contrasting results were obtained by Christie and Phillips (1979), who found no decline in the recall of matrix patterns in two experiments where the retention interval was varied between 3 and 15 seconds. Thus neither the temporal discrimination nor passive decay explanations seem to apply to this kind of material. Further evidence was provided by Meudell (1977) who showed in a one-trial experiment that recall of four marked locations in a matrix did not decline progressively, but was fully diminished after the shortest duration of interference (3 sec.). A similar conclusion was reached by Bruce (1977), who measured recall of simple arrays of coloured shapes, followed by a mental arithmetic task. She found that the loss in performance was complete after only 5 seconds of interference. Finally, Kroll and Parks (1978) using the Posner letter-matching paradigm found a reduction in the physical-identity RT advantage which was substantially the same after 4.5 or 8.0 seconds of interpolated arithmetic, or 12 seconds of mental rotation. These results do not support the idea of a short-term trace which undergoes a slow, progressive decay in the absence of rehearsal. They suggest that there is a more or less immediate loss in the information available, when attention is directed to some other task.

'Decay' of long-term visual memory

A number of studies involving recognition memory for natural scenes have shown that a slow decline in performance occurs which is measurable over periods of weeks and months rather than days (Shepard,

1967; Nickerson, 1968; Standing, Conezio and Haber, 1970; Gaffan, 1978). Such durability is not confined to meaningful materials; Rock and Englestein (1959) showed that recognition of a single novel configuration initially presented for 20 seconds was still high after 3-4 weeks. This long-term decay is clearly several orders of magnitude different from the time course of the decline in performance found in studies of short-term visual memory.

The results discussed so far suggest that there is a short-term component to visual memory which is maintained by an active rehearsal process. If this activity is prevented by a concurrent task, performance falls immediately to a lower level, which may be stable over very long periods of time.

Recency in visual memory.

The serial position curve for novel visual materials has been investigated by a number of workers. For free recall of matrix patterns, Christie and Phillips (1979) found that the final item was recalled first, and more accurately than the preceding items. Serial position curves showing the same features (a flat prerecency portion and a unitary recency effect) were obtained using single probe recognition tests, and reverse serial order recognition tests (Phillips and Christie, 1977a). A related task used by Swanson (1977) involved the presentation of a series of random shapes in different spatial locations, followed by a cued recall test where one probe item was shown and the subject was asked to report its location. A recency effect was found for the final item in the series when older learning-deficient children (over ten years) were used as subjects. The importance of these procedures is that they test memory for the final item soon after the presentation sequence. If interference follows the presentation of the last item, the advantage for that item is lost (Phillips and Christie, 1977a). These results are consistent with

the view that the recency effect is due to rehearsal of the final item in the series. Hence the recency effect should not be found in studies where the recognition test items are presented in a random order (e.g. Young, 1974). Two studies which do not conform are those of Loftus (1974), who reported a unitary recency effect with randomized-order testing, and Hines (1975) who demonstrated a recency effect resistant to interpolated interference. However, both studies used successive presentations, so that all items except the last were masked by the following item in the series. The advantage for the final item may therefore be due to an increase in the effective study time, brought about by visual persistence, as shown by Hulme and Merikle (1976).

Rather different results are obtained when complex natural scenes are used as materials. Shiffrin (1973) presented series of 10, 20 or 40 pictures, followed by immediate free recall. The serial position effects were small compared to those found with word lists, a finding confirmed by Weaver (1974) and Tabachnick and Brotsky (1976). A later study (Weaver and Stanny, 1978) investigated recency effects in short series of complex natural pictures, followed by an immediate two-alternative probe recognition test. Under these conditions no recency effects were seen. However, recency effects could be induced by giving an unexpected signal just prior to the final item, informing the subject that the next item would be tested. This result shows that voluntary processes may enhance memory for this kind of material, but the interpretation is uncertain. The informative signal may have its effect through directed forgetting of the earlier items, more intensive study of the final item, or rehearsal of the final item. However, if rehearsal is the origin of this recency effect, it has to be explained why the rehearsal does not normally occur with this type of material, but occurs readily with the novel materials discussed above. One possibility,

discussed by Potter (private communication) is that memory for natural scenes is based on conceptual, rather than visual descriptions. Another feasible explanation is the difficulty of rehearsing complex materials when, as will as be seen, only a limited processing capacity is available.

Several criticisms have been advanced against the view that recency effects in verbal free recall are the consequence of short-term memory (Baddeley and Hitch, 1977; Bernbach, 1975). First, recency effects are found in incidental learning paradigms, and hence are not always the result of an active rehearsal strategy. Secondly, the recency portion of the free recall curve is resistant to articulatory suppression (Levy, 1971), and is not based on phonemic encoding (Craik, 1968). Thirdly, recency effects are found in long-term verbal memory (e.g. Tzeng, 1973; Bjork and Whitten, 1974).

These findings show that under some circumstances, recency in verbal tasks is not due to short-term storage or active rehearsal processes. The explanation that has been offered is that recency may reflect a retrieval strategy, involving a temporally ordered, backwards search through episodic memory. While this may be true of verbal memory, it is difficult to see how this explanation can apply to the recency effects found with novel visual materials. It does not explain why recency with such materials is confined to one item, nor its susceptibility to interference. Both findings are easily accounted for in terms of active rehearsal of the final item in the series. In addition, long-term recency effects have not so far been reported for novel visual materials.

A note on primacy effects.

Although not direct measures of short-term memory, primacy effects in verbal memory are thought to be the consequence of rehearsal (e.g. Rundus, 1971). These effects are easily explained as the rehearsal set for verbal materials typically consists of several items, so that

the first few items in a verbal string receive more rehearsals on average than later items. There are two essential conditions for this: rehearsal of earlier items at some point later in the series, plus a memory advantage contingent on the number of rehearsals each item receives.

It is interesting that in many visual memory studies primacy effects have been minimal or absent. Thus Shiffrin (1973) using a technique very similar to those of verbal memory studies (e.g. Murdock, 1962) found no primacy effects. A number of other studies involving the serial presentation of natural scenes (Shaffer and Shiffrin, 1972; Potter and Levy, 1969; Tabachnick and Brotsky, 1976; Weaver and Stanny, 1978) or novel materials (Phillips and Christie, 1977a; Christie and Phillips, 1979; Young, 1974; Hines, 1975; Swanson, 1977) have also failed to show primacy effects.

The absence of primacy effects from visual serial position curves suggests that either rehearsal processes do not lead to increases in subsequent memory, or that equal rehearsal time is given to each item in the series. There is some evidence from studies using natural scenes as materials that continued rehearsal in the absence of the stimulus may give rise to an increase in later recognition (e.g. Tversky and Sherman, 1975; Weaver and Stanny, 1978; Intraub, 1979). Nevertheless, primacy effects for these materials are small or absent. The alternative explanation receives some support from studies which suggest that processing continues on one visual item until the next is presented. This evidence is based on unitary recency effects observed with variable list lengths (e.g. Phillips and Christie, 1977a) or studies of rapid sequential presentations (e.g. Potter and Levy, 1969). Unlike verbal memory, where several items can be held in buffer storage and rehearsed together, visual processing is restricted to one item at a time. Thus the early items in

the string do not receive additional rehearsal opportunities, and primacy effects contingent upon unequal rehearsal are not found with visual materials.

Types of interference effective for short- and long-term visual memory.

The previous discussions have provided evidence that performance in short-term visual memory tasks is subject to interference. This section will examine the types of interference that are effective, and the implications for models of visual memory.

A large number of studies have shown modality-specific interference effects involving visual and verbal cognition. As noted above, this evidence is one of the empirical foundations for the distinction of visual and verbal processing systems. Dual task experiments involving the disruption of performance by competition within the same modality have also contributed to the development of working memory theory. (e.g. Brooks, 1967, 1968; Baddeley, Grant, Wight and Thomson, 1974). Within the present context, a number of experiments have used a primary task involving the retention of verbal or visual items, followed by interference in either of the two modalities. Under these conditions, a crossover effect has been found by workers using a variety of stimulus materials and interference tasks (e.g. Margrain, 1967; Salthouse, 1975; Yuille and Ternes, 1975). This suggests that visual short-term memory involves a modality-specific component, which is susceptible to interference from tasks presented in the same modality; but resistant to cross-modal interference. Logically, however, the crossover effect does not carry this implication; the data can be accounted for by postulating just one modality-specific component, for example an auditory/verbal buffer store (Phillips and Christie, 1977b).

The usual interpretation of crossover experiments is in terms of general purpose and specialized processors. Evidence that short-term

visual memory involves general purpose resources for its maintenance comes, for example, from the studies of Yuille and Ternes (1975) and Salthouse (1975). These showed that there was substantial interference with visual memory arising from concurrent tasks presented in the opposite, auditory/verbal modality, compared to the no-interference control conditions. A corollary of this is that interference with short-term visual memory should be a function of the mental load of the interfering task, whatever its modality. Supporting evidence comes from Posner and Konick (1966) and Hines (1978) who found increasing deficits in short-term visual memory as the difficulty of their visually presented arithmetic interference tasks was increased. Yuille and Ternes (1975) reported interference with visual memory when the concurrent task involved backwards counting by threes, but not when it involved forward counting by one. Phillips and Christie (1977a, 1977b) showed that reading or listening to a string of digits during the retention interval had no effect on the short-term recognition of matrix patterns, but that adding the digits (presented visually or auditorially) led to substantial interference. These studies show that the mental load of the interference task has important consequences for short-term visual memory, suggesting that there is a large central component.

Further evidence concerning interference with short-term visual memory comes from experiments using the Posner letter-matching paradigm. Posner et al. (1969) found that the RT difference between physical and name matches disappeared when subjects were required to add two digits, visually presented between the first and second letters. However, simple mental arithmetic involving auditory presentations had no effect on letter-matching RT's for practiced subjects (Boies, 1969). Reviewing the evidence in 1969, Posner concluded that the crucial variable might be the modality of the interpolated task or its mental load.

Kroll and Parks (1978) reported a diminution in the physical-identity RT advantage by interpolated tasks such as mental rotation of a random shape, reading visually presented digits, or mental arithmetic. However, shadowing auditory digits had no effect on letter matching, suggesting that there is a modality-specific component. Proctor (1978) found that interpolated mental arithmetic had no effect on the letter matching task when presented auditorially, but a large effect when presented visually. He concluded that short-term visual memory did not require central processing capacity, but was modality-specific. This seems an unwarranted conclusion since (a) his mental arithmetic task was very easy (b) the timing of interference was different in the auditory and visual conditions and (c) the RT differences between conditions were relatively small, and may have been due to matching in long-term visual memory (Kroll and Parks, 1978; Hintzman and Summers, 1973). Moreover, in the visual interference condition, Proctor presented the digits to be added along with the target letter, so the visual presentations used in his letter matching task were of different kinds.

As it stands, therefore, evidence from this paradigm suggests that the visual code is disrupted by tasks with a high mental load, or by attending to subsequent visual inputs. In mild contrast to this, short-term memory for novel materials such as matrix patterns is disrupted by demanding tasks presented in any modality, while relatively undemanding visual tasks, such as reading, have little or no effect. The discrepancy between these results may be explained in terms of the similarity of materials used in the primary and interference tasks or in terms of the incentive to maintain a visual representation of the target. With both paradigms, 'passive' regard of closely similar visual material does not disrupt short-term performance (e.g. Yuille and Ternes, 1975; Proctor, 1978).

In contrast, the available evidence suggests that visual similarity is an important factor in long-term interference. Using simple visual materials, both Meudell (1977) and Bruce (1977) demonstrated PI effects after the first trial of a visual recall task. Yuille and Fox (1973) demonstrated release from PI in a task requiring subjects to recall pictures by drawing, when the visual form of the objects was changed.

Visual similarity effects may explain the finding that the interference caused by an interpolated recognition test for a similar shape is greater than that caused by remembering a string of digits (Hines and Smith, 1977). Phillips and Christie (1977a) and Christie and Phillips (1979) obtained measures of long-term performance when (a) several similar items were presented in sequence on each trial, and (b) where only one item was presented, followed by an unrelated interference task. Performance was typically lower when several items were presented on each trial, which can be best explained as a deficit in long-term performance resulting from inter-item interference. Hines (1978) reported the effects of following a target presentation by a secondary task consisting of the presentation and test of a second item. He found that retention of the target increased with the dissimilarity of the target and distractor items. Unfortunately, he did not measure independently the level of difficulty of the secondary tasks, and the result may be partly a function of their mental load.

Thus, the available evidence, although perhaps not conclusive, and certainly not copious, does suggest that different types of interference operate in short-term and long-term visual memory.

The differential capacities of short- and long-term visual memory.

It is clear that long-term visual memory has an indefinitely large capacity. Several empirical confirmations of this have been made

using highly discriminable natural scenes (e.g. Standing, 1973). In contrast, a number of observations suggest that the short-term component has a small capacity. There is some controversy concerning the implications of this for the functional distinction of visual memory. Some memory theorists (e.g. Craik and Lockhart, 1972; Postman, 1975) dismiss this type of evidence entirely. Part of the problem lies in specifying what are to be considered as the contents of short- and long-term memory, before proceeding to measure them.

However, if the content of short-term visual memory is taken to be the information available at test after a brief single exposure, followed by a short unfilled retention interval, then there is abundant evidence showing that this information is severely limited. Demonstrations of this have a long history, including the early studies on span of apprehension (reviewed by Woodworth and Schlosberg, 1954). Recent studies on the recall of novel visual items include those of Bruce (1977) who presented arrays of simple coloured shapes, and found that about five attributes (of colour, shape or location) were available for immediate recall. Other studies have shown that the accuracy of reproduction of matrix patterns depends on the information load, determined by the number of repeated segments within a pattern (Schnore and Partington, 1967), or the presence of symmetry or repetition along one axis (Attneave, 1955; Deregowski, 1978). One early study using brief presentations of natural scenes suggested that the amount of information available for recall was very high (Haber and Erdelyi, 1967), but later studies showed that the apparent high capacity was an artefact due to the high response rates, and the possibility of making inferences from the scene (Erdelyi, 1970).

A number of recognition studies using novel patterns have also suggested that short-term capacity is severely limited. An important

methodological point is that the distractors should be constructed by making a small constant alteration to the target. Increasing the complexity of the target thus increases the demands placed on short-term memory. Using this technique White (1957) and Phillips (1974) showed that immediate recognition performance fell, as complexity increased. Using the inverse technique, Paivio and Bleasdale (1974) showed that performance decreased as the target and distractors were made more similar.

Finally, evidence from the Posner letter-matching paradigm supports this claim. There is a physical match RT advantage for short ISIs when one or two letters are presented (Posner and Keele, 1967; Parks and Kroll, 1975), but this does not extend to cases where 4 or more letters are presented (Posner and Taylor, 1969; see also Hochberg, 1968).

Neuropsychological evidence

Substantial support for the STM/LTM dichotomy in verbal memory comes from neuropsychological studies which show that selective impairment of one component can arise in pathological cases. The evidence arising from clinical studies of visual memory is rather less convincing.

A few clinical studies of localised brain lesions have used tests suitable for the measurement of short-term visual memory. Kelter, Cohen, Engel, List and Strohner (1977) showed pictures of 'snowflakes' to subjects for 3 sec. followed by a 5 sec. retention interval, which was either unfilled, or filled by a card-sorting task. Normal controls performed better with unfilled retention intervals, but non-aphasic brain damaged patients and non-fluent aphasics performed worse than the controls, and equally well in the filled and unfilled retention intervals. Moreover, fluent aphasics performed better after the filled intervals. Thus although conditions were appropriate for the rehearsal of visual

information, the patient groups did not do so. Other studies of immediate visual recognition have found that right brain-damaged patients are less impaired than patients with left hemisphere lesions, and left non-aphasics are better than aphasics (Gainotti, Caltagirone and Miceli, 1978; De Renzi and Spinnler, 1966). Two studies involving the recognition of random shapes after short, unfilled retention intervals also found evidence of left hemisphere involvement. Levin, Grossman and Kelly (1976) reported a negative correlation between recognition performance and the severity of aphasia. Bisiach and Faglioni (1974) found a greater impairment in simultaneous and delayed matching in patients with left hemisphere damage, compared to right hemisphere patients. Warrington and James (1967) found no difference between right and left hemisphere patients in a test involving the immediate recognition of matrix patterns, although there was some evidence of gross impairment in right parietal patients.

Thus a number of independent neurological studies of short-term visual memory for novel visual materials have found deficits resulting from mainly posterior lesions in either hemisphere, which are possibly more severe with left-sided lesions. In contrast, long-term visual memory shows greater impairment with right-sided lesions (e.g. De Renzi, Faglioni and Villa, 1977a; De Renzi, Faglioni and Previdi, 1977; De Renzi, 1968). Complementary evidence comes from studies of normal subjects, which have demonstrated a left visual field advantage for novel materials with retention intervals exceeding 10 seconds or so. With short unfilled delays there is either no visual field preference, or a slight advantage for the right visual field (e.g. Bevilacqua, Capitani, Luzzatti and Spinnler, 1979; Dee and Fontenot, 1973; Moscovitch, Scullion and Christie, 1976).

Studies of visual memory in amnesic patients suggest that they are impaired in comparison to control subjects. This is true for

long-term recognition of pictures (Huppert and Piercy, 1977), line drawings (Williams and Owen, 1977), unfamiliar faces (Dricker, Butters, Berman, Samuels and Carey, 1978) or random shapes (De Luca, Cermak and Butters, 1975). Both Dricker et al. (1978) and De Luca et al. (1975) included short-term memory tests involving simultaneous matching or matching after unfilled retention intervals. In both cases the amnesics were worse than controls. Thus although for verbal materials amnesics show gross impairment only on long-term tasks (e.g. Baddeley and Warrington; 1970), they show deficits in both short- and long-term retention for visual materials. Deficits in short-term visual retention have now been found in a number of patient groups, including schizophrenics (Kelter et al., 1977). It is possible that this widespread deficit results from a failure of attention in maintaining visual rehearsal over short retention intervals, although rehearsal does occur for short spatial sequences (De Renzi, Faglioni and Previdi, 1977).

Evidence from spatial memory tasks also supports a distinction between short-term and long-term processing. Impairment of spatial memory span is associated with posterior lesions in either hemisphere (e.g. De Renzi and Nichelli, 1975; De Renzi, Faglioni and Previdi, 1977). However, if a filled or unfilled delay is interposed before recall of a spatial sequence, right hemisphere patients perform worse than controls or patients with left-hemisphere damage (De Renzi, Faglioni and Previdi, 1977). Deficits in long-term spatial learning and topographical amnesia arise from right posterior lesions (De Renzi, Faglioni and Villa, 1977b). More conclusive evidence for the dissociation of short- and long-term spatial memory is provided by patients who are impaired selectively on spatial span (e.g. De Renzi and Nichelli, 1975) or in long-term spatial learning (e.g. De Renzi, Faglioni and Villa, 1977b). It is interesting to note that the patient M.A. described in the latter study showed normal performance on several long-term visual memory tasks, although

her performance on simple maze learning was extremely poor.

To summarise, the neuropsychological evidence supports a distinction between long- and short-term spatial memory, but the evidence is less clear with respect to visual memory studies. However, there is a need for more clinical studies which measure visual memory under both short-term and long-term conditions; comparisons between the existing studies are made difficult by inconsistencies in the patient groups and the types of testing procedure used.

1.3 Summary of Evidence and Methodologies.

To summarise, the evidence reviewed in the previous section provides support for the view that there are two components to visual memory, and gives an outline of their properties. The short-term component has a limited capacity, and is restricted to the final item of a series. It does not have a fixed rate of decay, but is lost very soon after the start of interpolated interference, or if the final memory item is followed by a retention test for another item in the series before it is tested. Moreover, even when the presentation and test conditions are right, a recency advantage may not appear unless special incentives are given. Taken together, these observations suggest that the short-term component is the consequence of an active process under voluntary control, which maintains visual information throughout the retention interval. This active process is referred to as visualization. In contrast to this, long-term visual memory retains information about any number of items, survives interference provided by a distracting task or the presentation of subsequent items, and shows no primacy or recency effects. According to the framework laid down by James (1890) the long-term component is part of secondary memory, and the acquisition processes which are required for this will be referred to as memorization.

The evidence reviewed above suggests a methodology for separating the two components. Since the short-term component is susceptible to interference from intellectually demanding tasks, and under some circumstances it decays over long unfilled intervals, short-term visual memory (STVM) is reflected in performance measured after short, unfilled retention intervals. The long-term component is measured when an interference task of high mental load is interpolated between the presentation of an item and its test. (The techniques used to provide interference are described in detail in the following chapter).

Some consideration should be given to the extent to which STVM and LTVM conditions determine and isolate the underlying processes. As noted above, STVM appears to depend on visualization, a voluntary control process. The conditions used cannot ensure that this process occurs, but they can provide appropriate incentives to encourage it. Presumably, under STVM conditions there may be a small, or even a substantial contribution from memorized information. The extent of this contribution can be assessed by the use of interpolated interference under similar presentation conditions. Conversely, LTVM may include a component of visualized information, if the interference task is not sufficiently demanding to prevent visualization. Further evidence pertaining to the methodological separation of these components is provided in Chapter 6.

1.4 Objectives and Overview.

Before starting this thesis, there was already considerable evidence in support of a dichotomy in visual memory, and much was known concerning the limitations of, and appropriate conditions for visualization. The work reported here has three main aims:

(a) to provide further evidence in support of the dichotomy in visual memory.

(b) to investigate the properties of the underlying processes, and the relationship between them.

(c) to contribute to an information-processing account of visual memory.

In order to simplify matters, all the experiments reported here involve visual memory for matrix patterns. Much ground work concerning memory for this type of pattern has been done by Phillips and his collaborators over several years. The advantages and disadvantages of these materials are discussed in the following chapter.

Despite the considerable knowledge of this area acquired from previous studies, a number of important empirical questions required investigation, and several of these are considered in this thesis. These questions, and the theoretical issues to which they are relevant are as follows:

(1) Is visualization always confined to the final attended item of a series, or are there circumstances where more than one item can be visualized? This is relevant to two issues, the capacity of short-term visual memory, and its compatibility with sequentially presented information.

(2) How does the distribution of remembered information across trials compare in STVM and LTVM? This has relevance to the issues of coding and retrieval in LTVM, and the nature of short-term forgetting.

(3) Do STVM and LTVM use similar codes to describe visual patterns? This is relevant to the general issue of coding in STM and LTM, and in particular with the distinction between physical coding in STM, and semantic coding in LTM.

(4) What are the effects of processing time at presentation on STVM and LTVM? This has relevance for a number of issues, but the chief concern is measurement and comparison of the times required to construct representations in STVM and LTVM.

(5) What are the effects of varying the time from stimulus offset to the start of interference? This is concerned with the issues of maintenance and elaborative rehearsal. In common with the previous question, it has considerable implications for the modal model as applied to visual memory.

(6) What effect does the duration of a recognition test probe have on STVM and LTVM? This is relevant to the general issue of retrieval processes; a particular concern is whether LTVM retrieval is mediated by the establishment of an STVM representation at test.

Each of these empirical questions and their theoretical implications will be discussed in turn in chapters 3-8. In chapter 9 an attempt is made to summarise these empirical findings and relate the conclusions to be drawn from them.

CHAPTER TWOGeneral Methods.

All the experiments reported in this thesis investigated memory for matrix patterns, and the majority were carried out using on-line control of a graphic display unit. To avoid unnecessary repetition the materials and apparatus will be described here. Specific details will be found in the method sections dealing with each experiment.

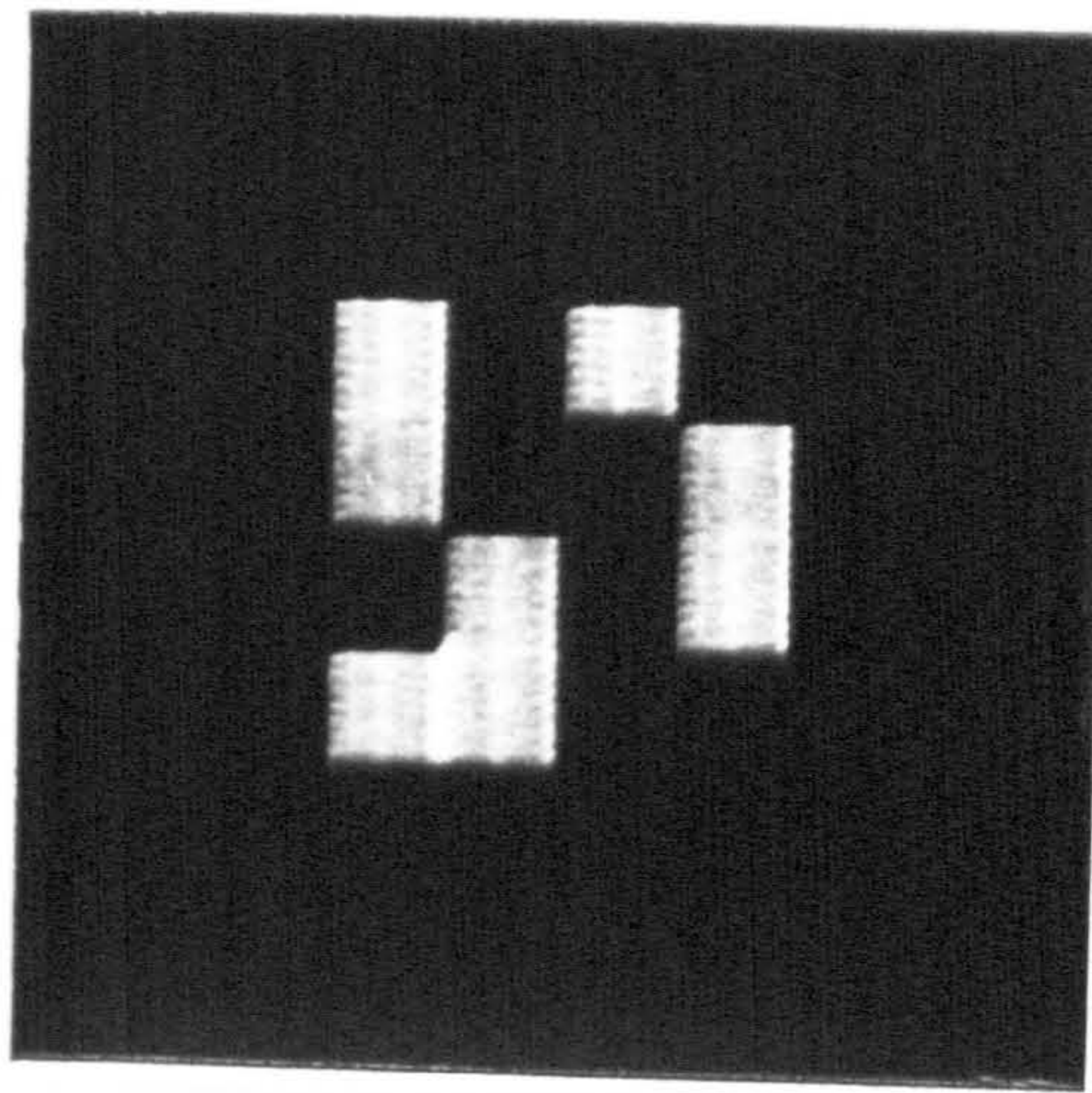
To begin, some consideration should be given to the choice of materials. One criticism often levelled against studies using novel visual patterns is that they are artificial and meaningless stimuli, and therefore quite unrelated to visual experience in the natural world. To some extent this criticism is valid; natural scenes may well involve processes and strategies which cannot be applied to simplified novel materials. Nevertheless, some aspects of everyday performance may depend on memory for visuo-spatial configurations not unlike those found in novel stimuli. (Memory for the spatial arrangements of objects may be one example, or memory for individual objects distinguished by their shapes or markings). Secondly, a number of visuo-spatial psychological functions involving the mental manipulation of objects or shapes can be performed with both familiar and novel materials (e.g. Cooper and Shepard, 1973; Cooper and Podgorny, 1976). Assembly tasks involving such mental operations often involve novel configurations (e.g. jigsaw puzzles). A third, practical consideration is that the use of novel materials enables better specification of the stimulus types, and better control of parameters such as homogeneity and complexity. These are especially important considerations within an experimental context, and more details are given below.

2.1 Matrix Patterns.

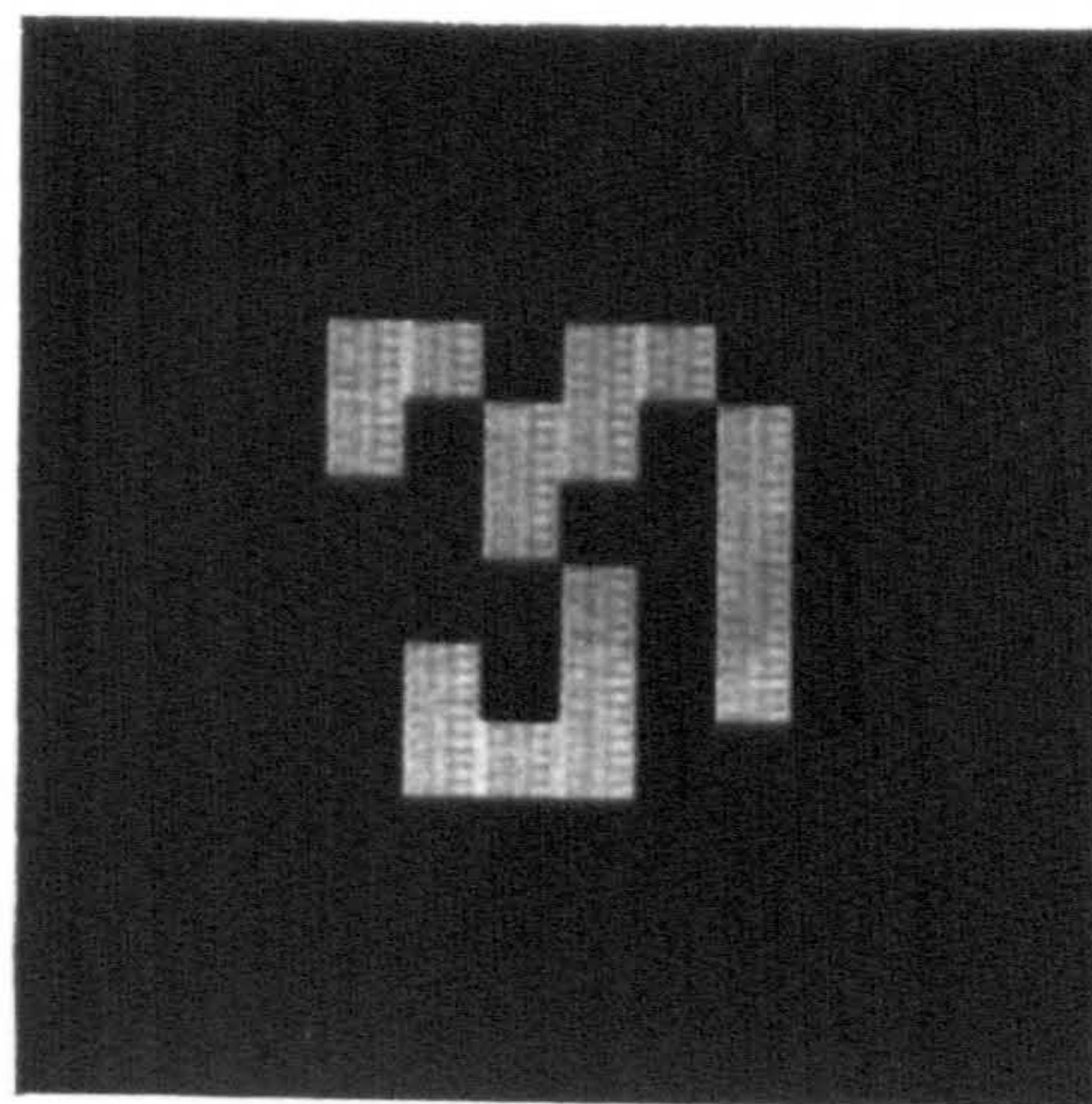
The basis for all the patterns used in these experiments was a rectangular matrix made up of square cells. To construct the patterns, a number of cells of the matrix were selected at random and were filled (i.e. displayed as light areas). Thus the patterns consist of a number of irregularly shaped light and dark areas, bounded by sides which are multiples of the length of side of the individual square cells (henceforth called the unit cell size), and where all the angles are right angles. In all the experiments except 3.2 and 3.3, the number of filled cells in the matrices was fixed at about half the total number of cells. While this restricts the potential variability of the patterns, it eliminates the cases where only a few cells are filled, or the converse; such patterns require accurate memory for position rather than shape information and thus tap a different dimension of visual memory (Frith, 1978). This was the only restriction placed on the generation of the matrices which were usually unfiltered. Typical examples of 4x4 and 6x6 matrices are depicted in Figure 2.1a.

Figure 2.1. Appearance of pattern displays, approximately actual size. Fig. 2.1a shows a typical 4x4 matrix pattern with a unit cell size of 6 mm. Fig. 2.1b shows a 6x6 pattern with a cell size of 4 mm. A slant pattern of the type used to provide interference is shown in Fig. 2.1c, with a unit cell size of 6 mm.

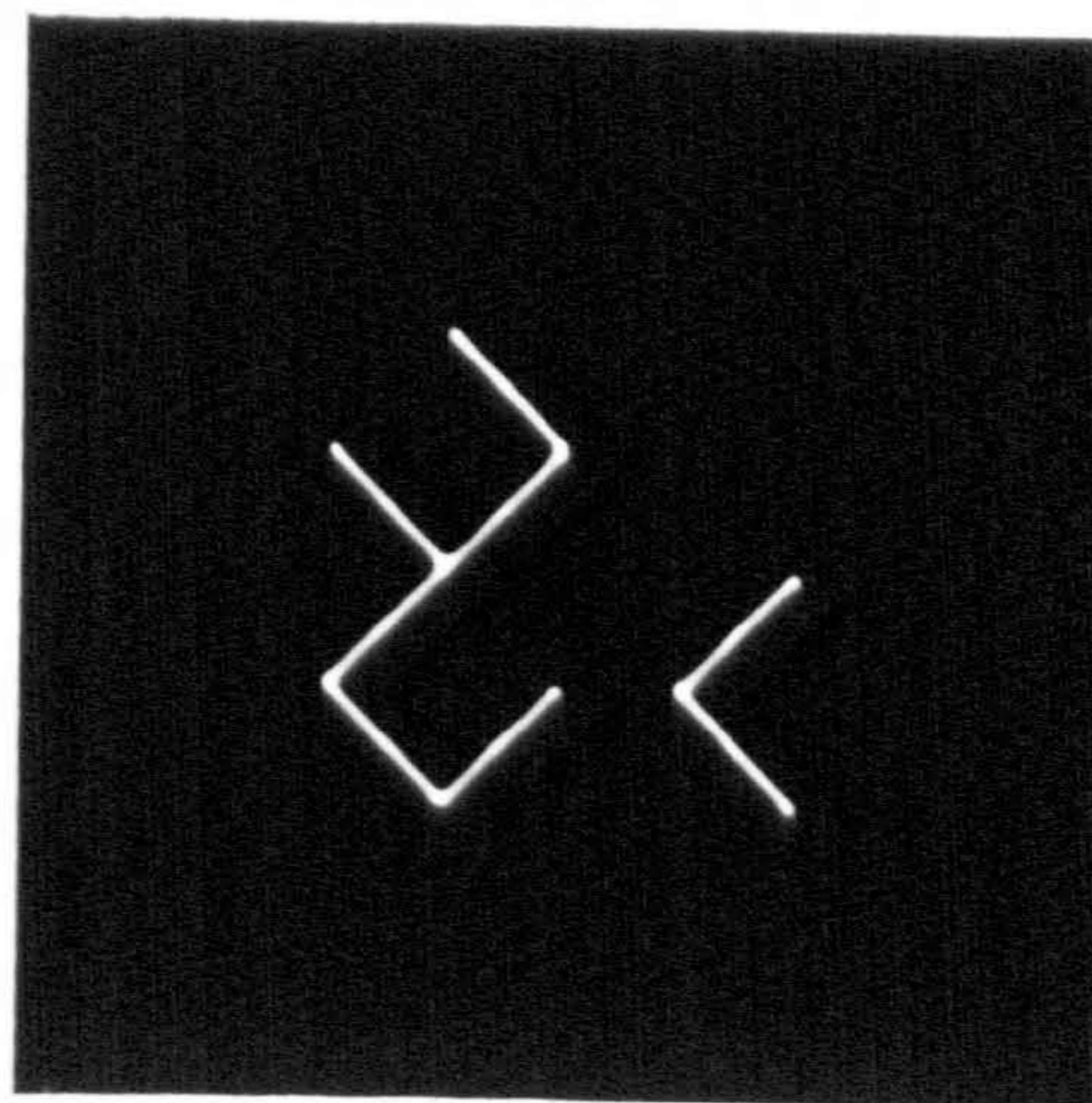
Fig. 2.1



a



b



c

(i) Advantages of matrix patterns.

Perhaps the main advantage of using novel patterns in visual memory studies is that it reduces the contribution made by verbal memory processes, and it does this in two ways. First, the shapes which occur in such patterns are frequently unfamiliar and non-representational. As such they do not resemble or look like any real-world objects or symbols that can be named. Secondly, it would be possible to specify these patterns by a verbal description, by subdividing each pattern and shape into a series of rectangles and squares. To do this would be a time-consuming procedure, and the resultant description, if veridical, would necessarily be lengthy. The argument is that novel patterns of this type can be encoded more efficiently as visual configurations than as verbal descriptions, although both are possible, and for some exceptional patterns the reverse may be true.

Matrix patterns, in particular, have a number of additional advantages. Complexity can be varied easily by increasing the number of cells in the matrix. The patterns are also tremendously variable. For a matrix of M cells with a fixed number, r , of cells filled the number of possible patterns in the set is given by

$$N = \frac{M!}{(M-r)! r!}$$

For 3x4, 4x4 and 6x6 matrices where $r = M/2$ this gives values of N of 224, 12870, and 9.08×10^9 , respectively.

A third advantage is that recognition distractors can be generated from presented patterns by changing the values of one or more cells in the matrix. The similarity between a target pattern and a distractor is readily controlled by changing the number of cells, d , which have different values in the original and distractor. It is not claimed that the similarity between any two patterns is a function of d . Such a claim would imply that the coding of patterns is based on the

individual cells. Rather, the claim is that the average degree of similarity between a set of patterns of size M , and any corresponding set of randomly generated distractors, will increase monotonically as a function of d .

In all the recognition experiments reported here, distractors were constructed from the TBR patterns by changing the values of an equal number of black and white cells. This ensures that the total number of cells filled is constant for both targets and distractors, so the response cannot be influenced by the relative brightnesses or densities of the stimuli.

(ii) Disadvantages of matrix patterns.

Apart from the criticisms of abstractness and lack of generality which were raised earlier there are a number of problems arising from the use of matrix patterns. First, although the matrices and distractors are constructed by a set of simple procedures which are common to all target/distractor pairs, the information required to provide the answer to a recognition test may vary widely across such pairs. For example, the choice can be based on global features such as symmetry, or scalar quantities such as the degree of complexity and the number of separate shapes. But in order to test visual memory, recognition should be based on the shape and position information specifying the pattern, i.e. a visual description. No attempt was made to control the presence of such features in pattern/distractor pairs. (Recall tests, of course, do not have this problem; the reconstruction of a pattern depends on the presence of a visual description.)

The same consideration applies to the distinction between shape and position information. In a recognition test where a distractor is generated in the way described, the two alternatives may differ by a change in one or more of the shapes of the patterns. Occasionally,

however, a distractor may differ only by a change in position of an isolated cell, or row of cells. Positional changes of this kind are rare, but they can be difficult to detect. This means that there may be a large degree of heterogeneity between test items. For recall tests the problem is more acute, since accuracy depends on specifying those cells which were filled in the target pattern. Thus there is a high penalty for transposition errors, where the shapes are described correctly, but recalled in the wrong location of the matrix. To reduce this type of error, recall targets were displayed inside a square which marked the perimeter of the matrix, and a similar frame of reference was provided at test. For both recognition and recall, the relative importance of shape and position information varies with the pattern density. In the majority of experiments reported here, patterns were used where half the cells of the matrix were filled (to maximise the importance of shape, rather than position information). Thus the contribution of shape and position should be relatively constant across different samples of patterns.

A third problem concerns figure/ground effects. In the recognition tests, matrix patterns were displayed as illuminated areas on a uniform dark background. Under these conditions they were usually described with the white areas as figure, although not always so. In the case of recall, where the perimeter of the target matrix was displayed, the definition of figure and ground is somewhat arbitrary, and subjects reported encoding the light or dark areas of the patterns. In this case, a presented stimulus may be interpreted as one of two possible patterns.

A final problem is that some easily identifiable and nameable forms sometimes occur in the patterns. Examples of these are letters (e.g. T,L,F) or geometric shapes such as crosses or squares. The contribution made by these familiar forms is examined in Experiments 5a and 5b.

Again, the implications for encoding processes depend on the nature of the test. For recognition, the name of the familiar shape may be sufficient, but for recall both shape and position information will also be important.

2.2 Interference.

Throughout this work, the methodological separation of STVM and LTVM is accomplished by two procedures: STVM is measured by giving the memory test for an item after a short, unfilled retention interval, whereas LTVM is measured after a period of intense interfering activity. In these experiments the object of interference is to prevent visualization of the target pattern, a function of the mental load of the interpolated task. Ideally, therefore, interference should deliver a high mental load soon after the stimulus presentation. Three kinds of interference are used here: the serial presentation of target matrix patterns, mental arithmetic and the visualization of a subsequent pattern which is phenomenally distinct from the target matrix pattern.

(i) Serial presentation.

A short series of matrix patterns is presented, followed by an immediate probe test for one item in the series. The assumption here is that subjects visualize each displayed pattern in the sequence until the next item is shown. If the retention test probes the final serial position, then there is a strong possibility that this item will be currently visualized at the time of test. However, visualization of the penultimate and previous items will have been disrupted by the successive presentations. Under these conditions, probing the final item (STVM) reflects visualization, whereas probing a previous item (LTVM) gives an estimate of memorization. Under other display conditions these assumptions may not hold; the subject may not visualize the final item, or may choose to

continue visualizing one of the previous items in the series (see Phillips and Christie, 1977b; Experiment III).

(ii) Mental arithmetic.

In this procedure a single item is shown on each trial, and memory is tested either immediately or after interpolated arithmetic. The arithmetic task involved the rapid addition of four single digits which were successively displayed at the rate of 2 digits/second. Each digit was displayed for 400 msec, with a gap of 100 msec before the next digit. The digits were the pre-programmed alphanumeric characters of the GT40 graphic display unit, and were based on a 6x8 dot matrix, 2.0 mm wide and 3.5 mm high.

The sum was made up using the random number generator, the sole constraint on the selection of the digits being that the total should exceed eleven. The subject was required to type the answer to the sum on the GT40 keyboard. Knowledge of results was provided by displaying the correct answer to the sum for 0.5 sec.

It will be realised that this is a complex task involving several components, any or all of which might lead to visual interference. The subject has to read the visually displayed numerals, perform the arithmetic, a task of high mental load, and then type the answer to the sum on the keyboard.

(iii) Slant patterns.

This type of interference is provided by visualizing a pattern of a phenomenally different class from the matrix patterns which provide the memory data. The slant patterns were made up from 4x4 matrices, by giving each cell one of three values. Four cells of the matrix, chosen at random, were filled by a diagonal line running from bottom left to top right, and four other cells were filled by the opposite

diagonal. The remaining cells were left unfilled. A typical example of a slant pattern is shown in Figure 2.1(b).

The intention in using these patterns was to provide a visual memory load which would prevent visualization of a previously shown matrix pattern, but could not be confused with it. Thus interference should be the result of competition for resources, rather than confusion due to similarity between the target and interference patterns.

2.3 Masking.

In all the experiments using the graphic display facilities, each display of a matrix or slant pattern was followed by a visual mask. There were two reasons for doing this. First, in several experiments very precise control of the stimulus presentation time was required. A long history of research into visual persistence (e.g. Haber and Standing, 1970) and iconic memory (e.g. Sperling, 1963; Liss, 1968) has shown that the effective stimulus duration exceeds the display time unless a mask follows the stimulus. The second reason for using a mask is that some physical persistence of the display was detectable several seconds after offset. This was due to a slow phase in the decay characteristics of the phosphor. The use of a mask with a similar configuration to the decaying display effectively eliminates this rather long duration persistence.

(i) Selection of the type of mask.

An extensive analysis by Turvey (1973) showed that there were two components to visual masking: peripheral masking, which was a function of the target and mask energies, restricted to monoptic and binocular presentations and phenomenally equivalent to target and mask integration, and central masking, which occurred dichoptically with pattern masks, was a function of stimulus-mask onset asynchrony, and appeared to be due to interruption of target processing by the mask.

In these experiments the aim was to prevent any effective processing after stimulus offset, and to do this the mask was selected according to certain criteria:

a) A pattern mask was used consisting of a chequerboard display with the same unit cell size as the stimulus patterns. A number of investigators have suggested that spatial frequency distribution is an important variable in determining the effectiveness of a pattern mask (e.g. White and Lorber, 1976, Growney, 1978). The type of mask used here has a large spatial frequency overlap with matrix patterns, although random matrices will generally contain some low frequency components which are not present in the mask.

b) The mask and stimulus were displayed at equal intensities.

c) The mask duration was a minimum of 200 msec, and thus exceeded the critical duration for brightness summation which is about 100 msec at scotopic levels of illumination, and about 20msec at photopic levels (e.g. Herrick, 1956; Roufs, 1972). Together with (b) this ensures that the mask was at least as bright as the stimulus.

d) The mask area was greater than the area of the stimulus pattern.

e) Where possible, the stimulus and mask were displayed with spatially coincidental contours. The aim was to ensure that no information could be read from the pattern if it was superimposed on the mask. If the contours of stimulus and mask were not coincidental, such as a 4x4 matrix on a 5x5 mask, then it might be possible to read the pattern when combined with the mask, as the pattern contours would be distinguishable.

This hypothesis was tested directly by setting up a dynamic display where a 4x4 matrix pattern and a chequered mask were displayed alternately for 20 msec each, so that the observer saw a fusion of the two stimuli, displayed at equal brightness. Under these conditions

it was possible to make out some features of the pattern where the contours did not coincide (5x5 mask). When the contours were aligned (6x6 mask) no information about the matrix pattern could be obtained.

2.4 Apparatus.

On-line control of the experiments was provided by a PDP 11/45 computer linked to a GT40 graphics terminal. Responses were made using the typewriter keyboard of the graphics terminal. Only a few keys of the entire layout were required, and these were marked as appropriate for each experiment. The keyboard was provided with a loudspeaker which could be used to deliver an audible click signal when required.

(i) Displays.

The main advantage of the graphic display unit was that it enabled displays to be built up from subroutines. Thus, to display a matrix pattern a subroutine was first generated which displayed a single filled cell. A set of additional instructions specified the location of that cell in screen coordinates. To display a whole pattern, instructions from the PDP 11/45 specified the screen positions of the filled cells, and these were displayed in order, scanning from left to right, and from top to bottom. Each pattern was drawn once within a fixed interval called the refresh cycle. The duration of a display was controlled by specifying the number of refresh cycles before the offset. Timing measurements showed that display duration was accurate to ± 1 msec.

Filled cells were made by a raster scanning alternate lines of the display unit. Great care was taken to ensure that adjacent cells were phenomenally fused. Faint, vertical striations were sometimes visible in displayed cells, due to slight modulations in the brightness of a displayed line. It is unlikely that this had any significant effect on the perception or encoding of the patterns.

Slant patterns were displayed in a similar fashion, where the subroutine specified a sloping line across either diagonal of a cell (Figure 2.1).

The GT40 was equipped with a light pen facility, which enabled the recall of matrix patterns by reconstructing a pattern display on the screen. Details of this technique are provided in the next chapter, under the Methods section of Experiment 3a.

(ii) Limitations of the display system.

The display unit was equipped with a cathode ray tube coated with a fast P31 phosphor with infra red. With this phosphor, the visible light emitted falls to 1% of its initial value within 0.25 msec. Nevertheless, persistence over periods of several seconds can be observed with high display intensities and low ambient illumination. To avoid any effects of prolonged persistence experiments were performed with high ambient illumination where possible. Masking of the stimulus patterns further ensured that the persistence did not extend the effective stimulus display time.

Two factors limited the refresh rate of the display. Because of the fast phosphor, phenomenal flicker appeared if the rate was slowed down below 30 msec per refresh cycle. If the refresh rate was increased beyond 20 msec/cycle the number of vectors that could be displayed was severely restricted. Consequently the refresh rate was fixed at 20 msec per display cycle for all the experiments reported here.

There were also some difficulties associated with the use of the light pen and tracking figure. These will be described in the Methods section of Experiment 3a.

(iii) Timing.

The time of every response and the start of each display was recorded by reading the software clock of the PDP 11/45. This clock

was driven by interrupts at a rate of 1 kHz generated by a temperature-compensated crystal oscillator, accurate to 2 ppm.

CHAPTER THREEVisualization Capacity3.1 Limitations on Visualization and the Unitary Recency Effect.

Evidence was reviewed in Chapter 1 showing that for visual materials presented and tested under appropriate conditions, there is a recency effect confined to the last attended item, due to visualization. It remains to be explained why visualization is confined to a single item. One plausible explanation is that matrix patterns are novel items, and a description of each one must be constructed at presentation. The processing load required to do this may be too great to allow concurrent visualization of preceding items. A second argument emphasizes that matrix patterns are composed of several elements. The notion of a visual 'item' is therefore ambiguous. Active rehearsal may extend over several elements of the final target pattern. In this sense, recency can be said to include several 'items'. However, if the whole matrix pattern is considered as one item, then the measured recency effect will be limited to that item, unless part of a previous pattern can be rehearsed at the same time. Finally, static visual presentations are distributed spatially, rather than temporally. It may therefore be appropriate for a short-term visual memory system to maintain contemporaneous information which is distributed spatially. This contrasts with verbal information which is broadcast and rehearsed as temporal sequences.

A number of recent investigations have shown differences in the free or probed recall of items presented in temporal or spatio-temporal sequences (e.g. Hitch, 1974; R.E. Anderson, 1976; Healy, 1975). Together, their results suggest that temporal order information is more accessible in verbal sequences, an advantage which may be related to phonemic encoding. In contrast, spatial order information may be more

accessible for visuo-spatial items. A different kind of evidence suggesting that visual STM is dependent on spatial position comes from Walker (1978). He showed that the physical identity RT advantage in Posner's letter-matching paradigm diminished as the spatial separation of target and probe items was increased.

Thus, two different types of explanation can be put forward to explain the unitary recency effect obtained with novel visual materials. One argues that recency is due to the limited capacity available for describing novel, complex items, the other that it is an artefact caused by distributing the items temporally, rather than spatially. Three hypotheses are outlined below, and evidence bearing on these will be presented in the course of this chapter.

(i) The capacity limit hypothesis.

Visualization as a process is confined to recent attended information. Any number of sequential displays may be visualized, up to a limit set by the available capacity. If this capacity is exceeded by a single item, then unitary recency will result.

(ii) The spatial displacement hypothesis.

Visualization of events is linked to their spatial location. A number of sequentially presented items may be visualized together, but only if the presentation is spatially distributed. The presentation of a later item at the same location renders the previous one inaccessible to visualization.

(iii) The temporal limit hypothesis.

Irrespective of visual information load, only one temporal presentation can be visualized at a time. When a series of items is distributed in time, whatever the spatial distribution, visualization is restricted to the latest attended item. Immediate memory for this item is a function of the limit imposed by visualization capacity.

The experiments to be described in this chapter are concerned with the limitations of visualization. In the first experiment, a recall technique is used to obtain a better estimate of visualization capacity. Experiments 3b and 3c investigate the effect on recency of spatially separating successive items using recognition and recall as measures of performance. Finally, Experiments 3d and 3e investigate the capacity limit hypothesis by examining the recency effects seen when sequences of simple patterns are presented.

3.2 Experiment 3a. Measurement of Visualization Capacity Using a Recall Technique.

In this experiment, STVM and LTVM were measured using a light pen and interactive graphic display to reconstruct matrix patterns. There are two advantages in using this method. First, it provides a means of estimating the amount of information encoded and stored on a single trial. Secondly, it records the accuracy of each successive choice made during recall. By instructing subjects to select first those parts of the pattern they remembered best it is possible to determine the number of cells which can be correctly reported on all trials. Therefore this recall technique enables measurement of both the average amount and the distribution of encoded information over trials.

The principal aim of the experiment was to measure visualization capacity in terms of the amount of a pattern which can be reliably reconstructed under STVM conditions. Since only one pattern was presented on each trial, the experiment is not directly informative about recency effects for matrix patterns. However, the investigation of visualization capacity is relevant to the question of visual recency effects. If only a fraction of the pattern is accurately and consistently recalled under STVM conditions, we should predict unitary recency effects for strings of patterns, by the capacity limit hypothesis. Other

findings of this experiment are relevant to the issues of retrieval and coding of matrix patterns, and will be dealt with in the chapters which discuss those issues.

Methods

Subjects. Thirty volunteers from the undergraduate subject panel were allocated to one of two groups. Each subject was run in a single session lasting up to one hour.

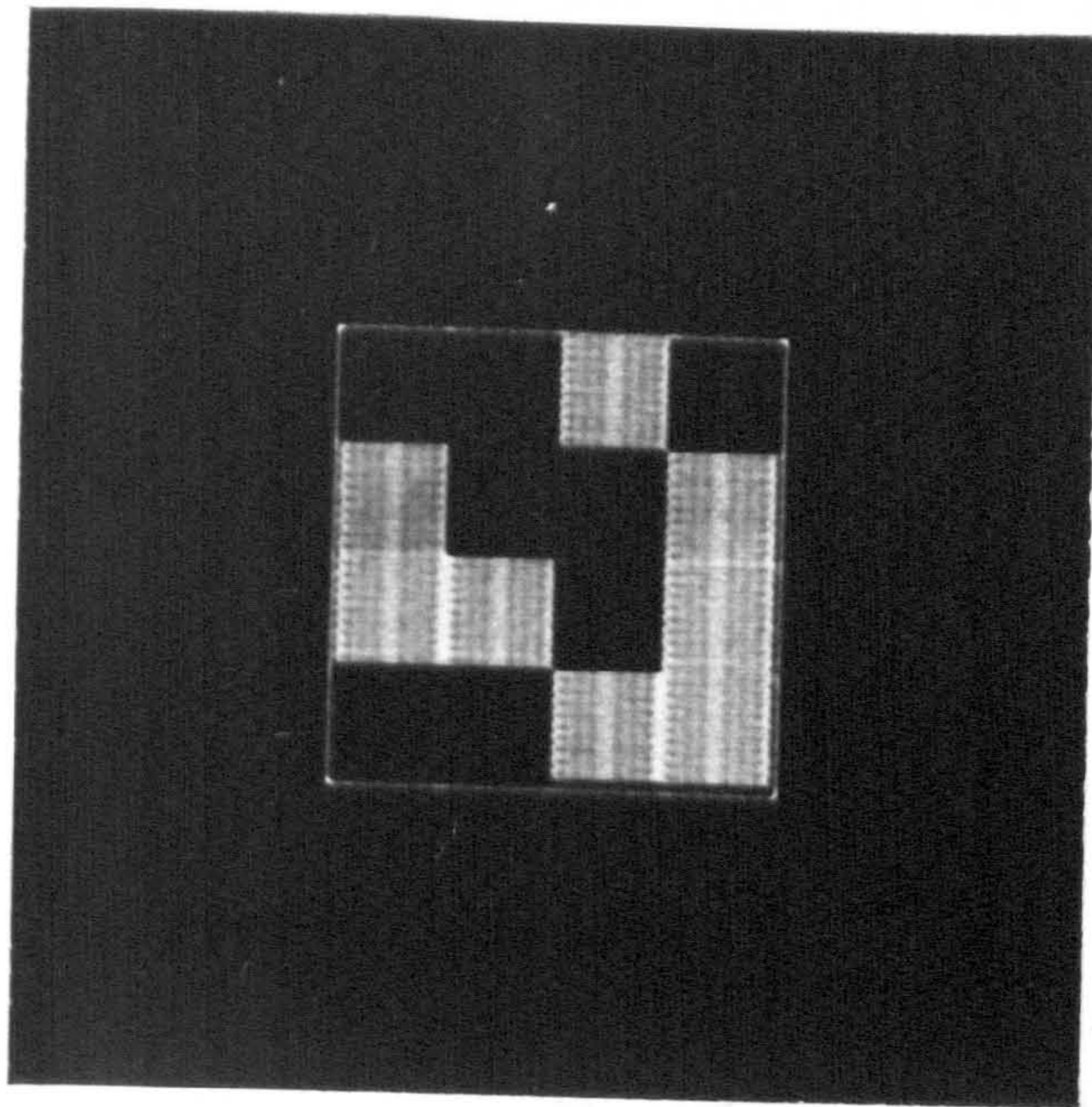
Design. In the experiment subjects were required to recall 32 matrix patterns, half of which were followed by mental arithmetic (LTVM condition) while the remainder were recalled after an unfilled interval (STVM condition). For group A the even-numbered patterns were tested under STVM conditions, and the odd-numbered patterns under LTVM. This was reversed for group B. For each subject the trials were presented in a different random order.

Materials. The stimulus patterns used for practice and in the main experiment consisted of 4x4 matrices with 8 cells filled. Twenty-five matrices were used in practice and a second set of 32 in the main experiment. Due to an oversight in programming these pattern sets were not disjoint; fourteen patterns were common to both sets. That this duplication was not detected by the experimenter at an early stage testifies to the low level of LTVM for these patterns. The duplicated patterns were tested under both interference conditions, so the experiment is not unduly biased.

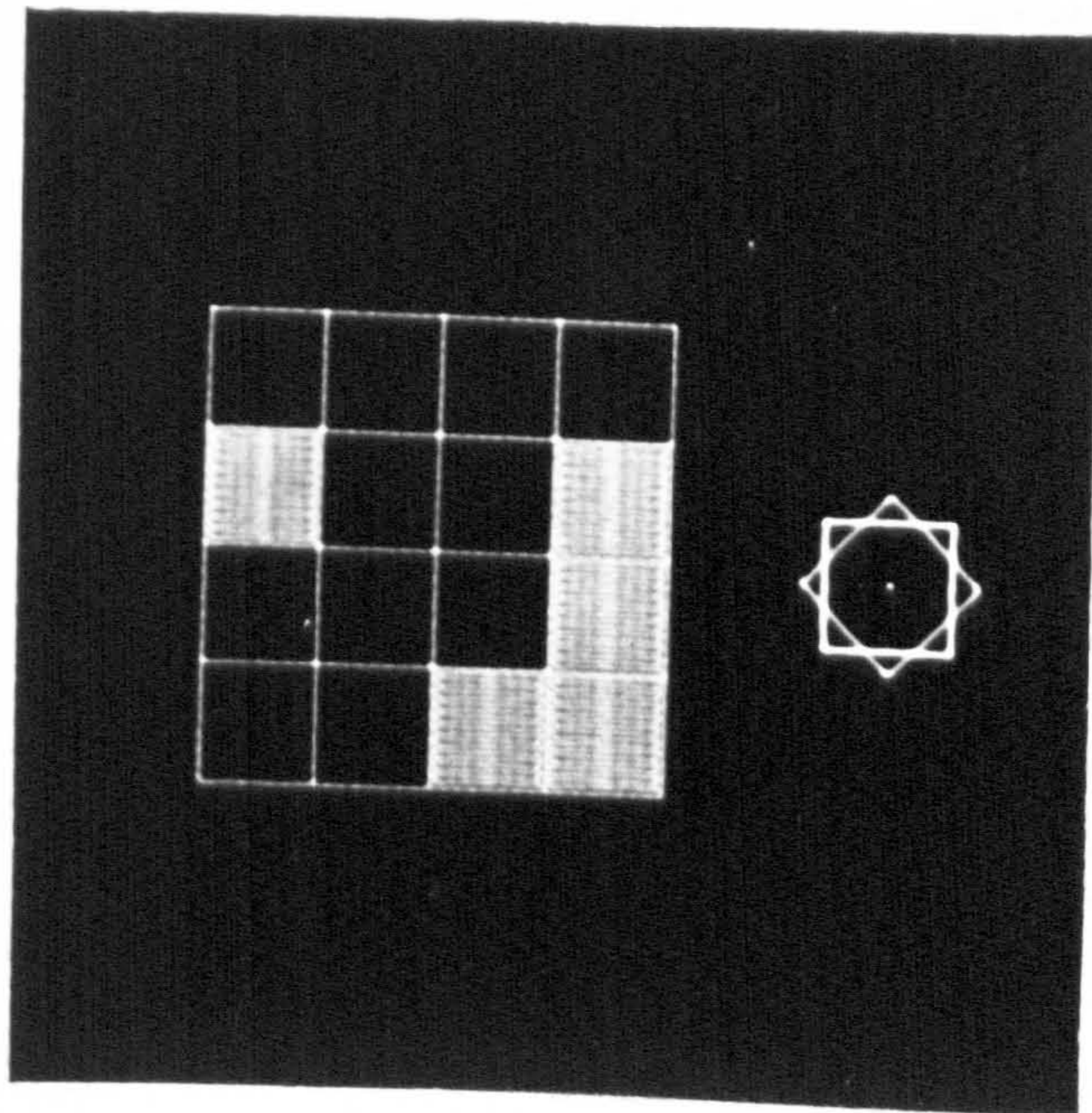
Stimulus displays. The target stimuli consisted of matrix patterns drawn with a unit cell size of 8 mm. To indicate the precise location of filled cells in the matrix, each pattern was enclosed in a square indicating the perimeter of the matrix. An example of this kind of stimulus pattern is shown in Figure 3.1(a).

Figure 3.1. The appearance of displays used in computerized recall experiments, shown actual size. Fig. 3.1a shows a 4x4 matrix pattern displayed as a target with the perimeter of the pattern drawn in. Figure 3.1b shows a recall grid where five cells of the above pattern have been filled. The tracking figure lies to the right of the grid.

Fig. 3-1



a



b

Masking. Each target was followed by a random noise mask, consisting of an 8x8 matrix with a unit cell size of 4 mm. Each cell in the mask matrix was filled with a probability of 0.25, and a new mask was generated and displayed on each trial. (This type of noise mask was used only for this experiment. All subsequent experiments use the chequered pattern masks described in the previous chapter).

Recall technique. At test a 4x4 grid was displayed on the screen, each cell corresponding to one cell of the target, with a unit cell size of 8 mm. The subject responded by using the light pen to guide the tracking figure, a moveable part of the display under light pen control. The figure itself consisted of two squares at a mutual angle of 45° , surrounding a central dot. In use, the subject placed the tracking figure over a cell of the matrix, and pressed a key to instruct the graphic display unit to record the position of the tracking figure in screen coordinates. From these coordinates, the intended cell of the grid was computed. The display was then modified by filling the selected cell of the grid. Figure 3.1b shows a partially completed recall grid and the tracking figure.

Subjects were instructed to select 8 cells of the grid in this way, and the program ensured that the required number of selections (placements) were made on each trial. Because errors frequently occurred when selecting cells, an erasure facility was built into the program. Subjects could erase any cell they had selected by placing the tracking square over it and activating the light pen; the filled cell then reverted to a blank one. When reconstruction of the pattern was complete, the grid display was terminated by moving the tracking figure to the right of the recall grid and pressing a key. Termination of the display was only possible if 8 unerased cells had been selected.

There were several difficulties associated with the use of the light pen and tracking figure. The most serious of these was that

the tracking figure was unstable and tended to 'flutter' around the end of the light pen, often oscillating over more than one cell of the recall grid. This made selection of the appropriate cell difficult. Moreover, this tendency was linked to the luminance of the display; if too high the tracking figure tended to flutter and if too low it was insensitive and failed to respond to movements of the light pen. Small changes in screen luminance due to warm-up of the display mechanism had a considerable effect.

This problem was never resolved satisfactorily, but performance of the system was optimised by keeping the ambient illumination low, so that the display could be clearly seen at a low screen luminance.

Interference. This was provided by a mental arithmetic sum involving the simultaneous display of four digits, separated by plus (+) signs and followed by an equals (=) sign. The subject attempted to type the correct answer to the sum during its four seconds display time. If the correct answer was entered, it was displayed on the screen. If not, the screen remained blank.

Procedure. To ensure optimal performance from each subject in this difficult task, the experiment and practice were entirely self-paced. Preceding each trial a fixation point was displayed in the centre of the screen. On initiating the trial the stimulus pattern was displayed for 1.5 sec, followed by the random mask for 0.5 sec. The next four seconds constituted either an unfilled interval, with a blank screen, or a period of mental arithmetic interference. The recall grid and tracking figure were then displayed and subjects attempted to reconstruct the pattern they had seen. No time limit was placed on recall.

Instructions. With the use of diagrams subjects were shown how to reconstruct a matrix pattern by selecting the cells of a grid. In the practice (25 trials), the experimenter demonstrated the procedure on the first trial, and watched the subject perform the task on the next few trials, prompting as necessary. The subjects completed the practice by themselves, and after a rest performed the 32 trials of the experiment. Four points were stressed by the experimenter:

- (i) To concentrate hard on the displayed pattern.
- (ii) To ignore the mask.
- (iii) If interference was given to try to answer the sum within the time limit.
- (iv) During recall, to reconstruct first any part of the pattern they could remember, and to guess the remainder if necessary.

Results.

The raw data collected consisted of the position and latency of each successive selection and erasure during the reconstruction of each pattern. An analysis program run on the raw data removed the erasure responses, leaving a record of the final cell choices in their serial order, and the accuracy and latency of each selection. Because of the large number of erasures the latency data were unreliable and were discarded.

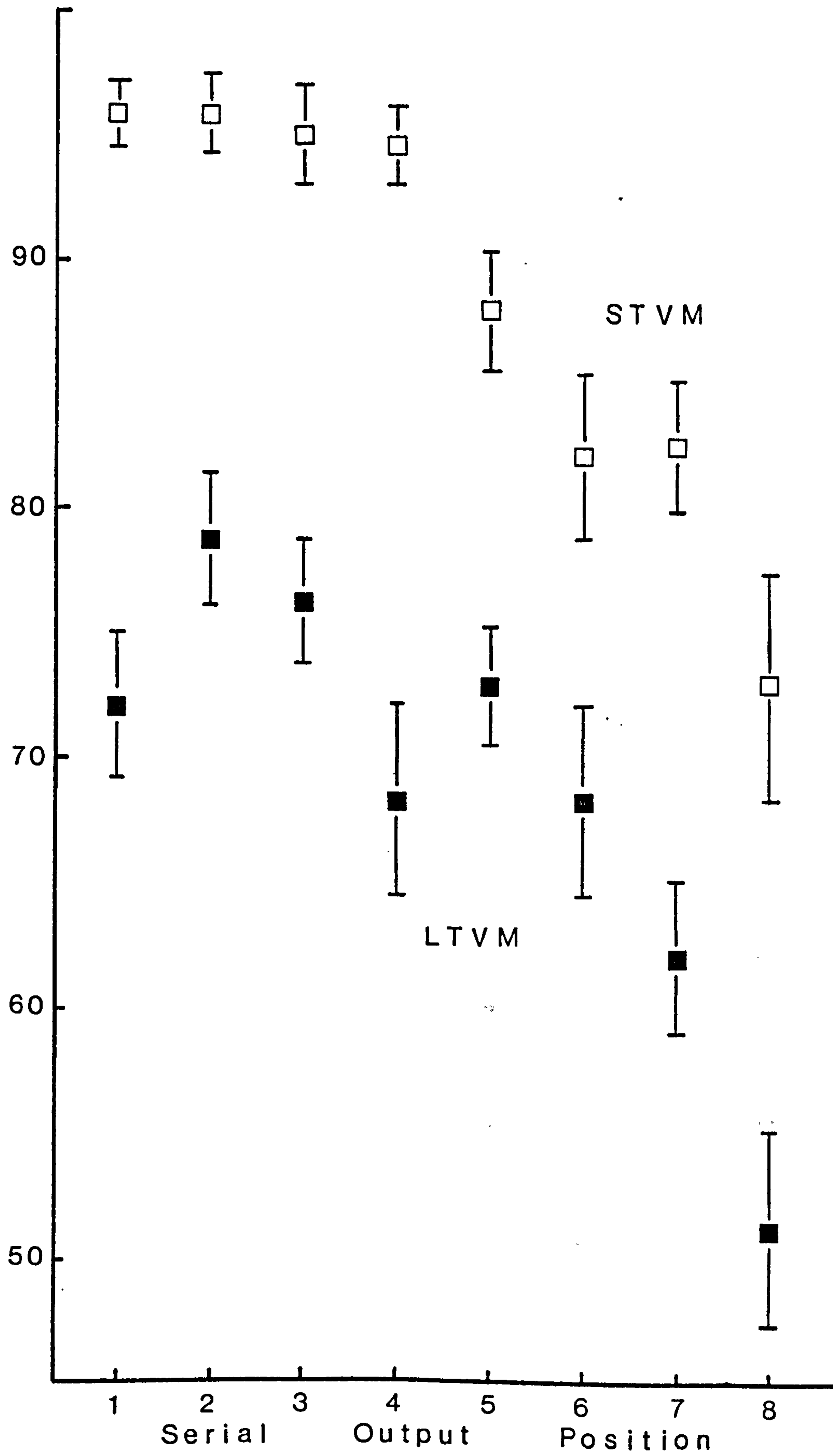
(i) Percentage of correct selections as a function of serial position.

Figure 3.2 shows the mean percentage of correct cell placements made at each serial output position in each interference condition for groups A and B. From the graphs it is clear that accuracy falls off monotonically with serial output position, and there is a large effect of interference. There are two interesting features of the data. First, selection of the first four cells under visualization conditions is extremely accurate, suggesting that on virtually every trial, part of the pattern corresponding to at least four cells can be recalled. Secondly, the shapes of the serial output functions are similar for STVM and LTVM, but about 25% lower in the latter case. Thus for LTVM, while the first 4-5 placements are more accurate than the later ones, there is no suggestion of consistent, high accuracy recall for part of these patterns.

Figure 3.2. The percent correct cell placements as a function of serial output position. Bars indicate standard errors. For each matrix eight cell placements were made during recall. In the STVM condition recall followed a 4 sec, unfilled interval; in the LTVM condition recall followed 4 sec of mental arithmetic. Figure 3.2a shows STVM and LTVM data for Group A. Figure 3.2b shows the corresponding data for Group B.

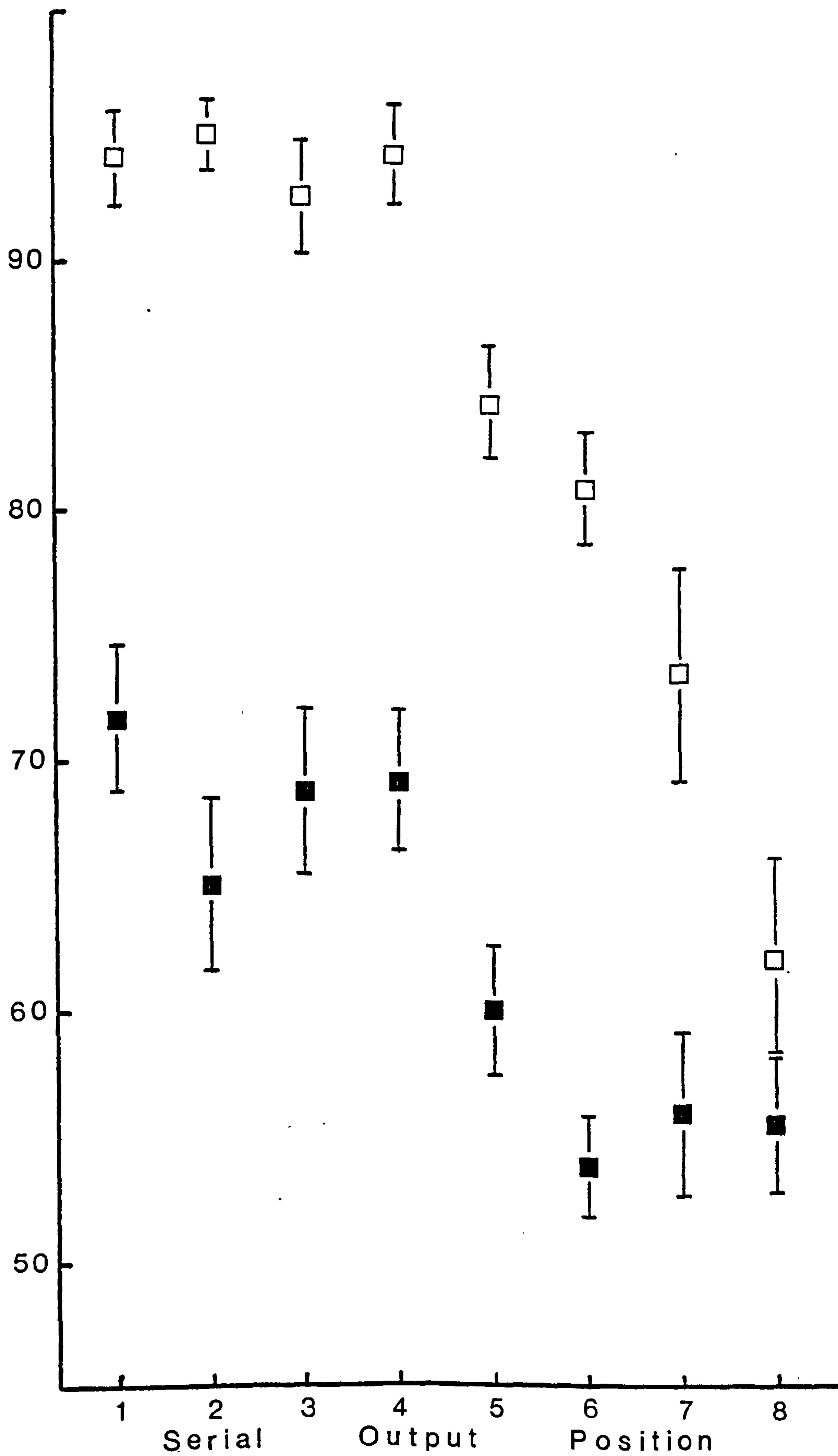
Percent Correct
Recall

Fig. 3-2 a



Percent Correct
Recall

Fig. 3.2 b



A split-plot analysis of variance was run on the data with groups as the between subjects factor, serial position and interference as within-subject factors. A summary is provided in Table 3.1. As expected, there were large effects of interference and serial position, but also a significant interaction between them. There was also a significant difference between groups, which may be partly explicable by non-random allocation of subjects. The three-way interaction may be explained by the chance level scores found in group B for the final serial positions, which gives a significant interaction of serial position x interference for this group, but not for group A.

(ii) The estimation of visualization capacity.

The overall percent correct score, averaging over both groups was 86.4% for the STVM condition. Since the probability of making a correct selection by chance alone is 50%, a guessing correction was applied to this score, using the formula:

$$X = \frac{S - P_g}{100 - P_g}$$

where X is the corrected score, S the uncorrected score and P_g the guessing probability expressed as a percentage.

The corrected score for STVM recall is 72%. Thus the number of known correct placements made on average is $8 \times 0.72 = 5.76$ cells per trial. (Expression of the result in this form does not imply that the patterns are encoded as arrays of single cells. Rather, this estimate is a measure of the average area of the pattern that can be reproduced accurately, in terms of the number of selections that are required to do so.)

A similar calculation can be applied to the LTVM condition. The overall percentage of correct selections was 65.6%, which after the guessing correction gives a score of 32%. The average amount recalled

TABLE 3.1

Analysis of Variance Summary: Percentage
of Correct Cell Selections During Recall.

	Source	df	SS	MS	F	Prob.
	Subjects	29	16215			
Between						
	Groups (A)	1	3061	3061	6.52	.016
	Error	28	13153	470		
Within						
	STVM/LTVM(B)	1	52088	52088	300.9	<.0001
	A x B	1	188	188	1.01	.307
	Error	28	4847	173		
	Output Position(C)	7	31080	4440	42.39	<.0001
	A x C	7	1166	166	1.59	.14
	Error	196	20529	105		
	B x C	7	1280	182	2.17	.038
	A x B x C	7	2398	343	4.07	.0004
	Error	196	16501	84.2		
	Total Within	450	130080			

under LTVM conditions is therefore $8 \times 0.32 = 2.56$ cells.

The estimation of visualization capacity depends upon certain assumptions made about the independence of STVM and LTVM. If visualization is used to supplement the memorized information which survives interference, then visualization capacity should be expressed as the difference between these STVM and LTVM estimates (i.e. $5.76 - 2.56 = 3.2$ cells). However, if visualization and memorization are independent processes, and STVM performance reflects mainly visualization, then visualization capacity is approximated by the STVM estimate of 5.76 cells. Later experiments will provide evidence in support of the second of these assumptions, and the latter figure is therefore likely to be a better estimate of visualization capacity.

(iii) The distribution of recall scores

Figure 3.3 shows histograms of the frequencies of each score, ranging from 0 to 8 cells correct (chance = 4 cells correct) for each group and interference condition. It is clear that under LTVM conditions a large proportion of recall attempts are no better than chance, and for group B chance level is the modal score. In contrast, under STVM conditions a large number of patterns are recalled with very high accuracy, and only a very few at chance level or below, as the data of Figure 3.2 would suggest. The percentage of patterns which are correctly recalled is 47.7% for STVM and 11.7% for LTVM.

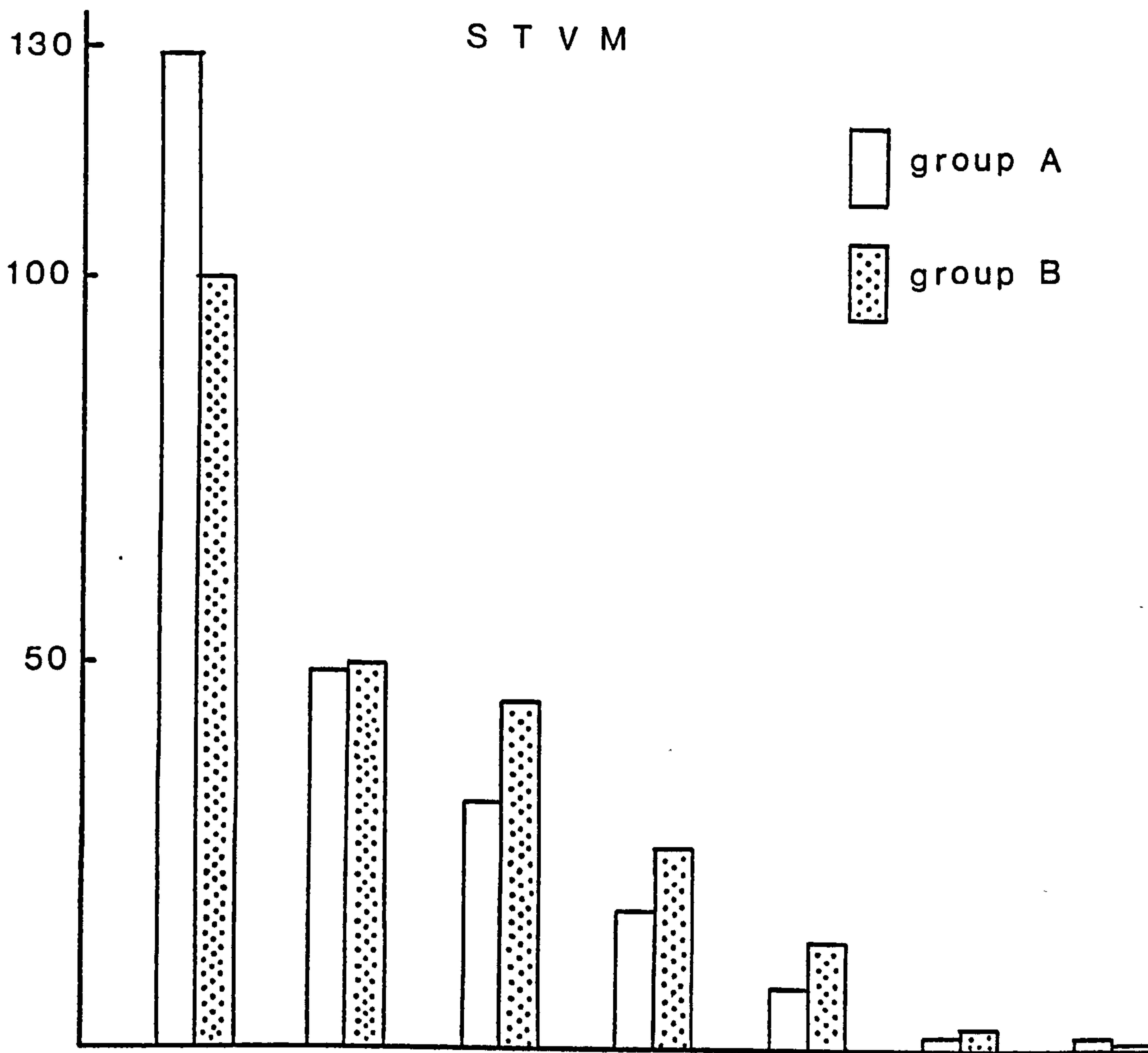
Discussion.

This experiment illustrates the advantages of a recall system for investigating visualization capacity where this falls short of the information load of one item. In addition, the serial output position data show that under STVM conditions at least four cells can be selected accurately on any trial. Comparable data are available in the literature from experiments published after the present study was completed.

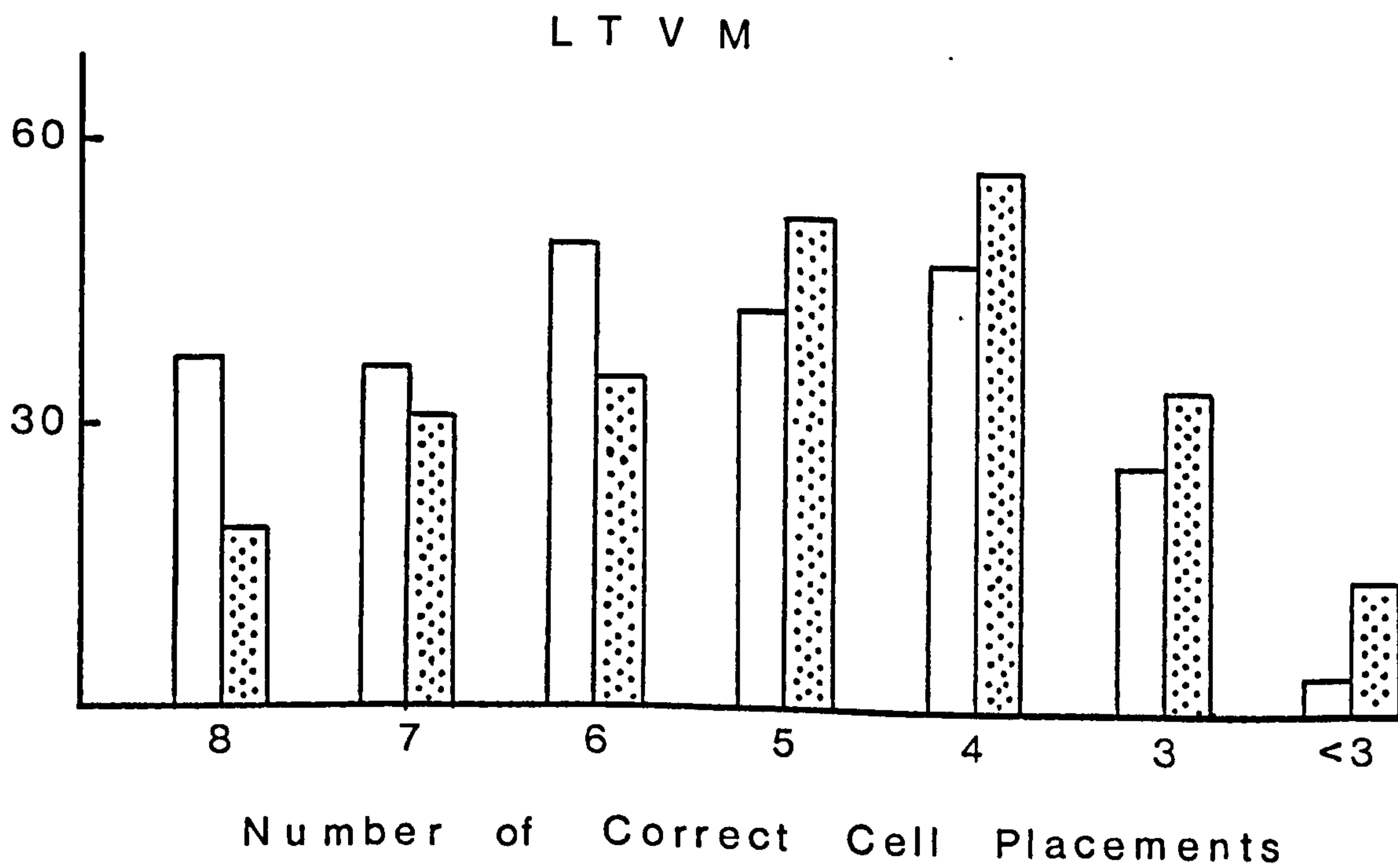
Figure 3.3. Frequency distributions of recall scores in Experiment 3a. Histograms show the total number of recall attempts for which the given number of cells were placed correctly. Eight correct placements indicates perfect recall of a matrix; four correct placements is the value expected by chance alone. Data are pooled separately for each group of subjects and for STVM and LTM conditions.

Fig. 3.3

Frequency



Frequency



Christie and Phillips (1979; Experiments 3 and 4) presented single 4x4 matrices for 1.5 sec, followed by a blank interval or mental arithmetic for a variable period (3, 9 or 15 sec). Recall was tested by filling the cells of a blank matrix using conventional drawing materials. Performance levels in their experiment were higher than in the present one, as measured by the overall percent correct (95% for STVM, and about 80% for LTVM) or the number of matrices recalled correctly (72% for STVM, 35% for LTVM). The lower performance in the present experiment may be accounted for by the difficulty of the recall task, which involved handling a complex, unfamiliar and cumbersome device. Handling the light pen may therefore have given rise to some output interference, resulting in lower scores. Evidence that output interference may occur was also provided by an experiment where, before recalling a matrix pattern, subjects were required to use the light pen to erase two or five dots which were displayed in separate cells of the matrix. Although subjects did not have to visualize these dots, the procedure of erasing them led to substantial interference, and lower scores. However, other interpretations besides output interference with visualization are possible, so the experiment will not be reported here. It should be noted that visualization capacity may be underestimated by the use of the light pen recall technique.

Only one published experiment has investigated accuracy of recall as a function of serial output position for this type of pattern. Bartram (1978) reported serial position curves for an immediate recall task involving 5x4 matrices. He used much shorter display times of 40 msec (unmasked) and found that recall accuracy was high for the first two serial output positions, and thereafter declined progressively.

The effect of interference on the serial position curves is interesting. If it led to a partial loss of information about each

pattern, the expected result would be a change in shape of the serial position curve. However, the result of interference is a change in level of the serial position curve, which is more consistent with the idea that interference leads to a complete loss of stored information on some trials. This is supported by the large number of chance level scores obtained (Figure 3.2). There are a number of possible reasons for this, such as retrieval failure, or transposition errors, and this question will be discussed in more detail in the next chapter.

3.3 Spatial Restrictions on Recency.

Serial position effects for verbal and visual materials have usually involved the presentation of successive items in the same spatial location. The unitary recency effect found with visual memory might arise as a consequence of this spatial restriction.

On a priori grounds we should expect the simultaneous visualization of two objects in the same spatial location to be a difficult mental operation. Most of our visual experience is with solid, opaque bodies which cannot co-exist in the same spatial location. Sophisticated visualization strategies might overcome this limitation, for example if the objects were visualized as intersecting transparent bodies, or objects alongside each other. However, such strategies would involve additional mental operations, possibly restricting the processing resources available for maintenance of the visual descriptions. Thus the spatial displacement hypothesis proposes that successive items cannot be visualized together if they are presented in the same spatial location.

A different explanation is that access to visual memory traces depends on spatial localization. One such theory, recently put forward by Broadbent and Broadbent (unpublished manuscript, 1978), proposed that each successive item displayed at the same location

overwrites information about the previous item which is held in a sensory store. As evidence, they showed that when a temporal sequence of visual patterns was displayed in separate spatial locations, no recency effects were found. There are three objections to this. First, sensory storage is easily distinguished from STVM, amongst other things by spatial displacement (Phillips, 1974). Unitary recency effects are found when sensory storage cannot be operating (e.g. Phillips and Christie, 1977a). Secondly, there are several procedural weaknesses in the Broadbents' experiments: the items were similar to each other, often repeated during the course of an experiment, and the amount of data collected was minimal. Thirdly, some contrary evidence exists. Christie and Phillips (1979, Experiment 5) used a pattern completion task where four items were arranged in a row in front of the subject, were shown in succession and tested in reverse order. A large unitary recency effect was found.

The following experiments (3b and 3c) involve the successive display of two matrix patterns in adjacent spatial locations. If visualization is limited to the last item displayed, then we should expect to find a unitary recency effect; but if visualization is restricted only by the spatial superimposition of items, as the spatial displacement hypothesis suggests, then both items should be visualizable. Experiment 3b used a recognition test, and Experiment 3c a recall test.

Two types of display were used, in which three-dimensional matrix patterns were constructed by placing 1" cubes on 4x4 grids. In one case, the cubes were placed on a 1" grid, so that the cubes were juxtaposed, while in the other display the grid cell size was 1½" so that each cube was separated from its neighbours. It was thought that separation of the cubes would lead to differences in coding which would be reflected in performance. This is irrelevant to the present

consideration, and is mentioned only for completeness.

Experiment 3b: Recognition of spatially separated matrix patterns.

Subjects. Sixteen subjects participated in this experiment, all of whom were recruited from the Part 1 subject panel. The subjects were randomly allocated to one of two groups, one of which was shown displays with separated elements, the other was shown displays with juxtaposed elements.

Apparatus and materials. The experiment was conducted at a table 4 ft. long by 2 ft. wide. Two white cardboard screens 10" wide and 10" high were used to obscure the subject's view of the stimulus displays. A third screen 10" high and 6" wide was placed between the two displays so that when one was exposed to the subject the other was still obscured. A fourth screen, 3" high served as a background to the stimulus displays and concealed the experimenter's materials. The arrangement is depicted in Figure 3.4.

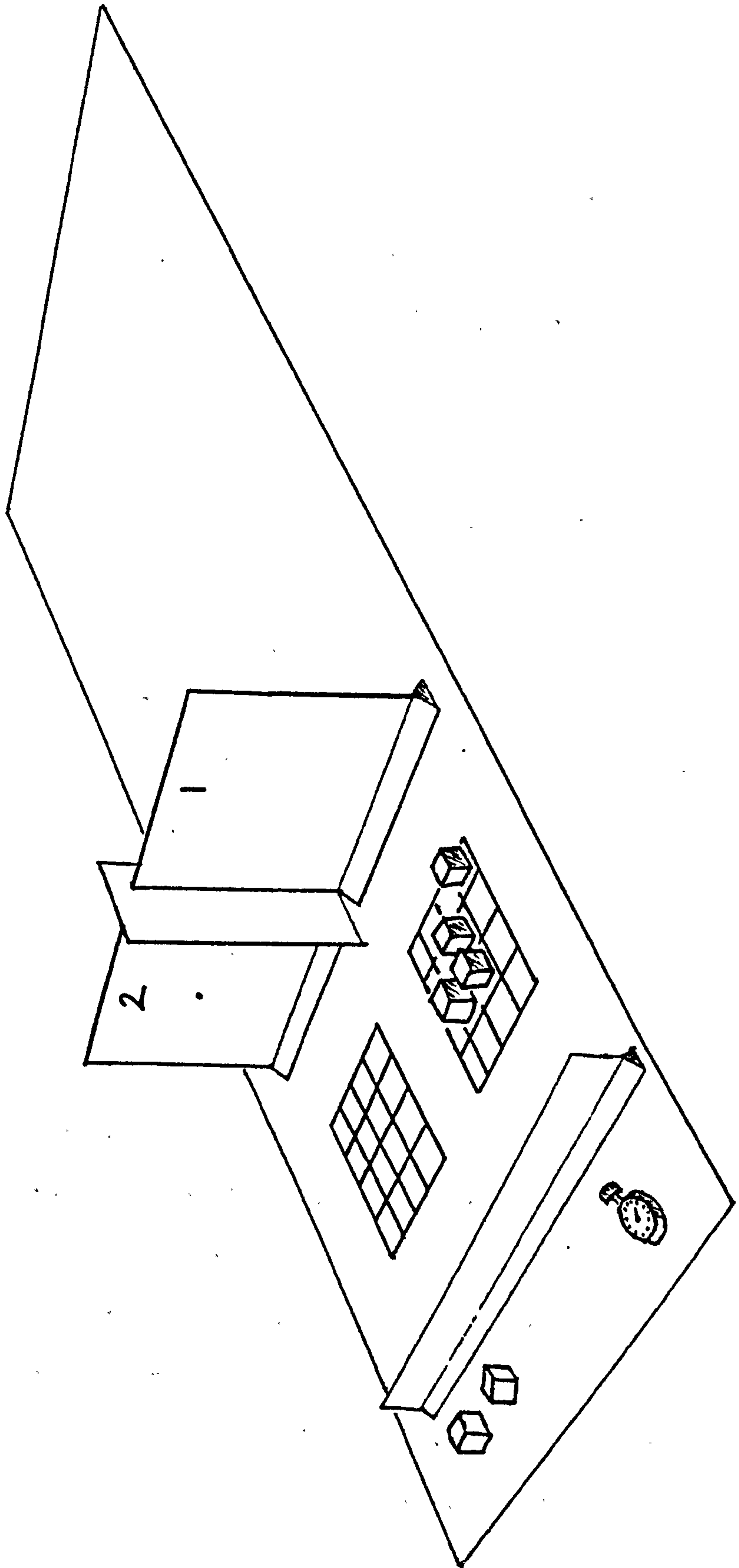
Stimuli were constructed by placing 1" cubes made from white perspex onto the individual squares of a 4x4 grid. The stimulus patterns were constructed by a random number generator, which allocated a value of 0 or 1 to each cell of a 4x4 matrix. Thus the number of cells occupied by cubes varied across patterns.

Procedure. Subjects were tested individually, and sat at one end of the table facing the experimenter, who sat at the other. The instructions were read aloud and two practice trials were given to familiarise the subject with the procedure.

On each trial, the experimenter made up the two stimulus patterns by placing the cubes on the cells of the grids, out of sight of the subject. The subject was then shown the stimuli in order, the left hand pattern first, then the right. Each pattern was shown for two seconds, by removing the occluding screens in turn, timed by a stopwatch.

Figure 3.4. Arrangement of the apparatus in Experiments 3b, 3c. Matrix patterns were constructed by placing 1" cubes on the cells of the 4x4 grids, which were concealed by the screens, marked '1' and '2'. The subject sat at the far end of the table and viewed the patterns when the screens were held aside by the experimenter.

Fig. 3·4



After the stimuli were exposed, the experimenter covertly made any change in the stimuli required by the recognition test. This was done with extreme care, so that the subject would not be able to guess from the experimenter's movements if a stimulus had been altered. Changing the displays in this way took about 5 seconds. The experimenter then revealed the stimuli again, this time in reverse order, starting with the right hand pattern. Each display was exposed until the subject responded by saying "same" or "different". Subjects were instructed to guess if they did not know the answer, and to be as accurate as possible.

Results and discussion.

The results show that recognition was very accurate for the second item shown on each trial (STVM) but much lower for the first item (LTVM). The mean percentage of correct responses for STVM was 86.0%, with a standard error of 2.25%. For LTVM the mean was 73.75%, with a standard error of 3.20%. The difference between these conditions was highly significant when tested by a paired-sample t - test ($t = 3.97$, $df = 15$; $p < .005$; one-tailed).

The result is clearly in conflict with the spatial displacement hypothesis. Even when successive items are presented in adjacent spatial locations, a recency effect is found. The data are in good agreement with those of Christie and Phillips (1979), who used a pattern completion task. A possible defence of the spatial displacement hypothesis involves criticism of the reverse serial order testing procedure. In this account, visualization of the first item in the presentation series is disrupted, not by the display of the second item, but by its retention test. Although this seems unlikely, the following experiment removes this objection by using a probe recall test.

One weakness in the design of Experiment 3b was that the same stimulus patterns were always shown as first or second items in the

presentation series. Thus there is a possible confounding between serial position effects and the items tested under each condition. The following experiment also avoids this problem.

Experiment 3c: Recall of spatially separated stimulus presentations.

Subjects. Twelve subjects participated, and were allocated at random to one of the two display conditions.

Design. The design was similar to the previous experiment.

Materials. The stimulus materials and presentation conditions were identical to those described previously. Subjects were provided with answer sheets on which to make their responses. Each sheet contained ten blank 4x4 matrices, which were given numbers corresponding to each trial.

Procedure. On each trial the experimenter made up two stimulus patterns by placing cubes in the appropriate places on the grids. These were shown to the subject for two seconds in turn by removing the stimulus screens. For half the subjects the order of display was the left hand pattern followed by the right, and for the other half this order was reversed. The screens were labelled '1' and '2', and these were interchanged as appropriate to indicate the display sequence. A four second retention interval followed, after which the experimenter called out the number "one" or "two". The subject then attempted to recall the stimulus pattern behind the designated screen, by marking the cells of the blank matrix provided. An unlimited time was allowed for recall.

After reading the instructions the experimenter demonstrated the procedure twice with dummy stimulus patterns. Twenty-five trials followed: five practice, and twenty experimental trials. At the end of the experiment subjects were asked to report the strategies they had used.

Results and discussion.

Each recall attempt was given a score corresponding to the number of correct cells (maximum = 16). For each subject, these scores were combined to give a percentage correct value for each interference condition.

The mean recall performance for STVM conditions was 72.7%, standard error 1.91%. For LTVM, the mean was 66.88% with a standard error of 1.53%. The difference in performance for the two recall conditions was significant by a t-test for paired samples ($t = 2.71$; $df = 11$; $p < .025$; one-tailed).

The presence of a recency effect under these conditions provides further evidence against the spatial displacement hypothesis. However, STVM recall in this experiment was unexpectedly low compared to that reported by Christie and Phillips (1979) which required free recall of a series of four matrix patterns. One explanation is that visualization of the second item is an advantage only when that item is probed, i.e. on half the trials. This may have provided inadequate incentive for subjects to visualize the second item, compared to the free recall situation. It is clear that subjects were not visualizing both items, since performance throughout was close to LTVM levels.

As well as rejecting the spatial displacement hypothesis, the present results are difficult to account for in terms of sensory overwriting. In the recognition test of Experiment 3b, items were presented in separate locations, and the probes were shown in identical locations. Thus no sensory overwriting should occur, since at each location no interfering display was interposed between the presentation of an item and its test. A similar prediction holds for Experiment 3c. In this case, recall performance was about equal in the two spatial position conditions, but overall performance was lower than expected -

a finding readily explained in terms of the costs of visualization, but difficult to account for by 'sensory' storage. For this and other reasons given above the sensory overwrite hypothesis is considered to be quite untenable.

More plausible is the notion that spatial location may have an effect on retrieval in visual memory. When displayed, items may receive a 'spatial tag' (an extreme example of this is provided by page location information in printed text; Rothkopf, 1971). Retrieval may then occur by an ordered search along a succession of these tags. Evidence that pictorial material may be preferentially ordered on a spatial dimension was provided by R.E. Anderson (1976). This type of theory predicts that recency effects should extend over a number of items, it cannot easily explain unitary recency. Nevertheless, when successive visual items are displayed in different spatial locations, unitary recency effects are found (e.g. Swanson, 1977; Christie and Phillips, 1979).

3.4 Recency as a Function of Pattern Complexity.

It has been shown that visualization capacity is insufficient to encode all possible 4x4 matrices. According to the capacity limit hypothesis, visualization may extend over a number of items presented in temporal sequence; the limit on the number of items visualized is set by the total information load. Thus if strings of 4x4 patterns are presented, recency effects will be confined to the last item since 4x4 patterns use up all (or nearly all) of visualization capacity. But if simpler patterns are used, the final item will not place such a demand on visualizing resources and some spare capacity will be available to visualize the previous item. Hence the prediction that as pattern complexity decreases, the recency effect will extend to the penultimate item. Two experiments were performed to test this prediction,

one using a pattern completion task (partial recall) the other using a recognition test.

Experiment 3d: Measurement of the serial position curve for simple patterns using a pattern completion task.

The rationale behind this experiment was simple, but a number of considerations and constraints led to some difficulties in the design. To test the above prediction, performance on the penultimate item must be compared with performance on earlier items. Therefore serial position data was recorded for the last four items in the presentation sequence. A further assumption is that the penultimate item would be visualized by subjects at presentation. If a fixed length string were shown on each trial subjects might opt for the strategy of visualizing only the final item. To encourage equivalent processing at presentation time for the critical items the length of string was varied. Consequently, in this and the following experiment, the number of items in the presentation series was randomly varied between four, five and six items, of which only the final four serial positions were tested. Pattern complexity was manipulated by changing the size of the matrix from which the patterns were constructed. The matrices used were 4x4, 3x4 and 3x3 cells in width and height, respectively.

Methods.

Subjects. Eight undergraduates participated in this experiment and were paid at the rate of 60p per hour. They were all drawn from a pool of subjects who were especially trained in the use of the light pen to recall matrix patterns. One subject was rejected because of a computer failure during the experimental session.

Design. A within-subjects design was used where each subject received ten trials under each of twelve conditions, formed

by combining three levels of pattern complexity with the four tested serial positions. Each trial consisted of the presentation of a test pattern and three, four, or five filler items which were never tested. The serial position of a particular test item was varied across subjects. In all, each test item was presented twice in each of the four critical serial positions. The conditions were given in a different random order for each subject.

Materials. The design demanded 40 trials at each level of complexity, and since up to six patterns were given on each trial this required 240 patterns at each level. For 3x3 matrix patterns there are only 120 possible alternatives with five cells filled. To avoid this limitation on variability, the 3x3 patterns were generated with either four or five cells filled, and the entire set of such patterns was used in this experiment. The 4x4 and 3x4 patterns were constructed by filling half the cells.

Patterns were generated in series of six, consisting of the five filler items and the test item for that series. For the filler items, each cell of the pattern was specified as filled or unfilled. For the test item, one of the filled cells was marked, this being the cell that was not displayed during recall. This cell was chosen at random from the filled cells, with the constraint that the test pattern could not be converted into one of the filler items by adding a cell. The complete set of patterns consisted of 40 such series at each of the three levels of complexity. There were no duplicates in the set of displayed patterns.

Another set of patterns was made up for use in the practice session. This consisted of 24 series with six patterns in each. Twelve series were made from 4x4 matrices with 6 cells filled, and the remainder used 3x4 matrices with 5 cells filled.

Procedure. The experiment was conducted in two sessions, lasting about 45 minutes each. In the first session the subject was instructed in the task, performed 24 practice trials and then completed sixty experimental trials. The second session, which took place on a subsequent day, consisted of five trials as warm up, followed by the remaining sixty trials.

A pattern completion task was used in this experiment. This involves presenting a test pattern which is complete except for one filled cell, which is left unfilled. The subject's task is to select the cell which, when filled, will complete the pattern. The particular advantage of this task is that it minimises the output interference, which may occur when the light pen system is used in pattern reproduction.

The experiment was self-paced, and each trial began with the display of a fixation point. By pressing a key the subject initiated a sequence of four, five or six display cycles, each consisting of the following events:

- a) The target or filler pattern, displayed for 3.0 sec.
- b) An interval of 40 msec with a blank screen.
- c) A 5x5 chequerboard mask, displayed for 260 msec.
- d) A blank screen for 200 msec before the next pattern.

The subject was informed that the series had ended by an audible click delivered by the GT40 keyboard, and simultaneous with the end of the last display cycle. The screen remained blank for a further 1.0 seconds. After this the recall grid was displayed, in which all the cells of the test pattern except one were filled. Using the tracking figure and light pen the subject selected one unfilled cell in an attempt to complete the pattern. The chosen cell was filled, but no feedback was provided about the correctness of the choice. The tracking figure was then moved to the right of the grid and the display was terminated.

A fixation point was displayed at the start of the next trial. A selection could not be corrected once made. The data recorded on each trial consisted of the selected cell and the response time. Because the procedure was tiring, a short rest period was provided after every ten trials. At the end of the experiment subjects were asked to report the strategies they had used at presentation and at test.

Results and discussion.

(i) Percent correct completions.

The raw data consisted of the number of correct completions made by each subject in each condition. Before statistical analysis a guessing correction was applied to these scores using the formula:

$$X = \frac{S - P_g}{100 - P_g}$$

where S is the number of correct completions, expressed as a percentage.

X is the corrected score.

P_g is the probability of guessing by chance alone, expressed as a percentage. This is equal to

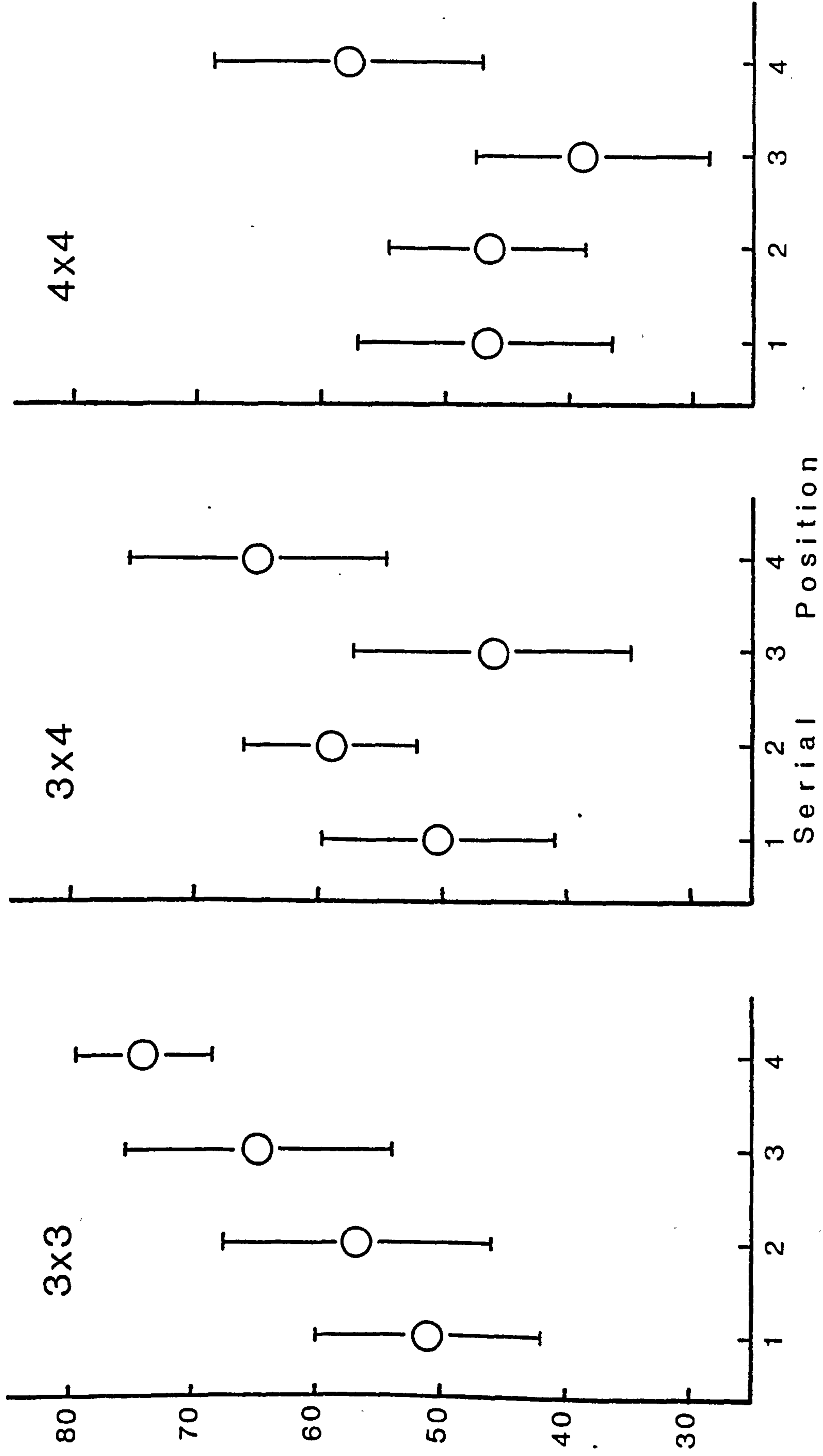
$(1/b) \times 100\%$ where b is the number of unfilled cells in the recall grid.

The mean values and standard errors of the corrected scores are plotted in Figure 3.5. An analysis of variance (two-way, with repeated measures) was run on the transformed scores, and this showed a significant effect of serial position ($F = 6.37$; $df = 3,21$; $p = .003$) and also of complexity ($F = 4.2$; $df = 2,14$; $p = .037$). The interaction was not significant ($F < 1.0$).

Figure 3.5. Mean percentage of correct pattern completions and standard errors as a function of serial position and pattern complexity. Serial positions 1-4 indicate the four final items in the presented series, with 4 being the most recent presentation. Matrix patterns with three levels of complexity were used: 3x3, 3x4, and 4x4.

Fig. 3.5

Percent Correct
Completions



As expected there is a serial position effect. Examination of Figure 3.5 suggests that for the simplest patterns, mean performance increases over the last four items, whereas for the most complex patterns any advantage is restricted to the final item. This would lend some support to the capacity limit hypothesis, but statistical confirmation was not found in the interaction of complexity and serial position. A separate analysis of variance was run on data from the 3x3 conditions alone, and this showed no significant effect of serial position ($F = 2.46$; $df = 3,21$; $p = .09$). Therefore the stronger prediction of an advantage of the penultimate item over the previous items could not be tested.

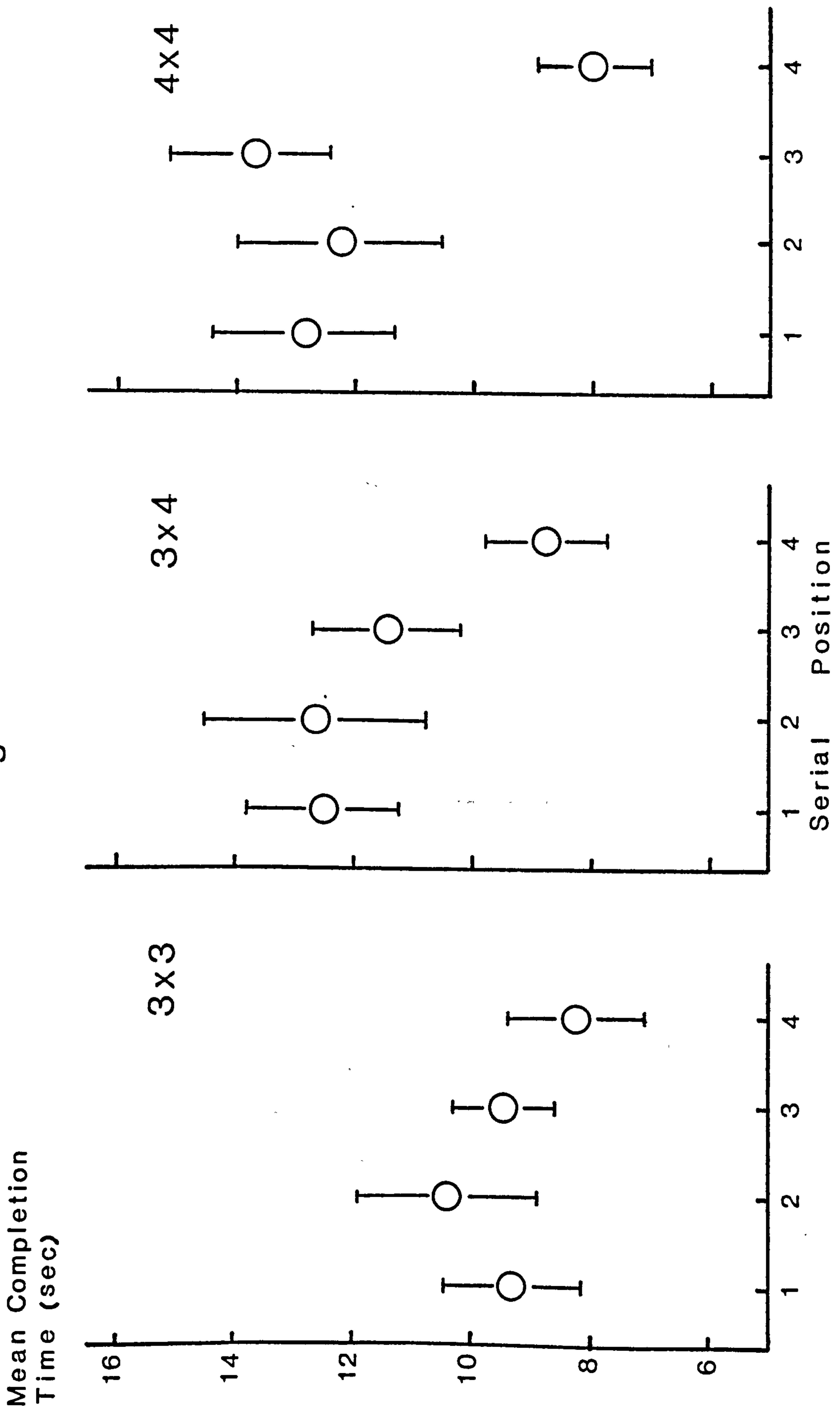
(ii) Response times.

The mean response times and standard errors for each condition are shown graphically in Figure 3.6. It can be seen that the RTs were very long. This is probably not a reflection of the difficulty in handling the light pen, since all eight subjects were highly skilled in its use. Responses were generally faster when the final item of a series was tested, but there is no evidence of any advantage for the penultimate item. The RT advantage for the final item increases as a function of complexity.

A two-way repeated measures analysis of variance showed highly significant effects of complexity ($F = 7.67$; $df = 2,14$; $p = .006$) and of serial position ($F = 6.82$; $df = 3,21$; $p = .002$). The interaction just failed to reach significance ($F = 2.18$; $df = 6,42$; $p = .064$).

Figure 3.6. Mean response times in seconds and standard errors for the pattern completion task, as a function of serial position and target complexity.

Fig. 3.6



(iii) Subjects' reports.

All subjects complained of the difficulty of this task. Despite the long display times, performance was well below ceiling levels even for the final item. The seven subjects who were asked to report their strategies all claimed they tried to see the patterns as pictures of objects or as letters. Three subjects reported looking for letter shapes in the patterns, and one of them rehearsed the letters verbally. Three others saw the patterns as arrays of objects or letters, and the remaining subject saw the patterns as arrangements of objects. Thus extremely complex encoding strategies were used, made possible by the long exposure duration.

At test time, the recall grid sometimes did provide an effective cue for the test pattern; subjects reported that when this occurred the completion test was quite easy. But when the grid did not act as an effective cue, complex search strategies were used. Four subjects reported imaging the recall grid with one filled cell added in all the possible locations, then attempting to recognise the imaged completed pattern. One of these subjects even used the tracking figure as an aid to imagery. This slow, serial process explains both the very long response times and the large effect of complexity on response time for the LTVM conditions.

The main conclusion of this experiment is that both serial position and pattern complexity have effects on visual memory as tested by a probe pattern completion task. There was no positive evidence in support of the capacity limit hypothesis, insofar as with simple patterns the recency effect did not extend over several items. However, two observations suggest that in this task LTVM processing may play a major role. First, complex strategies were used during presentation and during retrieval. Secondly, performance on the

case of the 3x3 patterns since the number of examples is limited. A count showed that there were 42 such duplications for the 3x3 pattern set, 14 duplications among the 3x4 patterns, and none for the 4x4 patterns, where all the presented items and distractors were different.

As before, a set of practice stimuli were generated, consisting of twelve series of 4x4 patterns, and twelve 3x4 patterns, with 6 and 5 cells filled, respectively.

Stimulus displays. Each stimulus matrix pattern was displayed in the centre of the screen, with a unit cell size of 6 mm. To reduce LTVM performance, the display time of each pattern was fixed at 600 msec. Each pattern was followed by a chequerboard pattern mask which was two cells larger than the stimulus along both dimensions. Thus a 3x3 pattern was followed by a 5x5 mask, a 3x4 pattern by a 5x6 mask and a 4x4 pattern by a 6x6 mask, where the contours of pattern and mask coincided. For the recognition task the two alternatives were displayed side by side on the screen with a unit cell size of 6 mm., and separated by a distance corresponding to the width of one pattern. The position of the correct alternatives was chosen randomly with the constraint that for each condition half the patterns would appear on the left, and half on the right.

Subjects responded by pressing one of two response keys, the '1' and 'ϕ' of the GT40 keyboard, corresponding to the side of the target pattern in the test display. After each response, feedback was given in the form of the words "CORRECT" or "WRONG", displayed in the centre of the screen for two seconds.

Procedure. Each subject completed the experiment in a single session which lasted about an hour. After reading the instructions, a practice of 24 trials was given, where each stimulus pattern was displayed for 1.0 seconds. The main experiment then took place in two blocks of 60 trials each, separated by a short rest.

On each trial of the experiment the subject started the display by pressing a key. The series of patterns was then presented, consisting of four, five or six display cycles, as described for the previous experiment, except that the stimulus display time was only 600 msec. An audible click indicated that the series had ended, and the two-alternative test followed a one second interval.

Subjects were instructed to look carefully at each pattern and were warned not to anticipate the end of the series. They were encouraged to be as accurate as possible.

Results and discussion.

(i) Percent correct recognition.

The mean percent correct responses for each condition are shown in Figure 3.7.

It is clear that there are pronounced recency effects at each level of complexity, and that performance on the penultimate and previous items decreases as complexity increases.

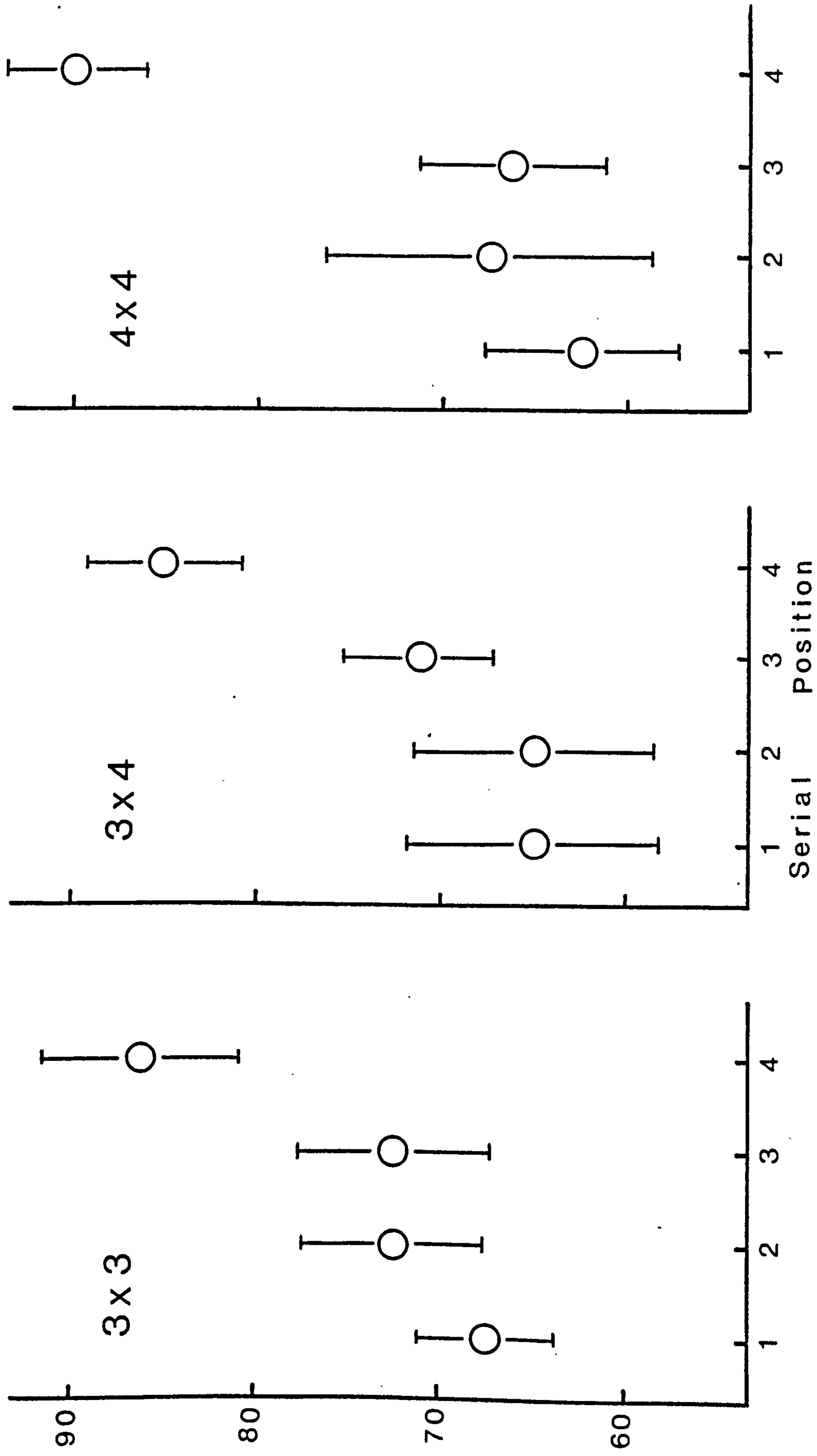
A two-way analysis of variance with repeated measures was run on the untransformed data. This showed an effect of serial position ($F = 13.26$; $df = 3,21$; $p = .0001$), but no significant effect of complexity ($F < 1.0$) and no significant interaction ($F < 1.0$). Separate analyses were run on the data from the 3x3 and 3x4 conditions. For the 3x3 condition alone there was no effect of serial position ($F = 2.34$; $df = 3,21$; $p = .10$), but a significant effect was found for the 3x4 condition ($F = 3.22$; $df = 3,21$; $p = .043$).

A Scheffé test was performed on the 3x4 data, to make a post hoc comparison between performance on the penultimate item, and the average performance on the two preceding items. This comparison failed to reach significance at the $p = .05$ level of confidence.

Figure 3.7. Mean percentage correct recognition and standard errors as a function of serial position and target pattern complexity. Serial positions 1-4 indicate the last four items in the series, with 4 the most recent. A two-alternative recognition test was used.

Percent Correct
Recognition

Fig. 3-7



(ii) Mean response time.

The mean response times and standard errors for each condition of this experiment are shown in Figure 3.8. Both serial position and complexity have large effects on response time, effects confirmed by a two-way repeated measures analysis of variance, where for serial position, $F(3,21) = 18.74$; $p < .0001$, and for complexity, $F(2,14) = 12.7$; $p = .0008$. Again, there is no significant interaction ($F < 1.0$). Separate analyses (one-way with repeated measures) were run on the response time data obtained from the 3x3 and 3x4 pattern conditions. These showed significant effects of serial position for 3x3 ($F = 4.25$; $df = 3,21$; $p = .017$) and 3x4 ($F = 10.9$; $df = 3,21$; $p = .0002$) conditions. Despite these large effects there was no tendency for the response times to the penultimate items to be faster, as would be expected if this item were visualized.

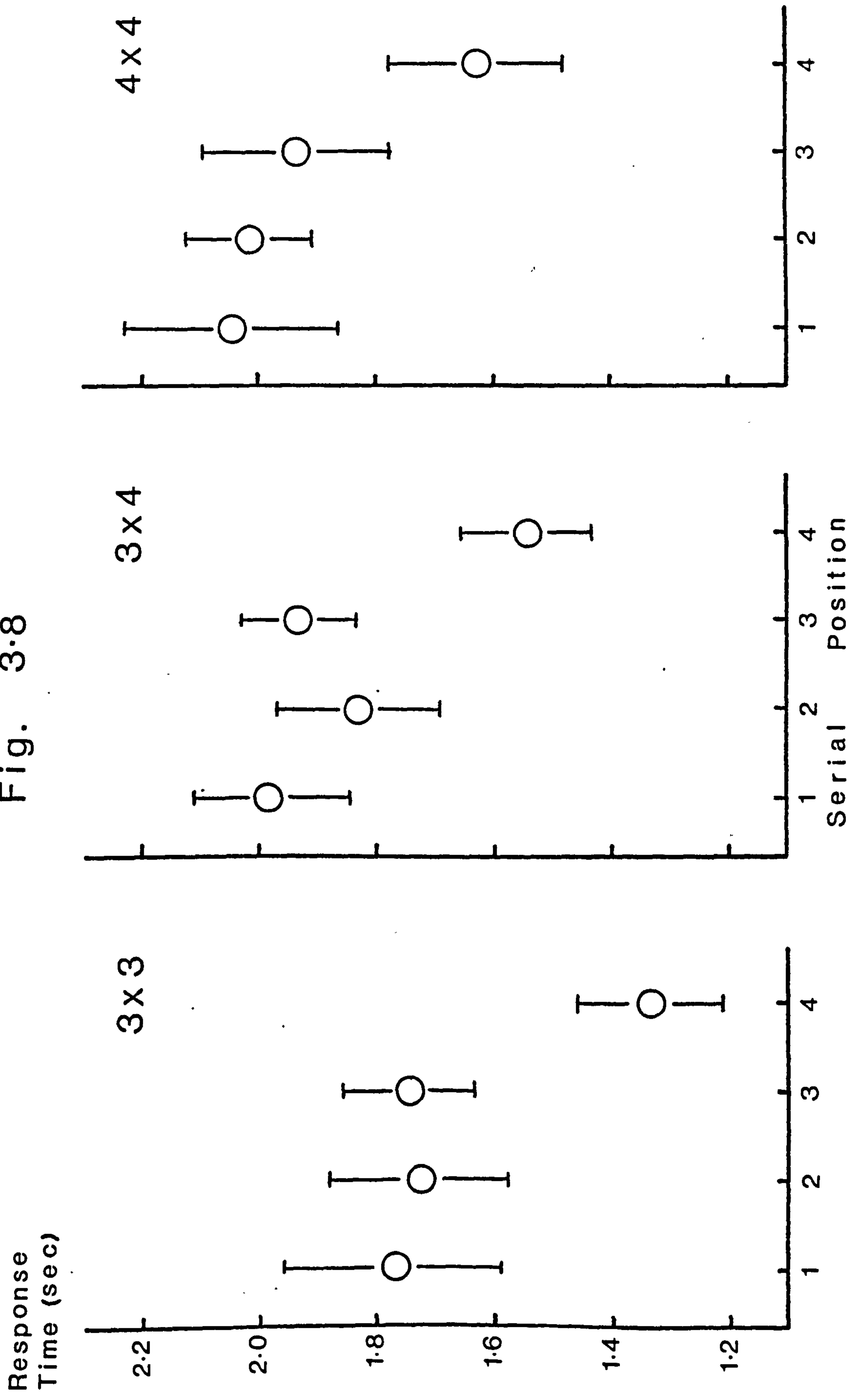
This experiment, like the preceding one, failed to demonstrate a recency advantage for the penultimate item when a series of simple matrix patterns were presented and followed by a probe retention test. It appears that with simple patterns, as with complex ones, visualization is restricted to the final item of a series. Thus there is no support for the capacity limit hypothesis.

3.5 Final Discussion and Conclusions.

The central concern of this chapter has been the relation between visualization and the unitary recency effects observed with novel visual items. Recency effects in themselves do not imply that short-term memory processes are operative. However, a large amount of evidence based on serial position curves and other paradigms suggests that the unitary recency effect for this type of material is due to the active process of visualizing the last attended item. If this is true, it has to be explained why visualization is confined to a single pattern. Three

**Figure 3.8. Mean response times and standard errors
for matrix pattern recognition, as a function of
target pattern complexity and serial position.**

Fig. 3.8



possibilities were suggested.

(i) The unitary recency effect is an artefact which results from the use of items sufficiently complex to demand all or nearly all of the available visualization capacity. An experiment involving the recall of single 4x4 patterns was used to measure visualization capacity, and showed that the amount of immediately available accurate information varied from a minimum of four cells to complete reproduction (8 cells). The average amount recalled correctly was 5.7 cell placements under STVM conditions. This figure may be underestimated because of output interference, but it suggests that visualization capacity may be fully engaged or exceeded by some 4x4 matrix patterns. Two experiments investigated the effect on the serial position curve of reducing pattern complexity. No evidence was found in support of an extended recency effect, even with the much simpler 3x3 patterns. The conclusion from this is that visualization is restricted to the final attended item in a temporal series, when the items are displayed in the same spatial location.

(ii) Visualization is restricted to the final item in a temporal series only if the items are shown in the same spatial location. This is refuted by two experiments in this chapter, which demonstrated recency effects when successive items were shown in adjacent spatial locations, and also by the results of a later experiment reported by Christie and Phillips (1979). Thus although there are a number of plausible reasons why recency in visual memory should be limited by spatial invariance, this does not seem to be the limiting factor.

(iii) The third hypothesis proposes that visualization is limited to the final attended item of a series. The amount of this item that is specified as visualized information is determined by the complexity of the item and visualization capacity. It is easy to account

for this by the assumption that perceptual analysis of a following pattern competes for the resources required for visualization. However, not all visual processing interferes with visualization; the 'passive' perception of a change in a display or the identification of familiar symbols have little, if any, effect (e.g. Phillips and Christie, 1977b). The interference seen with sequential presentations may be due to the attentional demands required to construct descriptions for novel visual patterns.

Finally, it should be mentioned that this experimental analysis is incomplete, and several things remain to be done. The most important is the investigation of serial position effects when simple visual patterns are presented in different spatial locations, and then tested by a probe recognition or recall test. To date, all the experiments involving spatially distributed items have used relatively complex patterns and sometimes also reverse serial order testing. The effects of encouraging different visualization strategies may also have interesting results. These experiments remain for the future; the conclusion at present is that visualization is a process with a limited descriptive capacity, confined to the most recent attended item of a temporal sequence.

CHAPTER FOUR

The Distribution of Available Information over Trials.

4.1 The Distribution of Information and its Implications.

In the previous chapter it was shown that, for the same presentation conditions, more information is available under STVM than under LTVM conditions, when averaged over trials. This chapter will examine the way in which STVM and LTVM information is distributed over trials, using recall and recognition techniques.

The marked differences in average performance in STVM and LTVM may arise in one of two extreme ways. First, interference may lead to a partial loss of information which is constant over all trials, so that less information is retained about each pattern. At the other extreme, there may be complete forgetting on some LTVM trials, while on others the available information is unaffected by interference.

This investigation is relevant to a number of issues concerning the STVM/LTVM dichotomy in visual memory. First, if we suppose that STVM and LTVM performance reflect the contents of separate stores which have independent inputs, then we would not expect a relation between the distributions of STVM and LTVM performance over trials. If, however, the stores are serially related, the distribution of LTVM scores will depend on both the contents of the short-term store, and the transfer process. If transfer can be conceived as an all-or-none process, then LTVM performance will be at chance level on some trials, but otherwise similar to that found in STVM (i.e. there will be a bimodal distribution of LTVM scores). On the other hand, if transfer is piecemeal and occurs at a constant, steady rate, then LTVM performance, although lower than STVM, will show a similar (and continuous) distribution over trials.

An explanation of the differences between STVM and LTVM can also be made in terms of retrieval, without proposing that there are two information stores. The assumption is that under STVM conditions, visualization of the pattern during the retention interval obviates the need for any retrieval process. Hence the deficit in LTVM performance is due to stored information which is not accessible. If retrieval is considered as an all-or-none process, then retrieval failure under LTVM conditions will lead to chance level performance, and a bimodal distribution of scores. Alternatively, retrieval of fragments of the pattern descriptions may occur, in which case LTVM performance will be continuously distributed. Retrieval explanations of this type also have to account for the similarities in performance measures obtained using recognition and recall. An unpublished experiment by D.F.M. Christie made use of randomized recall or recognition tests within a block of trials, where retention was tested under STVM or LTVM conditions. The results suggested that the same information was available in recognition as in recall. Thus if retrieval failure is the origin of the LTVM deficit, then this occurs equally for both recall and recognition.

Another type of explanation is that contextual information, such as a 'time tag' is required for recall and recognition. Errors or omissions in contextual information may lead subjects to recall an item presented on a previous trial, or fail to recognise the target because it has the wrong contextual label. This explanation also predicts a discontinuous distribution of LTVM performance over trials.

Finally, differences in the distribution of performance over trials may be explained in terms of coding. If the same type of internal descriptions underlie STVM and LTVM performance, there would be grounds for expecting a qualitatively similar distribution of performance scores over a number of trials. On the other hand, STVM and

LTVM performance may be based on quite different internal descriptions. With randomized interference, the encoding processes are assumed to be the same for STVM and LTVM presentations, but this situation could arise if certain attributes of STVM descriptions are selectively eroded by interference. In this case, some patterns which may be amenable to encoding with the operations available in STVM may not be readily specified by LTVM descriptors. Hence performance may be differentially distributed in the two conditions.

The two experiments reported here provide more evidence about the distribution of information over trials in both STVM and LTVM. Experiment 4a involves a recall paradigm similar to Experiment 3a, but using more highly trained subjects, and several different kinds of feedback designed to provide retrieval cues, and reduce transposition and other output errors. Experiment 4b involves recognition, and examines performance under STVM and LTVM as a function of distractor similarity.

4.2 Experiment 4a: The Effect of Feedback on Recall of Matrix Patterns under STVM and LTVM Conditions.

This experiment measured the recall of matrix patterns under STVM and LTVM conditions. As well as providing more quantitative data concerning the information available to STVM and LTVM, this experiment investigated the effects of different types of feedback from the display. In one condition, subjects were given no indication during recall if a cell placement was correct or not. A second condition informed the subject about the correctness of each response as it was made, while a third condition informed the subject about all previous responses, and involved reconstructing the original pattern during recall.

The rationale for using these types of feedback arises

from the large number of chance level recall attempts in Experiment 3a. If these are due to transposition errors, then the provision of useful feedback should enable the subject to locate the pattern within the recall grid, and thus reduce the error. Feedback should also improve recall if retrieval failure has occurred in those cases where:

(a) The subject has retrieved several patterns, but is uncertain which one was presented on the current trial.

(b) Part of the target pattern can act as an effective retrieval cue for the remainder.

However, feedback of this kind will not have any effect if total forgetting has occurred, or if an incomplete pattern is not an effective retrieval cue. The three types of feedback are described below in more detail.

Methods.

Subjects. Eighteen subjects were used in this experiment. Of these, twelve were drawn from a special pool of undergraduates trained to use the light pen and paid at the rate of 60p per hour. The remainder were unpaid. All except the single postgraduate subject were naive with respect to the display apparatus and light pen before the experiment began. Each subject attended a training session ($\frac{1}{2}$ hr.) and three experimental sessions lasting for one hour each, which were at least one day apart.

Design. All subjects were tested under the six conditions formed by combining the three types of feedback with two levels of interference. For each session the type of feedback was fixed and the subjects completed sixteen STVM and sixteen LTVM trials in a randomized order. The order of presentation of these three types of feedback and the pattern set shown under each of the six conditions were counterbalanced between subjects.

Types of feedback. This task required the subject to select all the cells in the recall grid which were filled in the target, and in doing so to make as few choices as possible. The feedback was intended to serve three functions:

(i) it indicated which of the sixteen cells of the grid had been selected

(ii) it indicated if a correct selection had been made, or not

(iii) it filled in the pattern corresponding to the selected cells, to provide a retrieval cue if the item had been forgotten. To do this, the display at recall was programmed in one of three ways:

(i) No feedback condition.

As each cell was selected in the recall grid a dot was placed in the centre of the cell.

(ii) Transient feedback.

A selected cell was filled if it was correct, and a dot was entered if it was incorrect. As each successive selection was made, any filled cell resulting from a previous correct choice was replaced by a dot. Thus at any time only one or no cells were filled in the display.

(iii) Cumulative feedback.

Each cell selected was filled if it was correct, and displayed a dot if incorrect. The filled cells remained on display until reconstruction was complete, so that the complete pattern gradually appeared.

Thus only the cumulative feedback condition provided substantial information about the appearance of the target pattern during recall. However, it is possible that subjects in the transient feedback condition could internally generate this information by remembering and then visualizing the cells which had been filled in the course of recall.

All subjects were instructed not to do this, and were warned that it would interfere with their attempt to recall the pattern.

Interference and retention intervals. Mental arithmetic was used as interference, in the form described in Chapter 2, section 2. Four digits were displayed in sequence, and the program waited until the subject had made a response before displaying the correct answer to the sum, for 0.5 sec, and then the recall grid.

On trials where no interference was given the retention intervals were matched to the duration of interference. For each LTVM trial the length of time from the mask offset to the display of the recall grid was timed, and this value was stored in a list by the computer. Each STVM trial used the top value in the list to time out the retention interval, and the next value on the list was substituted. If the first trial (or trials) was under STVM conditions, the retention interval chosen was the average of the LTVM values in the practice session.

Materials. The stimulus materials consisted of 96 matrix patterns (4x4 with 8 cells filled). Three different sets with twenty patterns in each were used for practice in each experimental session. In the training session the stimulus patterns were 4x4 matrices with 6 cells filled, which were generated on-line. In all sessions the stimuli were followed by a 5x5 chequerboard mask displayed for 0.5 seconds. The unit cell size for stimuli and masks was 8 mm.

Training. Each subject attended a half-hour session for training with the light pen before the experimental sessions. Instruction was given informally. The apparatus was explained to the subject, and he was told how to use the screen luminance control to stabilise the tracking figure. The experimenter first demonstrated the procedure, and then watched the subject complete a number of trials, prompting as necessary. The sessions consisted of a series of STVM trials, with a 4.0

sec delay between presentation and test, followed by a series of LTVM trials where mental arithmetic interference was provided between stimulus and recall. The number of trials of each type was at the discretion of the experimenter, the aim being to ensure that the subjects were competent and fluent in using the light pen, and to give them some practice in combining the two tasks. For both types of trial the stimulus patterns were displayed for 1.5 sec, followed by the mask for 0.5 sec. Each cell selected during reconstruction of the patterns was displayed as a filled cell, irrespective of its value in the target. Correction of responses was not permitted.

Procedure. On each of the experimental sessions the subject was asked to read the instructions, and was informed about the type of feedback to be used. Twenty practice trials were given followed by the thirty-two experimental trials, during which each pattern of one of the three test sets was shown under STVM or LTVM conditions. The order of presentation of patterns and interference conditions was randomized.

Each trial began with the display of a fixation point. By pressing a key the subject called the target stimulus, which was displayed for 1.5 sec followed by the 5x5 mask. This was followed by a period of mental arithmetic, during which the subject was required to solve a four-digit sum, or an equivalent unfilled delay. The recall grid was then shown, and the subject's task was to select the eight cells which were filled in the target, and to continue selecting cells until this was achieved. The subject was informed when all eight cells had been selected by a loud click from the GT40 loudspeaker, and at the same time the display became unresponsive. The subject then terminated the display before going on to the next trial. At the start of each session subjects were instructed to perform the task accurately and to make as few selections as possible.

Results and discussion.

The raw data consisted of the accuracy and latency of each successive placement. Unfortunately, the latency data were unreliable due to the difficulty of handling the light pen, and consequently these were discarded. From the accuracy data the overall probability of making a correct choice in the first eight selections was calculated for each subject. The mean values were 0.906 for STVM and 0.721 for LTVM. This difference in performance is attributable only to interference since for each subject the STVM retention intervals were timed to equal those for LTVM, as described above. In terms of the number of filled cells correctly placed, STVM performance is equivalent to an average of 6.5 cells, while LTVM is equivalent to 3.54 cells.

The accuracy data were analysed further in three ways. First, the probability of a correct selection (P_c) was measured as a function of serial output position, as in Experiment 3a. Secondly, the effect of feedback was examined more closely by measuring P_c for the next cell placement made after each correct response. This measure, which will be given the notation P_{c_n} / CR_{n-1} (where n signifies the serial output position), expresses the probability of a correct choice given that 1, 2...7 correct choices have previously been made. Finally, the distribution of recall scores were examined, where these were expressed as the number of correct choices made in the first eight selections. These will be discussed in turn.

(i) The percent correct at each serial output position.

Figure 4.1 shows the values of P_c for each serial output position, averaged across subjects. Since the number of placements varies from 8 to 16 across trials, each trial contributes to the first 8 serial output positions, and thereafter the data become progressively more noisy. From the graphs it is clear that P_c falls as a function of

Figure 4.1. The probability of correctly selecting a cell during recall as a function of serial output position. Figure 4.1a shows three curves, one for each of the feedback conditions, measured under STVM conditions. Figure 4.1b shows corresponding data for the LTVM conditions. Each point is based on 16 trials from each of 18 subjects. Data from the first 15 serial positions only are shown; when the 16th choice is made, it is always correct.

Fig. 4.1 a

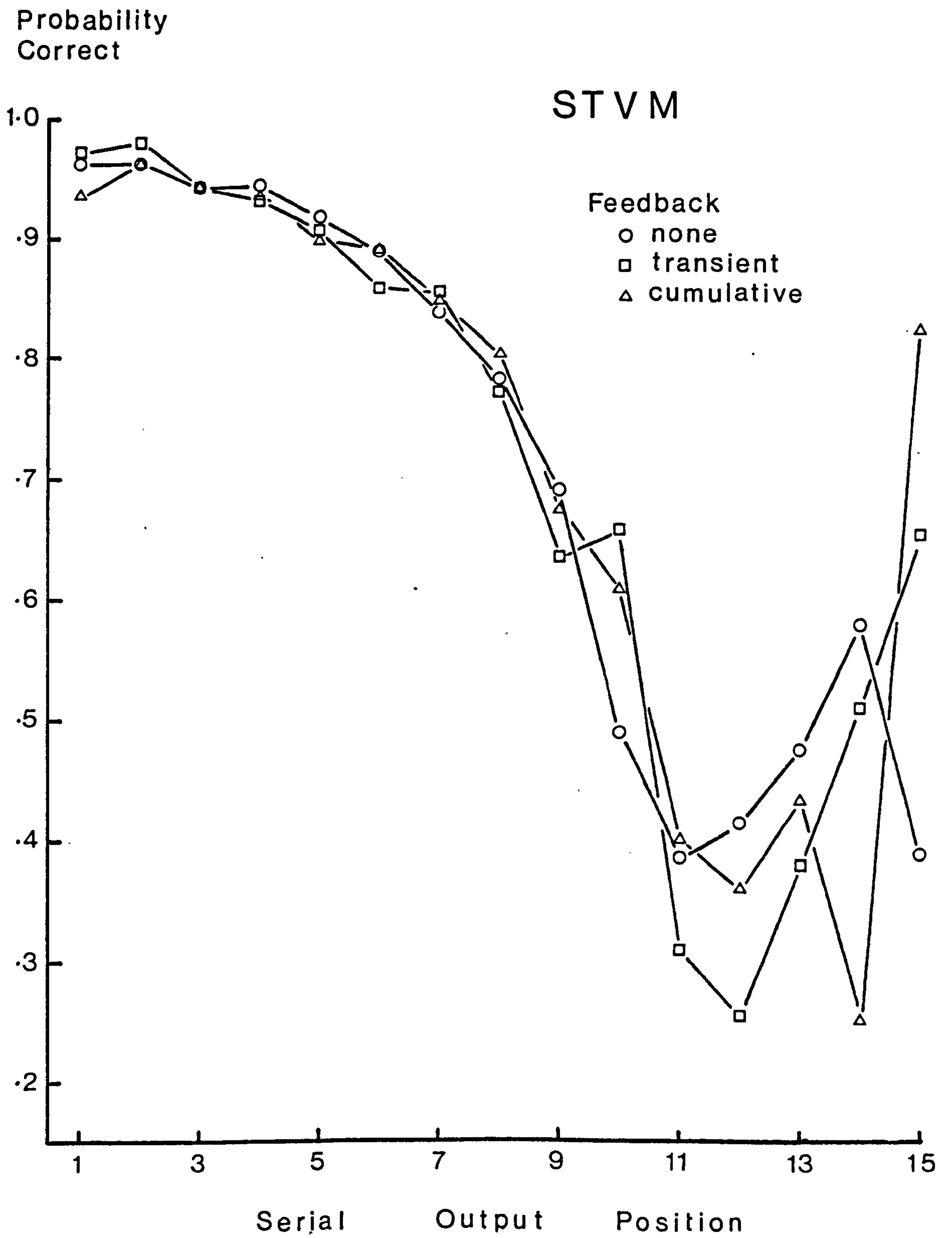
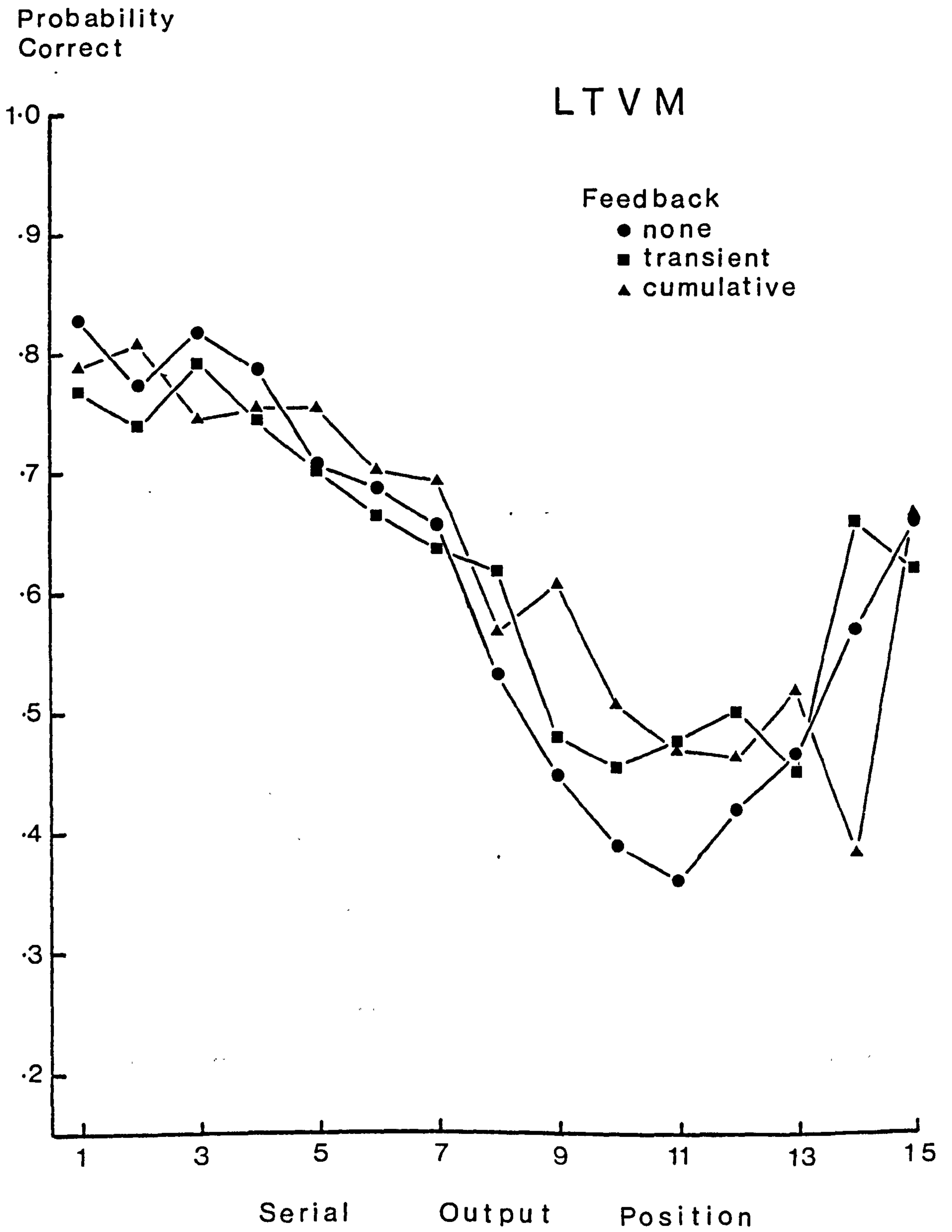


Fig. 4-1 b



serial position, reaching a minimum at positions 11-12, and then rises. This late rise in performance is due to the fact that fewer choices remain, so the probability of guessing correctly increases. The final selection, is, of course, always correct, on the few occasions that it is made. It will be seen that the P_c for serial positions 11-13 is lower for the STVM conditions. This is a reflection of the increased accuracy of the early part of recall; fewer correct cells are still unselected at this stage of recall.

Recall over the first eight serial positions can be compared with that obtained in Experiment 3a, the main procedural difference being that no corrections could be made in the present experiment. The serial position curves obtained in the two experiments are quite similar. For STVM the first five cells were selected with a P_c above .9, falling to .8 for the eighth choice. For LTVM the initial probability is about .8, falling in a similar manner. An analysis of variance run on data collected from the first eight serial positions showed highly significant effects of interference and serial position. The type of feedback had no effect, and there were no significant interactions, although the three-way interaction (interference condition x serial position x feedback condition) approached significance. A summary of this analysis is provided in Table 4.1.

Taken alone, these data suggest that recall accuracy is high under STVM conditions, and consistently lower under LTVM, even for the first serial positions selected. The LTVM performance is higher than in Experiment 3a, which may reflect the greater amount of practice these subjects had, or their greater facility in handling the light pen.

TABLE 4.1

Analysis of Variance Summary:

Probability correct selection for each of the first
eight serial output positions.

Source	df	SS	MS	F	P
Subjects	17	3.972			
Feedback condition (A)	2	0.016	0.008	0.34	0.72
Error	34	0.807	0.024		
Interference condition (B)	1	7.338	7.34	149.44	<.0001
Error	17	0.835	0.049		
Serial position (C)	7	3.572	0.51	37.06	<.0001
Error	119	1.639	0.014		
AxB	2	0.011	0.006	0.54	0.59
Error	34	0.346	0.010		
AxC	14	0.128	0.009	1.292	0.213
Error	238	1.682	0.007		
BxC	7	0.057	0.008	0.933	0.515
Error	119	1.047	0.009		
AxBxC	14	0.155	0.011	1.663	0.064
Error	238	1.589	0.007		
Total Within	846	19.222			

A more important result is that feedback had no clear effect on recall for either interference condition. This is perhaps surprising since the feedback conditions can potentially provide retrieval cues during recall, or reduce errors due to the transposition of elements within the matrix. One problem with the P_c measure is that the amount of feedback provided by the display does not vary directly with serial output position. To examine the effect of feedback more closely, the data were reanalysed as follows.

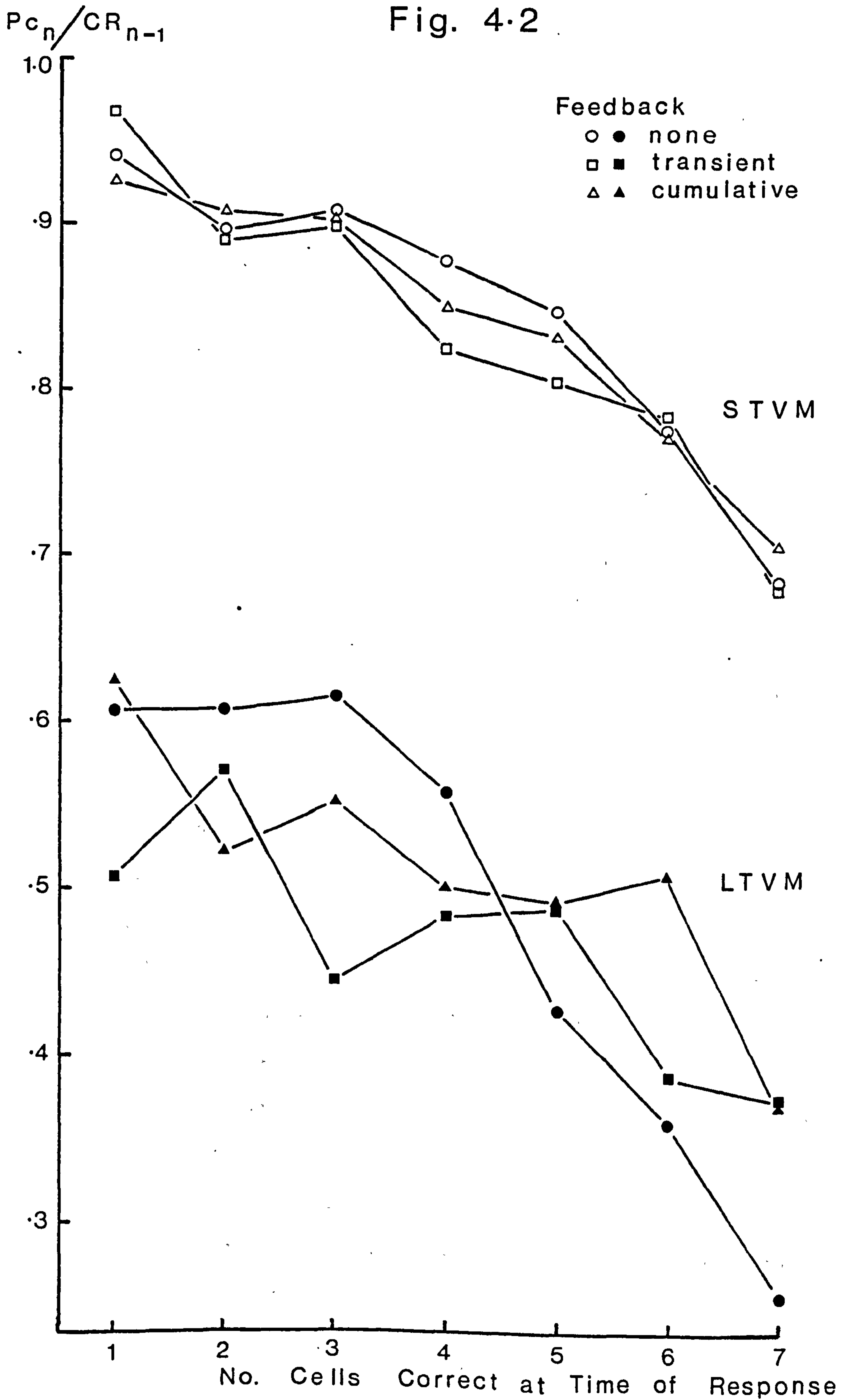
- (ii) The probability of a correct response, given that the previous selection was correct.

In the cumulative feedback condition, as each correct selection is made, another filled cell is placed in the recall grid. The reconstructed pattern receives seven such increments in information during recall, and the assumption is that each cell added to the display provides an increase in cue effectiveness, since the partially reconstructed pattern acquires more features in common with the target. The probability of making a correct selection in the cumulative feedback condition should therefore increase as a function of the number of previous correct selections, relative to the other feedback conditions. A similar argument suggests that if subjects can use feedback to avoid transposition errors, there should be an advantage for both the cumulative and transient feedback conditions, over the no feedback condition. This advantage should appear at an early stage in recall.

For each subject, the index P_{c_n} / CR_{n-1} was calculated for each of the seven possible prior correct selections. A guessing correction was applied to each value, based on the average ratio of correct to incorrect cells available for selection at each stage. The corrected data are plotted in Figure 4.2 for both STVM and LTVM conditions.

Figure 4.2. The probability of correctly selecting a cell during recall given that the previous placement was correct, plotted as a function of the total number of cells correct at the time of responding. Data are corrected for guessing as described in the text. Separate curves are drawn for recall measured with each type of feedback under STVM and LTVM conditions.

Fig. 4.2



The most important predicted result was an interaction between feedback condition and stage of recall for LTVM, but not for STVM. This was confirmed in a three-way analysis of variance with repeated measures on all factors, a summary of which is provided in Table 4.2. Separate analyses of variance (two-way, with repeated measures) were run on the STVM and LTVM data. As expected, the results show a large effect of stage of recall on STVM ($F = 23.9$; $df = 6,102$; $p < .0001$), but no significant effect of feedback condition ($F < 1.0$), and no interaction ($F < 1.0$). For LTVM there is again a highly significant effect of stage of recall ($F = 12.28$; $df = 6,102$; $p < .0001$), and no effect of feedback condition ($F < 1.0$). But in this case the interaction of stage of recall and feedback was highly significant ($F = 3.3$; $df = 12,204$; $p = .002$).

As anticipated, the kind of feedback provided by the display had little effect on STVM. Recall was high under these conditions, and any beneficial effect of feedback would be masked by ceiling effects, at least over the early serial output positions. However, for the later positions (7-8) where errors are relatively frequent, there is no evidence of any feedback effect. The prediction for LTVM was that feedback should facilitate recall, either by reducing the possible contribution of transposition errors, by preventing the recall of a competing trace, or by providing partial retrieval cues. However, the obtained pattern of results are not in accord with these predictions, and they defy most attempts at explanation. It is possible that these differences between feedback conditions result, not from the feedback itself, but from encoding differences during the pattern display. Subjects may have varied their encoding strategy to compensate for any difficulties posed by the three kinds of feedback. Under blocked presentations this

TABLE 4.2

Analysis of Variance Summary:

Probability of a correct response, given that
the immediately preceding response was correct.

<u>Scores corrected for guessing.</u>					
Source	df	SS	MS	F	P
Subjects	17	12.91			
Feedback condition (A)	2	.095	.048	.571	.575
Error	34	2.83	.083		
Interference condition (B)	1	23.44	23.44	109.94	<.0001
Error	17	3.62	.213		
No. of correct prior selections (C)	6	4.99	.83	27.52	<.0001
Error	102	3.08	.03		
AxB	2	.048	.024	.58	.57
Error	34	1.410	.041		
AxC	12	.43	.036	2.16	.015
Error	204	3.39	.017		
BxC	6	.036	.006	.027	.95
Error	102	2.217	.022		
AxBxC	12	.505	.042	2.50	.004
Error	204	3.43	.017		
Total Within	738	49.5			

is always liable to happen, but unfortunately the experiment was too complicated (from the subject's viewpoint) to randomize the kind of feedback given.

The results of this experiment can be said to confirm the shapes of the serial output position curves found in Experiment 3a. However, they do not indicate that feedback has a beneficial effect on recall either by reducing transposition errors, or by enabling retrieval. Of the many possible sources of error in recall, transpositions and retrieval failure were investigated because they offered plausible explanations for the high frequency of chance level scores in the earlier experiment. Thus, if performance on most LTVM trials was above chance, we should not expect transient or cumulative feedback to have large effects. The following section describes the distribution of recall scores over trials. A further assumption in the case of cumulative feedback is that a partially complete matrix can act as an effective retrieval cue. Some evidence against this was provided in Experiment 3d, where a pattern completion task was used. According to the subject's reports, the probe pattern with one cell missing did not act as an effective retrieval cue, and searching strategies were used in an attempt to determine the missing cell.

(iii) The distribution of recall scores.

The number of correct cell placements made in the first eight selections was recorded for each recall attempt by each subject. These data, pooled across subjects, are plotted as histograms for each condition in Figure 4.3. The STVM data show clearly that on the majority of trials recall was completely correct, and there were very few instances when more than two wrong selections were made.

Figure 4.3. Frequency distributions of recall scores obtained in Experiment 4a. Histograms show the number of recall attempts for which the given number of cells were correctly placed in the first eight selections. Eight correct placements indicates recall without error. Data are pooled separately for each type of feedback; STVM data in Fig. 4.3a and LTVM data in Figure 4.3b.

Fig. 4.3 a

S T V M

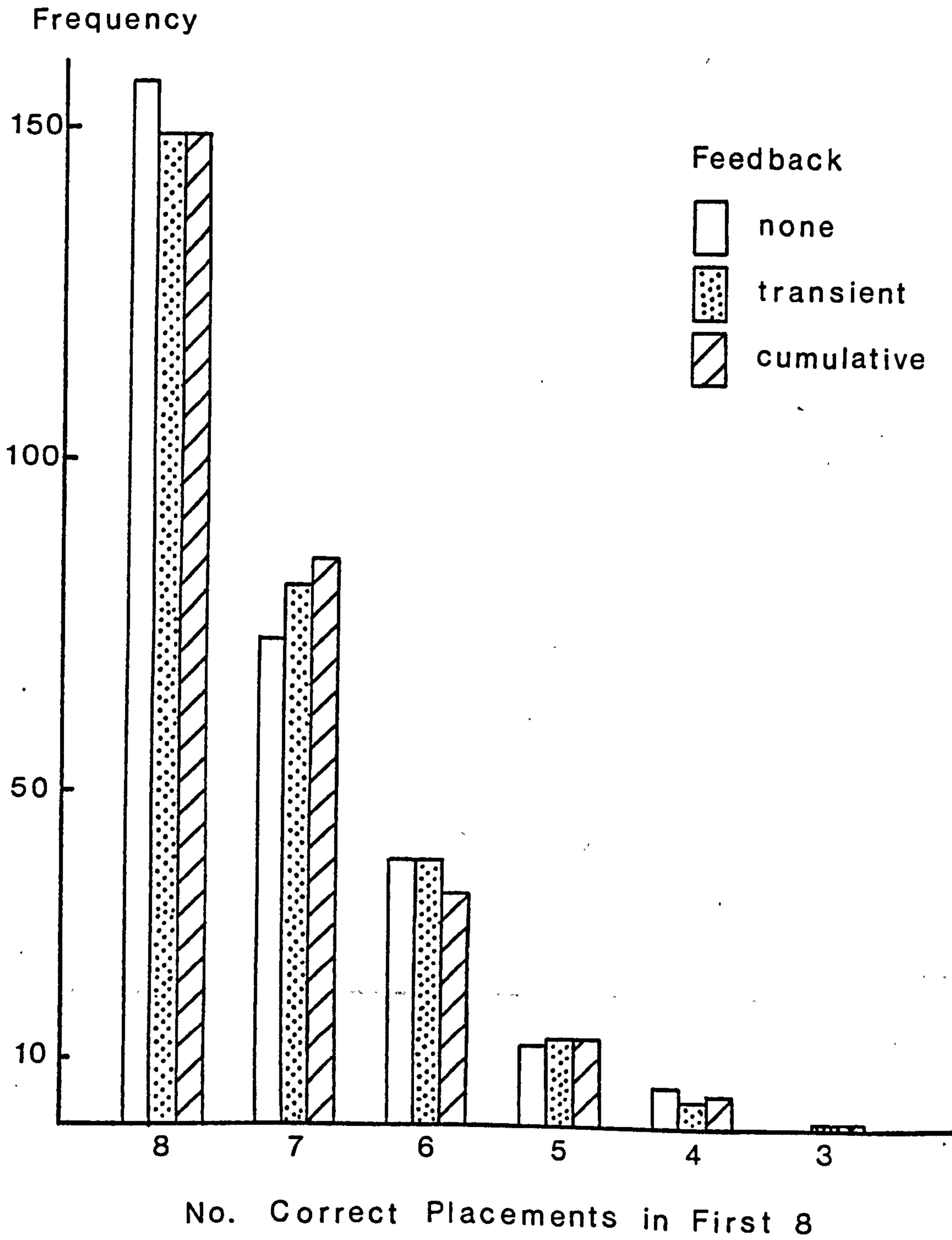
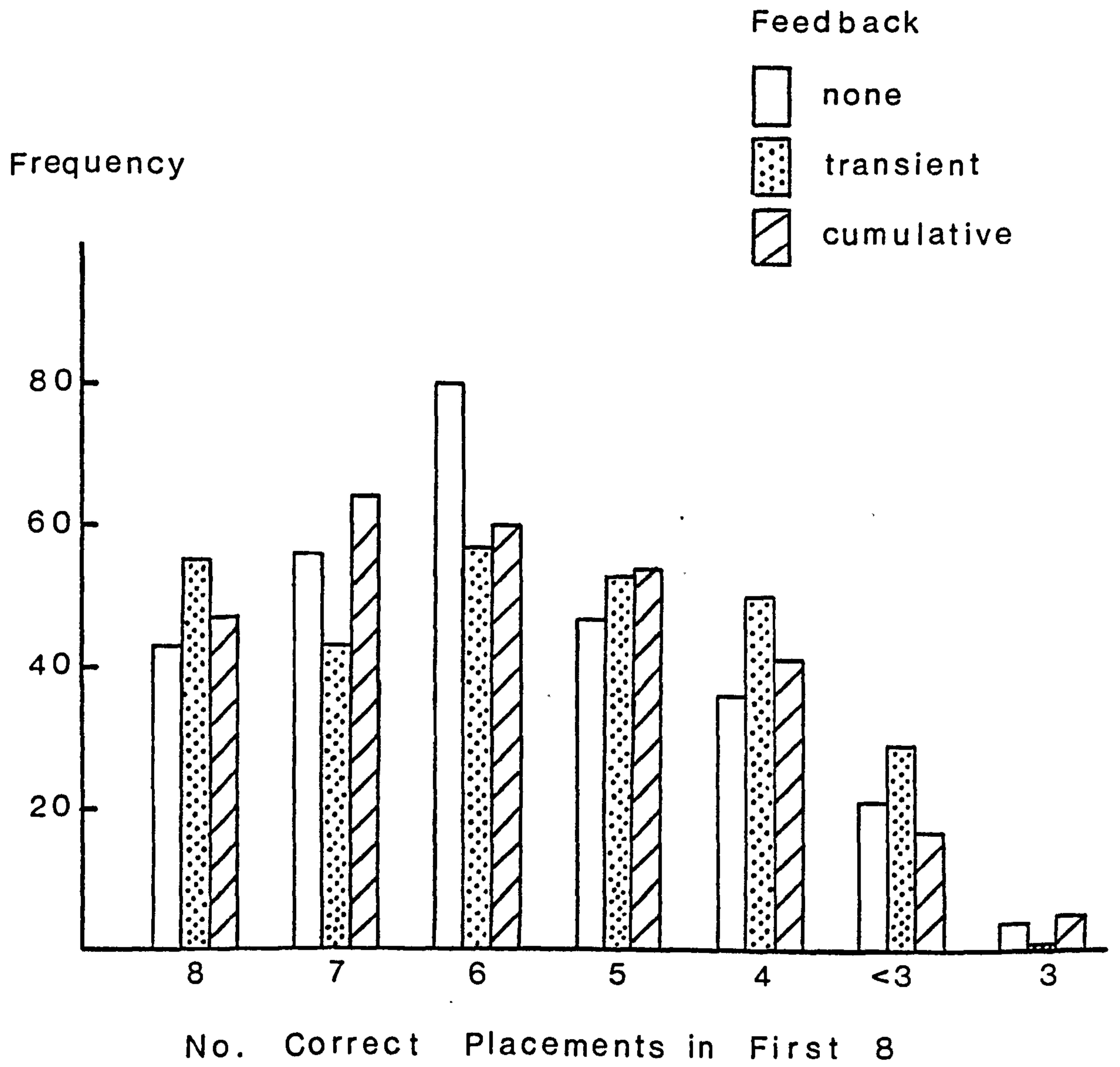


Fig 4.3 b

L T V M



This demonstrates again that the complete specification of many 4x4 matrix patterns lies within visualization capacity. In comparison, performance under LTVM conditions was much more variable across trials. Only 1/6 of the trials resulted in complete, error-free recall, while 1/4 of all recall attempts yielded chance level performance (four or fewer correct choices in the first eight selections). These results are in good general agreement with those of Christie and Phillips (1979) except that both STVM and LTVM performances are somewhat lower, a difference which is probably due to the high output interference in this task, as explained in Chapter 3.

Examination of the distribution of recall scores in Experiment 3a suggested that complete forgetting occurred on some trials, and that this could account for the difference between STVM and LTVM recall. While the present data suggest that on some trials complete forgetting may occur, it is not possible to account for the entire STVM/LTVM difference on this basis. It seems that interference brings about a variable loss in the information available to the subject, rather than all-or-none forgetting. If the assumption is made that retrieval is an all-or-none process then this experiment rejects the view that retrieval failure alone underlies the STVM/LTVM difference.

Finally, it is clear that the feedback condition has little or no effect on the distribution of recall scores found under STVM or LTVM conditions. In particular the frequencies of chance level scores are unaffected by feedback during recall. This suggests that transposition errors, or selecting for output the wrong item from a number of competing available traces, are not errors which make a large contribution to poor performance in LTVM.

4.3 Experiment 4b: The Effect of Distractor Similarity on Recognition under STVM and LTVM Conditions.

The previous experiment investigated the distribution of

information over trials, using a recall procedure and asking subjects to report all the information available on each trial. In this experiment, the same question will be pursued using a recognition test, by varying the similarity between the target and the distractor. If partial information about a target is available at test, then increasing the target/distractor difference will lead to an increase in performance. However, if retention is perfect, or no information about the pattern is available, the difference between the target and distractor will have no effect on recognition. (I am grateful to Mr. A.S. Chamove for pointing this out). A similar argument was advanced by Paivio and Bleasdale (1974) in their investigation of the decay of STVM.

In this experiment STVM and LTVM recognition were measured, using two levels of similarity between the targets and their paired distractors. It can be shown that where information is available on each trial, the effect of distractor similarity depends on the mean level of performance. To avoid this complication, display time was varied so that STVM and LTVM performance were equal when the recognition test involved highly similar target/distractor pairs. Previous experiments had shown that LTVM recognition for 4x4 matrices using a target/distractor difference (d) of two cells, and a display time of 400 msec, was roughly equal to STVM recognition for the same stimulus set and a display time of 100 msec. If, under these conditions, the distribution of information over trials is the same for STVM and LTVM, then increasing the value of d will have equivalent effects on STVM and LTVM performance.

Methods.

Subjects. Eight unpaid subjects were recruited from the undergraduate subject panel.

Design. Three variables were manipulated in this experiment: interference (STVM/LTVM), display time (100 msec/400 msec) and the

similarity of the recognition test alternatives ($\underline{d} = 2$; $\underline{d} = 4$). All the variables were manipulated within subjects, so the experiment conformed to a 2x2x2 repeated measures design. The order of presentation of the 8 conditions was randomized, and the patterns displayed under each condition were rotated between subjects. In all, each pattern was shown once under each condition. For the sake of brevity the four combinations of display time and interference will be referred to as the presentation conditions, and designated $STVM_{100}$, $STVM_{400}$, $LTVM_{100}$, and $LTVM_{400}$.

Apparatus and materials. The experiment was carried out using the GT40 graphics terminal. All the responses in this experiment were two-alternative choices, and so only two keys of the GT40 keyboard were required. The keys used were the numerals '1' and '0' of a standard typewriter layout, and were marked 'left' and 'right' respectively.

The stimulus patterns and distractors were 4x4 matrix patterns with 8 cells filled. From each target pattern, two distractors were constructed, one by changing the values of two cells, the other by changing 6 cells. Two hundred sets of targets and distractors were made up in this way, without duplications. In the recognition test the original pattern and one of the distractors were displayed side by side, separated by a distance of 25 mm. The side on which the target was displayed was determined randomly, with the constraint that for each condition, the target should be presented equally often in each test position. The unit cell size for both the targets and distractors was 6 mm, and the viewing distance was 60 cm.

Interference. Slant patterns were used to provide interference in this experiment. As described in the general methods chapter, these patterns were constructed from a 4x4 matrix, by displaying the cell diagonals rather than the cells themselves. Four cells of the

matrix were chosen at random, and the 45° diagonals of these cells were displayed. Also displayed were the 135° diagonals of four other cells. Thus each slant pattern consisted of 8 short line segments. Distractors were generated from these by selecting one cell of each type (i.e. black, 45° diagonal, 135° diagonal) and interchanging their values. During the experiment, the interference patterns and their corresponding distractors were selected at random without replacement from a large set of 250 pattern/distractor pairs.

Training. Subjects were given three training sessions before the start of the experiment proper. The first consisted of fifteen trials practice at the interference task, which was made easy by using a display time of 1.0 seconds. In the second part, matrix patterns were shown for 0.5 sec, followed by a mask for 200 msec, and then an unfilled interval of 1.0 sec on half the trials, chosen at random, or interpolated interference (with a target display time of 0.5 sec) on the remainder. In this practice the alternatives presented at test differed by just two cells, and twenty trials were given. In the final stage of training, 32 trials were delivered with a procedure identical to that of the main experiment. .

Subjects were given extensive written instructions at each stage of training, and were prompted and corrected as necessary by the experimenter.

Procedure. After the training sessions, the subject completed two blocks of 80 trials, separated by a short break. In each block, ten trials were given under each of the 8 conditions, in a random sequence. There was a short rest period of twenty seconds after every twenty trials. Each trial began with the display of a fixation point, and subjects pressed either of the two response keys to start the display sequence. A matrix pattern was then displayed for either

100 msec or 400 msec, followed by the mask for 200 msec. On STVM trials, an interval of 1.0 sec with a blank screen preceded the retention test. On LTVM trials the screen was blank for 0.5 sec followed by the interference task, and a further 0.5 sec before the retention test. The two alternatives were displayed until the subject made a choice response. Knowledge of results was provided by the words "CORRECT" or "WRONG" displayed on the screen. Information about both choice responses was given on LTVM trials.

Subjects were instructed to be as accurate as possible when choosing the correct alternative for both tasks. They were further instructed to concentrate on each pattern presented, and to continue to think about it until either a second pattern was shown (i.e. on LTVM trials) or until the recognition test was given.

Results and discussion.

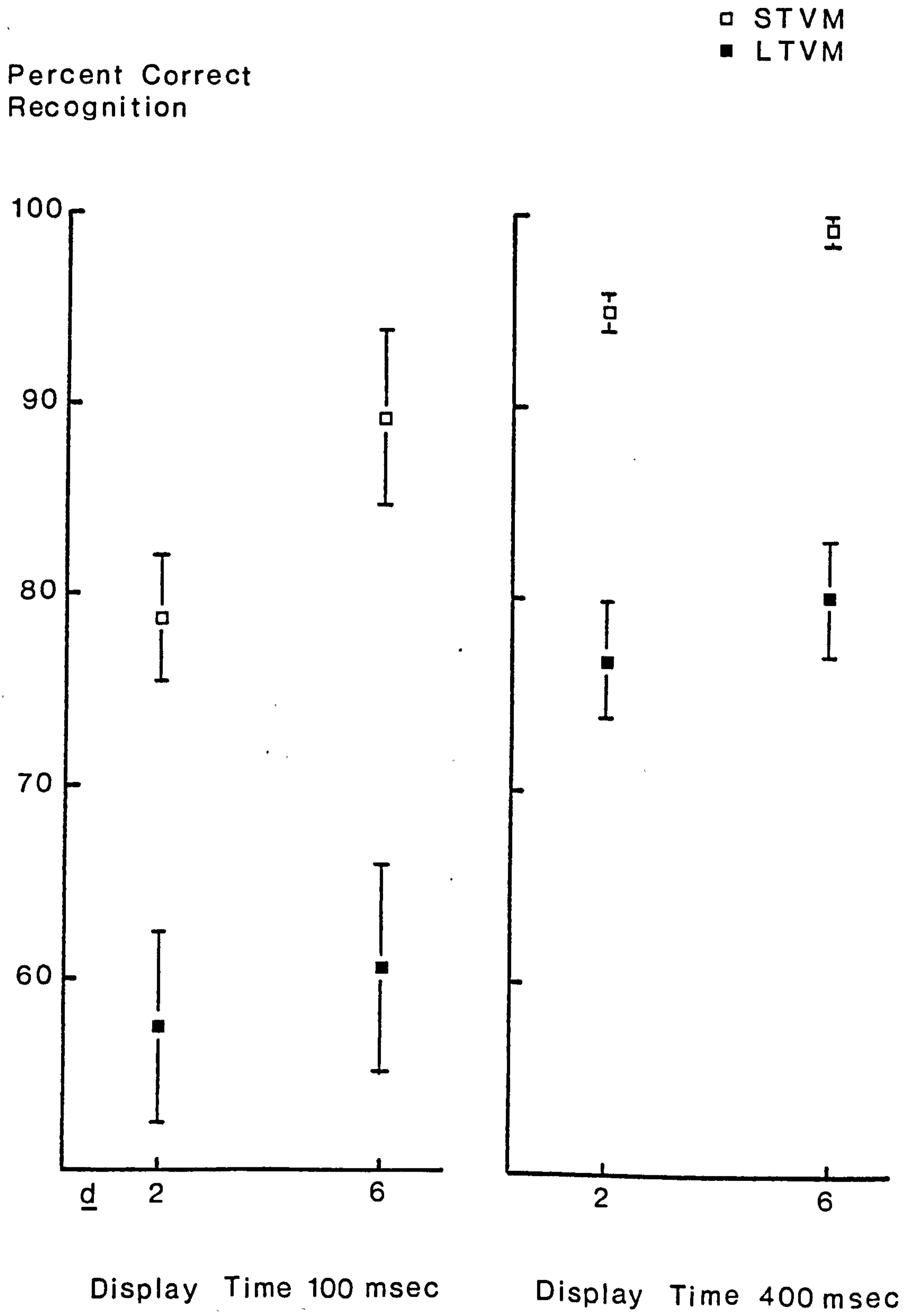
(i) Percent correct recognition.

The percentage of correct choices made under each condition are plotted in Figure 4.4. This shows that the manipulation of display time was successful in equalizing performance in the $STVM_{100}$ and $LTVM_{400}$ conditions, where the mean percent correct scores were 78.8% and 76.9%, ($d = 2$), and the standard errors are also about the same. However, increasing the distractor dissimilarity had a much greater effect on the $STVM_{100}$ condition than on the $LTVM_{400}$ condition, strongly suggesting that the distribution of information over trials was different in the two cases.

Statistical confirmation of this was sought in two ways. First, by a two-way repeated measures analysis of variance run on the $STVM_{100}$ and $LTVM_{400}$ conditions. The test results showed no significant effect of presentation condition ($F = 2.30$; $df = 1,7$; $p = .17$), but a highly significant effect of distractor similarity ($F = 21.72$; $df = 1,7$;

Figure 4.4. Percent correct recognition on a two-alternative test as a function of d , the number of cells differing between the target and distractor. Bars indicate standard errors. The effect of d is shown on recognition measured under STVM and LTVM conditions, following target displays of 100 msec and 400 msec duration.

Fig. 4.4



$p = .0025$). However, the interaction between these two variables was not significant ($F = 1.34$; $df = 1,7$; $p = .285$). The second method employed involved separate comparisons of the two distractor conditions, using one-tailed t -tests. For the $STVM_{100}$ presentation conditions, there was a significant difference in performance between the two distractor conditions ($t = 2.55$; $df = 7$; $p < .025$). However, there was no significant difference when this comparison was tested for the $LTVM_{400}$ conditions ($t = 1.11$; $df = 7$; $p > .1$).

This result should be treated with some caution, since the difference between the $STVM$ and $LTVM$ conditions is relatively small, and the analysis of variance failed to show a significant interaction. Nevertheless, it suggests that although mean recognition performance was the same when using a difficult recognition test, $LTVM$ was less sensitive to an increase in distractor dissimilarity than $STVM$. This means that on a number of $LTVM$ trials the subjects' performance is not assisted when the target is accompanied by a very dissimilar distractor. This would be expected if retention of the original pattern was very high, or very low. An alternative explanation is that the difference in distribution of information in $STVM$ and $LTVM$ arises not between trials, but between subjects. This is ruled out by the fact that the standard errors for the $STVM_{100}$ and $LTVM_{400}$ conditions were similar. Further confirmation is provided by the performance measures of individual subjects, which are listed in Appendix A, Table 1.

In passing, it may be noted that distractor similarity had little effect on the $STVM_{400}$ or $LTVM_{100}$ conditions. This was expected since performance in the former case was close to ceiling levels, and in the other case, just above chance level.

(ii) Mean response time (RT).

The mean RTs for each condition of this experiment are plotted

in Figure 4.5. From this it is clear that both display time and distractor similarity have large effects on RT under STVM conditions, but there is little effect of either variable on LTVM RTs. Again, the important comparison is between the STVM₁₀₀ and LTVM₄₀₀ conditions. When distractors are similar to the targets ($\underline{d} = 2$), the mean RTs are about equal. But when distractors are dissimilar ($\underline{d} = 6$), the STVM₁₀₀ RT decreases by a much greater amount than the LTVM₄₀₀ RT. A two-way analysis of variance with presentation condition and distractor similarity as within-subjects variables showed significant effects of presentation condition ($F = 7.88$; $df = 1,7$; $p = .026$), and of \underline{d} ($F = 17.69$; $df = 1,7$; $p = .0042$). The interaction was non-significant ($F = 2.03$; $df = 1,7$; $p = .195$). A t-test for paired samples applied to the STVM₁₀₀ data showed a significant difference between the two distractor conditions ($t = 3.09$; $df = 7$; $p < .01$; one-tailed). The corresponding comparison in the LTVM₄₀₀ condition was not significant ($t = 0.97$; $df = 7$; $.15 < p < .2$). Thus similar results have been found for both the percent correct and response time measure; both showing an effect of \underline{d} under the STVM₁₀₀ presentation condition.

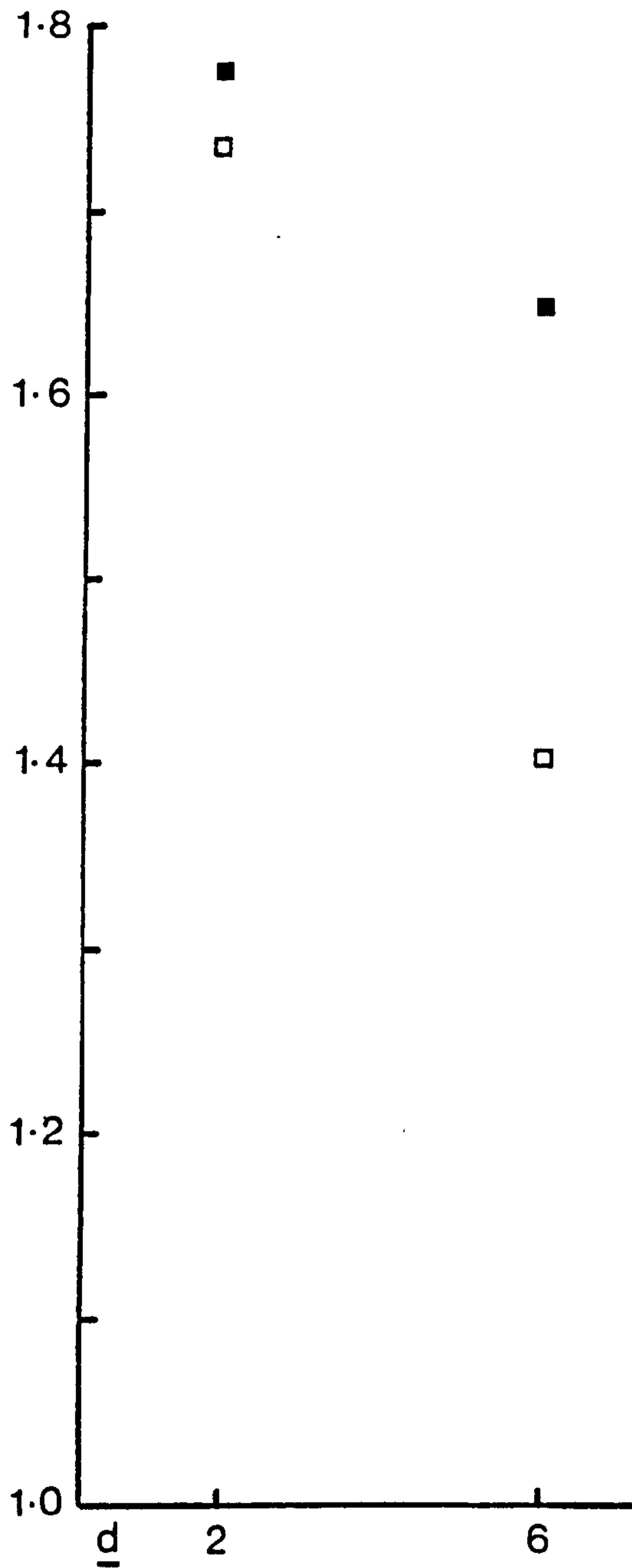
Two general points also arise from the RT data. First, the differences in performance between conditions cannot be explained by a speed accuracy trade-off. Secondly, it is clear from the results that increasing display time had a much larger effect on STVM RTs than on LTVM RTs, although in both cases there were large increases in the accuracy of recognition. The effect was statistically significant when tested by the interaction of display time and interference condition in a three-way analysis of variance ($F = 14.7$; $df = 1,7$; $p = .0065$). This insensitivity of LTVM response time measures in recognition tests occurred in a number of other experiments to be reported.

Figure 4.5. Mean response time in a two-alternative recognition test as a function of d . Data for STVM and LTVM conditions are plotted for target display times of 100 msec and 400 msec.

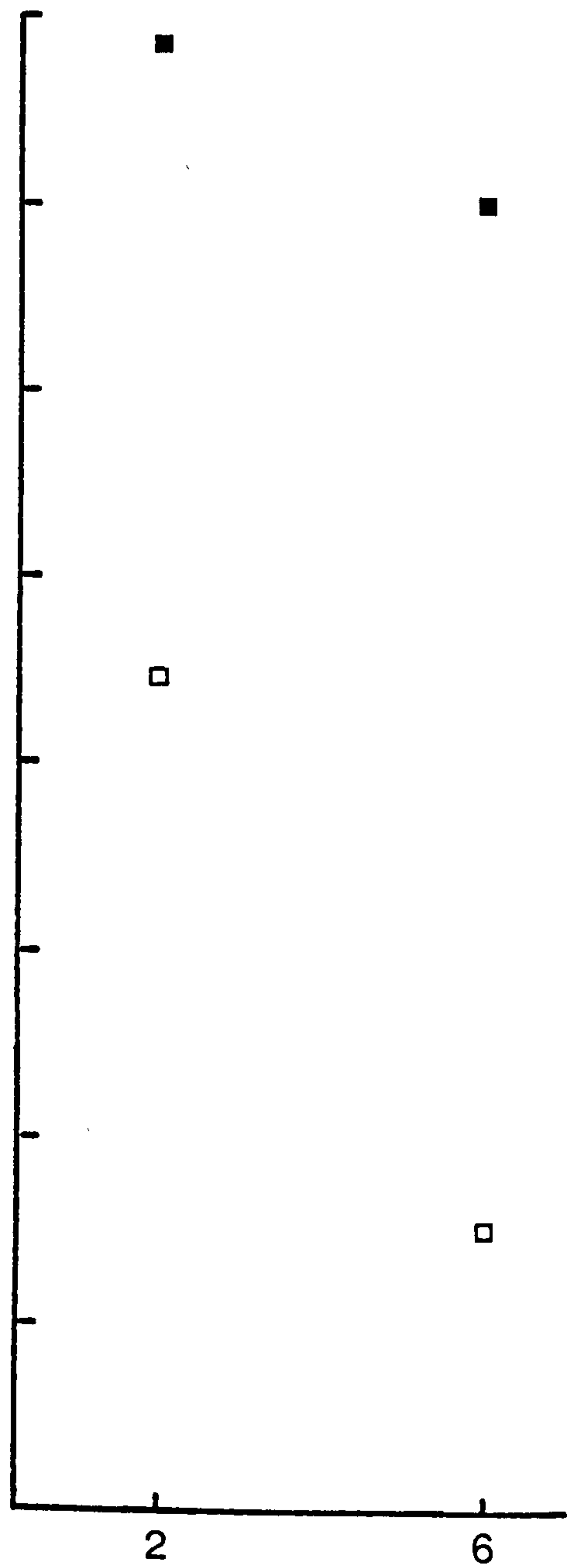
Fig. 4.5

□ STVM
■ LTVM

Mean RT (sec)



Display Time 100 msec



Display Time 400 msec

(iii) Performance on the interference task.

An assumption implicit in comparisons of the LTVM data is that the amount of interference provided by the slant patterns is the same in each of the four LTVM conditions. To ensure that this was the case, two measures of performance were taken on the interference task itself: the percentage of correct choices and the mean response time on the two alternative forced-choice test. Table 4.3 gives the mean values and standard errors for both measures of performance, pooled for each LTVM condition. It is clear that performance is consistently fast and accurate on the interference task in all the conditions of this experiment. A one-way analysis of variance run on the percent correct data showed no significant differences between the four LTVM conditions ($F < 1.0$) and a similar analysis run on the mean response times was also non-significant ($F < 1.0$). Thus the differences in performance on the main task under LTVM conditions cannot be attributed to fortuitous differences in the degree of difficulty of the interference task.

4.4 Final Discussion and Conclusions.

This chapter set out to examine the distribution of information available to STVM and LTVM, using two techniques: the reconstruction of matrix patterns and the effect of distractor similarity in a two-alternative forced choice recognition test. Both experiments provide evidence that the distribution of performance over trials is different under STVM and LTVM conditions.

Experiment 4a compared STVM and LTVM recall with a fixed display time of 1.5 sec. Under STVM conditions, patterns were reproduced without error on the majority of trials, while the serial output position curves suggested that partial information about the target was available on every trial. For LTVM recall, patterns were reproduced correctly on about one quarter of the total trials, and a similar proportion of recall

TABLE 4.3

Mean Performance on the Interference Task for Each
LTVM condition: Percent Correct and RT measures.

	Display time (msec) 100			400	
	<u>d</u>	2	6	2	6
<u>Percent Correct</u>					
Mean	95		96.25	96.25	97.5
S.E.	1.89		2.63	1.83	1.64
<u>Response Times</u>					
Mean	1.34		1.31	1.29	1.25
S.E.	0.125		.081	.065	.095

attempts were at chance level. On the majority of occasions, LTVM recall was partially correct. This result contrasts with that of Experiment 3a, which showed that LTVM performance was at chance level on a large proportion of trials, suggesting that the difference between STVM and LTVM performance could be accounted for by all-or-none forgetting. Experiment 4a and the results reported by Christie and Phillips (1979) show that on the majority of trials, interference leads to partial, rather than complete forgetting.

The second experiment manipulated display time to equalize STVM and LTVM performance with highly similar target/distractor pairs. Under these conditions, LTVM was less sensitive than STVM to a decrease in the similarity of targets and distractors used in the recognition test. The conclusion is that LTVM differs from STVM in the way that information is distributed over trials, although the precise form of the distribution cannot be inferred from the data.

Thus the empirical results of two experiments support the view that the information available in STVM and LTVM is not distributed in the same way over trials. The results are incomplete, since the recall technique has only been used with relatively long display times. Bartram (1978) obtained serial output position curves for STVM recall, using matrix patterns with very brief exposures. His results showed that recall of a small part of the pattern (about two cells) occurred with high accuracy on each trial, which he explained as the output of the first 'chunk'. With longer exposures, recall of the second chunk was more accurate (Bartram, 1978) and there is evidence that increases in chunk size may also occur (Egan and Schwartz, 1979). No LTVM recall data is currently available for short display times.

The main theoretical implications of these experiments are in terms of the comparison of STVM and LTVM performance, i.e. the

forgetting which takes place as a result of interference. One such interpretation is that LTVM involves retrieval of the correct pattern, and that when retrieval breaks down, all information about the pattern is lost. This chapter provides evidence against this interpretation since:

- (a) Partial recall was observed under LTVM conditions.
- (b) The provision of feedback during recall did not elevate performance.
- (c) If the assumption is made that recognition does not involve retrieval processes, then the fact that LTVM performance is lower than STVM when measured by a recognition test may also be taken as evidence against this all-or-none retrieval interpretation.

A related interpretation, that LTVM performance fails because the wrong item is retrieved for recall can also be rejected.

The evidence concerning partial forgetting as a result of interference, and the variability of recall scores under LTVM conditions are consistent with the idea of two independent stores. An equally plausible account is that there is a single store, in which patterns are encoded as multi-component traces (Bower, 1967) where the elements may be lost (or become inaccessible) independently. The difference between STVM and LTVM performance can be explained in terms of the differential sensitivity of the elements to interference. This account is similar to Jones' (1979) description of differential rates of forgetting for different visual attributes, with the exception that he considered forgetting as a function of time, rather than interference.

If this interpretation is correct, it follows that the descriptors available in STVM have general applicability to matrix patterns, since something of each pattern is remembered. However,

descriptions of a type which is resistant to interference may not be readily constructed for some matrix patterns. The nature of these descriptions will be discussed more fully in the next chapter.

CHAPTER FIVEThe Coding of Matrix Patterns in STVM and LTVM

This chapter is concerned with the coding of matrix patterns in STVM and LTVM. In particular, it investigates the part played by familiar nameable elements occurring in patterns which are otherwise novel and difficult to describe verbally. Any memorial advantage for such items could be due to the fact that they are familiar, that they have meaning, or that they have an alternative 'verbal' code. No attempt will be made to isolate the effects of familiarity, meaning or naming. Without prejudice to other usages, these familiar elements will be referred to as 'semantic' information, and the operations of detecting and utilising such elements for internal descriptions will be called "semantic categorisation" or "semantic interpretation". In contrast, specifications of a pattern in terms of visual properties such as shape and contour will be called "figural descriptions".

Although a large number of verbal memory studies have been concerned with the role of semantic information in memory, relatively few visual memory studies have addressed this problem. Several theories of visual memory have considered the types of coding used in visual descriptions, and their relation to performance. These are discussed in the following section.

5.1 Theories of Coding in Visual Memory.

One recent proposal has claimed that performance on visual memory tasks is based on verbal descriptions of visual stimuli. The evidence cited for this 'verbal loop' hypothesis (Glanzer and Clark, 1963; 1964) is that for some types of material, the length of verbal descriptions gives a better prediction of immediate recall than either information

theory or Gestalt theory considerations. However, equally consistent with this data is the theory that the length of the measured verbal description is related to the complexity of the underlying visual representation. Evidence that verbal processes may contribute to STVM recall is provided by Cohen and Granstrom (1970), using novel patterns. Conclusive evidence that STVM is not mediated entirely by verbal descriptions is provided by the many selective interference studies (e.g. Brooks, 1967; Salthouse, 1975). The importance of "verbal describability" for LTVM of natural scenes was investigated by Wyant, Banks, Berger and Wright (1972). Recognition was measured as a function of the verbal describability or visual similarity of the alternatives in a two-choice test. Although verbal describability had a large effect on recognition it could not provide a complete account of their results, more so when short exposure times were used.

Less extreme than the verbal loop hypothesis is the levels of processing theory put forward by Craik and Lockhart (1972), which claims that the durability of stored information is directly related to the depth of processing. This theory has recently been criticised, as the notion of depth is vague and ill-defined (Baddeley, 1978). However, it is reasonable to claim that figural descriptions are at a lower level in general than semantic categorizations, and hence should be less durable. Evidence against this is provided by experiments which demonstrate long-term retention of incidental details, such as memory for text orientation or page location (e.g. Kolers, 1977; Rothkopf, 1971).

A third theory proposes that visual information must be labelled or classified in order to be accessible. One advocate of this idea is Cohen (1977). In her view, semantic categorization is necessary for retrieval:

"How can items be accessed and retrieved from memory if they are not labelled or classified? Sense data from other modalities like smell and taste are difficult to evoke at will if they cannot be named or described, so it seems likely that visual perceptions need to be labelled or classified if they are to be readily accessible".(p.38).

This implies that figural descriptions can enter long-term storage, but only in conjunction with semantic categorizations. Novel stimuli, therefore must be stored as modifications of pre-existing, familiar representations.

Evidence against the view that visual memory is accessible only via semantic information was provided by Frost (1972) who found that verbal free recall of pictures of common objects clustered according to their visual properties. A further demonstration was given by Yuille and Fox (1973), who demonstrated release of PI for pictures of objects when the shape of the objects was changed. In addition, a few studies have shown that recall of visual displays can be cued by the presentation of visual attributes (e.g. Jones, 1979; Bower and Glass, 1976).

The preceding theories have claimed that memory for visual properties (such as configurations) is absent, transient or dependent on semantic information. In contrast to this conception of visual descriptions as subordinate or degenerate information stands the view that such descriptions store essential information which is remembered and accessed independently. Evidence in support of this comes from a study by Bahrick and Boucher (1968). They presented subjects with a series of line drawings, and later measured (i) recall of the object names and (ii) recognition of the original drawings each of which was presented with nine distractor drawings of the same class of object. There was no significant correlation between performance on these tasks, suggesting that semantic category information is independent of figurative detail.

Further evidence comes from a number of experiments using 'doodles' or Vanderplas shapes. With both types of material it is well known that supplying a semantic interpretation or increasing association value improves subsequent recognition (e.g. Fontenot, 1973; Feuge and Ellis, 1968; Clark, 1968; Bower, Karlin and Dueck, 1975). A number of interpretations are possible: the semantic interpretation may increase attention to the item during presentation, or it may emphasize one or more distinctive features of the item. If recognition is mediated by the semantic interpretation, then a change in the interpretation at test time should lead to misrecognition. Price and Slive (1970) presented Vanderplas figures together with relevant labels, and collected subjects' associations to these figures during the recognition test. When subjects produced the original association at test, recognition was high. Performance was lower when subjects produced a different association to a figure at test, but was still above chance level. Unfortunately they do not report hits and false alarms for items eliciting different associations at test, so this result could be due to response bias. However, this explanation cannot account for the results of Bostrom's (1970) thorough study of the effects of relevant and irrelevant verbal labels on recognition of random shapes. Recognition confidence ratings were higher for targets than distractors, both when label recall occurred at test, and when it did not. Thus LTVM recognition in this study was not mediated by label recall.

Similar findings on the independence of visual and semantic information have emerged from studies by Klatzky and Rafnel (1976), and Rafnel and Klatzky (1978). They showed that cued recall of doodles could occur by means of semantically appropriate or meaningless labels supplied at presentation and at test. They also investigated recognition of doodles using a two-alternative test where the distractors differed from the targets by a small figural change, which either preserved the semantic

interpretation, or was incompatible with it. Recognition was enhanced when semantic interpretations were supplied along with the items at presentation - but only when the second type of distractor was used. Small figural changes were detected equally when semantic interpretations were not supplied at presentation or were not useful at test.

A small number of studies have provided evidence on the roles of semantic and figural information under STVM conditions. Bisiach and Faglioni (1974) measured recognition of Vanderplas shapes after a 5 second, unfilled delay, and found no effect of association value, in brain damaged patients or controls. Another neuropsychological study by Levin et al. (1976) found no effect of association value on recognition after a 10 second, unfilled delay in patients or controls. In contrast, Cermak (1977) found effects of semantic interpretation under STVM conditions, using free-form stimuli. Targets consisted of outline shapes with internal details which encouraged a particular semantic interpretation. The comparison stimuli, presented after a short delay, were outline shapes which were (a) identical to the target outline (b) were different outlines compatible with the target's semantic interpretation or (c) were different outlines incompatible with the target interpretation. After very short unfilled delays (300 msec) distractors were more easily detected if their outlines were incompatible with the semantic interpretation specified for the target. While this paradigm has a number of advantages, it suffers from using different target and comparison stimuli, only the former having internal contours. This may make it difficult to construct figural descriptions of the target outline, which can then be compared to the test stimulus. Moreover, the same results would be expected if subjects (a) remembered the semantic interpretation or (b) the interpretation merely emphasized particular contours in the figural descriptions.

The above studies show that figural descriptions may be

stored and utilized under LTVM conditions, without the support of semantic categorizations or verbal labelling. Nevertheless, the recovery of a label, semantic interpretation or informative detail (Loftus and Kallman, 1979) is a powerful aid to LTVM recognition. With respect to STVM, the roles of semantic and figural information are less clear. Two of the studies used were neurophysiological, while Cermak's study used conditions which may have obscured the relevant target parameters, making figural description of the target an unreliable procedure. The aim of the experiments described below is to assess the contributions of semantic categorizations and figural descriptions in the recognition of matrix patterns, and to do this for both STVM and LTVM conditions. It is suggested that, as a working hypothesis, LTVM is considered to depend mainly on semantic categorizations, while STVM rests on figural descriptions. The next section considers the coding of matrix patterns in more detail.

5.2 Coding of Matrix Patterns in STVM and LTVM.

It is pertinent to consider the form of the figural descriptions which are assumed to underlie STVM, and which are maintained by visualization. One possibility is that visualization preserves a 'picture' or 'image' of the original scene, i.e. where the pattern of light in the original array has a topographical correspondence with some internal spatial framework. This seems unlikely in view of the limited capacity of visualization and the large redundancy involved. Considerable savings would be achieved by representing patterns as a two-dimensional array of binary values, each specifying a light or dark cell. All such topographic representations involve descriptions whose complexity depends only on matrix size. Hence all 4x4 matrices should be equally easy to visualize.

There is overwhelming evidence against this notion. Schnore and Partington (1967) found that immediate recall of 4x4 matrix patterns

varied as a function of information content. Deregowski (1978) and Garner (1974) also showed that structurally simpler patterns can be recalled more accurately. Further evidence is provided by Experiment 3a, where STVM recall was measured for each of 32 patterns, averaged over 16 subjects. The mean number of cells correctly selected during STVM is listed for each pattern in Appendix A, Table 2. These data show wide variations in the accuracy of performance across patterns. A one-way, repeated measures analysis of variance, with patterns as the within-subjects factor, showed a significant effect for group A ($F = 2.79$; $df = 15,210$; $p = .006$) and also for group B ($F = 5.36$; $df = 15,210$; $p < .0001$). Similar significant differences across patterns were also found for LTVM recall.

These results show that matrix patterns are not coded internally as topographic arrays; the patterns must be organised such that each cell is not coded independently of its neighbours. A plausible suggestion is that matrix patterns are described as arrays of light and/or dark shapes in a fixed spatial relation to each other. Supporting evidence comes from Bartram (1978), who analysed the timing of responses in the recall of 5x4 patterns. He showed that recall consisted of a series of 'chunks', defined as segments of the recalled pattern which were constructed rapidly, and well separated from other segments by longer inter-response times. The probability of a correct placement was constant within a chunk, but decreased between successive chunks, suggesting that chunks were remembered or forgotten as units. In nearly all cases, chunks consisted of a few adjacent cells, showing that grouping and spatial proximity are major factors in the subjective organization of matrix patterns.

This type of organization does not imply that the coding is visual. Similar results might be found if two-dimensional binary arrays were coded verbally (Glanzer and Clark, 1963). Further progress towards specifying and understanding visual descriptions requires a theory of how

patterns are decomposed into subunits, and how these fragments are articulated. A number of suggestions have been made for certain types of visual pattern but mostly these are based on subjective intuition, and are restricted in application (e.g. Bower and Glass, 1976; Garner, 1974). The most general theory is probably Leenwenberg's (1971) theory of structural information. But this cannot be applied to matrix patterns, since it does not have terms for expressing relative position or the relative sizes of the pattern fragments.

The above considerations apply only to figural descriptions, which are computed at the time of presentation. While it seems unlikely that matrix patterns can be specified entirely as familiar elements, a contribution may arise from semantic categorizations. First, when matrix patterns are generated randomly, a number of familiar shapes, including letters such as F, T, L, can occur, and the chance that one such shape will occur in a pattern is quite high. Secondly, even completely unfamiliar patterns can be given semantic interpretations. It has long been known that random configurations provided by textured surfaces or inkblots can be given subjective interpretations if examined for a few seconds. The underlying process is probably one of grouping or selecting certain elements whose configuration maps on to a stored visual description of an object or scene. Artists have regarded this as a valuable exercise in visual imagination, e.g. Gombrich, (1977), p.158.

In the same way, matrix patterns can be interpreted as pictures or scenes if the separate shapes are interpreted as objects, provided the display times are long enough. One example is provided by Experiment 3b, where subjects are shown matrix patterns for 3 seconds. They reported using complex encoding strategies, which involved the interpretation of the patterns as pictures. However, that experiment was not designed to investigate the use of such strategies, or the effects they had on performance.

To investigate this question further, a pilot experiment measured LTVM recognition in two groups of four subjects. One group was trained and encouraged to use a semantic interpretation strategy, the other to concentrate on a purely visual description of the pattern.

Memorization training was accomplished by means of a special procedure whereby the subject controlled the target duration by pressing a key to start and stop the display. A two-alternative recognition test followed after a four second retention interval. The two groups of subjects were given different instructions to encourage semantic interpretations or visual processing. For semantic interpretations the essential part of the instructions ran as follows:

"... relate the pattern that you see to an object, symbol or scene that you know. Try to see the pattern as a picture of something and think up a suitable title for it. This title need not be a single word, it can be a short phrase. But the important thing is that your title relates to the picture you see in the pattern."

For the visual encoding group the corresponding section was:

"... make a very close examination of each pattern. Study the pattern thoroughly and run your eyes over it. Note the shapes of the white blocks and every angle in their outline. Note their relative sizes. Study the positions of the blocks relative to each other. Do this as carefully as you can, so that if you were required to do so, you could draw the pattern freehand."

After twenty trials memorization training subjects were given practice at the mental arithmetic interference task. In the experiment itself, 20 trials were given at each of four display times, 0.3, 1.0, 2.0, 4.0 sec, presented in a random order. At the end of the test, subjects were asked to state the strategies they had used, and whether the display time had limited their ability to carry out these strategies. The main

result of interest is the effect of display time on memorization for the two groups. The mean recognition performance under the four display time conditions is given in Table 5.1. As expected, there was a significant increase in performance as display time increased from 300 msec to 4.0 sec ($F = 4.06$; $df = 3,18$; $p = .0022$). But there was no effect of memorization strategy ($F < 1.0$), and no significant interaction of memorization strategy and display time ($F < 1.0$). When asked about their performance the semantic interpretation group reported that they managed to find a description for a large proportion of the patterns given the longer display times, but not with the shorter display times. Subjects in both groups reported seeing letters or other familiar shapes in the patterns, and that these were helpful in remembering them. Therefore it is possible that performance was equal in the two groups (a) because the induced strategies were equally effective (or ineffective) or (b) because judgments were based on semantic information common to both groups. Two types of semantic information may be involved: the detection of familiar configurations which have meaning, and the process of interpreting a novel configuration as a picture. The latter process has a large number of degrees of freedom. If the semantic interpretation is to provide a basis for recognition, it can only be effective if the distractor does not conform to the same interpretation. Clearly, it is difficult to ensure that this occurs when subjects are free to generate their own interpretations. In contrast, the occurrence of overlearned familiar forms forces one interpretation on the viewer, and it is possible to generate distractors known to have a different interpretation. The next section describes two experiments which investigate the effect of familiar, highly overlearned shapes on STVM and LTVM for matrix patterns.

TABLE 5.1
Percent correct Recognition as a Function of
Display Time and Encoding Strategy

Strategy	Display Time (sec)			
	0.3	1.0	2.0	4.0
Associative encoding				
Mean	73.75	85.0	83.75	92.5
S.E.	10.88	4.16	3.75	2.5
Visual encoding				
Mean	77.5	85	87.5	88.75
S.E.	1.44	3.54	3.23	4.27

5.3 The Effect of Familiar Nameable Shapes on STVM and LTVM

Recognition of Matrix Patterns.

According to the working hypothesis, STVM performance is based on figural descriptions, while LTVM utilises semantic categorizations. To investigate this question further, a special set of matrix patterns was constructed in which targets and distractors differed by a small change made to one segment of the pattern. This segment was constructed so that these small changes in the figural description could alter the semantic categorization, or leave it unchanged.

To do this, target patterns were constructed which incorporated a letter shape as a familiar meaningful element (referred to as the V_1 shape), or a non-letter shape similar in size and complexity (the N_1 shape). The distractors were made by incorporating modifications of these shapes, one of which was a variant of the letter shape, preserving the identity of the letter (the V_2 shape), the other being a variant of the non-letter shape (N_2). Thus if a V_1 shape was part of the target, and V_2 part of the distractor, or N_1 formed part of the target and N_2 part of the distractor, then the target and distractor would differ by only a figural change. Semantic changes occurred when V_1 was presented in the target and N_1 in the distractor, and vice versa. Details of the construction of the V_1 , V_2 , N_1 and N_2 shapes, which will be referred to as the critical shapes, are given below. The combinations of these shapes in the target and distractor patterns make up the four stimulus conditions, which will be referred to by the notation $V_1V_2, V_1N_1, N_1V_1, N_1N_2$, where the first term refers to the target shape, the second to the distractor shape.

The theories outlined at the start of this chapter propose three different roles for semantic information in visual memory, leading to different predictions for LTVM performance:

(a) If semantic information alone is stored in LTVM, then any difference between a target and distractor which does not involve a semantic change will not be detected. Thus performance on the V_1V_2 and N_1N_2 conditions should be low, while that for the V_1N_1 condition should be high.

(b) If semantic categorizations are necessary only for the retrieval of visual information, but figural descriptions are also stored in LTVM, then the predictions depend on further assumptions concerning retrieval processes in recognition:

(i) If retrieval is not required in recognition, performance should be the same for all conditions

(ii) If retrieval processes dependent on semantic coding are necessary for recognition, then performance will be higher when the target contains semantic information i.e. $V_1V_2 = V_1N_1 > N_1V_1 = N_1N_2$.

(c) If semantic categorizations and figural descriptions make independent contributions to LTVM, then performance should be substantial for all four conditions, but higher in the V_1N_1 and N_1V_1 conditions where semantic and figural information can contribute.

In accord with the working hypothesis, it is assumed that STVM recognition depends only on figural descriptions, so that performance is determined by figural complexity. Therefore STVM performance should be the same in all four stimulus conditions.

Stimulus materials.

The aim was to construct a set of targets and distractors to make up the four stimulus conditions, where the overall pattern complexity and the difference between any target/distractor pair would be held constant. Thus any differences between stimulus conditions could be attributed to the detection of semantic or figural changes between the

targets and distractors. The first stage was the construction of the critical shapes, as follows:

(a) A letter shape (V_1) was designed using a square cell format, with the constraints that it was of such a size and shape that it could be conveniently embedded in a 6x6 matrix.

(b) By the addition or deletion of a single cell, two variants of this shape were constructed, one which looked like the same letter of the alphabet (V_2), and the other which did not closely resemble any letter (N_1).

(c) Another non-letter shape was constructed from N_1 by adding or deleting a single cell, so that the resulting shape (N_2) had the same number of cells as V_1 .

An illustrated example of the construction of critical shapes is provided in Figure 5.1.

Thirty-two sets of critical shapes were made up in this way, using twelve letters of the alphabet in upper and/or lower case. These were used in the next stage, generation of the pattern sets, each of which consisted of four 6x6 matrix patterns. Within a pattern set, each member consisted of one of the four related critical shapes (V_1, V_2, N_1 or N_2), plus a common background. Four pattern sets were generated from each set of critical shapes. Two of these had the critical shapes located in one quadrant of the matrix, while in the other two, the critical shapes were placed in another quadrant. Each of the four pattern sets used a different common background. The process of constructing a pattern set is shown in Figure 5.2. A detailed account of the procedure used to generate the stimuli is provided in Appendix B.

Validation of the critical shapes.

The key assumption behind the construction of the stimulus materials is that the V_1 and V_2 -shapes look like the same letter of the

Figure 5.1. The method of constructing a set of four critical shapes, based on the letter 'T'.

For further details see text.

Fig. 5.1

Construction of Critical Shapes

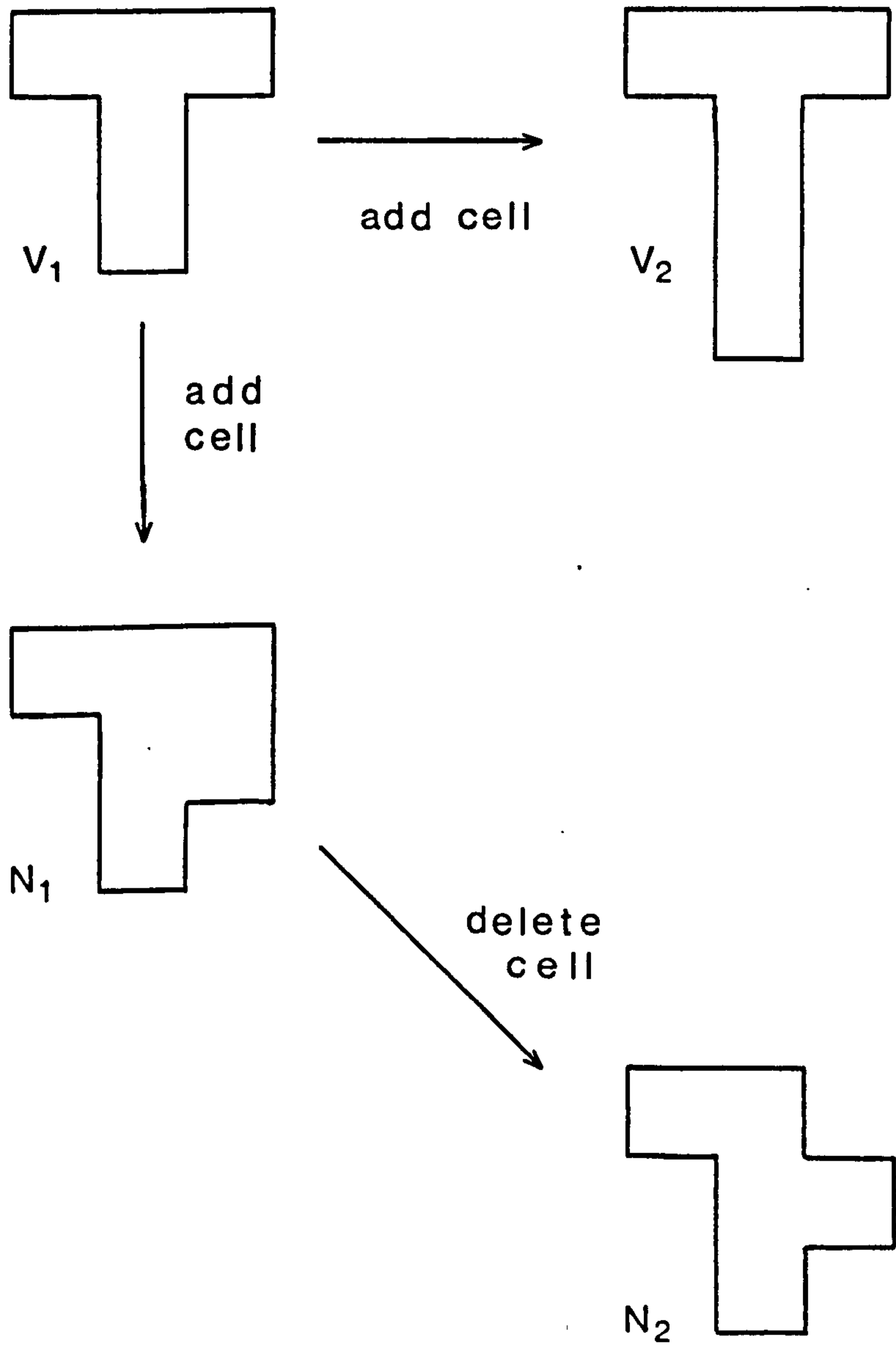
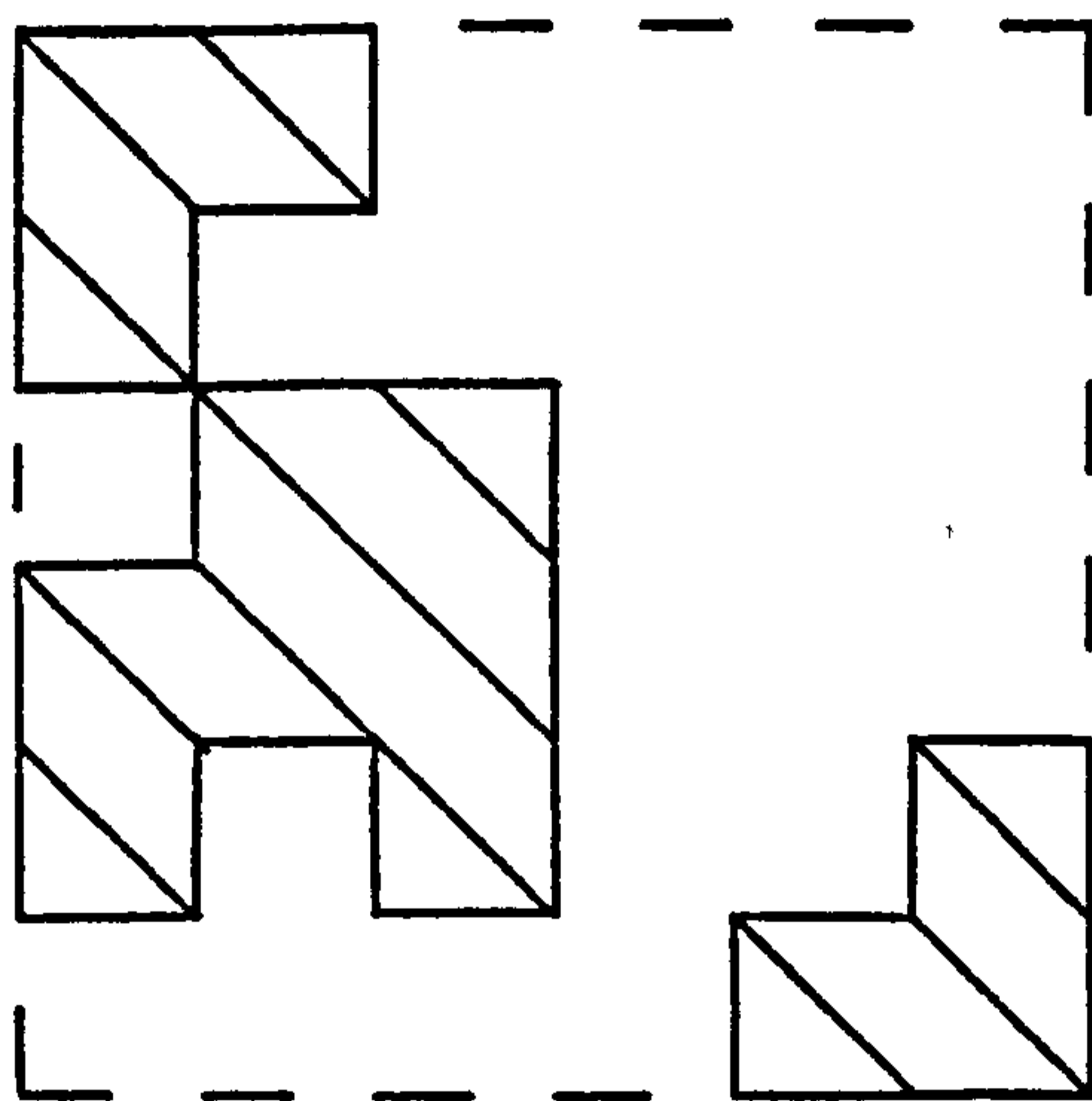


Figure 5.2. The construction of a set of four patterns using the critical shapes shown in Fig. 5.1. Fig. 5.2a shows the background common to all members of the set. Fig. 5.2b shows the four patterns, with the unshaded critical shapes inserted.

Fig. 5.2

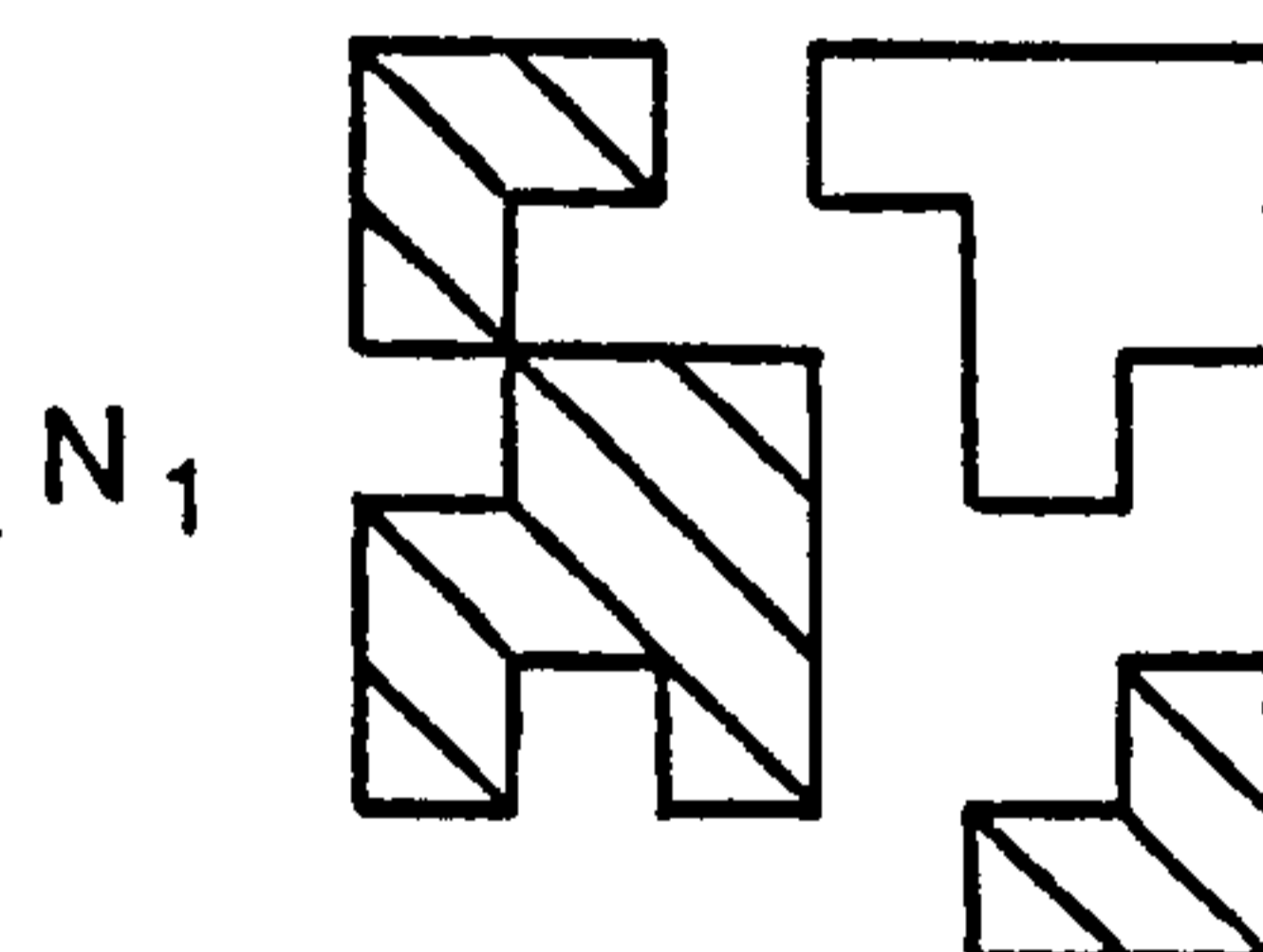
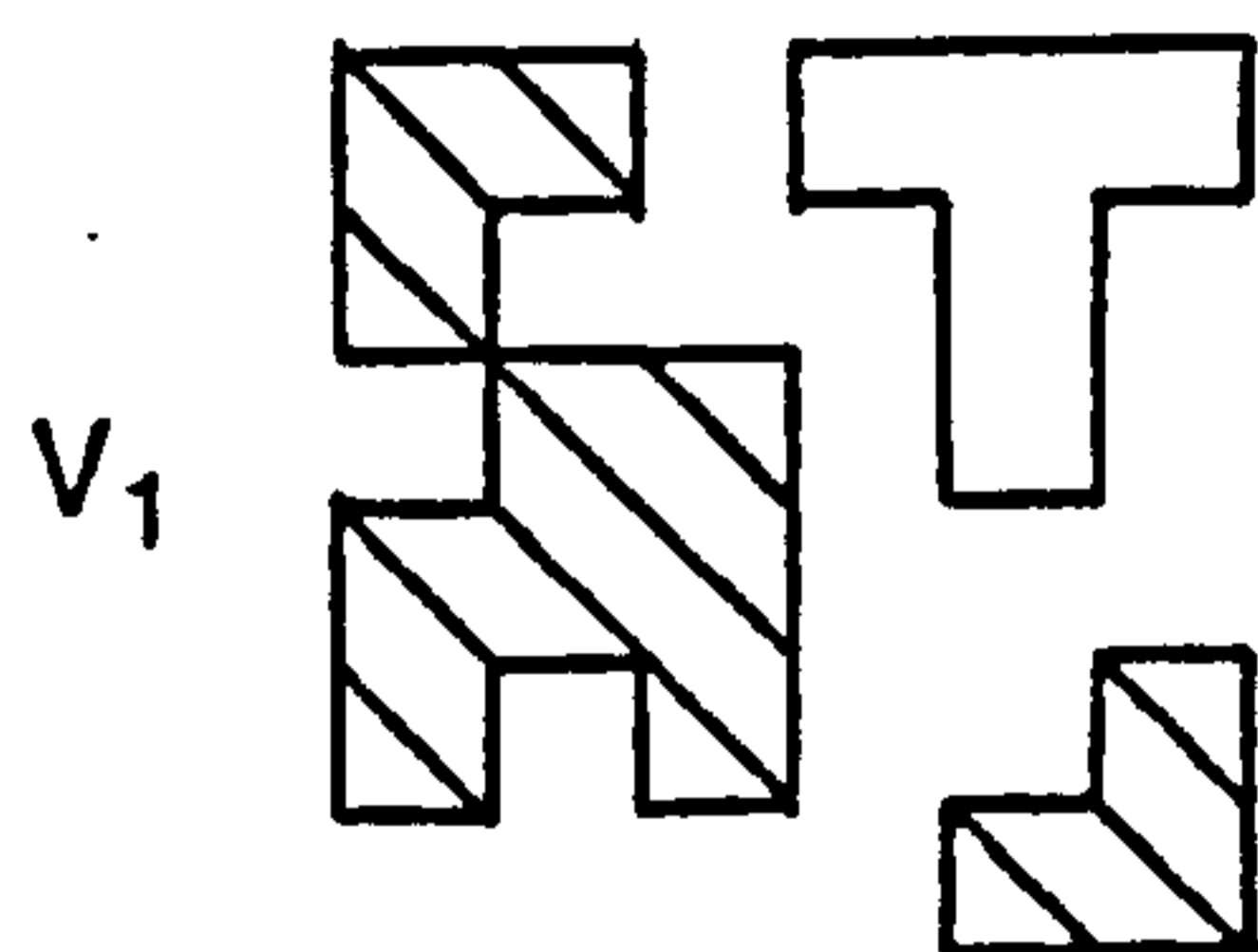
Construction of a Pattern Set

(a) Common Background

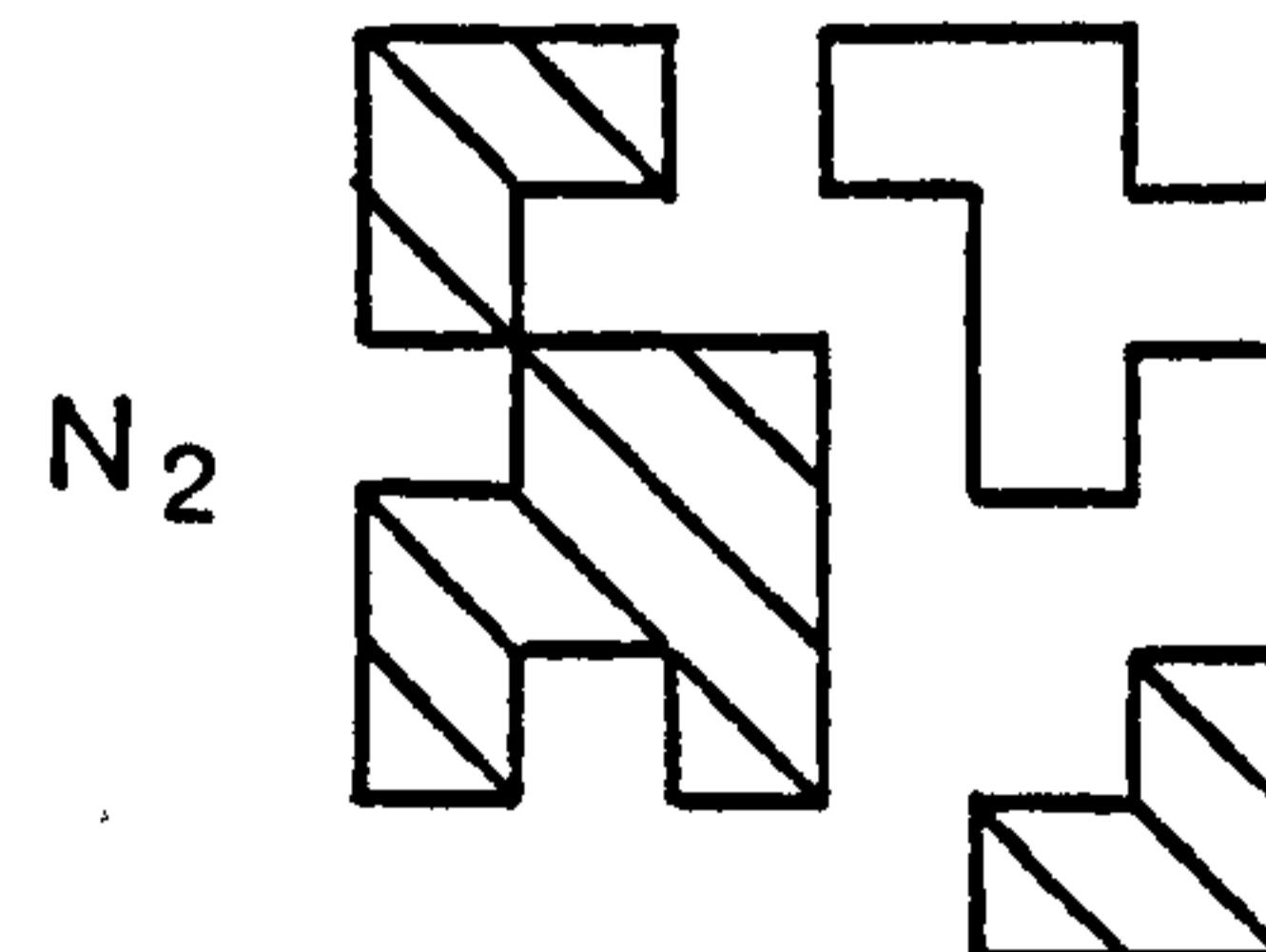
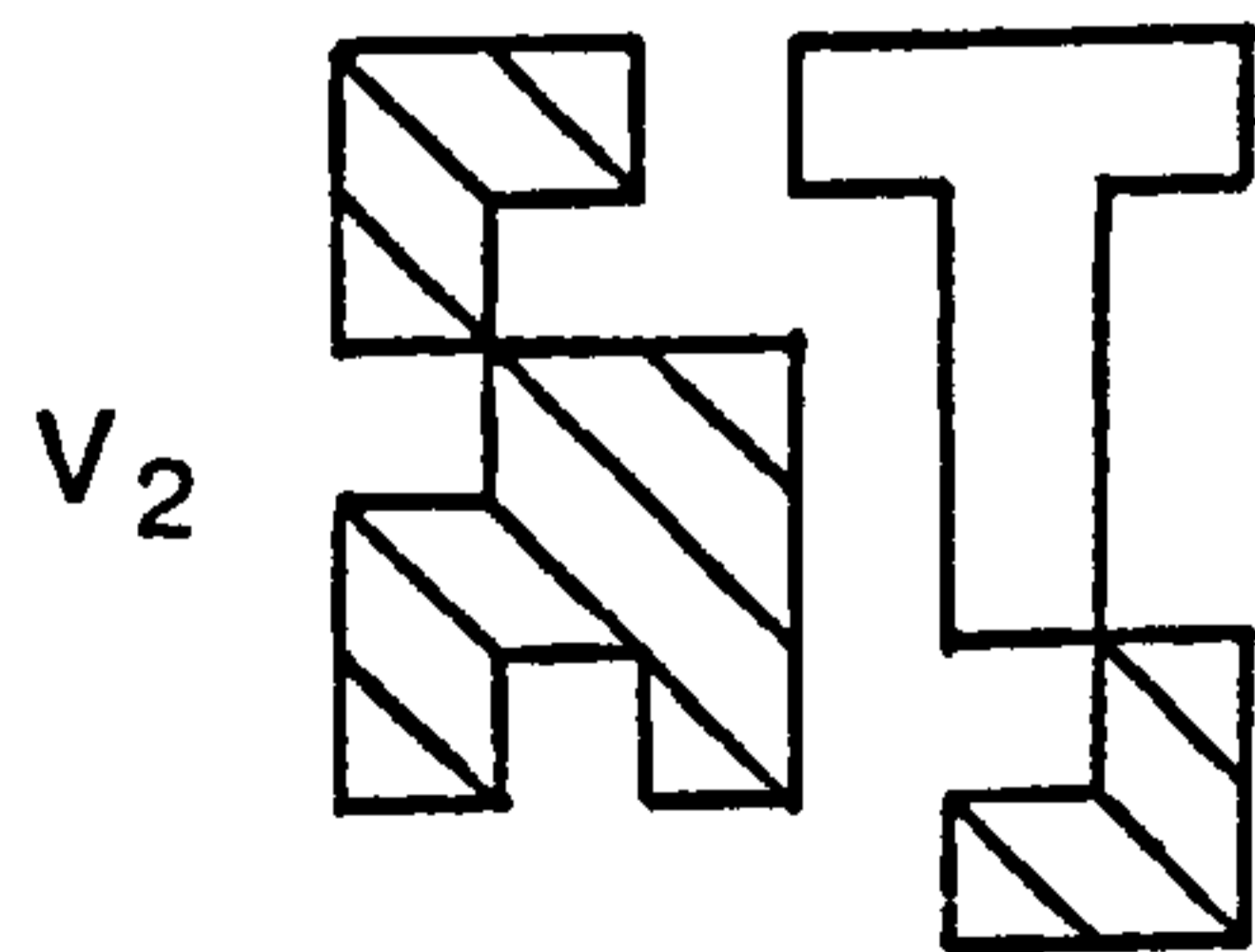


(b) Critical Shapes inserted in top right quadrant

Targets



Distractors



alphabet, whereas the N_1 and N_2 shapes do not look like any letter. However, it is difficult to construct an unambiguous set of shapes when faced by the constraints of a small, coarse-grained matrix. While the critical shapes were drawn up by the experimenter, the success of these experiments depends on the interpretation of the stimuli by naive subjects during the experimental session. The validity of the stimulus conditions was examined by a survey in which 69 naive subjects were given a questionnaire containing drawings of all the critical shapes. They were asked to look quickly at each shape in turn, and write down the letter of the alphabet it most resembled, or to indicate that it did not look like any letter.

Each of the critical shapes was then classified as a particular letter or as a non-letter if more than 50% of the survey responses were in agreement. Table 5.2 presents the results of the survey. It shows the number of critical shapes within each experimenter-defined category which were classified in the same way by the majority of subjects participating in the survey. It can be seen that there is a high agreement between these two sources. Table 5.3 shows the agreement between stimulus conditions as drawn up by the experimenter, and those based on the survey data. Of the total of 128 stimulus conditions, the survey data and the original classification agreed in 92 cases. Thus, although there may be some misclassifications, we can expect large differences between the stimulus conditions in the way the shapes are interpreted as letters or non-letters. Full details of the survey, and a facsimile of the questionnaire is provided in Appendix C.

Experiment 5a: Memory for matrix patterns containing familiar and unfamiliar shapes, under blocked STVM and LTVM conditions.

In this experiment, subjects were given two blocks of 64 forced-choice recognition trials. One block consisted of STVM trials with

TABLE 5.2

Agreement between the Definition of CriticalShapes, according to(i) the Experimenter's Classification and (ii) the Survey Ratings.

Experimenter's definition	Survey ratings	
	Agreement with experimenter	Misclassifications.
V ₁	29	3
V ₂	29	3
N ₁	25	7
N ₂	26	6

TABLE 5.3

Agreement between Stimulus Conditions:

(i) Defined by the Experimenter and (ii) Defined by
Survey Ratings of the Critical Shapes.

Experimenter's definition	Definition according to Subject			
	No category*	V_1V_2	V_1N_1 (or N_1V_1)	N_1N_2
V_1V_2	2	27	2	1
V_1N_1 (or N_1V_1)	6	2	22	2
N_1N_2	3	0	8	21

*The no category column contains all the cases where the survey data failed to show a clear preference in specifying one or both of the shapes, plus a few instances where the shapes were classified as different letters.

short (300 msec) display times; the other involved LTVM trials with display times of 2.0 sec. Display time was manipulated to equalize the mean level of performance under the two conditions. Each block of experimental trials was preceded by a training procedure. Half the subjects received the STVM condition first, the other half the LTVM condition first.

Methods.

Subjects. Sixteen subjects were recruited from the Part I subject panel. Two subjects were rejected and replaced, one because her performance was just above chance level, the other because she encoded the unfilled rather than the filled cells of the pattern.

Displays. Target patterns were displayed as 6x6 matrices with a cell size of 4 mm. In the STVM condition the display duration was 300 msec, and in the LTVM condition it was 2.0 sec. Each target display was followed by an 8x8 chequered mask with the same cell size as the target, shown for 200 msec.

Interference. On LTVM trials interference was provided by the display of a slant pattern for 500 msec, followed by a cross-hatched mask for 200 msec, and a delay of 0.5 sec before the two-alternative recognition test. The test alternatives were displayed side by side until the subject responded.

Retention test. This was a two-alternative forced choice test where the target and distractor were displayed side by side and separated by a distance of 25 mm. Responses were made by pressing one of two keys, arranged as in Experiment 4b. The alternatives were shown for 2.0 sec, and the subject could respond at any time during or after the display. The display time of the test was limited to two seconds to encourage subjects to respond quickly after observing the matrix pattern alternatives. Previous experiments had shown that when the choice was difficult,

especially under LTVM conditions, subjects choice response times were sometimes very long, in the order of from three to four seconds (even longer for some subjects). Close study of the alternatives for such long periods might lead the subjects to adopt unusual strategies. Two seconds was the value chosen for the test display time, since this enabled subjects to see the alternatives clearly, and was longer than the mean LTVM response time found in a number of experiments. Immediately after the matrix pattern recognition test, knowledge of results was provided for one (STVM) or both (LTVM) recognition choices, by the words "CORRECT" or "WRONG" displayed for two seconds.

Training. Training specific to each interference condition was given prior to the experimental block of trials. Before the STVM test, subjects received 15 practice trials without interference where the display time of the target was 2.0 sec, then a further 15 trials with a display time of 300 msec. Before the LTVM condition subjects were first given 15 trials practice on the interference task, where each slant pattern was displayed for one second. This was followed by twenty trials practice using a procedure identical to the experimental task, where target matrix patterns were shown for 2.0 sec and the interference patterns for 0.5 sec. In the practice trials of both conditions the matrix patterns were 5x5 matrices with 12 cells filled, followed by a 7x7 chequerboard mask displayed for 200 msec.

Procedure. The experiment consisted of a single session lasting about one hour. Subjects were given a block of 64 trials under both STVM and LTVM conditions, each preceded by training. At the end of the session subjects were asked to fill in a short questionnaire to find out about their strategies when performing the task, and whether they guessed the purpose of the experiment.

Each trial began with the display of a fixation point, and the subject pressed one of the response keys to initiate the display of the target matrix pattern. This was followed by a mask and then, in the STVM condition, by an interval of 1.0 sec before the two-alternative test. In the LTVM condition, the mask was followed by a blank screen lasting for 0.5 sec, and then the interference task. A further interval of 0.5 sec preceded the recognition test. A short rest interval was provided after every 16 trials. Subjects were instructed to concentrate hard and to try to remember the patterns, but they were not given specific instructions about the possible presence of letter shapes in the patterns.

Results and discussion.

On each trial the raw data consisted of the accuracy and response time of the two-alternative recognition choices, for the matrix patterns (STVM and LTVM) and the interference patterns (LTVM only). Sections (i) and (ii) below describe the effects of interference and stimulus conditions on accuracy of recognition and response time respectively. Performance on the interference task will be examined in section (iii), and the subjects' reports in section (iv).

(i) Percent correct recognition.

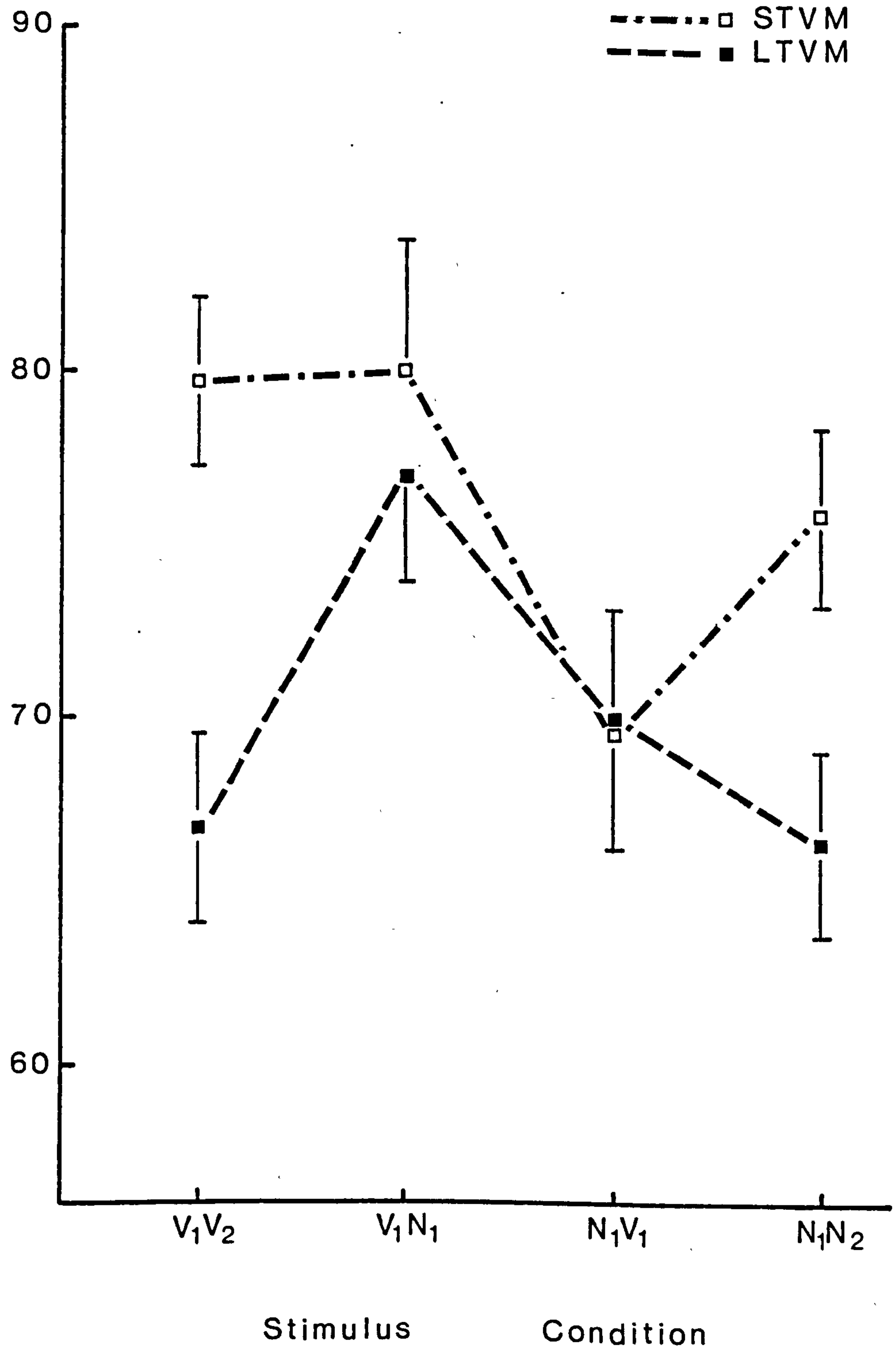
The mean percent correct recognition and standard error for each of the eight conditions are displayed in Figure 5.3. A two-way analysis of variance was run on the data with repeated measures on both factors (stimulus condition and interference condition). This showed significant effects of interference ($F = 8.14$; $df = 1,15$; $p = 0.012$), stimulus condition ($F = 3.74$; $df = 3,45$; $p = .017$), and a significant interaction between them ($F = 3.095$; $df = 3,45$; $p = .036$).

Clearly, the manipulation of extending the LTVM display time to equalize performance in the STVM and LTVM conditions was not successful.

Figure 5.3. Percent correct recognition as a function of the four stimulus conditions. STVM and LTVM trials were blocked with unequal display times. Bars indicate the standard errors.

Fig. 5.3

Percent Correct
Recognition



However, the difference between the interference conditions (6%) is small relative to the variations observed between stimulus conditions, and floor and ceiling effects are avoided. It is unlikely therefore that the interaction between interference and stimulus conditions is a secondary consequence of the difference in mean level of performance. The interaction shows that the stimulus condition (and, by extension the utilisation of semantic or visual information) has a different effect on STVM and LTVM conditions. To examine this further, separate analyses of variance were run on the STVM and LTVM data; these showed significant effects of stimulus condition on STVM ($F = 4.33$; $df = 3,45$; $p = .009$), and LTVM ($F = .2.89$; $df = 3,45$; $p = .045$).

With respect to STVM, the prediction was that recognition would depend only on figural information, and therefore performance should be similar in all four stimulus conditions. The results show that recognition is rarely, if at all, based solely on semantic category information, since performance in the V_1V_2 and V_1N_1 conditions is roughly equal, and N_1V_1 performance does not exceed N_1N_2 . However, recognition is better in the V_1V_2 and V_1N_1 conditions, where a familiar shape was present in the target patterns. These results support a 'schema with corrections' interpretation, whereby economy of description is achieved by describing novel items or modifications of familiar ones. An alternative interpretation is that subjects selectively attend to familiar elements in the patterns, as discussed below.

For LTVM recognition the results are quite different. Performance in the V_1N_1 condition is superior to that in the V_1V_2 condition ($t = 2.93$; $df = 15$; $p < .01$; one-tailed), and also superior to that in the N_1N_2 condition ($t = 2.71$; $df = 15$; $p < .01$). These results support any theory which suggests that LTVM depends wholly or in part on semantic categorization of familiar elements. In addition, both V_1V_2 and N_1N_2 performance are above

chance level, suggesting that more than just semantic information is remembered. However, this is not a strong conclusion since the LTVM display times were long, perhaps allowing other semantic interpretations of the pattern elements, and since the response to some misclassified stimulus conditions are included in the data.

(ii) Mean response times.

The mean response times for each condition are listed in Table 5.4, together with the overall means and standard errors. A two-way analysis of variance with repeated measures was run on the data and showed significant effects of the interference condition ($F = 19.76$; $df = 1,15$; $p = .0005$) and stimulus condition ($F = 3.01$; $df = 3,45$; $p = .039$), but the interaction was non-significant ($F = .85$; $df = 3,45$; $p = .52$). Two one-way analyses were run on the STVM and LTVM data separately, and showed a significant effect of pattern type on STVM response time ($F = 3.92$; $df = 3,45$; $p = .014$) but no effect on LTVM response time ($F = 1.32$; $df = 3,45$; $p = .28$). Again this confirms the insensitivity of the response time measure to changes affecting LTVM performance.

(iii) Performance on the interference task.

Table 5.5 gives the mean performance on the interference task for each LTVM stimulus condition, using both percent correct recognition and response time measures. It is clear from this that performance is consistently high for all the stimulus pattern conditions. An analysis of variance (one-way, with repeated measures) was run on both sets of data and showed that there was no significant difference between the conditions when either accuracy ($F < 1.0$) or response time ($F = 1.41$; $df = 3,45$; $p = .25$) measures were used. Thus any differences in performance between the stimulus conditions on the main task are unlikely to be the result of chance variations in mental load caused by the interference task.

TABLE 5.4
Mean Response Time as a function of
Stimulus condition and Interference condition.

	Stimulus Condition			
	$V_1 V_2$	$V_1 N_1$	$N_1 V_1$	$N_1 N_2$
STVM (300 msec)				
Mean	1.434	1.310	1.459	1.406
S.E.	.121	.109	.134	.120
LTVM (2.0 sec)				
Mean	1.886	1.730	1.771	1.800
S.E.	.158	.106	.124	.158

TABLE 5.5

Performance on the Interference Task
for each Stimulus condition.

	Stimulus Condition			
	V_1V_2	V_1N_1	N_1V_1	N_1N_2
<u>Percent Correct Recognition</u>				
Mean	96.48	96.09	94.92	97.27
S.E.	.98	.78	1.73	.98
<u>Response Time</u>				
Mean	1.118	1.128	1.059	1.118
S.E.	.067	.059	.059	.064

(iv) Subjective reports

At the end of the experimental session subjects were asked to complete a short questionnaire. They were asked to state:

- (a) What they thought the purpose of the experiment was.
- (b) Whether they tried to memorize the whole pattern, or just a part of it, on the majority of STVM and LTVM trials.
- (c) The strategies they used when memorizing matrix patterns in the LTVM condition.
- (d) If they saw any letter shapes in the patterns during the STVM or LTVM trials.

Four subjects thought the experiment had something to do with the effect of letter shapes on memory for patterns, the rest thought it was more generally concerned with the effect of interference. Half the subjects reported trying to memorize the whole pattern in the STVM condition, but only one subject reported doing this for the LTVM condition, even though the display time was much longer. Twelve subjects stated that with the long display times (LTVM condition) they concentrated on a distinctive feature of the pattern, such as a letter shape. Two other subjects said they tried to make a semantic interpretation of the pattern, relating it to meaningful objects. All subjects reported seeing at least some letters in the patterns, under both viewing conditions.

Two results here are of particular interest. First, all the subjects reported seeing the letter shapes, although the majority of subjects did not think the experiment was particularly concerned with them. Second, in the STVM condition with a very short display time half the subjects reported trying to encode the whole pattern, but fewer subjects claimed to do this in the LTVM condition. Instead they tried to identify a distinctive feature (a letter shape or unusual configuration) which they thought would enable them to recognize the correct alternative. This supports the view of

Loftus and his colleagues that long-term recognition of pictures depends on the identification of distinctive features.

To summarize, this experiment showed clear differences in the utilization of semantic categorizations and figural descriptions under STVM and LTVM conditions. These differences may reflect the operation of two specialized encoding strategies, since the presentation conditions were blocked and display times were unequal. Alternatively, the differences could arise at a later stage, if, for example, both semantic categorizations and figural descriptions were initially made, and the latter were particularly sensitive to interference. The following experiment therefore used a fixed, short display time (300 msec) and STVM and LTVM trials were randomized, to prevent the occurrence of different encoding strategies during the target display.

Experiment 5b: Memory for matrix patterns containing familiar and unfamiliar shapes using a fixed display time and randomized interference.

Methods.

The apparatus and materials were the same as those used in the previous experiment. As the interference conditions were presented in a random order, subjects received initial training in the task, followed by a single block of 128 experimental trials. Apart from this randomization, the design was identical to that of the previous experiment. As before, the pattern sets contributing to each stimulus and interference condition were rotated between the 16 subjects.

Subjects. Sixteen first-year psychology undergraduates served as subjects; three of the original sixteen were discarded and replaced. Two of these reported that they encoded the dark areas of each pattern. The third was rejected because he performed poorly on the interference task (more than 25% errors).

Training. Subjects first received sixteen trials practice at the interference task, where each slant pattern was displayed for one second. In the second training procedure, twenty trials were given, half under STVM and the other half under LTVM conditions, in a random order. The display time of the matrix patterns (5x5 with 12 cells filled) was 1.0 sec, and the interference patterns were displayed for 500 msec. The recognition test alternatives were displayed until the subject responded. The third and final practice consisted of 32 trials where the procedure was identical to that of the main experiment. Knowledge of results was provided on every trial throughout the training sessions and the main experiment.

Procedure. The 128 experimental trials were presented as four blocks of 32 trials, separated by a rest period of one minute. Each one of the 32 sets of critical shapes was sampled in each block, and each time a particular set was sampled it was presented as a different pattern set in a different stimulus condition. As before, subjects were instructed to concentrate hard and try to remember the target patterns. They were also instructed to concentrate on the interference patterns, and were encouraged to perform accurately on the interference task. At the end of the session subjects were asked to complete a short questionnaire similar to that used in Experiment 5a.

On each trial the subject initiated the display sequence by pressing one of the two response keys. The target was displayed for 300 msec followed by the 8x8 mask for 200 msec. On STVM trials the recognition test followed after a delay of one second. On LTVM trials a delay of 0.5 seconds was followed by the interference task, and a further delay of 0.5 seconds preceded the recognition test. The alternatives in the recognition test were displayed for two seconds.

Results and discussion.

(i) Percent correct recognition.

The overall means and standard errors are plotted in Figure 5.4.

Once again, the results show that performance in both STVM and LTVM depends on the four stimulus conditions. A two-way analysis of variance was run on these data. This showed a significant effect of stimulus condition ($F = 6.41$; $df = 3,45$; $p = .0011$), and as expected a massive effect of interference ($F = 44.50$; $df = 1,15$; $p < .0001$). But the interaction was not significant ($F < 1.0$). Separate analyses of variance were run for each interference condition, and these showed a marginally non-significant effect of stimulus condition on STVM ($F = 2.34$; $df = 3,45$; $p = .085$), and a significant effect on LTVM ($F = 3.89$; $df = 3,45$; $p = .0015$).

As in the previous experiment, LTVM varies with the stimulus condition, with the poorest performance in V_1V_2 and N_1N_2 . The difference between the V_1V_2 and V_1N_1 conditions is significant ($t = 3.56$; $df = 15$; $p < .005$; one-tailed), as is the difference between V_1N_1 and N_1N_2 ($t = 2.93$; $df = 15$; $p < .01$). This confirms the previous experiment in showing that on some LTVM trials, recognition is based on the semantic category of the critical shape, rather than on the shape itself. The overall performance is lower than in Experiment 5a, but the results show that familiar shapes embedded in 6x6 matrix patterns can be detected with display times as short as 300 msec.

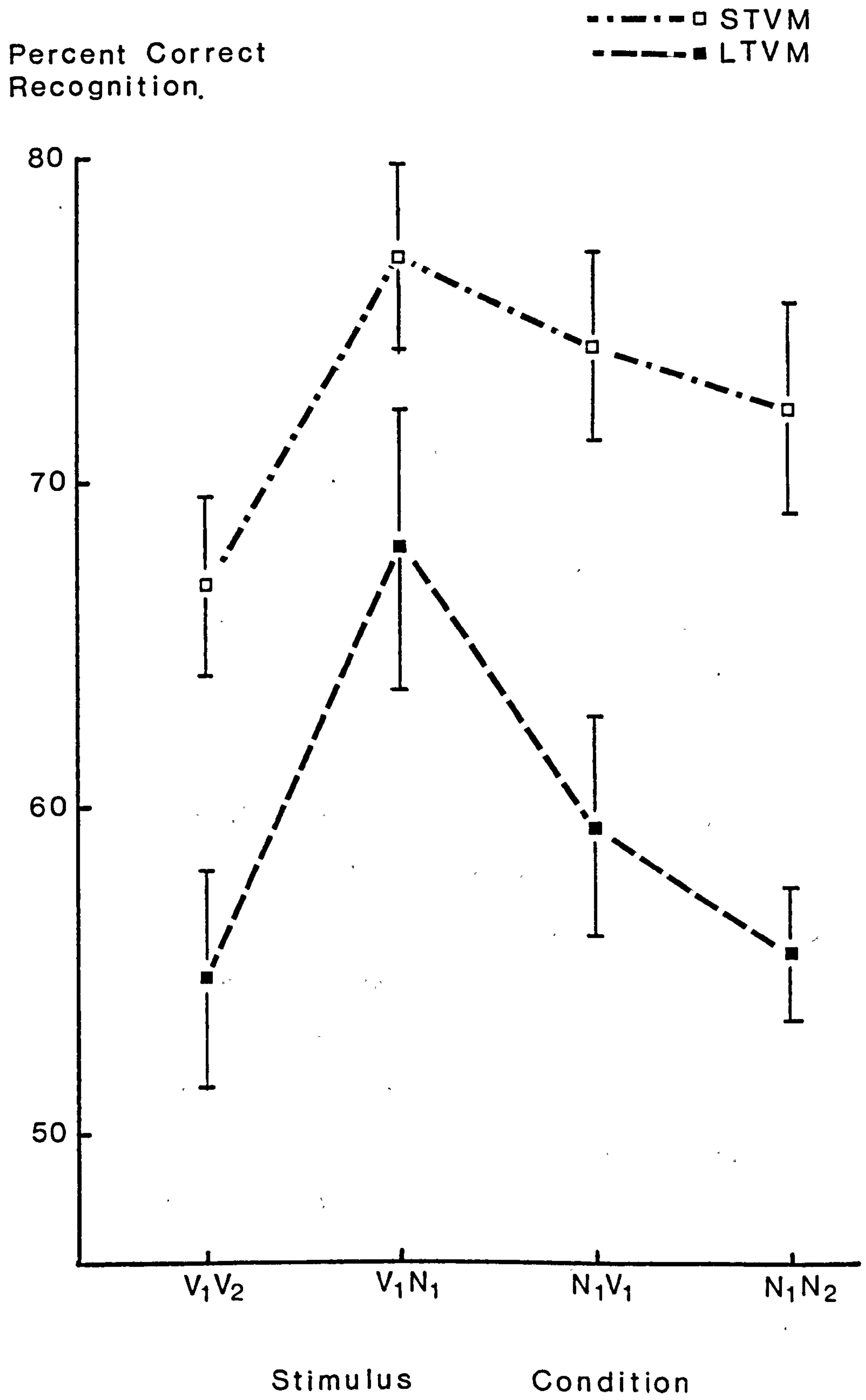
More surprising are the STVM results which show higher performance in the V_1N_1 condition than in V_1V_2 , a difference which is significant by a t-test ($t = 2.86$; $df = 15$; $p < .01$). This suggests that on some STVM trials only semantic category information is available during the recognition test. Performance in the V_1V_2 condition is even lower than that in the N_1N_2 condition, but this difference is not significant ($t = 1.4$; $df = 15$; $p > .05$; one-tailed).

(ii) Mean response times.

The mean response times for each condition, and the standard errors are listed in Table 5.6. A two-way analysis of variance with

Figure 5.4. Percent correct recognition as a function of the four stimulus conditions. Display time was fixed at 300 msec, STVM and LTVM trials were randomized. Bars indicate standard errors around each mean.

Fig. 5.4



repeated measures was run on these data, and showed that there was a significant effect of interference ($F = 4.35$; $df = 1,15$; $p = .05$), but no significant effect of stimulus condition, ($F = 1.5$; $df = 3,45$; $p = .23$) and no interaction ($F = 1.68$; $df = 3,45$; $p = .18$). The effect of stimulus condition on STVM response times found in Experiment 5a here failed to reach significance ($F = 2.23$; $df = 3,45$; $p = .096$).

(iii) Performance on the interference task.

Two measures of performance were taken on the interference task, and these were compared across stimulus conditions. The percentage of correct recognition choices in each stimulus condition and the mean response times are listed in Table 5.7. It can be seen that performance on this task was consistently high, and the response times were fast. The small differences between the stimulus conditions were not significant when tested by a one-way analysis of variance when either percent correct ($F < 1.0$) or response time ($F < 1.0$) measures were used.

(iv) Subjective reports.

The questionnaire used was similar to that of Experiment 5a, modified slightly since the display conditions in this experiment were the same for all trials. Four subjects suspected that the experiment was concerned with the effect of letter shapes on recognition, although all the subjects reported seeing some letters embedded in the patterns. Fourteen subjects stated that they tried to remember just a part of the pattern, and all but one of these adopted the strategy of looking for a distinctive feature in the pattern. Both subjects who tried to remember the whole pattern showed chance level LTVM performance.

5.4 Final Discussion and Conclusions.

The results of these experiments have a number of implications for the coding of matrix patterns and other visual stimuli. Before

TABLE 5.6

Mean Response Times as a function of
Stimulus Condition and Interference Condition.

	Stimulus Condition			
	V_1V_2	V_1N_1	N_1V_1	N_1N_2
STVM				
Mean	1.770	1.645	1.685	1.762
S.E.	.087	.084	.099	.113
LTVM				
Mean	1.855	1.788	1.848	1.792
S.E.	.099	.092	.102	.103

TABLE 5.7.

Mean Performance on the Interference Task
for Each Stimulus Condition.

	Stimulus Condition			
	$V_1 V_2$	$V_1 N_1$	$N_1 V_1$	$N_1 N_2$
<u>Percent Correct Recognition</u>				
Mean	90.63	91.02	92.19	94.14
S.E.	2.21	1.80	2.58	1.93
<u>Response Times</u>				
Mean	1.200	1.158	1.164	1.178
S.E.	.062	.071	.073	.062

discussing these, two qualifications must be stated, which arise from the methods used.

(i) The survey data showed that some target/distractor pairs in each stimulus condition were misclassified, and that there was considerable inter-subject variability in the identification of the critical shapes as letters. For these and other reasons each stimulus condition may not reflect the operation of purely semantic or purely figural processes. However, to be informative the experiment requires only relative differences in the application of semantic and figural processes to the four stimulus conditions. The large number of consistent ratings in the survey data, together with the subjects' reports that letters were clearly seen in the patterns shows that this condition was met.

(ii) Correct recognition did not require encoding the entire pattern, but only one part of it, the critical shape. Therefore subjects may have adopted a focal strategy, selecting one shape of the pattern, which was likely to be changed in the distractor. If a shape resembled a letter, then there was a strong likelihood that this would be the critical shape. Such strategies may account for differences between the V_1 and N_1 target conditions (for example in the STVM conditions of Experiment 5a). It cannot account for differences between conditions arising from the use of different distractors.

The main implications of these results for the encoding of matrix patterns are as follows:

(1) Semantic effects in recognition memory.

These experiments and a number of others (e.g. Rafnel and Klatzky, 1978; Wiseman and Neisser, 1974) have shown clear effects of semantic categorization on recognition memory. Therefore, to the extent that recognition does not involve retrieval processes, this result poses

problems for Cohen's (1977) claim that semantic categorization is essential for the retrieval of sensory impressions. It is possible that retrieval processes are involved in LTVM recognition, but this is unlikely to be the case for STVM, where semantic effects were found in Experiment 5b.

(2) The role of semantic categorizations in LTVM.

In both experiments, significant differences were found between the V_1V_2 and V_1N_1 conditions, indicating that on some trials recognition was based on the semantic categorization of the critical shape. Given that this information is available in LTVM, we can ask if this is required to support figural descriptions, or if figural descriptions themselves provide the basis for LTVM recognition. If figural descriptions were utilised in LTVM, but only for shapes with available semantic interpretations, then performance in the V_1V_2 condition should exceed that in the N_1N_2 condition. This was not the case in either experiment, and so it is unlikely that the description of visual forms in LTVM is accomplished entirely by the modification of existing schemas.

Evidence that LTVM may be based on figural descriptions is provided by the above chance performance in conditions V_1V_2 and N_1N_2 . However, this may be explained in terms of the partial misclassification of the stimulus conditions. Better evidence for the contribution of figural descriptions to LTVM is provided by Rafnel and Klatzky (1978) and Bostrom (1970).

(3) Semantic categorizations in STVM: the effect of experimental context.

The initial working hypothesis was that STVM performance was based on figural descriptions alone, and hence would not be influenced by the stimulus conditions. Both experiments refute this claim. In Experiment 5a it was shown that performance was higher when the target patterns included familiar shapes. This may be explained in terms of focal attention to the critical shape, or it may indicate that the encoding

processes underlying visualization make use of familiar shapes in building figural descriptions of the targets. In contrast, Experiment 5b showed that STVM recognition was sometimes based on the semantic category of the critical shape. In both experiments the STVM trials were identical, but in Experiment 5a they were blocked, and in Experiment 5b they were randomly interspersed with LTVM trials. The difference between these STVM conditions may be explained as the result of coding or rehearsal strategies.

(i) Coding.

Under 'pure' STVM conditions it may be advantageous to encode matrix patterns as figural descriptions, whereas under randomized interference semantic categorizations may be important because of their contribution to LTVM. The problem that remains is why both types of description cannot be encoded in the latter case. Classifying familiar alphabetic characters should not put a high demand on processing capacity, but searching for letters in an array of assorted shapes, or interpreting shapes as letters may have considerable costs.

(ii) Rehearsal.

Another explanation for the differences between the STVM conditions of these experiments is that both figural descriptions and semantic categorizations are encoded, but that figural descriptions rely more on visualization throughout the retention interval. We then have to explain why visualization is more common under the conditions of Experiment 5a. One answer is that voluntary control processes such as visualization may be more difficult to organize during complex tasks. Another consideration is that there is little advantage in visualizing to maintain a figural description once the critical shape has been identified as a letter. (If figural descriptions are susceptible to interference there will be little advantage in visualizing on LTVM trials, while on half the STVM trials,

semantic information alone will be enough to perform the task). This explanation will account nicely for the observation that STVM performance in the V_1V_2 condition of Experiment 5b is lower than that in the N_1N_2 condition. However, this difference is not statistically reliable, and this interpretation is tentative.

Some support for the idea of context-dependent visualization is provided by a comparison of the overall STVM performance in Experiments 5a and 5b. In the latter experiment, the accuracy of recognition was much lower, and the response times much longer, consistent with the idea that visualization was less frequent. Further support comes from Posner et al. (1969), using the letter-matching paradigm. They found that the RT advantage for physical identity matches was greater and persisted for longer when subjects were tested under 'pure' conditions, i.e. blocks of trials where 'same' matches were always based on physical identity or always on name identity. In 'mixed' conditions, the physical identity RT advantage was much smaller.

(4) Comparison with the auditory/verbal modality.

Many studies investigating verbal memory suggest that STM is phonemically coded, whereas LTM is semantically encoded (e.g. Conrad, 1964; Baddeley, 1966a, 1966b). The finding that figural descriptions are maintained in STVM but to a lesser degree in LTVM (Experiment 5a) supports a visual counterpart to this idea. Although the results of Experiment 5b appear to be in conflict, they can be accommodated by claiming that visualization does not occur so readily under randomized conditions, or that active verbal rehearsal is used. The rehearsal of a letter name may be advantageous in that it has a low mental load, and it might well be possible to rehearse this subvocally throughout the interference task. Indeed, it is likely that having examined a pattern, subjects rehearse any features

that come to mind, in the most appropriate modality. Phenomenally there is a suggestion that rehearsal processes such as subvocalization or visualization involve the iteration of specific phonemic/articulatory or figural forms. It is difficult to conceive of an analogous state involving the active rehearsal of purely 'semantic' information.

CHAPTER SIX

The Effects of Stimulus Display Time on STVM and LTVM.

This and the following chapters explore the consequences of manipulating the time available for (a) studying the materials at presentation (b) rehearsal and (c) identifying the pattern at test. Despite the change of emphasis the essential questions are the same; to provide further evidence for the distinction of STVM and LTVM, and to determine the relation between the underlying processes. The particular concern of this chapter is the effect of display time on STVM and LTVM. There is much evidence to show that this is an important variable for visual materials, and that increasing the display time increases the amount of information remembered from a visual presentation. The following section reviews this evidence and its implications for visual information processing.

6.1 Display Time Effects in Visual Memory Studies.

A great deal of evidence shows that the duration of a visual display is an important variable in visual memory. Of direct concern here are those studies which show the effects of display time on STVM and LTVM performance, and the recent claim that display time effects support a serial modal model of visual memory, where information is transferred from STVM to LTVM. These will be dealt with in turn.

(i) STVM studies.

In the terminology used here, STVM refers to memory for visual displays which is tested in the absence of the stimulus or sensory representation, and after a short unfilled retention interval. The large number of studies which have used a backwards masking paradigm to investigate the extraction of information from brief visual displays can

be subsumed under this heading. The majority of such experiments have used arrays of familiar letters or numeric symbols as stimuli. This has the advantage that recall techniques can be used, but neglects one important aspect of visual information processing, its ability to form descriptions of novel configurations. The results of these experiments show that information is extracted rapidly from a post-masked display for 100 msec or so, up to an asymptote of 4 - 5 letters (e.g. Sperling, 1963, 1967; Liss, 1968; Allport, 1968). Beyond this there is some evidence of a much slower increase in information (e.g. Coltheart, 1972; Scarborough, 1972; Mackworth, 1963; Henderson, 1972). This typical result will be referred to as the alphanumeric readout function.

The interpretation of this function is still open to question. Sperling (1967) proposed that the rapid rising phase indicated the rate of character identification (about 10 msec per item) and the asymptote of 4 - 5 items represented a limit imposed by verbal STM. A later proposal by Coltheart (1972) suggested that the rapid phase was the consequence of a visual descriptive process and the asymptote was the limit on visual STM. The slow increase observed beyond the asymptote was attributed to verbalization, since it corresponded roughly to the rate of implicit speech. Evidence in support of this view was provided by Wolford and Hollingsworth (1974) who showed that for asymptotic performance in the full report procedure there was a high incidence of visual intrusions, but no evidence of acoustic confusion errors. Miller (1972) found no effect of acoustic similarity on immediate partial or full report from tachistoscopic presentations of letter arrays, although visual similarity had a considerable effect.

Allport (1977) has recently questioned two implications of the Coltheart model. First, he claims that if the initial phase reflected the operation of a visual descriptive process based on graphemic features,

then performance should be the same for single letters, letters in words, or letter-like shapes. Clear differences in both readout rate and full report asymptote are found under these conditions. His second claim argues against the proposal that visual processing is prior to semantic categorization. Experiments by Marcel (1980, in press) show that semantic information may be accessible when the masking interval is so short that the stimulus is phenomenally invisible. Allport's proposal is that matching of graphemic and lexical information is necessary before report can occur in backward masking paradigms; and that different processing systems handle the two types of information. Perhaps the main objection is his assumption that visual descriptions are based on elementary graphemic features, even for highly overlearned stimuli. Another difficulty is that very few studies have so far been able to replicate Marcel's results on subliminal lexical priming.

A few studies have measured immediate memory for unfamiliar stimuli after tachistoscopic presentation in a backward masking paradigm. Allport (1968) used a display of broken rings (Landolt C's) in four different orientations. Compared to alphanumeric displays the measured readout rate was slower (i.e. fewer rings than digits were reported correctly for the same exposure time), but for both kinds of material the rapid rising phase reached an asymptote at about the same exposure time (80-100 msec). The reason behind the difference in performance may be that the broken ring stimuli are more confusable, and are differentiated by just one visual parameter, orientation. Den Heyer, Ryan and MacDonald (1976) used stimuli consisting of a number of shapes placed in the cells of a 6x4 matrix. They varied the display time of the stimulus, and found that the accuracy of report for both item and location information increased as display time rose from 30 to 110 msec. However, at the longest display time there is no evidence that an asymptote has been reached. In

one condition reported in their paper, Hines and Smith (1977), displayed random polygons for 50 msec, followed by a mask after a variable delay. Performance on an immediate recognition test increased as the stimulus onset asynchrony (SOA) rose from 50 msec to 300 msec. Since recognition performance at the longer SOA's was very high, it is possible that the asymptote in their study was corrupted by ceiling effects.

Thus, three studies using different non-verbal materials have shown that the information extracted from a display increases rapidly as a function of display time or SOA in a backward masking paradigm, up to an asymptote. This corresponds to the findings with alphanumeric stimuli, except that the parameters of the readout function vary with the type of display used. However, in all these cases the rapid readout phase appears to be complete by 150 - 300 msec. Studies which have measured STVM for novel materials as a function of longer display times (e.g. Phillips and Christie, 1977a) have reported little or no effect of prolonged exposure.

(ii) LTVM studies.

A number of experiments have shown that increasing the display time of pictures presented in series improves retention. In typical cases, the series length was varied from 5 to 40 items, and significant increases in recognition or recall have been found when display times were varied between 0.2 and 5.0 seconds (e.g. Shaffer and Shiffrin, 1972; Shiffrin, 1973; Weaver, 1974; Tversky and Sherman, 1975).

Perhaps the most thorough account of display time effects on picture recognition has been made by Loftus and his colleagues. An early study monitored subjects' eye movements, and found recognition was a function of the number of fixations made during presentation (Loftus, 1972). Later experiments by Loftus and Bell (1975) showed large increases in LTVM as display time increased from 50 msec to 500 msec, and the probability of recognizing a detail of the test picture increased over the

same range of display times. They proposed two components to visual recognition memory: general visual information, which accrues gradually over exposure time, and memory for specific details, which increases as a function of the number of fixations. Loftus and Kallman (1979) went on to show that performance is also enhanced when subjects are asked to report details during the target exposure.

A few studies have varied the display time of novel visual materials and measured recognition under LTVM conditions. Clark (1968) presented 20 Vanderplas figures in series with exposure times of 200 or 500 msec, and found no difference in recognition performance. Visual persistence, however, was uncontrolled. More recently, Hines (1975) has shown clear differences in LTVM performance for the same kind of stimuli as a function of display time. In this study items were presented successively, so that each acted as a mask for the preceding item. Loftus (1974) presented series of random line figures with display times ranging from 125 msec to 2000 msec. The results showed an increase of d' as a function of display time. Phillips and Christie (1977a) found a significant increase in LTVM recognition as display time was extended from 0.5 to 2.0 seconds. One condition of Hines and Smith's (1977) study involved the presentation and immediate recognition of a distractor shape interpolated between the presentation and test of the target item, thereby conforming to an LTVM paradigm. Display time was fixed, and the target-distractor onset asynchrony (SOA) was varied. The results showed a slow increase in LTVM as SOA increased from 50 msec to 300 msec. Beyond this point the LTVM function flattened off, presumably because the sensory representation did not persist through the longer SOAs.

Thus studies of display time effects on LTVM have shown that performance increases as display time is extended from 50 msec up to several seconds. This is true for both natural pictures and novel visual

materials. In addition, there is some evidence that LTVM for natural scenes depends on two components: memory for the general configuration, and memory for specific, informative details. The second of these may depend on fixation rate rather than display time.

(iii) Display time studies and the 'modal' model.

An interesting new paradigm has been developed by Potter (Potter and Levy, 1969; Potter, 1975; Potter, 1976) in which pictures of natural scenes or objects are shown in rapid sequential presentation. When targets are specified before the sequence, either by a verbal description, or a preview of the item, they can be detected with display times as short as 110 msec. But subsequent memory for the non-target items is very poor, suggesting that they are identified at presentation, and later forgotten. Potter's explanation is that brief presentations of natural scenes result in a short-term conceptual memory, which is resistant to masking, but susceptible to interference from later attended presentations. In support of this claim she was able to show that when very brief exposures were used, and target pictures were preceded and followed by a pattern mask, recognition memory was high, provided there was a long interval (in her case 4.5 sec) before the next attended target presentation. Two stages seem to be involved: (i) the rapid readout of information from the display into short-term conceptual memory, at which stage identification takes place, and (ii) the subsequent consolidation of this information into long-term visual memory, a process which is disrupted by interference. The time parameters are important. For pictures of natural scenes she claims that identification can take place with exposures of 100 msec or so, but long-term recognition appears to require longer display times, with a median value of about 400 msec.

Potter's theory is a variation on the modal model of memory, where information is first read into a short-term memory, and then is

'consolidated' in LTVM.

A similar conclusion was reached by Hines and Smith (1977), based on their study where STVM and LTVM were measured as a function of target-distractor onset asynchrony. In their view, LTVM performance was low with short processing times because little of the STVM information had been converted into a more permanent form.

6.2 Implications of Display Time Effects on STVM and LTVM.

From these studies, it is clear that the display time of a picture is a potent variable affecting both the amount of information available for immediate report (STVM) and subsequent recognition memory (LTVM). The aim of the following experiments was to determine the effect of display time on STVM and LTVM for the same kind of novel visual materials, measured under similar conditions. The results have a number of implications for the nature of STVM and LTVM, and the relation between them:

(i) they may provide further support for the dissociation of STVM and LTVM (ii) they provide a test of the serial modal model and (iii) they have implications for the representations on which STVM and LTVM are based.

At the simplest level, if display time has different effects on STVM and LTVM, then this could provide further evidence for a functional dissociation. There is a suggestion from several experiments in the literature that STVM and LTVM are not affected in the same way by display time (e.g. Phillips and Christie, 1977a; Hines and Smith, 1977), when measured for similar stimuli under appropriate conditions.

The effect of display time on STVM and LTVM also provides a test of the modal model of memory. According to this model, information from the display is encoded in a limited capacity short-term store (STS) and from there is transferred to a long-term store (LTS). The essence of this model is that all information in LTS is a consequence of transfer from STS. Two general predictions follow from this: transfer from STS to LTS

should take place in the absence of the stimulus, and any procedure which limits the information available to STS should also affect LTS.

The first prediction, which has been tested a number of times using verbal and visual materials, is the concern of the next chapter. Here, the main concern is the second prediction, and the following experiments use display time to limit the information available to STVM. If all information arrives in LTVM after transfer from STVM, then STVM and LTVM should be similarly (but perhaps not identically) related to display time. An exact prediction of the relationships of STVM and LTVM to display time cannot be made without making further assumptions about transfer to LTVM and the information content of STVM. However, if it is assumed that the amount of information transferred to LTVM before interference is a monotonic function of the amount in STVM, then it follows that STVM and LTVM should both increase over the same range of display time values. It can further be argued that once all the information about an item is encoded in STVM, then prolonging the display time will not be a necessary condition for increasing the information in LTVM.

Another way of looking at this type of experiment emphasizes that these stimuli are novel visual patterns. Remembering a pattern depends on constructing a visual description for it during presentation. Thus manipulating display time provides an indirect approach to the problems of the last chapter. If STVM and LTVM are based on different underlying descriptions, which are constructed from the stimulus at display time, then we should expect STVM and LTVM to vary in quite different ways as a function of display time. However, the converse is not necessarily true. If STVM and LTVM are differently related to display time, this does not mean that different pattern descriptions are involved; changes in trace strength, consolidation or the number of retrieval cues could all bring about a change in memory without changing the way in which the patterns are described.

6.3 Experiment 6a: The Effect of Display Time on STVM and LTVM.

In this experiment, both STVM and LTVM were measured as a function of display time. Each target display was followed by a mask to eliminate sensory persistence, and mental arithmetic was used to provide interference. In addition to the theoretical considerations which are listed in detail above, this experiment also provides empirical data concerning the rate of acquisition of information from novel visual displays, i.e. the time required to construct visual representations in STVM and LTVM.

Methods.

Subjects. Eight first year undergraduates served as subjects.

Apparatus. All stimuli were displayed on the GT40 terminal, and all responses were made using the alphanumeric keyboard. Only the numerals and three other marked keys were used, these being: the top left key of the keyboard, which was used to start each trial, and the keys 'B' and 'N' of a standard typewriter layout which were used to make the choice response in the recognition test. These keys were labelled 'START', 'LEFT' and 'RIGHT' respectively.

Stimulus materials. Target stimuli were 4x4 matrix patterns with 8 cells filled. Distractors were made from these by selecting one filled and one unfilled cell and changing their values. A set of 320 target/distractor pairs was constructed such that no pattern was duplicated. The unit cell size was fixed at 6 mm and the viewing distance was 50 cm.

Masking. The mask consisted of a 6x6 chequerboard pattern, with the same cell size as the target and centred on the same point, so that target and mask contours coincided. In all conditions the mask appeared at target offset, for a duration of 200 msec.

Interference. A sequence of four single-digit numbers was displayed, each one lasting for 400 msec with a 100 msec gap between them. After the sequence the screen remained blank until the subject responded by typing the two-digit answer to the sum on the keyboard with his left hand. The correct answer was then displayed for 500 msec. The digits which made up the sum were chosen at run time by a random number generator, with the constraint that the total should be greater than eleven.

Retention test. The target and its distractor were displayed on the screen with the same dimensions as before, and separated by 25 mm. On half the trials of each condition the target appeared on the left side of the screen, and on the right side for the remainder. The subject indicated the position of the target by pressing one of the adjacent keys, marked 'LEFT' and 'RIGHT', using the index or middle finger of the right hand, respectively. Knowledge of results was provided by a message displayed for two seconds after each choice.

Procedure. This experiment was conducted in two sessions of one hour's duration. The first session began with a training task of 40 trials, in which the targets were displayed for 1.0 sec and interference was given on every trial. Following this, subjects performed 32 practice trials with exactly the same procedure as that used for data collection. The first session ended with a block of 96 experimental trials. In the second session, which was at least one day later, subjects performed sixteen practice trials as warm-up, and then two blocks of 96 and 128 trials separated by a short rest.

A fixation point was displayed at the start of each trial, until the subject initiated the display sequence by pressing the 'START' key. The target stimulus was displayed immediately, followed by the mask. After this, there was either a 1.0 sec unfilled retention interval or a 0.5 sec delay followed by interference. The target and distractor were

then displayed together in the recognition test, until the subject made a choice response. Display of the feedback message terminated the trial.

The data collected consisted of the accuracy and latency of responses on each recognition test, and also the accuracy and time taken to solve interference problems. As the procedure was quite tiring a short rest was introduced after every 20 trials, with longer pauses between blocks of trials.

Design. In this experiment eight display times were used: 60, 80, 100, 120, 200, 300, 400 and 600 msec. These values were chosen on the basis of a series of pilot experiments which showed that STVM was at chance level for targets displayed for 40 msec or less, and reached ceiling levels with display times between 200 and 300 msec. With the two interference conditions this gives a total of sixteen conditions for the experiment. Each subject performed twenty trials in each condition, with the order of conditions completely randomized within each block of trials. Thus before each trial the subject was unaware of the stimulus display time, and after the mask was still uncertain whether interference or an unfilled interval would follow. Of the 320 target/distractor pairs, the odd-numbered ones were displayed only under STVM conditions, the remainder only under LTVM conditions. The stimulus pairs allocated to each interference condition were rotated, so that across all subjects each pattern was shown once in each display time condition.

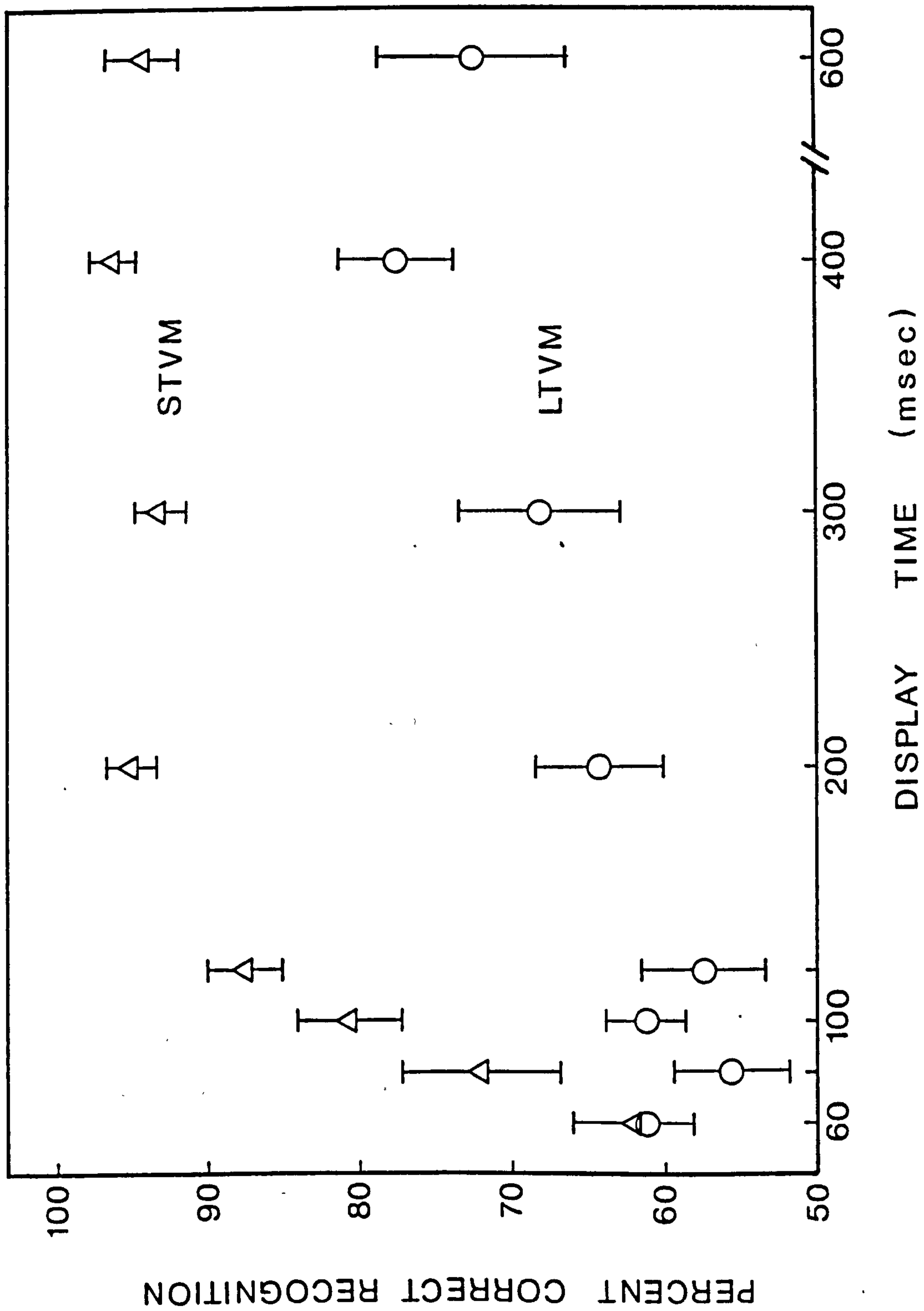
Results.

(i) Percent correct recognition.

Figure 6.1 shows the overall mean recognition performance for each condition of this experiment, along with the standard errors. It is clear that STVM increases rapidly as display time rises from 60 msec to 200 msec, while LTVM increases more slowly over a wider range of display

Figure 6.1. Percent correct responses on a forced-choice recognition task as a function of display time, tested under STVM and LTVM conditions. Bars around each point indicate standard errors.

Fig. 6.1



times. A two-way, repeated measures analysis of variance was run on the data and showed significant effects of display time, ($F = 14.40$; $df = 7,49$; $p < .0001$), and interference ($F = 603.6$; $df = 1,7$; $p < .0001$). The interaction was also highly significant ($F = 3.53$; $df = 7,49$; $p = < .004$). Separate, one-way ANOVAs, using data from either the STVM or LTVM conditions, showed that display time had a significant effect on both STVM ($F = 21.58$; $df = 7,49$; $p = < .0001$), and also on LTVM ($F = 3.27$; $df = 7,49$; $p = < .0064$).

(ii) Mean response times.

Figure 6.2 shows the mean response times (RTs) in each of the display time and interference conditions. There was a large variation in the mean RT across subjects, as might be expected in an experiment with little practice and a stress on accuracy of performance. Nevertheless, the results clearly show that under STVM conditions the response latency decreases as display time increases, but this is not the case for LTVM. This was confirmed statistically by one-way analyses of variance (with display time as the within-subjects variable) run on the STVM and LTVM data separately. Display time had a significant effect on STVM response time ($F = 4.33$; $df = 7,49$; $p = .0009$), but no demonstrable effect on LTVM response time ($F < 1.0$).

(iii) Performance on the interference task.

Two measures of performance were recorded for the mental arithmetic interference task: the percentage of sums solved correctly, and the mean solution time (measured from the onset of the first digit to the time when the answer was typed on the keyboard). The mean values and standard errors for both measures of performance are given in Table 6.1. It can be seen that performance on the interference task is generally accurate and rapid, and also it is consistent across display time conditions.

Figure 6.2. Mean response time in the forced-choice recognition test as a function of display time, for STVM conditions (triangles) and LTVM conditions (circles). The standard errors, which were large, are not shown.

Fig. 6-2

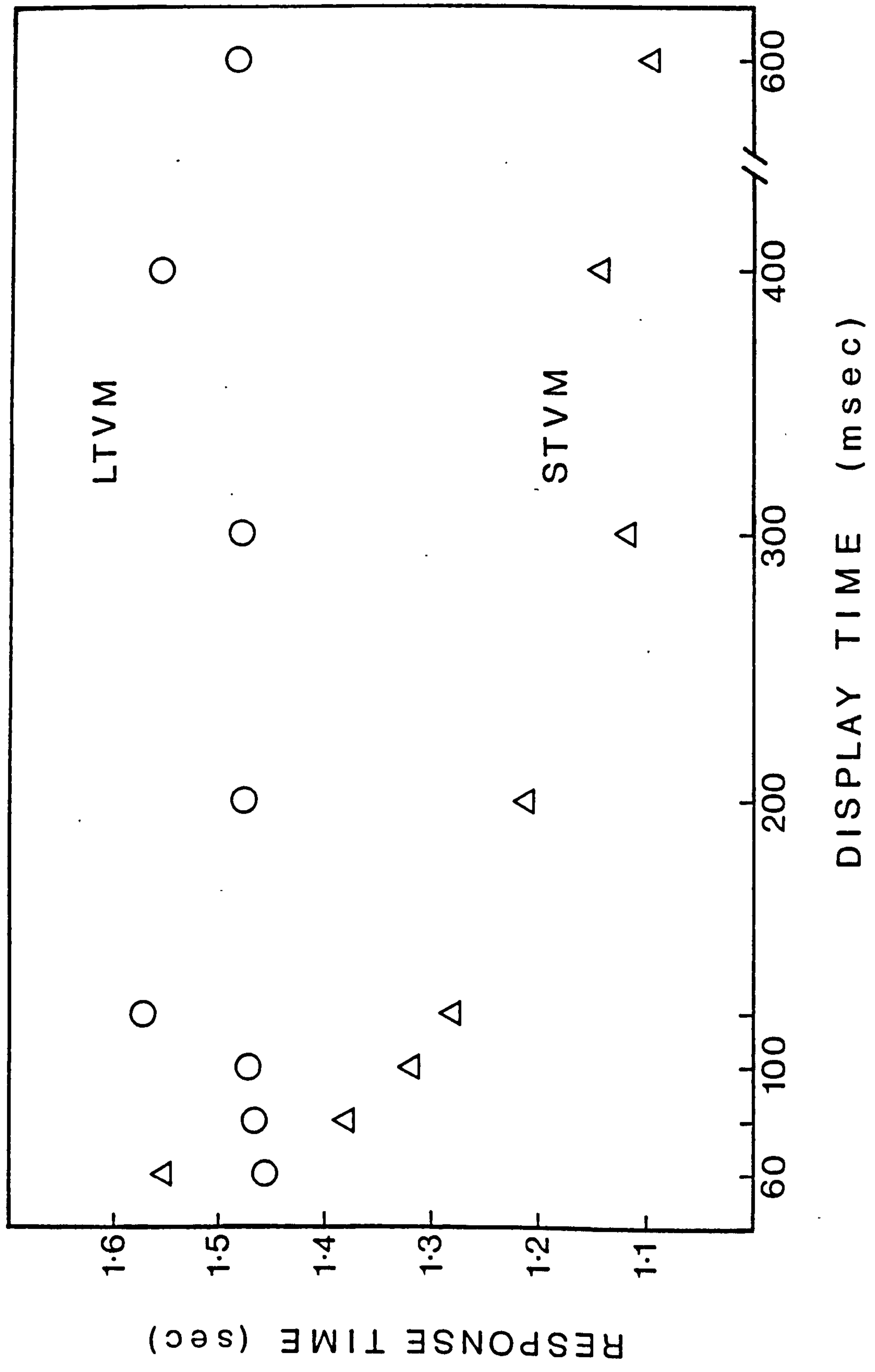


TABLE 6.1

Performance on Mental Arithmetic InterferenceTask for Each LTVM condition

Display Time (msec).

Performance Measure	60	80	100	120	200	300	400	600
Percent sums Correct								
Mean	86.875	86.875	81.25	80.625	81.875	81.25	81.875	84.375
S.E.	3.78	2.66	6.18	4.77	5.17	6.66	5.34	3.59
Solution Time								
Mean	4.54	4.53	4.54	4.64	4.72	4.64	4.62	4.62
S.E.	.19	.18	.22	.28	.43	.22	.29	.24

Two one-way analyses of variance were run on the data, and showed that there were no significant differences between the display time conditions when either the percentage of sums correct ($F = 1.39$; $df = 7,49$; $p = .23$) or mean solution time ($F < 1.0$) was used as the index of performance. Thus, since performance on the interference task is constant across the display time conditions, the differences in LTVM performance with display time cannot be due to random fluctuations in the difficulty of the interference task.

Discussion.

The results of this experiment show that STVM and LTVM are differentially affected by display time. In the former condition recognition rose from close to chance levels with a display time of 60 msec to an asymptote at near ceiling levels with display times of 200 msec and longer. In contrast, LTVM recognition showed little or no increase as display time increased from 60 msec to 120 msec, and thereafter showed a slow, irregular increase over a time range extending up to at least 400 msec. This dissociation of STVM and LTVM by display time receives support from the response time data. Increasing display time led to shorter RTs in the STVM conditions, but had no effect on LTVM response latencies. With both measures the significant interaction of display time and interference conditions provides statistical confirmation of the dissociation. Taken at face value, therefore, these results demonstrate that STVM and LTVM cannot be based on the same underlying processes.

One objection that can be raised to these data is that the overall levels of performance are quite different in the two interference conditions. STVM recognition was close to ceiling levels with a 200 msec display time, so that any further potential increase with longer display times would not be reflected in the measured performance. Even so, it is hard to imagine that there is a close relation between the STVM and LTVM

effects of display time, given the rapid increase of STVM recognition at short display times, which was entirely absent from the LTVM data. But conceivably, if the overall level of STVM performance was reduced, the time course of STVM growth as a function of display time might differ. The following section describes an experiment where the growth of STVM with display time was measured using more complex patterns, which were known to exceed the visualization capacity.

After this, the results of both experiments will be discussed more comprehensively.

6.4 Experiment 6b: The Increase of STVM for Simple and Complex Patterns as a Function of Display Time.

A considerable amount of evidence from Chapter 3 and elsewhere shows that visualization capacity is restricted to a limited amount of information from a single pattern. This capacity limit for most subjects appears to be close to that required to describe any 4x4 matrix pattern. In the previous experiment, ceiling effects may have distorted the function relating STVM to display time. Two important features of the display time function may have been obscured: the display time at which the rapid input phase comes to an end, and the possibility of a subsequent phase during which information is gained at a slow rate, similar to that observed in the alphanumeric readout function. To overcome this problem, this experiment used complex (6x6) matrix patterns as stimuli, and measured the growth of STVM with display time. Two conditions using simple (4x4) patterns were also run to provide comparison data, and to confirm the results of the previous experiment.

Increasing the number of cells in the matrix provides a convenient (but not the only) way of generating complex patterns with a high information load. Using this technique, Phillips (1974) demonstrated that STVM performance decreased as complexity increased. The problem for

the present investigation was to select a matrix size which avoided ceiling effects, but was not so complex that visualization would have little effect on STVM performance. Phillips (1974), using a slightly more difficult retention test than the one used here, found that percent correct recognition of 6x6 matrix patterns with a display time and retention interval of one second was about 68%. Pilot experiments confirmed that the use of patterns with this level of complexity avoided both floor and ceiling effects. A second reason for increasing the information load by extending the matrix is that it preserves the structure of the patterns. Whatever descriptive processes take place during the presentation of a 4x4 matrix with 8 cells filled, it seems likely that similar processes will operate on 6x6 matrices with 18 cells filled, since the geometrical composition of the patterns is quite similar.

When pattern complexity is increased in this way, a choice has to be made between keeping the cell size constant, and so increasing the retinal area stimulated, or making a compensatory reduction in cell size for the more complex patterns. Experiments involving the detection of familiar patterns suggest that low spatial frequency information is more rapidly extracted from visual displays (e.g. Navon, 1977; Tolhurst, 1975). If the retinal area of the simple and complex patterns in this experiment were fixed, the simple patterns would have a lower distribution of spatial frequencies and this factor alone might influence the display time function. Spatial frequency distribution is also an important factor in visual masking (White and Lorber, 1976; Growney, 1978). Therefore in this experiment the same cell size was used for both the 4x4 and 6x6 target patterns, and also for the masking stimulus. But the larger angle subtended by the more complex patterns means that part of the patterns will be projected on to more peripheral parts of the retinae. Any difference in performance between the simple and complex

pattern conditions might then be due to processing differences arising from the retinal projection, rather than the information load. A third type of display was used to control for this. In this condition, simple patterns were displayed in a location displaced from the centre of fixation, so that the most peripheral parts of the targets fell on the same retinal locations as the corners of the centrally placed complex patterns. The arrangement of the three stimulus conditions with respect to the centre of fixation is shown in Figure 6.3.

If the rate of description of a pattern is affected by small shifts in retinal location, then there should be a difference between 4x4 patterns displayed centrally, and those displayed eccentrically. Any comparison of simple and complex pattern conditions will then have to take this factor into account. Conversely, if there is no difference between the two 4x4 conditions, then retinal location is not an important factor. Any differences in performance between the 4x4 and 6x6 conditions must be due to pattern complexity, since the important visual factors (spatial frequency distribution, luminance, masking, etc.) are controlled.

To summarise, three stimulus pattern conditions were used in this experiment: 4x4 central, 4x4 eccentric, 6x6 central. The aim was to measure the effect of display time on the growth of STVM when potential visualization capacity was exceeded by the stimulus patterns.

Methods.

Subjects. Twenty-four first year psychology undergraduates served as subjects, to fulfil a course requirement. They were allocated at random to one of three equal groups, each of which was shown a different stimulus type. One subject in the 6x6 pattern condition was replaced because her recognition performance was only just above chance level (56%) for the longest display time.

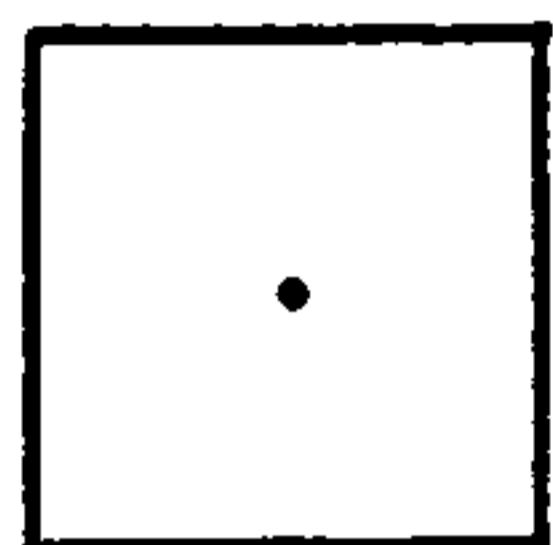
Figure 6.3 Stimulus displays used in Experiment 6b

Figure 6.3a shows the perimeter of a 4x4 and a 6x6 matrix, both centred on the fixation point, indicated by a dot.

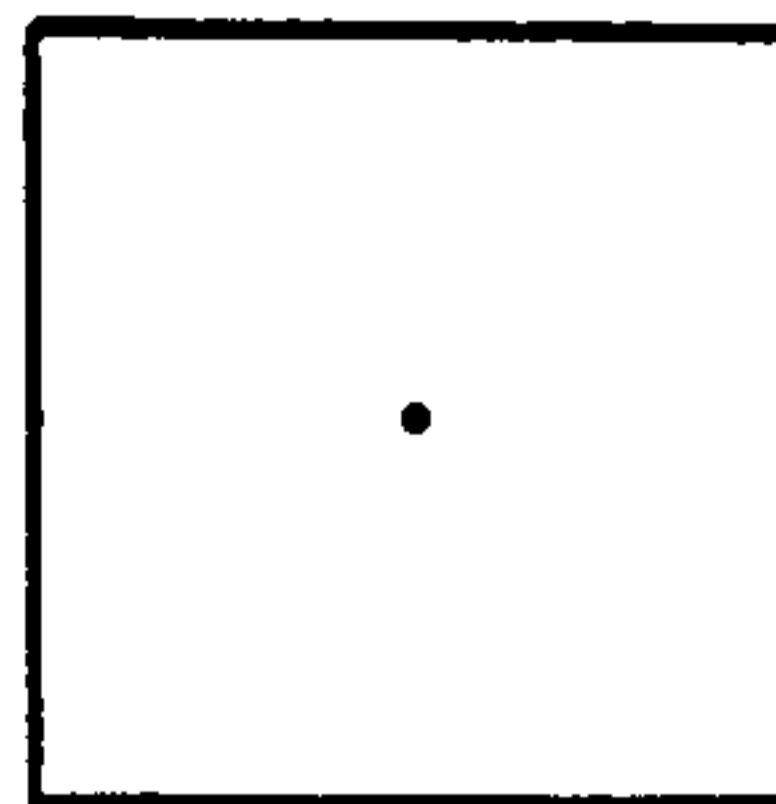
Figure 6.3b shows the four possible positions of 4x4 eccentric matrices relative to the fixation point and the perimeter of a centred 6x6 pattern. Drawings indicate actual sizes of displayed matrices.

Fig. 6.3

a

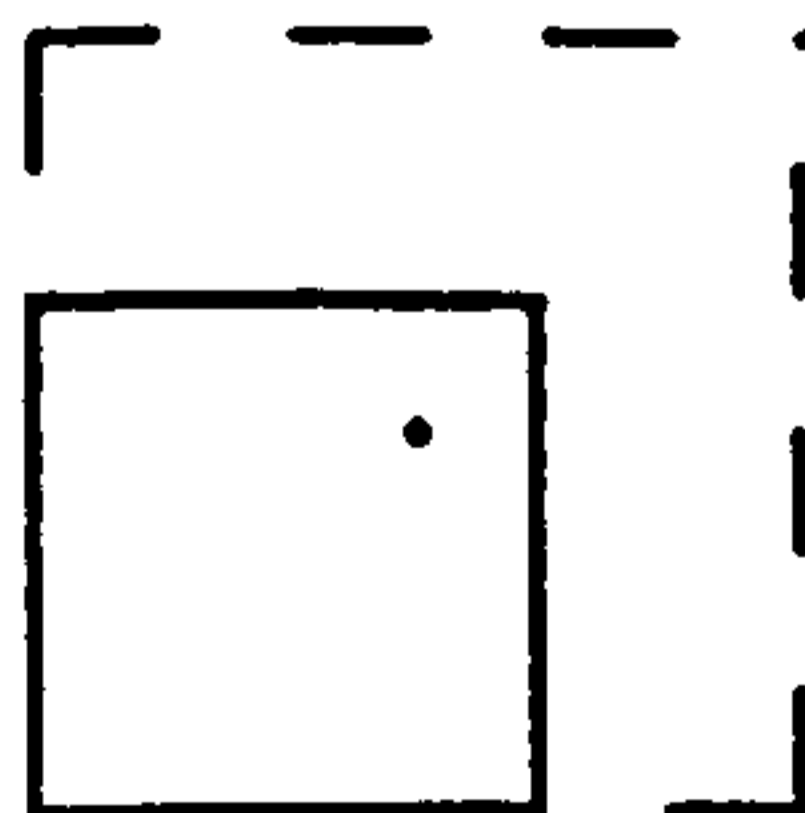
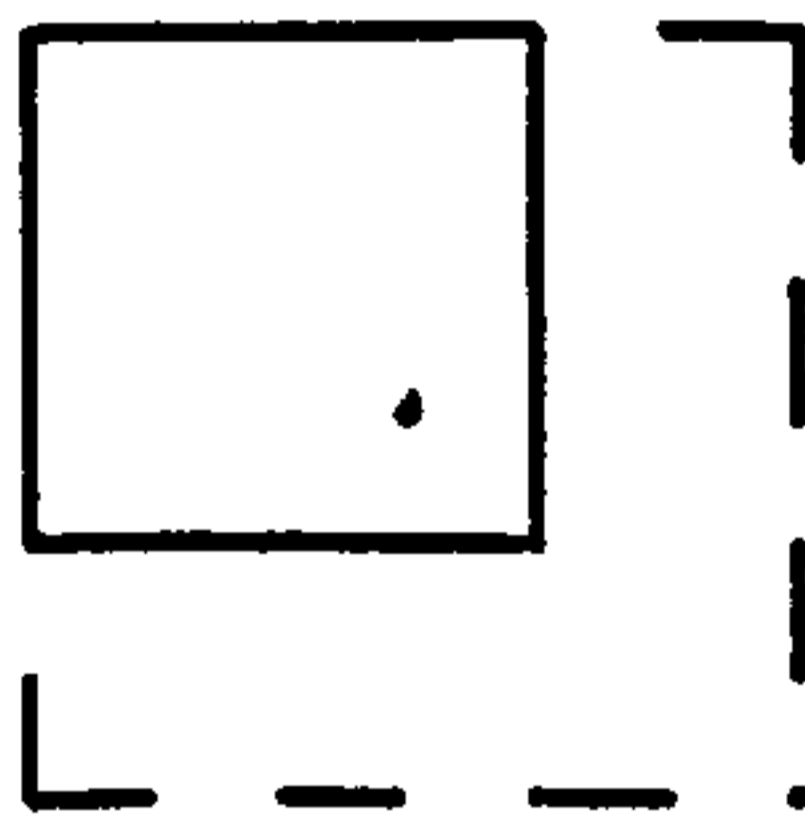


4x4 central

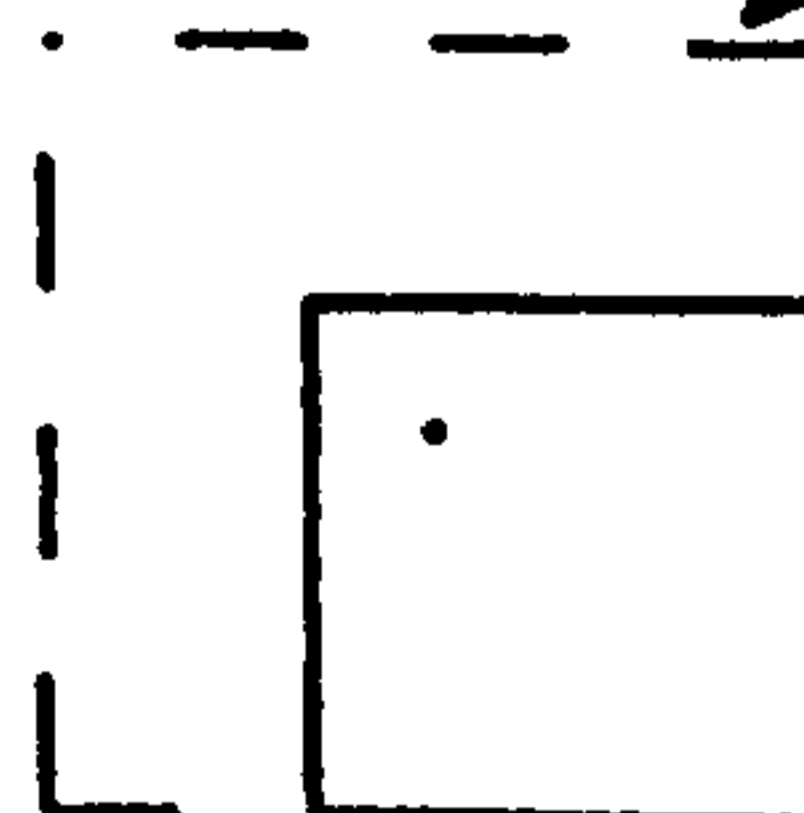
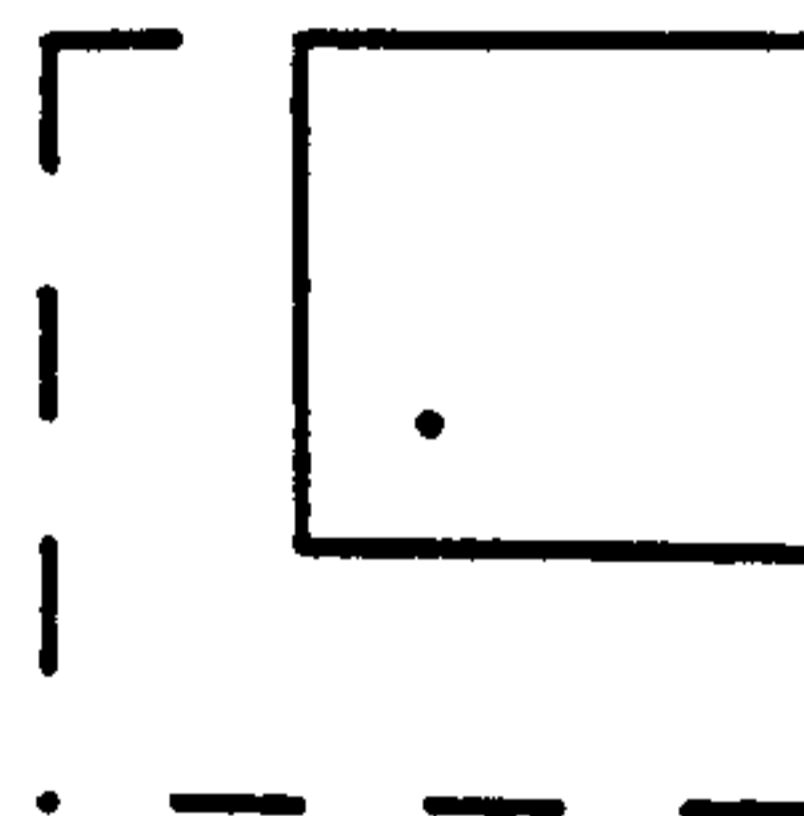


6x6 central

b



4x4



eccentric

perimeter
6x6

Design. A mixed design was used where stimulus type (4x4 central, 4x4 eccentric and 6x6 central) was varied between subjects, and display time was the within subjects factor. Eight display times were used (60, 100, 140, 200, 260, 320, 400 and 600 msec). For each subject the display times were given in a random order. Within each stimulus type condition, the patterns displayed at each display time were rotated between subjects.

Stimulus materials. Two sets of patterns and distractors were constructed for use in this experiment: a set of 240 simple target/distractor pairs (in which 8 cells were filled in a 4x4 matrix) and a set of 240 complex pairs (in which 18 cells were filled in a 6x6 matrix). In both sets the patterns and distractors differed by two cells. A third set of patterns and distractors was constructed from 5x5 matrices with 12 cells filled. These were used as practice stimuli.

Apparatus. The apparatus and response keys were arranged as in Experiment 4b.

Since one display condition was varied between subjects in this experiment, care was taken to ensure that the screen luminance was set to the same level for each subject. To do this, a standard square was displayed on the GT40. The screen luminance control was then adjusted to give a standard luminance reading on a logarithmic response electronic photometer. This reading was also checked at the end of each session, as a precaution against drift.

Displays. To avoid exceeding the display capacity of the GT40, the unit cell size of all the patterns used in this experiment was reduced from 6mm to 4mm. The viewing distance was fixed at about 50 cm. In the 4x4 and 6x6 central conditions, the target pattern was centred on the fixation point. In the 4x4 eccentric condition the centre of the target was displaced one cell to the right or left and one cell upwards or downwards.

The four possible positions are illustrated in Figure 6.3b.

Masking. The mask used was an 8x8 chequerboard, centred on the fixation point. It was displayed at target offset for a duration of 600 msec and followed by an interval of 400 msec during which the screen remained blank. The mask duration was increased in this experiment to ensure that the display time functions of Experiment 6a were not the result of incomplete masking. In this experiment the total mask energy is at least equal to and usually much greater than that of the preceding target.

Retention test. In the two-alternative forced choice test, the target pattern and distractor were displayed side by side, and separated by the width of one matrix (16 mm for the 4x4 conditions, 25 mm for the 6x6 patterns). The alternatives were displayed until the subject made a response. Knowledge of results was then provided by a message displayed for two seconds.

Training. Subjects were given two practice runs before starting the main experiment. The first consisted of sixteen trials in which the display time and retention interval were fixed at one second, and an intermediate size of pattern was used (5x5 matrices with 12 cells filled). In the second practice run, 40 trials were given with stimulus materials and procedure identical to those of the main experiment.

Procedure. The experiment itself consisted of two blocks of 96 and 104 trials. Within each block an equal number of trials were given with each display time. The experiment was self-paced, and the subject initiated each trial by pressing either of the two response keys. The instructions encouraged subjects to look at the fixation point before starting the display sequence, and to be as accurate as possible in the recognition test.

Results.

(i) Percent correct recognition.

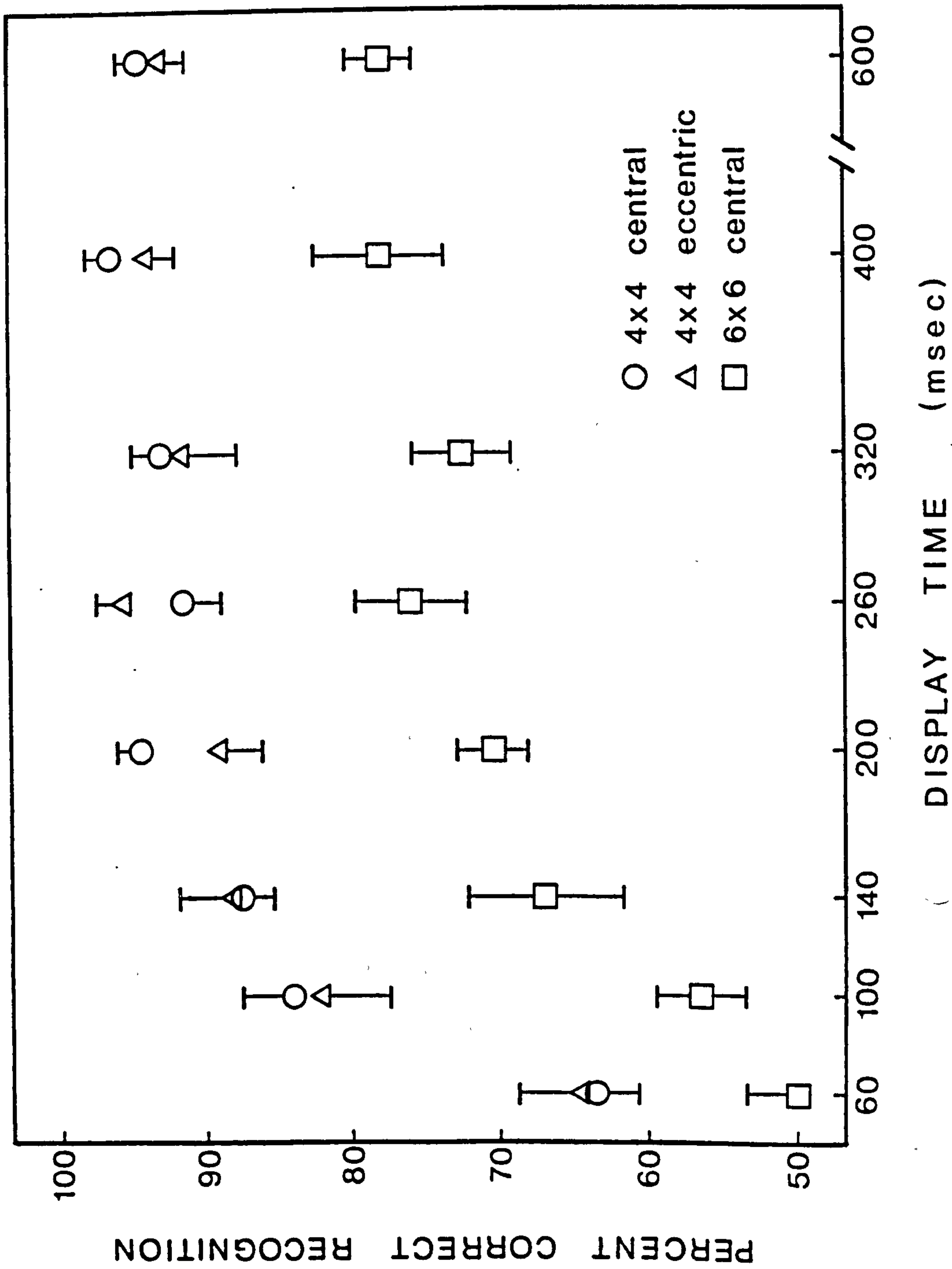
The mean recognition performance for each of the display time conditions is plotted in Figure 6.4. From these results it is clear that performance is very similar in the two 4x4 conditions, but is much lower for the more complex patterns. A two-way analysis of variance was run on these data with one factor between (stimulus type) and one within (display time). This analysis shows significant effects of stimulus type ($F = 40.82$; $df = 2,21$; $p < .0001$), and display time ($F = 41.22$; $df = 7,147$; $p < .0001$). The interaction was non-significant ($F < 1.0$).

To test if there was any difference between the 4x4 conditions, a separate two-way analysis was run on the data from these two groups alone. The outcome was that the between subjects factor (central versus eccentric placement) was non-significant ($F < 1.0$), while display time was again highly significant ($F = 37.2$; $df = 7,98$; $p < .0001$). The interaction was also non-significant ($F < 1.0$).

Close inspection of Figure 6.4 shows that for the 4x4 conditions, recognition increases with display time up to a value of 200 msec or possibly 260 msec, which is consistent with the data of Experiment 6a. The results obtained with complex patterns suggest that the effects of display time on this condition are quite similar. The main difference was that performance measured at 60 msec display time was at chance level. Thereafter, STVM performance increased with display times up to 260 msec. Beyond this point, doubling the display time to 600 msec produced little or no increment in performance. Unfortunately, it is not possible to provide statistical confirmation of these summary descriptions of the curves of Figure 6.4, because of the large standard errors. Post hoc Scheffé tests were used to make pairwise comparisons of performance at each display time. These showed no significant differences between any pair taken from the 140, 200, 260, 320, 400 and 600 msec display time conditions, although there was a

Figure 6.4 Percent correct responses on forced-choice STVM recognition, for three types of stimulus display as a function of display time. Stimulus arrangements with respect to fixation were as shown in Figure 6.3. Bars around each point indicate the standard errors of the means.

Fig.6.4



significant difference between the 100 msec and 600 msec display time values. This was true for both the 4x4 and 6x6 conditions. Much more data would be required to provide confirmation of the display time at which STVM saturates and the asymptote is reached. Inspection of the curves of Figures 6.1 and 6.4 suggests that between 200 and 300 msec would be a reasonable estimate.

(ii) Mean response time.

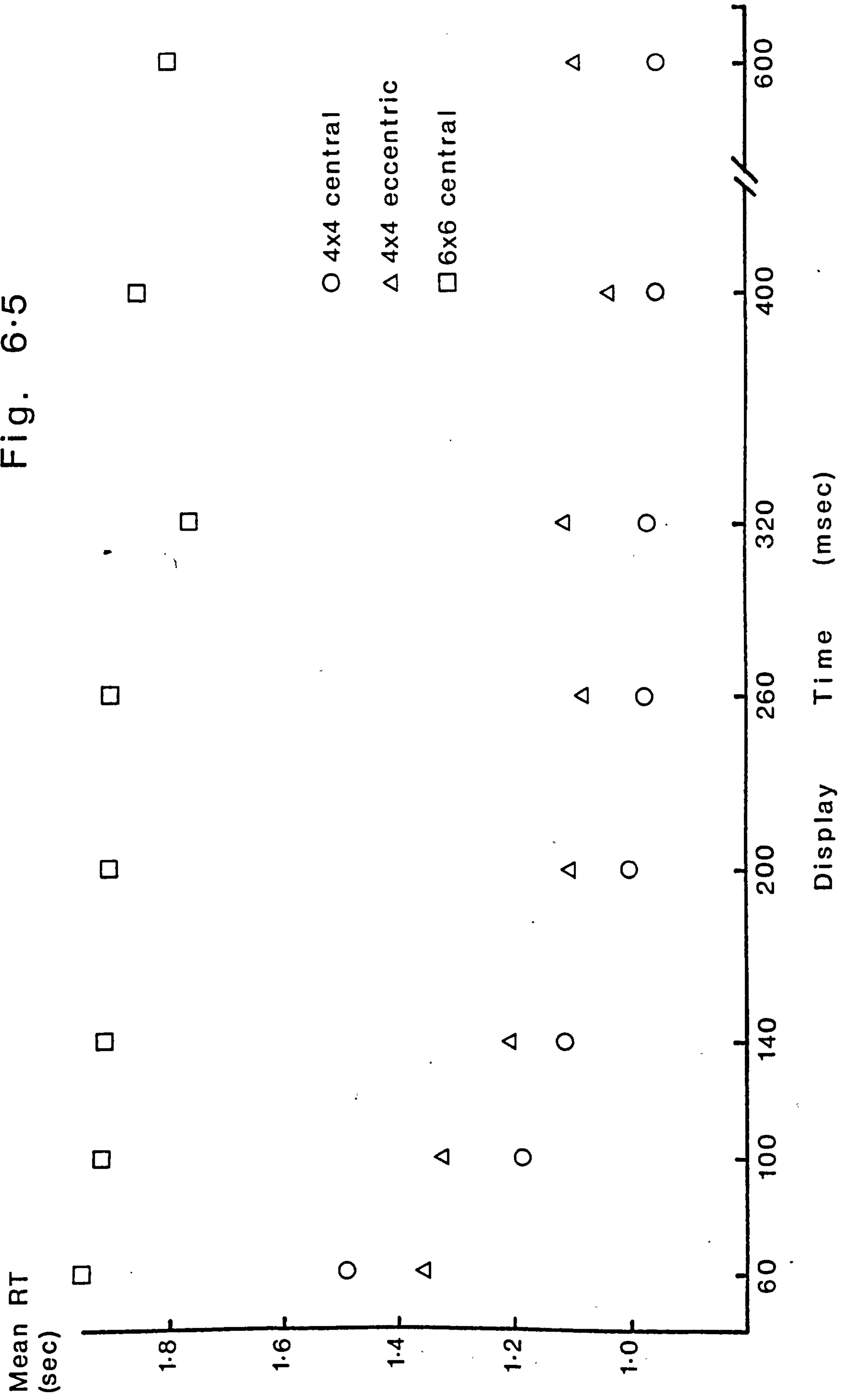
Again, accuracy rather than speed was stressed in this experiment, and the RTs are highly variable across subjects. Figure 6.5 shows the RTs for each stimulus type at each display time.

In general, the results show that as display time increases, response time decreases. For the 4x4 conditions this effect is quite marked as display time increases to 200 msec, but for the 6x6 condition there is no such trend over the same range of display times.

A two-way analysis of variance with one factor between (stimulus type) and one within (display time) was run on these data. This revealed a significant effect of stimulus type ($F = 9.6$; $df = 2,21$; $p = .0012$), and of display time ($F = 7.9$; $df = 7,147$; $p < .0001$). The interaction, however, failed to reach significance ($F = 1.29$; $df = 14,147$; $p = .22$). Thus it cannot be concluded that display time has different effects on recognition response times for simple and complex patterns. Inspection of Figure 6.5 shows that the RTs for the 4x4 central condition were consistently lower than those of the 4x4 eccentric condition. A separate two-way analysis of variance was run on data from these two groups of subjects. This showed no significant difference on the between-subjects factor, retinal location, ($F < 1.0$) and no significant interaction of this factor with display time ($F < 1.0$). There was a highly significant effect of display time in this analysis of the 4x4 conditions, but no significant

**Figure 6.5 Mean response times on the forced-choice
recognition test for three types of stimulus display,
as a function of display time.**

Fig. 6.5



effect of display time when a repeated measures analysis of variance was run on the mean RT of subjects in the 6x6 condition ($F < 1.0$).

(iii) Estimation of visualization capacity.

The data of this experiment, showing asymptotic recognition performance for two sizes of matrix, allow an estimation of the maximum number of cells which can be visualized, averaged over a sample of such patterns. In order to do this, a simple model of recognition is required. It is assumed that when a matrix pattern consisting of n black and n white cells is presented, that subjects encode an equal number, c , of black and white cells. The probability of correctly identifying a target at test, P_r , is the probability that at least one of the cells changed in the distractor will be one of those cells encoded during presentation. Treating black and white cells independently we then have:

$$P_r = 1 - \left(\frac{n-c}{n}\right)^2$$

$$c = n(1 - (1 - P_r)^{\frac{1}{2}})$$

For 4x4 patterns, the percent correct recognition at asymptote, P_c , was about 93%. Application of a guessing correction then gives a value of P_r of 0.86. For 6x6 matrices, performance at asymptote was around 75%, giving a P_r of 0.5.

The derived values of c are thus 5.0 cells for 4x4 patterns, and 5.27 cells for 6x6 patterns. The agreement between these estimates suggests that similar encoding processes underlie STVM recognition of 4x4 and 6x6 patterns.

Summing up, the results of this experiment show that for complex patterns which exceed visualization capacity, the readout of information in a backward masking paradigm is similar to that found with simpler matrix patterns. There is a rapid accumulation of information

over the first 200-260 msec of display time, followed by a phase where the gain of information is much slower. The close correspondence between the results for the two sizes of pattern can be accounted for by assuming that the same descriptive processes are used for both, and that more information is required to perform well on the recognition test for complex patterns. However, two aspects of the data are anomalous: (a) the results suggest that with complex patterns the initial readout of information is delayed, and (b) the mean RT for the complex patterns did not change as a function of display time.

Both anomalies may be consequences of the lower level of performance observed with complex patterns, rather than direct effects of target pattern complexity. This was tested by a further experiment involving STVM recognition of 4x4 and 6x6 patterns, in which the similarity of targets and distractors was manipulated to equalize performance for each matrix size. STVM performance with 6x6 matrices ($d = 6$) was above chance with 60 msec of display time, and as display time increased, the mean RT decreased in a similar way for both simple and complex patterns. Hence the slight anomalies found between the 4x4 and 6x6 conditions of Experiment 6b may be accounted for by differences in overall performance, although other explanations are not ruled out.

6.5 Final Discussion and Conclusions.

These experiments have examined the recognition of novel visual patterns as a function of the time for which they were displayed. The results provide empirical data on the time required to read visual information into STVM and the time required to construct memorable representations. These will be discussed first, followed by the considerations of three theoretical points: the dissociation of STVM and LTVM, the implication of the results for single trace theories of visual memory,

and implications for the serial modal model.

(1) The readout function for visual information.

All the STVM readout functions described here show a rapid increase in performance as display time is increased to 200 or possibly 260 msec, followed by an asymptote whose level depends on pattern complexity. This result provides strong support for the view that visualization is a rapid input, limited capacity process. Its capacity appears to be close to the amount of information needed to specify any 4x4 random element matrix pattern. Further, the data show that visual descriptions involving this amount of information can be computed from novel displays in about 120-200 msec.

The results of Experiments 6a and 6b, together with several others, suggest that the readout of novel visual information from a display may take up to 200 msec or even longer. This finding has consequences for the interpretation of eye movements which have often been overlooked. For example, Potter (1976), who used pictures of natural scenes, found that 100 msec of display time was required for detection of the semantic content. If this were true, visual processing could be speeded up by decreasing the fixation time and increasing the number of fixations to ten per second. Her answer is that lower fixation rates are required for memorization:

"the normal rate of eye fixations... represents a reasonable compromise between the need for rapid monitoring of the environment for significant events and the need to remember some portion of what one has seen". (Potter, 1976; p. 521).

The results described here suggest an alternative. For novel materials, displays of the order of a fixation time may be required to compute descriptions of the visuo-spatial relations of the patterns, up to

the limit set by visualization capacity. Although novel STVM descriptions are constructed rapidly, they are not so fast that a 250 msec fixation time is unnecessarily long. This may also apply to the spatial and configurational description of natural scenes, aspects which were not tested in Potter's paradigm which involved the presentation of highly dissimilar pictures.

The STVM display time function is similar to the alphanumeric readout function insofar as it involves an initial, rapid input, followed by an asymptote whose level depends on the nature of the material. One important difference is that the STVM display time function increases over a wider range of display times. This would be expected if it took longer to construct the visual description of a novel pattern, than to identify a regular array of highly overlearned symbols. In keeping with this explanation, unpublished experiments by Phillips have shown that highly familiar matrix patterns can be described with much shorter display times than novel ones. These results pose problems for Loftus' (1976) theory that visual description proceeds for a fixed time of about 100 msec at the onset of each fixation. Rather, they suggest that visual description continues to completion or until STVM is saturated.

Sperling's (1967) account of the alphanumeric readout function was that the rapid readout phase was due to character identification, and the asymptote was a limit imposed by verbal STM. This explanation cannot apply to the STVM display time function, since matrix patterns are difficult to describe verbally. Coltheart's (1972) model, which proposes that the asymptote is a restriction imposed by the limited capacity of STVM, is more consistent with the present data.

Experiment 6b showed no evidence of a slow readout phase as display time increased from 260 msec to 600 msec. Coltheart's model would

predict this, since the implicit naming which accounts for the second limb of the alphanumeric readout function cannot be used to describe matrix patterns. But this leads to a counter-intuitive position: it suggests that a visual presentation exceeding STVM capacity and not amenable to verbal description cannot be learned completely, no matter how long the display time. Presumably in such cases LTVM, which has an indefinitely large capacity, can be used to supplement the visualized information.

Two other points can be dealt with here. First, the close similarity between the STVM display time functions for the 4x4 patterns in Experiments 6a and 6b rules out any explanation in terms of visual masking. In Experiment 6b the mask energy exceeded the target energy for all but the longest display time condition. It is also known that when a pattern and chequered mask of equal brightness are superimposed, the target is completely obscured by the mask. Therefore energy integration of target and mask cannot account for either of these STVM display time functions. The second point is that small, random perturbations of the target position in Experiment 6b had no effect on the display time function. It follows that the rapid descriptive processes which take place during display time are independent of the precise retinal location, and do not require advance information of the stimulus position. It should be stressed that these eccentric displacements are small; the central 4x4 patterns subtended an angle of 1.8° in width, while the eccentric targets fell within an area 2.9° wide. All stimuli therefore fell within the fovea, which extends across 5.2° of visual angle (Rodieck, 1973). With larger displacements, changes in performance would be expected because of the limited resolution of peripheral vision.

(2) The display time required for memorization.

The function relating LTVM to display time (Figure 6.1),

shows that a small amount of memorable information can be read from very brief (60 msec) displays. Thereafter, LTVM improves slowly and irregularly as the display time is increased up to at least 400 msec. However, the display time required for accurate memorization of 4x4 matrix patterns is much greater than this. Phillips and Christie (1977a) found that recognition performance was well below ceiling levels with display times of 2.0 seconds, and some results to be described in the following chapter show that LTVM is incomplete with display times as long as 2.6 seconds. Two features of these data have to be explained:

(i) Why there is a low, but measurable level of performance at short display times, which is about the same as STVM performance under the same display conditions.

(ii) Why such long displays are required to achieve high LTVM recognition.

The rapid acquisition of small amounts of information may be due to the inhomogeneity of the pattern set. While it is true that these patterns are novel, and a full description of each pattern must be constructed to achieve perfect performance, it is also the case that some simple, distinctive and familiar shapes do occur in the patterns. The arguments of the preceding section, and the evidence of Experiment 5a, suggest that these familiar shapes will be read most rapidly into STVM. If these were also the most memorable items, then we can explain the coincidence of STVM and LTVM performance at short display times. Unfortunately there is no direct evidence to support this explanation, which must remain speculative.

It is clear that much longer display times are needed for accurate performance under LTVM than under STVM conditions. This implies that additional processing, which is necessary for LTVM, takes place after a full, visualizable description of the pattern has been constructed.

There are two general kinds of explanation for this. One is that the additional processing involves an elaborated description of the item, involving associations between the item, its context, long-term knowledge and possible retrieval cues. The other type of explanation is that the additional time is required for consolidation of the STVM description. This explanation is favoured by Potter (1976), although it is not clear from her paper what sort of process consolidation is. The data of Experiment 6a show that it cannot be a process requiring a fixed amount of display time in addition to that required for STVM, for the LTVM display time function would then lag on the STVM curve.

Thus as far as the present experiments are concerned, additional display time is required for memorization of patterns after visualization is complete. The additional time appears to be highly variable, although it is not certain what processing goes on during this time. It is presumed, however, that the additional processes lead to an increase in the durability, discriminability or retrievability of the trace, whether by computing new descriptions of the target patterns, new associations to their context or new retrieval cues, or by consolidating the visualized description.

In Experiment 6a, display time was varied, and the interval from display offset to the start of interference was fixed. The extent to which LTVM processing occurs during the display time or during the interval before the start of interference cannot be determined from these results alone, but will be considered in detail in the next chapter.

(3) The dissociation of STVM and LTVM.

It is clear that STVM and LTVM performance differ to the extent that they have diverse display time requirements. This finding poses problems for any theory that denies the validity of the STM/LTM distinction, and interprets the performance differences before and after

interference as different stages or states in the history of a single trace. Similarly, it rules out the notion that STVM is equivalent to 'activated' LTVM. The results imply that, at the time of the retention test, STVM and LTVM differ either in terms of their underlying representations, or in terms of processes that operate on a common representation, or both.

This dissociation also has methodological implications. First, the data suggest that a good separation of STVM and LTVM has been achieved by the randomized interference procedure involving the addition of four, visually presented digits. If a small residual component of STVM had survived interference we should expect an increase in LTVM performance as display time increased from 60 msec to 120 msec. Secondly, they suggest procedures for isolating the two components. The use of a short display time (200 msec) followed by an immediate recognition test should give a high performance in STVM which is relatively uncontaminated by LTVM. To achieve high LTVM performance, long display times and in interference task with a high mental load are required.

(4) The implications of these results for the representations underlying visualization and memorization.

The results of these experiments show that different display times are needed for the construction of STVM and LTVM representations. The results have relevance for a number of questions concerning the nature of STVM and LTVM storage. Perhaps the most fundamental of these is whether different descriptions are involved in STVM or LTVM, or whether there is just one description in two discrete loci of memory.

Single trace theory in its simplest form (e.g. Melton, 1963) cannot account for these results. However, more complex versions can explain these data by assuming that the memory trace is a multi-component

system (Bower, 1967), that these components are encoded at different rates, and that they show differential rates of decay or differential susceptibility to interference (Wickelgren, 1975; Jones, 1979). The results are accounted for quite well by the levels of processing theory, which proposes that the initial, rapid but unstable visualized representation is progressively elaborated and supplemented by information which is more resistant to interference. To account for the fact that LTVM is above chance level at very short display times, this theory must also assume that some stimuli can be processed to 'deep' levels very quickly. This may occur if highly familiar shapes appear in the target pattern. The wide variability between patterns in terms of ease of LTVM encoding is supplemented by the findings of Chapter Four.

An alternative view also proposes a single description of the pattern in memory, but the crucial factor for LTVM is whether it is accessible after interference. By this account, the additional display time that is required for LTVM is used to construct retrieval cues, which may involve or may not involve making changes to the pattern description. But there are a number of problems with the view that retrieval differences alone underlie the STVM/LTVM distinction. It has to be explained why the difference is found equally for recall and recognition, and one version also predicts that all-or-none forgetting should occur, whereas Experiment 4a suggested that it did not. If retrieval requires elaboration of the pattern description, then this theory approximates closely to a level of processing account. If it requires only the specification of the experimental context, such as the time and place, then it is hard to see why such large variations in display time are required for LTVM processing.

To summarize, these data are consistent with three approaches to the STVM/LTVM distinction: (i) the idea that there are two separate

stores, one of which is labile with a rapid input, the other durable but with a slow input (ii) there is one store of information, and the durability of the information depends on the nature of the pattern description (iii) there is one store of information, access to which requires a retrieval process in LTVM, which is at least partially dependent on pattern content. Using current techniques it may not be possible to distinguish between the general cases (ii) and (iii). One of these claims that the STVM/LTVM difference is the result of a storage failure, the other attributes it to a retrieval failure. As a description of the results the two are interchangeable. But case (i), which proposes separate memory stores, can be considered in relation to the serial modal model, which makes more specific predictions.

(5) Implications for the modal model.

The modal model makes the explicit assumption that there are two stores, and that information is transferred from the short-term to the long-term store. In this view, the immediate substrate for LTVM is information in STVM, so once the pattern has been encoded into STVM there is no further requirement for display time. Thus STVM and LTVM should show similar display time functions. More specifically, if the amount of information transferred is a linear or monotonic function of the amount in STVM, then LTVM should not increase with display time after STVM reaches the asymptote. Experiment 6a shows that this is not the case. However, the results can still be accommodated by the modal model if we assume that a very slow transfer of information from STVM to LTVM takes place throughout the total processing time (the interval from stimulus onset to the start of interference). The data are consistent with a transfer model where information starts to arrive in LTVM after 500 msec of processing time, and continues to increase after this at a slow rate. This complication arises because in Experiment 6a the total processing time was not

fixed, but covaried with display time. However, arguments will be raised in the next chapter which make this serial transfer explanation unlikely.

To summarize, the experiments of this chapter measured the increase of STVM and LTVM performance as a function of display time. The empirical findings were:

(i) STVM increased as display times were lengthened from 60 msec to 200 msec, or possibly 260 msec, followed by an asymptote.

(ii) For LTVM there was a slow, irregular increase with display time up to at least 400 msec.

The main conclusions from this are:

(a) Display time reveals a functional dissociation of STVM and LTVM.

(b) STVM descriptions are constructed rapidly, up to a limit imposed by STVM capacity. This provides some support for Coltheart's (1972) interpretation that the alphanumeric readout function is determined partly by short-term visual storage.

(c) Longer display times (and by implication more stimulus processing) are required to encode all patterns in LTVM. It is not certain whether the additional processing makes the trace more durable, more retrievable, or is involved in the transfer of information from short-term to a long-term store.

CHAPTER SEVENThe Effects of Post-stimulus ProcessingTime on LTVM.7.1 Theoretical and Empirical Considerations.

The experiments of the previous chapter showed that when display time was varied, much longer exposures were required to memorize 4x4 matrix patterns than to visualize them. It was concluded that memorization involves additional processes besides the initial short-term description of a pattern, although the nature of these processes remains uncertain. The interpretation of Experiment 6a is simplified by the assumption that the additional LTVM processing takes place only during the display time. However, this assumption may be unwarranted since, according to the modal model, all information arrives in LTS after transfer from STS. In terms of the present paradigm, this means that the substrate for entry to LTVM is not the stimulus itself, but STVM. Hence, if the STVM description is complete, any further processing necessary for LTVM should occur either in the presence or in the absence of the stimulus. This chapter will assess the contribution of stimulus display time and post-stimulus processing time to the memorization of visual patterns.

The literature dealing with this issue is confusing, because of the variety of materials used, and because a number of interpretations have been applied to the results. Shaffer and Shiffrin (1972) presented a series of pictures to subjects and varied display time and ISI in a randomized way. They found no effect of increasing ISI under these conditions. However, similar studies involving the presentation of series of pictures where ISI was varied between subjects (Lutz and Scheirer, 1974; Tversky and Sherman, 1975; Weaver, 1974; Weaver and Stanny, 1978), or was blocked between trials (Intraub, 1979), show clear increases of long-term recognition with ISI. Indirect evidence for processing during

an ISI of 4.5 sec was presented by Potter (1976), who compared recognition of pictures presented in a rapid sequence with briefly presented pictures preceded and followed by a visual noise mask, and separated from the next item by an interval of 4.5 sec. Thus experiments using pictures of natural scenes largely agree that ISI has clear effects on LTVM.

With novel visual materials the position is particularly unclear. Young (1974) presented series of random polygons, and varied the ISI (between subjects) from 0 to 4.0 sec. Increasing the ISI from 1.0 to 4.0 sec had no effect on subsequent recognition. There was a significant difference between the 0 and 1.0 sec ISI conditions, but this may result from visual persistence. Phillips and Christie (1977a) presented short sequences of matrix patterns, and found no increase in LTVM when ISI was varied from 0.5 to 2.0 sec, between sequences. Finally, Hines and Smith (1977) presented random polygons for a fixed duration of 50 msec, and varied the interval before interference between subjects. Their results are difficult to interpret because of inadequate masking, but they suggest that there is a slight increase in LTVM as stimulus-interference asynchrony increases from 600 msec to 2400 msec. Thus there is no convincing evidence that increasing post-stimulus processing time has a substantial effect on LTVM for novel visual configurations, although it appears to have a considerable effect when natural scenes are used as materials.

One explanation for this discrepancy is that natural scenes can be described verbally. It is known that presentation rate has large effects on verbal recall (e.g. Glanzer and Cunitz, 1966), and this effect may be mediated via rehearsal (Rundus, 1971). As further support for this argument Lutz and Scheirer (1974) found similar effects of ISI on recognition of object names and pictures, which they attributed to verbal rehearsal. Against this, a number of studies have used similar pictures in an attempt to reduce verbal coding, and still have found large

ISI effects (e.g. Weaver, 1974). Evidence also exists to show that the verbal description (Bahrick and Boucher, 1968; Weaver and Stanny, 1978) and naming latency (Intraub, 1979) of pictures are not important factors in visual recognition memory.

Lichtenstein and Keren (1979) made the stronger claim that post-stimulus processing was more effective for LTVM than display time processing. They tested initial and final recognition of line figures presented under two conditions; in one condition the figures were displayed for 12 sec, and in the other for 6 sec, followed by 6 sec of processing time. Final recognition performance was better for the latter condition, suggesting that post-stimulus processing time was more effective than display time. There are two objections to the methods they used. First, the display times were much longer than those used in other studies, so information may have been in LTVM by the end of the first exposure, irrespective of post-stimulus processing. Secondly, the final recognition performance was confounded by presenting the initial test after a delay (Modigliani, 1976).

The following experiment is concerned with two related questions. First, what is the relative contribution of display time and post-stimulus processing time towards the establishment of LTVM for novel configurations? Secondly, does LTVM increase with the length of time for which an STVM representation is maintained, as the modal model predicts?

7.2 Experiment 7a: The Relative Contributions of Display Time and Post-stimulus Processing Time to Long-term Recognition.

In this experiment, LTVM was measured in a number of conditions where total processing time was varied. In one set of conditions the stimulus display remained on throughout the total processing time, until just before interference. In the other set of conditions, display time was fixed at 300 msec, and post-stimulus processing time was varied.

Thus the experiment allowed a comparison of the effects of increasing display time and increasing post-stimulus processing time on LTVM.

Methods.

Subjects. Sixteen undergraduates served as subjects, to fulfil part of a course requirement.

Design. The aim of this experiment was to provide a set of matched conditions where the interval from target onset to the start of interference was held constant, and consisted mainly of display time in one set of conditions, but mainly post-stimulus processing time in the other set. The eight display conditions are listed in Table 7.1. Condition 1 involved a display time of 300 msec, and a post-stimulus processing time of 400 msec, including the mask display time of 200 msec. Thus for this condition the total processing time was 700 msec, and this was lengthened in the remaining LTVM conditions to 900, 1300 or 3000 msec, by extending either the display time (conditions 2, 3 and 4), or post-stimulus processing time (conditions 5, 6 and 7). Condition 8 presented no interference, and was included to check that subjects visualized the matrix pattern throughout the post-stimulus processing time.

Each subject was given 128 trials, sixteen in each of the eight conditions, presented in a random order. The matrix patterns shown under each condition were rotated between subjects, so that in all, each pattern was shown twice in each condition. The interference patterns used in conditions 1 to 7 were selected at random without replacement, in a different order for each subject.

Stimulus materials. A new set of 250 target/distractor pairs were generated for this experiment, each pattern consisting of a 4x4 matrix with 8 cells filled. After each target display a 6x6 chequered mask was displayed for 200 msec. The unit cell size was fixed at 6 mm, and the viewing distance was 60 cm.

TABLE 7.1

Combinations of Display Time and Off-Time
Used in the Conditions of Experiment 7a.

CONDITION	Display time	Mask duration	Dark time	Total Processing time	STVM or LTVM
1	300	200	200	700	LTVM
2	500	200	200	900	LTVM
3	900	200	200	1300	LTVM
4	2600	200	200	3000	LTVM
5	300	200	400	900	LTVM
6	300	200	800	1300	LTVM
7	300	200	2500	3000	LTVM
8	300	200	3000	3500	STVM

Note: (i) All times in milliseconds.

(ii) Dark time is the interval from mask offset to the start of interference (conditions 1 to 7) or the retention test (condition 8).

Interference. The mental arithmetic task used to provide interference in Experiment 6a has the disadvantage that it extends over about four seconds during which time the mental load fluctuates considerably. Hence there is some uncertainty as to the moment when visualization of the preceding target ceases. To overcome this objection, interference was provided by slant patterns, displayed for 0.5 sec and followed by an immediate two-alternative recognition test. The use of a short display time, a short retention interval and the appropriate instructions all emphasised the need to visualize the interference patterns. The onset of interference is therefore assumed to occur during the display time of these patterns.

Display of the interference pattern was followed by a cross-hatched mask for 200 msec. After a blank interval of 0.5 sec, the two test alternatives were displayed side by side, 25 mm apart, until the subject made a choice. The unit cell size of the interference patterns was also 6 mm. A set of 250 slant patterns and their distractors were generated for use as interference. Details of the construction procedure are given in Chapter 2, section 2.

Training. In the first stage of training, subjects received sixteen trials practice at the interference task alone, where each interference pattern was displayed for 1.0 seconds. The next stage (30 trials) involved the presentation of matrix pattern targets for 0.5 sec, followed by the chequered mask and then a blank interval of 0.5 sec. On half the trials this was followed by an immediate recognition test, and on the other half, selected at random, by the interference task, and then a further delay of 0.5 sec before the matrix pattern recognition test. The third practice consisted of 32 trials at the experimental task, with conditions as set out in Table 7.1. In all the practice and experimental trials, two keys were marked and used to make the choice responses, as in Experiment 4b.

Procedure. In the experiment subjects were given instructions to concentrate on and rehearse each target pattern they were shown, and to be as accurate as possible. They were warned not to ignore the interference task. The experiment was administered as two blocks of 64 trials each. In each block 8 trials of each kind were given in a random order. A short rest was given after every 22 trials, with a longer pause between the blocks. The trials were self-paced and knowledge of results about the choice responses was provided at the end of each trial.

Results.

Four performance measures were taken: the percentage of correct choices and the mean response time in the matrix pattern recognition test, and the two equivalent measures on the interference task for conditions 1 to 7.

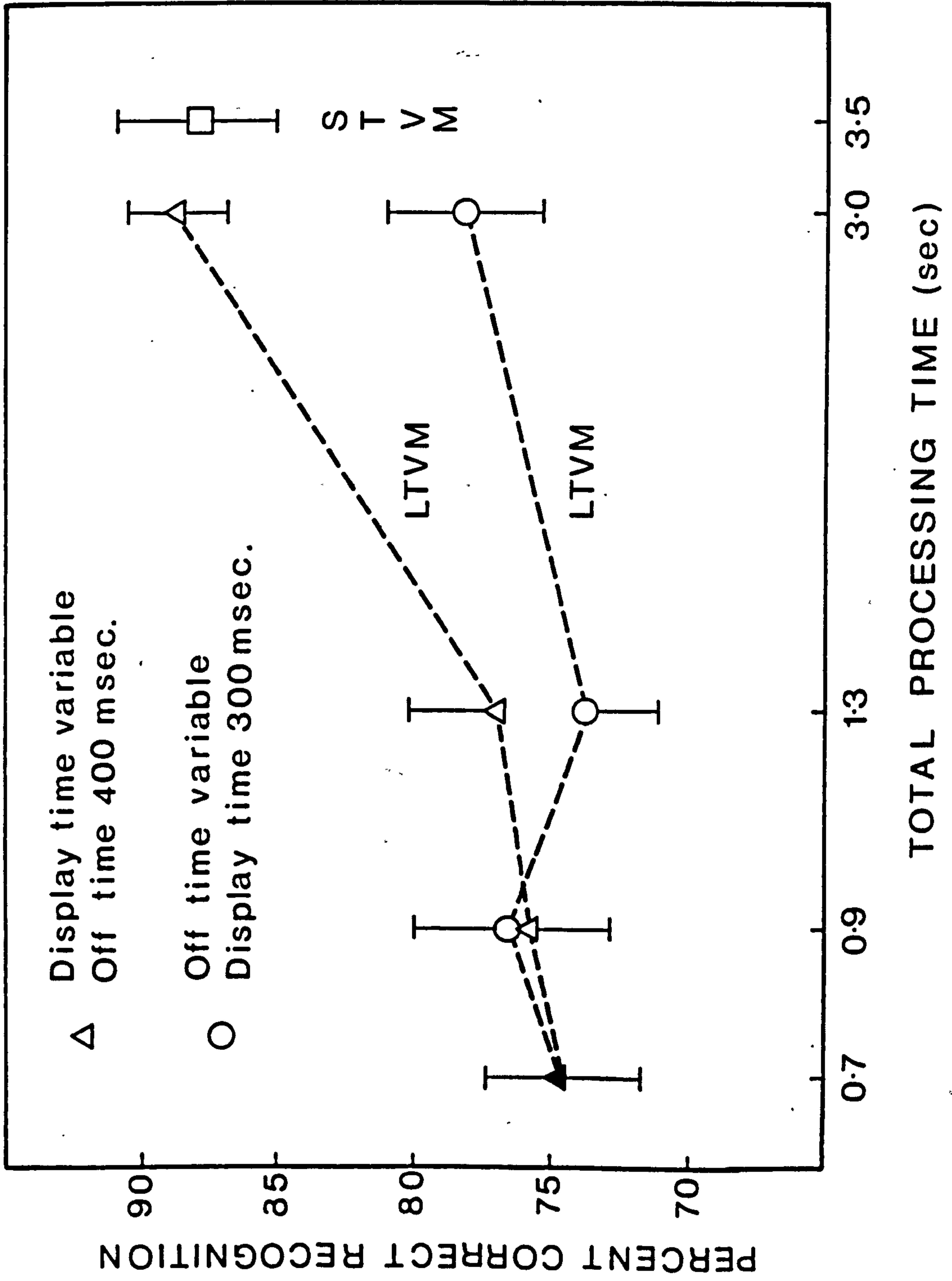
(i) Percent correct recognition.

The mean percent correct recognition choices for the matrix patterns, together with the overall means and standard errors, are plotted in Figure 7.1. From the results it is clear that LTM performance increases as display time increases (conditions 2 - 4), but there is little or no increase with post-stimulus processing time (conditions 5 - 7). Condition 8 shows that in the absence of interference, memory for the target is high (88%) with a retention interval of 3.5 sec, which is longer than the longest post-stimulus processing time. This indicates that the matrix pattern trace was available at the time when interference was given in conditions 5 - 7.

A two-way analysis of variance with repeated measures on both factors was run on the data from conditions 2 to 7 inclusive. The factors were total processing time and stimulus availability (display time versus post-stimulus processing time). The summary of this analysis in Table 7.2 shows that both factors were significant, as was the interaction

Figure 7.1. Mean percentage of correct forced choice recognition as a function of total processing time (log.scale). Bars indicate standard errors. For the LTVM conditions, total processing time is the time from target onset to interference pattern onset. In one set of LTVM conditions display time was varied; in the other set, post-stimulus processing time (off time) was varied. For the STVM condition, the interval from target onset to the recognition test was 3.5 sec.

Fig. 7.1



between them. To provide confirmation of this, separate analyses (one-way, with repeated measures) examined the effects of increasing display time (comparison of conditions 2, 3 and 4) and post-stimulus processing time (conditions 5, 6 and 7). Increasing the display time was shown to have a significant effect ($F = 8.95$; $df = 2,30$; $p = .001$), but increasing the post-stimulus processing time had no such effect ($F = .79$; $df = 2,30$; $p = .53$). This demonstrates that display time and post-stimulus processing time do not have equivalent effects on LTVM.

(ii) Mean response time.

The mean response times for each condition along with the standard errors are plotted in Figure 7.2. It is clear from this that the mean RTs in all seven LTVM conditions are about equal and consistently longer than the STVM response times of condition 8. An analysis of variance (one-way with repeated measures) was run on the data from all 8 conditions, and showed a significant effect of conditions on the RT measure ($F = 3.49$; $df = 7,105$; $p = .0022$). But when condition 8 was excluded from the analysis, there was no significant difference between the seven LTVM conditions ($F = 1.26$; $df = 6,90$; $p = .28$). These results are consistent with those of Chapter 6. Generally, response times are shorter under STVM conditions, but RT appears to be an insensitive index of LTVM performance.

(iii) Performance on the interference task.

It is possible that any differences in recognition performance in the LTVM conditions is due to differences in the degree of interference rather than to the display conditions. To test this possibility, two performance measures of the interference task were taken for conditions 1-7. Table 7.3 gives the mean percentage of correct recognition choices and the mean response times for the slant pattern recognition test.

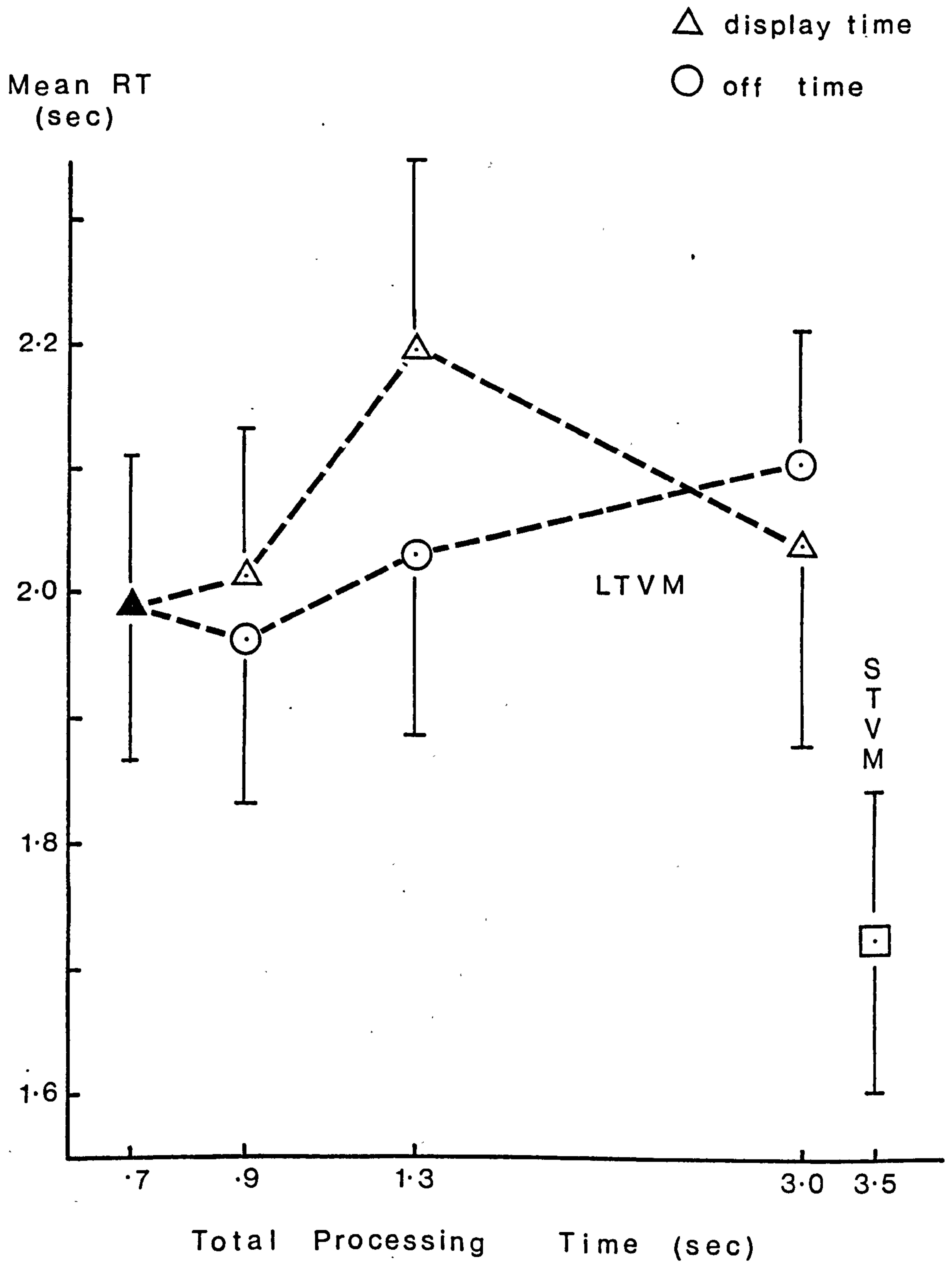
TABLE 7.2

Analysis of Variance Summary Table. Percent
correct Recognition as a Function of Total Processing
time and Stimulus Availability.

Source	df	SS	MS	F	P
Subjects	15	4742.4			
Stimulus Availability (A)	1	443.1	443.1	4.58	.047
Error	15	1451.4	96.8		
Total Processing Time (B)	2	1247.6	623.8	5.63	.0084
Error	30	3322.8	110.8		
AXB	2	529.8	264.9	3.54	.0407
Error	30	2243.6	74.8		
Total within	80	9238.3			

Figure 7.2 Mean response times and standard errors for the recognition of matrix patterns as a function of total processing time. In the LTVM conditions either display time or off time was varied. In the STVM condition no interference was given and the interval from target onset to the test was 3.5 sec.

Fig. 7.2



Performance on the interference task was both fast and accurate, suggesting that subjects were visualizing the slant patterns. Two analyses of variance were run on the data, comparing performance on the interference task for all seven conditions (one-way, with repeated measures). There were no significant differences when either the percent correct score ($F < 1.0$) or response time ($F < 1.0$) was used as the dependent variable.

As a further check, two more ANOVAs (two-way, with repeated measures) were run on the data, where the conditions were arranged according to the two main variables, total processing time and stimulus availability. For the percent correct measure there was no effect of either variable on the interference task, nor was there any significant interaction. But for the response time measure on the interference task there was a significant interaction of total processing time and stimulus availability ($F = 4.29$; $df = 2,30$; $p = 0.023$). The mean RTs on the interference task are plotted in Figure 7.3, and it is apparent from this that the source of the interaction is largely the long RT in the display time condition with a total processing time of 900 msec. It is possible that in the main task, subjects received a different degree of interference in this condition. But this alone could not explain the results on the main task since there is no correspondence between the interactions in the main and secondary tasks. Moreover, since there was no interaction when percent correct was used as the measure of the secondary task performance, it is likely that this result is a Type I error.

(iv) Analysis of the effect of post-stimulus processing time for high and low visualizers.

Inspection of the raw data showed that there was a wide variation of performance on condition 8 across subjects. One possible explanation for the absence of any post-stimulus processing time effect is that a number of subjects may have forgotten the matrix pattern target at some point between stimulus offset and interference. To explore this

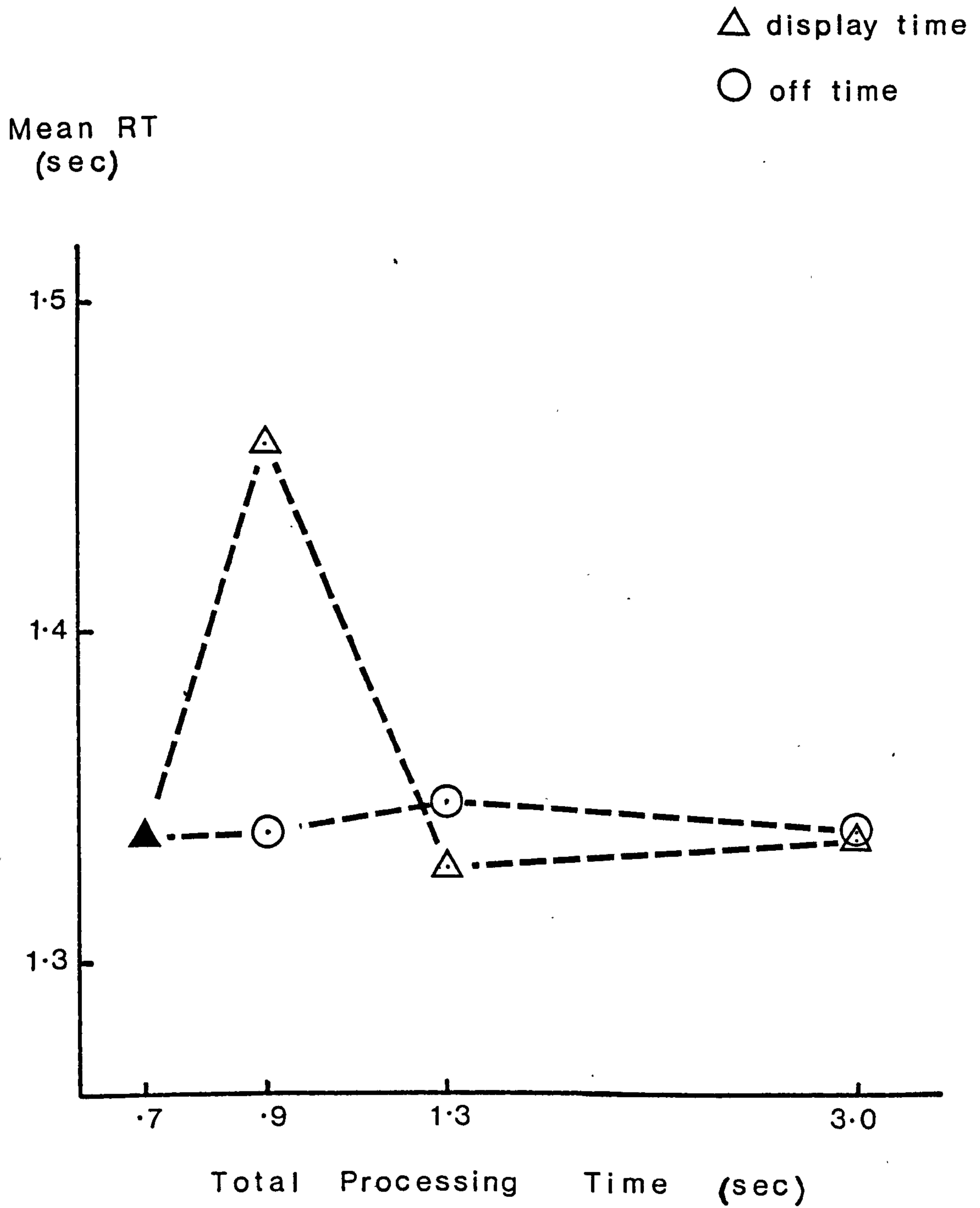
TABLE 7.3

Performance on Interference Task for
LTVM Conditions.

	Condition						
	1	2	3	4	5	6	7
Percent Correct							
Mean	91.4	91.4	93.8	93.8	92.2	94.1	93.4
S.E.	1.88	1.70	1.61	1.89	1.66	1.56	1.56
Mean Response Time							
Mean	1.34	1.46	1.33	1.34	1.34	1.35	1.34
S.E.	.078	.110	.076	.093	.079	.077	.083

Figure 7.3 Mean response times on the interference task (slant pattern recognition) as a function of total processing time. LTVM conditions only.

Fig. 7.3



further, the 16 subjects were divided into two groups, the high- and low-visualizers.

An index of visualization was devised, based on performance differences under STVM and LTVM conditions with short display times. An estimate of LTVM performance with short display times was made by averaging the percent correct scores of conditions 1, 2 and 5. This average value was subtracted from the STVM score obtained in condition 8 to give the index of visualization. The values of this index for each subject are listed in Table 7.4. The subjects with the eight highest indices were allocated to the high-visualizing group, the remainder to the low-visualizing group.

The mean recognition performance of these two groups, along with the standard errors, are listed in Table 7.5. It is apparent that high-visualizers performed extremely well in the STVM condition, with a mean percent correct of about 97%. But they also performed better than the low-visualizers in nearly all the conditions, including the LTVM conditions with long display times, where visualization would not necessarily be an advantage. The visualization index may therefore reflect good general ability on the task as a whole. A two-way analysis of variance with one factor between (high-versus low-visualizers) and one within (post-stimulus processing time, conditions 5 - 7) was run on these data. There was a significant effect of the between subjects variable ($F = 5.3$; $df = 1,14$; $p = .035$) but no significant effect of post-stimulus processing time ($F = .78$; $df = 2,28$; $p = .53$), and the interaction also failed to reach significance ($F < 1.0$). Two one-way analyses of variance with repeated measures were run on data from the high-visualizing group. The first compared performance in conditions 2, 3 and 4, and showed a significant effect of display time ($F = 4.84$; $df = 2,14$; $p = .025$). However, there was no significant effect of post-stimulus processing time when conditions 5, 6 and 7 were compared ($F < 1.0$).

TABLE 7.4

Division of Subjects into High- and
Low-Visualizers, by the Visualization Index.

<u>Subject</u>	<u>Visualization Index</u>	<u>High(H) or Low(L)</u> <u>Visualizer?</u>
1	0	L
2	8.33	L
3	8.33	L
4	22.92	H
5	31.25	H
6	4.17	L
7	20.83	H
8	10.4	L
9	20.83	H
10	-2.08	L
11	4.17	L
12	20.83	H
13	14.58	H
14	0	L
15	10.42	H
16	16.67	H

TABLE 7.5

Percent Correct Recognition in Each
Condition, for High- and Low-Visualization Subjects.

	Condition							
	1	2	3	4	5	6	7	8
High Visualizers								
Mean	75.78	75.78	82.03	91.41	79.69	80.47	82.03	96.88
S.E.	2.19	3.99	3.43	2.62	3.87	2.19	4.64	1.18
Low Visualizers								
Mean	73.44	75.78	71.88	85.94	73.44	67.19	74.22	78.91
S.E.	5.38	4.33	5.15	2.29	5.88	3.49	2.75	3.53

Thus when a group of subjects is known to have a high retention for the original target at the end of a long post-stimulus processing time, showing that the target has been visualized throughout the interval, there is no apparent increase in LTVM as a function of the time for which the item has been visualized.

7.3 Discussion and Conclusions.

This experiment shows that the length of time for which a matrix pattern is visualized after a brief presentation has little or no effect on LTVM, but the continued display of the pattern for the same length of time leads to a significant increase in LTVM. This result has a number of implications: it confirms and extends the findings of Experiment 6a, it demonstrates that visualization of a pattern and visual inspection of a display are not equivalent processes, and it has implications for the modal model as applied to visual memory. These aspects will be dealt with in turn.

(i) The effect of display time on LTVM.

Experiment 6a showed that a visualizable description of a pattern was constructed rapidly during display time, requiring only 200 - 300 msec for its completion. In contrast, LTVM increased more slowly as display time was extended up to 400 msec. The present experiment is in good agreement. With a display time of 300 msec, STVM recognition is high, even when tested after a retention interval of 3.5 sec. Secondly, LTVM recognition in this experiment was comparable to that found in Experiment 6a, where the display conditions were very similar (although the interference was different). Finally, it was argued in conjunction with the earlier experiment that LTVM increases slowly and irregularly over a wide range of display times. The present results confirm this, since LTVM shows a significant increase as display time is increased

from 300 msec to 2600 msec, and even at this comparatively long display time, is not at ceiling levels. For both experiments the conclusion is that LTVM depends upon prolonging the stimulus display beyond the point where a visual description has been constructed from it. Visualization and memorization have different display time requirements.

(ii) The relation between visualization and memorization.

Increasing the post-stimulus processing time from 400 msec to 2700 msec in this experiment had no effect on LTVM, even though it was shown that an accurate description of the pattern was available during this time. Visualization of a pattern for an extended period is clearly not sufficient for memorization.

The result finds support in the data of Phillips and Christie (1977a) who found no increase in LTVM when the off time between sequential presentations of matrix patterns was varied, but a substantial increase when display time was extended. It contradicts the view recently put forward by Lichtenstein and Keren (1979) that imagery and perception are equipotent for establishing long-term representations. A number of other experiments show substantial effects of post-stimulus processing time without claiming that it is as effective as display time for augmenting LTVM. (e.g. Tversky and Sherman, 1975; Weaver, 1974). The discrepancies between these experiments and the present one may be due to differences in the type of stimuli used, the opportunities for verbal encoding, or the conditions of presentation.

(iii) Implications for the modal model of memory.

According to the modal model (e.g. Atkinson and Shiffrin, 1968), information from a display is first encoded in STM, and later transferred to LTM. To account for the serial position effects seen in free and probed recall experiments, Atkinson and Shiffrin (1968) and

and also Waugh and Norman (1965) proposed that information transfer from STM to LTM is a function of the time for which information is held in STM.

Clearly, the results of Experiment 7a are contrary to this proposal. In the short display time conditions subjects were instructed to visualize the target throughout the post-stimulus processing time, which varied from 400 msec to 2700 msec. Recognition was high in condition 8, showing that subjects had complied with this instruction. Yet the duration of visualization had no discernible effect on subsequent LTVM.

These results also clarify the interpretation of Experiment 6a. It was shown there that STVM and LTVM are differentially affected by display time, an idea which is incompatible with the serial modal model. However, the modal model could be saved by claiming that transfer from STVM to LTVM was still in progress at the time the interference task was given. By this account, increasing the display time involved an increase in the total processing time available for STVM - LTVM transfer. To control for this possibility, the total processing time should be made constant by counterbalancing display time and post-stimulus processing time. In the case of Experiment 6a, this would entail varying the post-stimulus processing time from 700 msec (in the longest display time condition) to 1240 msec (in the shortest). The results of the present experiment suggest that no further transfer from STVM to LTVM would result if this procedural alteration had been made. Thus Experiments 6a and 7a both argue against the application of the modal model to visual memory. Two other ways of interpreting the results may be more successful:-

(i) Maintenance and elaboration.

Craik and Lockhart (1972) proposed two kinds of rehearsal: elaborative rehearsal which increases the depth of processing, and

leads to greater trace durability, and maintenance rehearsal, which does neither. The effects of display time and post-stimulus processing time on LTVM are readily explained if it is assumed that the elaborative recoding of a target pattern can only take place during the display time. Thus the slow increase in LTVM as display time increases is the consequence of a progressive elaboration of this type of material. The additional assumption required is that elaboration stops when the stimulus is removed, even though a fairly accurate representation remains. This assumption is not entirely ad hoc; the limited capacity of visualization suggests a reason for it. If maintenance and elaboration require a common, limited-capacity processing resource, then elaboration will be easier when the display is still present and concurrent maintenance is not necessary. But if the visual memory load approaches or exceeds visualization capacity, there will be none to spare for elaborating the trace, which will therefore be ephemeral.

(ii) 'Consolidation' immediately after stimulus offset.

Potter (1976) has provided evidence that accurate identification of target pictures can occur with display times as short as 100 msec, but delayed recognition memory (LTVM) for sequentially presented items is poor when the display time is less than 500 msec. She interprets these results in terms of a short-term conceptual memory, which is resistant to pattern masking but susceptible to interference from a following picture. Memorization in her scheme requires an additional process of 'consolidating' this short-term trace. One experiment (Potter, 1976; Experiment III) shows that this process can occur in the absence of the stimulus, a result clearly in conflict with the present findings. One possible resolution is in terms of differences in the materials used. If naming the pictures were part of the consolidation process, then this could occur after stimulus offset, and it would not be effective with

matrix patterns as stimuli. However, Intraub (1979) has recently shown that the recognition of pictures presented at high rates does not interact with the naming latency of these pictures. Potter (private communication) suggests that consolidation involves conceptual processing, rather than naming, and so it is clearly seen only when natural or meaningful pictures are used. A second possibility is a 'consolidation' process which occurs at target offset, is of limited duration (0.5 sec or so) and so is disrupted only if interference follows immediately after the target offset. All the experiments reported here have allowed an interval of at least 400 msec from target offset to the start of interference. Any process critical for LTVM that takes place during this time would be disrupted in Potter's experiments, but not those reported in this thesis.

To summarize, the main conclusions from this chapter are:

- (i) Memorization takes place during display time, but much more slowly, if at all, during post-stimulus processing time.
- (ii) Extended visualization is not equivalent to perception, and provides an insufficient basis for memorization.
- (iii) The prediction of the modal model, that transfer of information between STVM and LTVM is a function of time in STVM, is not supported.

CHAPTER EIGHTThe Effects of Recognition Test Duration.8.1 Possible Consequences of Restricting Test Time.

This chapter will consider the effects of recognition test duration on STVM and LTVM. The main concern is the nature of the processes operating during the retrieval and comparison stages. If STVM and LTVM involve qualitatively different operations during the recognition test, then any variable which influences performance at this stage may reveal a dissociation. This section considers the possibility that the duration of the recognition test (test time) will influence STVM and LTVM in different ways.

Several considerations suggest that STVM and LTVM processes may differ during the recognition test. Prior to the test pattern display, the subject is in one of two states, depending largely on the type of trial. On STVM trials, the subject rehearses the target pattern until the test, and therefore has certain expectancies about the test pattern. Under LTVM conditions, where interference prevents rehearsal of the target, there is no such expectancy. Another consideration is that retrieval processes may be required for LTVM recognition, but not for STVM. Rehearsal not only preserves information about the target, it isolates this information from traces of patterns presented on previous trials. A third, empirical consideration is that recognition choice RTs are generally longer under LTVM than under STVM conditions, even when the performance levels are the same (for example, conditions 4 and 8 of Experiment 7a).

Given these considerations, it is conceivable that test time will show a dissociation of STVM and LTVM. First, rehearsal of the target provides the subject with a model which can be compared with the test pattern. Without this, the subject must use test time to construct a

representation of the test probe, and make this the basis for any comparison. Expectancy may also influence the rate at which information is extracted from the display; an expected pattern may be read more quickly. A third possibility follows from the notion of encoding specificity. In this view, recognition of the target will take place only if the test pattern is encoded in the same way that it was encoded at presentation. If a number of encoding variations are possible, LTVM recognition may be delayed while these are constructed and matched against the memory trace. To extend this argument further, it is known that LTVM improves as display time is increased up to at least 2.6 sec. By one plausible account, this time is required for encoding the target in a way which will be resistant to interference. If reiteration of the same encoding processes is required at test, then recognition should increase over a similarly extended range of test times. This will not apply in the case of STVM, where the target is under rehearsal at the time of test.

However, other considerations suggest that test time may have little, if any, differential effect on STVM and LTVM. Whatever the recognition processes are, it is likely that an early stage in a recognition test involves making a description of the test pattern. If this initial descriptive process is the same for both STVM and LTVM conditions (i.e. expectancy has little or no effect in facilitating the STVM description), and no other processes require the test pattern display, then test time will have the same effect on both conditions. An alternative is that under LTVM conditions, retrieval of the target trace takes place before the test pattern is presented. In this case, performance will be influenced by the time available for retrieval from the end of interference to the test pattern display. If retrieval consistently occurs before the recognition test, then the representation will be in mind at the time of test for both LTVM and STVM conditions. Hence there should be no differential effect of test duration.

The following experiments were undertaken to answer two questions in particular about the test time requirements for STVM and LTVM recognition. First, does LTVM recognition need a test exposure longer than that required for the construction of an STVM representation? Secondly, is readout from the test pattern under STVM and LTVM conditions affected by the single previous exposure of the pattern? Both experiments and questions are relevant to the more general issue of a dissociation of STVM and LTVM with respect to test time.

8.2 Experiment 8a: The Effect of Short (300 msec) and Long (2.0 sec) Test Pattern Exposures on STVM and LTVM.

This experiment was performed to find out (i) if LTVM required a longer test time than STVM and (ii) more specifically, if LTVM requires a longer test time than that necessary for the construction of a short-term description. To do this, two test time values were used: one of 300 msec (which is known from Experiments 6a and 6b to be adequate for the construction of short-term descriptions) and one of 2.0 sec, which is longer than the average response time observed under LTVM conditions. The experimental hypothesis is that if LTVM recognition involves complex encoding or retrieval processes at test time, then performance will be higher with the longer test time, and there will be a dissociation of STVM and LTVM. If, however, LTVM recognition is mediated by the prior establishment of a short-term representation, then performance will be the same in the two test time conditions, and neither STVM nor LTVM will be affected by the test time manipulation.

Methods.

Subjects. Eight undergraduates from the departmental subject panel participated to fulfil a course requirement.

Design. The experiment investigated the effects of two test

times (300 msec, 2.0 sec) on STVM and LTVM recognition. In order to avoid ceiling effects, two display times were used, 80 msec and 600 msec. Thus there were four display conditions, formed by the combination of display time and interference conditions. These will be referred to as $STVM_{80}$, $STVM_{600}$, $LTVM_{80}$, $LTVM_{600}$. All three factors were combined within subjects to give a 2x2x2 design with repeated measures. The patterns displayed under each of the 8 conditions were rotated between subjects, so that for all subjects each target was shown once in each condition. The choice of using the target or distractor as the test pattern was determined by the target pattern, and was not varied between the other conditions.

Apparatus. The response keys used were the numerals (in the interference task) and three other marked keys. The key at the extreme top left of the keyboard was marked 'START' and was used to initiate each trial. Two adjacent keys ('B' and 'N') at the bottom of the keyboard were labelled 'SAME' and 'DIFFERENT' respectively, and were used for the choice response.

Stimulus materials. A set of 4x4 matrix patterns with 6 cells filled was constructed for use in the first training session. Distractors for these patterns were generated on-line. Two further sets of 4x4 matrix patterns with 8 cells filled were made up for use in the second practice and main experiment. These consisted of target/distractor pairs where target and distractor differed by two cell values.

For all patterns and masks the unit cell size was 6 mm.

Masking. Each target was followed by the display of a 6x6 chequerboard mask, which was displayed for 200 msec. A similar mask followed the display of the test pattern.

Interference. A mental arithmetic task of the type described in Chapter 2 was used to provide interference.

**PAGE
NUMBERS
CUT OFF
IN
ORIGINAL**

Recognition test. The usual two-alternative forced choice procedure is unsuitable for this kind of experiment, since the short test times would prevent subjects from fixating both alternatives. A same/different test was therefore given, where either the target or the distractor was displayed in the centre of the screen. To ensure fixation of the pattern, a warning signal was given to the subject 1.0 sec before the test, and a fixation point was displayed in the centre of the screen throughout this foreperiod. This test pattern was followed by the chequered mask to remove any effects of iconic persistence. Subjects responded by pressing the 'SAME' key with the index finger, or the 'DIFFERENT' key with the middle finger of their right hand, and they were instructed to keep this hand in position ready to respond. Knowledge of results was provided by displaying the words 'CORRECT' or 'WRONG' immediately after each response. For all eight conditions of this experiment, on half the trials the test pattern was the same as the target, and on the other half it was different.

Training. Subjects were given two training sessions before the start of the main experiment. The first consisted of 40 trials where the target pattern (a 4x4 matrix with 6 filled cells) was displayed for 1.0 sec, and interference was given on every trial. This was followed immediately by a same/different recognition test, where the test pattern was displayed until the subject responded. The second practice involved 32 trials with a procedure and materials similar to those of the main experiment.

Procedure. The experiment consisted of 160 trials, 20 in each of the 8 conditions, presented in a random order. On each trial the subject initiated the display sequence, which began with the display of the target and pattern mask. In the STVM conditions, there was a delay of 1.5 sec, while a fixation point was displayed. In the LTVM conditions, the interference task was given, followed by the fixation point for 1.0

sec. In both cases a warning signal was given 1.0 sec before the recognition test display. Subjects were instructed to respond to the test pattern as soon as they had decided whether it was the same as the target or a distractor. They were encouraged to be accurate.

Results.

(i) Percent correct recognition.

Figure 8.1 shows the mean percent correct for each display condition together with the standard errors. A three-way analysis of variance with repeated measures was run on these data, and a summary of this is provided in Table 8.1. This shows significant effects of display time, interference and a significant interaction between them. All three effects support the findings of Experiment 6a. But there is no significant effect of test time on recognition, nor any significant interaction of test time and any other variable.

This surprising absence of test time effects could be due to irregularities in the data, such as floor or ceiling levels of performance. Considering the LTVM conditions with 600 msec display time ($LTVM_{600}$) all subjects scored at above chance level when performance was averaged over both test time conditions, so floor effects are unlikely. For the $STVM_{80}$ condition one subject (subject 4, see Appendix A, Table 3) did score at about chance level, but the performance averaged over all subjects was about two standard errors above chance level. Moreover, if we consider the individual subjects in the $STVM_{80}$ and $LTVM_{600}$ conditions, we find that in each case four subjects show an increase in performance with the longer test times, while four subjects show a reduction in performance. Thus for the $STVM_{80}$ and $LTVM_{600}$ conditions, the absence of any test time effects is not due to statistical irregularities in the data.

One other feature deserves comment. The display time values

Figure 8.1 Mean percent correct choices on a same/different recognition test as a function of test pattern exposure time. Target patterns were displayed for 80 msec or 600 msec, and were followed by an unfilled interval of 1.5 sec (STVM) or a mental arithmetic task (LTVM). Bars indicate standard errors.

Fig. 8·1

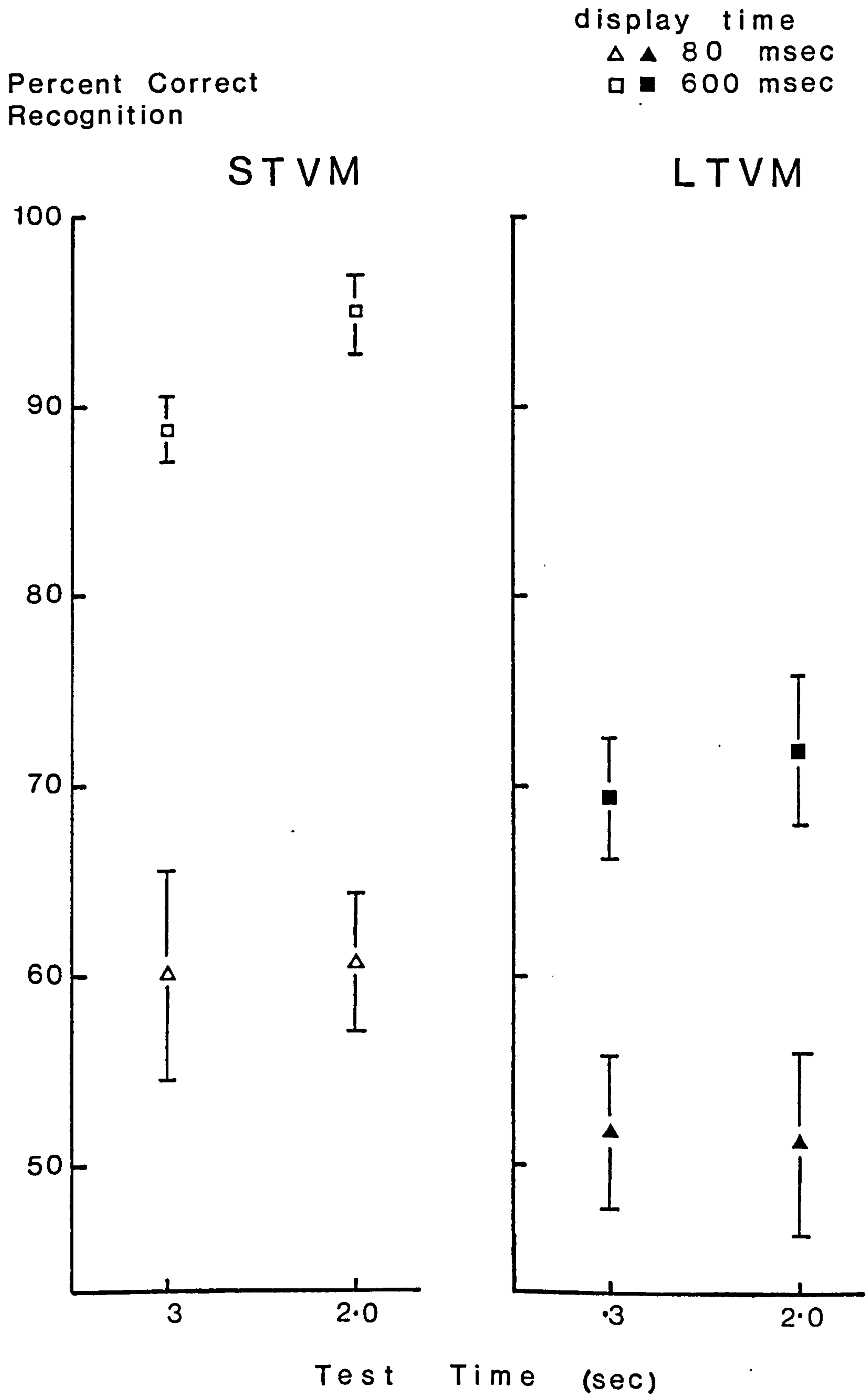


TABLE 8.1

Analysis of Variance Summary: Percent Correct
Recognition as a Function of Display Time, Interference
and Test Time.

Source	df	SS	MS	F	P
Subjects	7	1910.94			
Interference(A)	1	3600.0	3600	63	.0002
Error	7	400.0	57.1		
Display Time(B)	1	10251.6	10251.6	58	.0002
Error	7	1235.9	176.6		
Test Time(C)	1	76.6	76.6	.896	.622
Error	7	598.4	85.5		
AxB	1	625.0	625	10.29	.015
Error	7	425.0	60.7		
AxC	1	25.0	25.0	0.18	.69
Error	7	987.5	141.0		
BxC	1	6.3	6.3	0.10	.76
Error	7	431.3	61.6		
Total Within	56	19162.5			

were chosen so that the $STVM_{80}$ performance should be roughly equal to that of the $LTVM_{600}$ conditions, a prediction based on the data of Experiment 6a. $LTVM$ performance levels conformed well to the prediction, but $STVM$ was about 10% lower than anticipated. The most likely origin of this discrepancy is the longer retention interval (1.5 sec) used in the present experiment, since $STVM$ under some conditions does decay with time. It should be noted that the procedure of this experiment is more complex than that of Experiment 6a. Because of this, some central resource capacity may be devoted to keeping track of the task, and so is not available for visualization.

(ii) Mean response times.

Inspection of the raw data for subject 6 indicated that one RT was 34.2 sec long, most probably the result of a procedural error. This response was excluded from the data, and the corrected mean RTs for each condition are listed in Table 8.2. (This correction applies only to the $LTVM$ condition with 600 msec display time, and 300 msec test time).

There is little difference between the overall means across conditions although on the whole the $STVM$ response times are shorter, particularly with the 600 msec display time. A three-way analysis of variance was run on these data and showed a significant effect of interference ($F = 20.51$; $df = 1,7$; $p = .003$). The effect of display time approached significance ($F = 3.51$; $df = 1,7$; $p = 0.1$), but there was no significant effect of test time ($F < 1.0$). None of the interactions approached significance.

(iii) Performance on the interference task.

Two measures of performance were taken on the interference task: the percentage of sums which were solved correctly, and the mean solution time. Table 8.3 gives the mean values and standard errors for both measures in all the $LTVM$ conditions of the experiment.

TABLE 8.2

Mean Response Times in Recognition Test as a
Function of Interference, Display Time and Test Time.

	Display Time = 80 msec		Display Time = 600 msec	
Test Time (msec)	300	2000	300	2000
STVM				
Mean	1.178	1.259	1.023	0.987
S.E.	.14	.23	.09	.08
LTVM				
Mean	1.285	1.280	1.240	1.225
S.E.	.13	.14	.13	.09

TABLE 8.3

Performance Measures on the Mental Arithmetic
Interference Task.

	Display Time = 80 msec		Display Time = 600 msec	
Test Time	300	2000	300	2000
Percent Correct				
Mean	78.125	80.625	82.5	81.25
S.E.	5.26	2.90	4.82	4.20
Solution Times				
Mean	6.037	5.831	6.027	5.937
S.E.	0.187	0.137	0.225	0.173

A one-way analysis of variance (with repeated measures) showed that there was no significant difference in the percentage of sums correct between the four LTVM conditions ($F < 1.0$). A similar analysis showed no significant difference when mean solution time was the performance measure ($F = 1.63$; $df = 3,21$; $p = .21$). Therefore any difference in performance between the LTVM conditions of the main task are unlikely to arise from chance variations in the interference task.

Discussion.

The results show that varying the duration of a recognition test pattern from 300 msec to 2 sec has no observable effect on STVM or LTVM. They provide no evidence that STVM and LTVM are differentially affected when test time is varied between these limits. This is surprising, since on several grounds we should expect STVM and LTVM to differ with respect to processing during the recognition test.

A resolution is possible insofar as STVM and LTVM may involve different processes during recognition and yet have similar requirements for test time. For example, retrieval could occur during the foreperiod, so the target pattern would be in mind at the time of the test exposure, as with STVM. Alternatively, the first stage in the recognition process might be to construct a visualizable description of the test pattern. If so, this process would be completed within 300 msec, and further extension of the test time should have no effect. It is conceivable that the rate at which the test pattern is described differs between STVM and LTVM, but shorter test times are required to resolve this issue, as in the following experiment.

One hypothesis that can be ruled out is the idea that the processes occurring during the initial presentation must be repeated during the test. It is known that very long display times are required to establish an accurate LTVM representation, and it is possible that this involves complex multiple encodings which are needed to overcome the effects of

interference. If recognition depended upon reiterating the encoding processes at test, then we should expect recognition to vary as a function of test time in the same way that it varies with display time. The results of this experiment show that this is not the case.

8.3 Experiment 8b: The Readout of Information from a Recognition Test Pattern under STVM and LTVM Conditions.

The previous experiment showed that increasing the duration of the recognition test pattern from 300 msec to 2.0 sec had no observable effect on STVM or LTVM. It follows that the information on which recognition was based was extracted from the test pattern within the first 300 msec of its display, for both interference conditions. This result would be expected if the establishment of a rapid, short-term trace provided the basis for recognition, enabling search for and comparison with the stored representation of the target.

In this experiment the effects of shorter test times were examined. The working hypothesis is that under LTVM conditions the subject has no expectation of the test pattern before it is presented. Therefore, the perceptual encoding operations used to form a short-term description (which we assume mediates retrieval and comparison) should be the same as in the target display. LTVM recognition will then be limited by those same visual descriptive processes which determine the growth of STVM with display time. If this is true, then the increase of LTVM as a function of test time should have the same time course as the growth of STVM with display time. The situations are not exactly equivalent; at test time the target has been seen once before, whereas at display time it is a novel stimulus. One assumption made here is that this single prior exposure does not significantly affect the rate of description at test time.

Quite different considerations apply in the case of STVM recognition, where the subject has a clear expectation of the test pattern

before it is presented. It is hypothesised that this expectation will facilitate the readout of information from the test pattern.

Methods.

Subjects. Eight undergraduates served as subjects in this experiment as part of a course requirement. One of the original eight was replaced because of failure to comply with the instructions.

Design. This experiment requires the measurement and comparison of STVM and LTVM as a function of test time. To do this, it is essential to avoid ceiling and floor effects, and to keep the mean level of performance in the same range for both interference conditions. Thus two display times were chosen (100 msec and 800 msec) such that STVM recognition with the shortest value would be approximately equal to LTVM with the longer display time. These two display times were combined factorially with the four test times (60, 80, 120 and 300 msec) and the interference conditions, making 16 conditions in all. Each subject received 20 trials under each condition over the course of the two 1 hour sessions. Thus the experiment conforms to a 2x2x4 design with all three factors repeated within subjects. The patterns shown were divided into four subsets, each of which was shown under one combination of interference and display time conditions. For each pattern, test time was rotated between subjects, so that all patterns were shown under all four test times.

Apparatus. The apparatus was identical to that of the previous experiment.

Stimulus materials. As in the previous experiment, a set of 4x4 matrix patterns with 6 cells filled were used in training the subjects. In the main experiment, a new set of 352 target/distractor pairs was generated (4x4 with 8 cells filled). The first 32 of these were used in practice, the remainder in the experiment itself.

Displays. The target displays and recognition tests were the same as in the previous experiment, except for the durations, which were altered. Masking was provided by a 6x6 chequered pattern which was displayed for 600 msec at the offset of each target and test pattern. The unit cell size was 6mm throughout, and the viewing distance was 60 cm. Apart from the mask there was no change to the display sequence. For both interference conditions a blank screen followed the target mask, lasting for 0.5 sec. After this, on STVM trials the fixation point was displayed simultaneously with the warning tone, and the recognition test followed 1.5 sec later. On LTVM trials the first digit of the sum followed the blank interval. At the end of interference, the answer to the sum was displayed for 0.5 sec, followed immediately by the fixation point and the warning tone.

Training. Subjects were introduced to the experimental task in three stages. The first consisted of 20 trials practice at the mental arithmetic task. On each self-paced trial the four digits were shown in succession, and subjects were required to type the answer to the sum with their left hand. The second practice involved 30 trials of a same/different recognition task. The target (a 4x4 pattern with 6 filled cells) was shown for 1.0 sec, and followed by interference on every trial. At test, the target or distractor was shown until the subject responded. Finally, 32 trials practice were given at the main experimental task, where interference was given on half the trials at random, and display and test times varied.

Procedure. Two sessions of one hour each were required to complete this experiment. In the first, subjects received the training procedures, followed by a block of 96 experimental trials. The second session began with a warm-up of 16 trials followed by two blocks of 96 and 128 experimental trials. A short rest was given after every 20 trials, with longer pauses between blocks.

The instructions warned the subjects that the test pattern would be shown for a very brief time, and told them to prepare for it. The subjects were encouraged to respond accurately; speed was not stressed.

Results.

(i) Percent correct recognition

The mean percentage of correct responses and standard errors for each condition are plotted in Figure 8.2. From this it is clear that recognition is superior in the STVM conditions, and increases as a function of display time and test time. These data were entered into an analysis of variance (three-way, with repeated measures on all three factors) which is summarised in Table 8.4.

If test time has differential effects on STVM and LTVM, there should be an interaction between test time and interference condition. However, this interaction was not significant. In a second analysis, the test time effects on the STVM₁₀₀ and LTVM₈₀₀ conditions were compared. Display time was varied to equalize performance in these two display conditions, and this manipulation was successful, the mean percent correct for STVM₁₀₀ and LTVM₈₀₀ being 73% and 70%, respectively. An analysis of variance run on data from these display conditions showed no effect of display condition ($F < 1.0$), but a significant effect of test time ($F = 4.83$; $df = 3,21$; $p = .01$). Again the interaction was not significant ($F = 1.5$; $df = 3,21$; $p = .24$). On the basis of these null results it cannot be concluded that test time has identical effects on STVM and LTVM. For one thing, the data are noisy, and there is some evidence of a change in response bias between conditions. Secondly, a coarse time scale was used to investigate the increase in recognition, involving measurement at only four values of test time. For these reasons, the strongest conclusion

Figure 8.2 Mean percent correct recognition and standard errors, as a function of test time in msec (log scale). Fig. 8.2a shows STVM performance for target patterns displayed for 100 msec and 800 msec. Fig. 8.2b shows LTVM performance for the same display times, measured after mental arithmetic interference.

Fig. 8-2 a

STVM

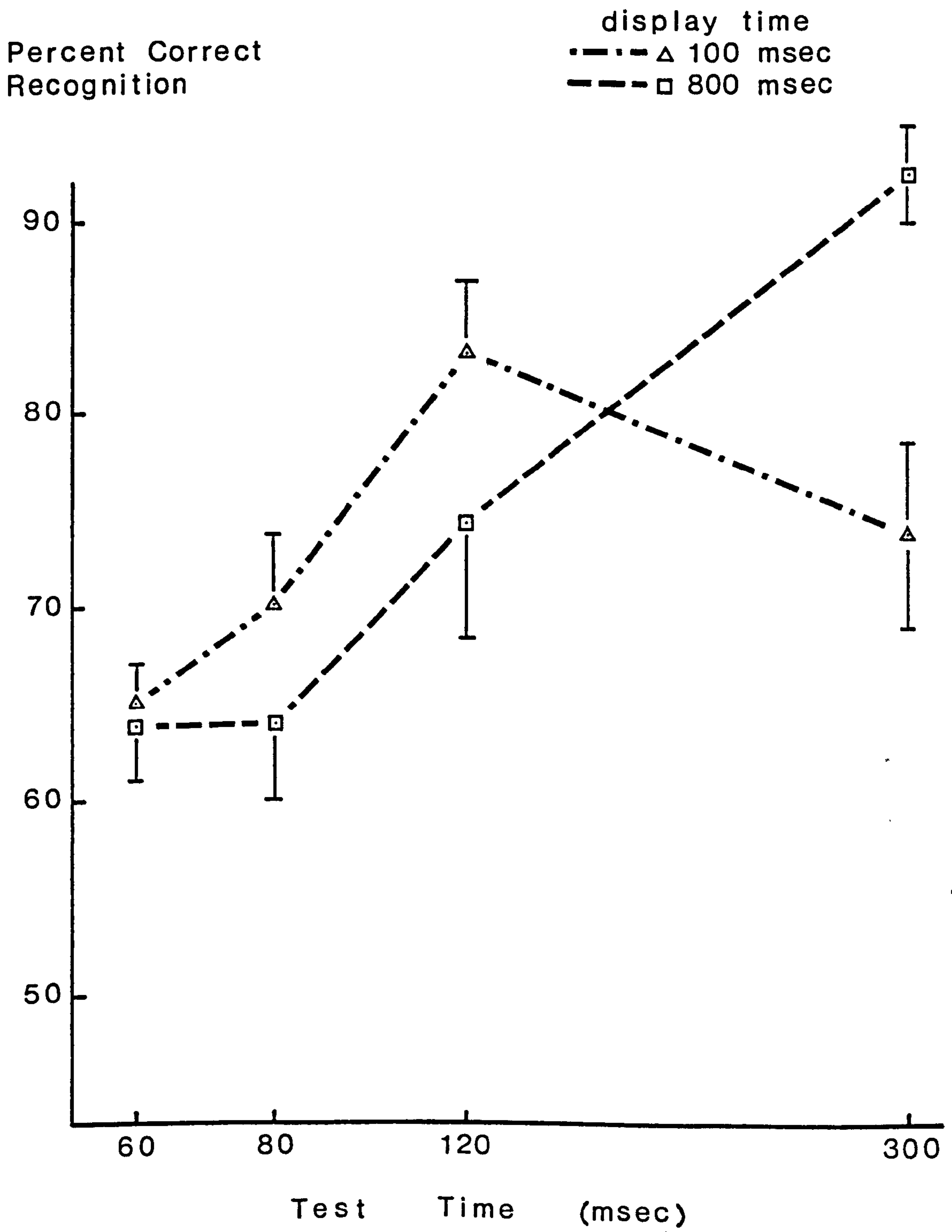


Fig. 8.2 b

LTVM

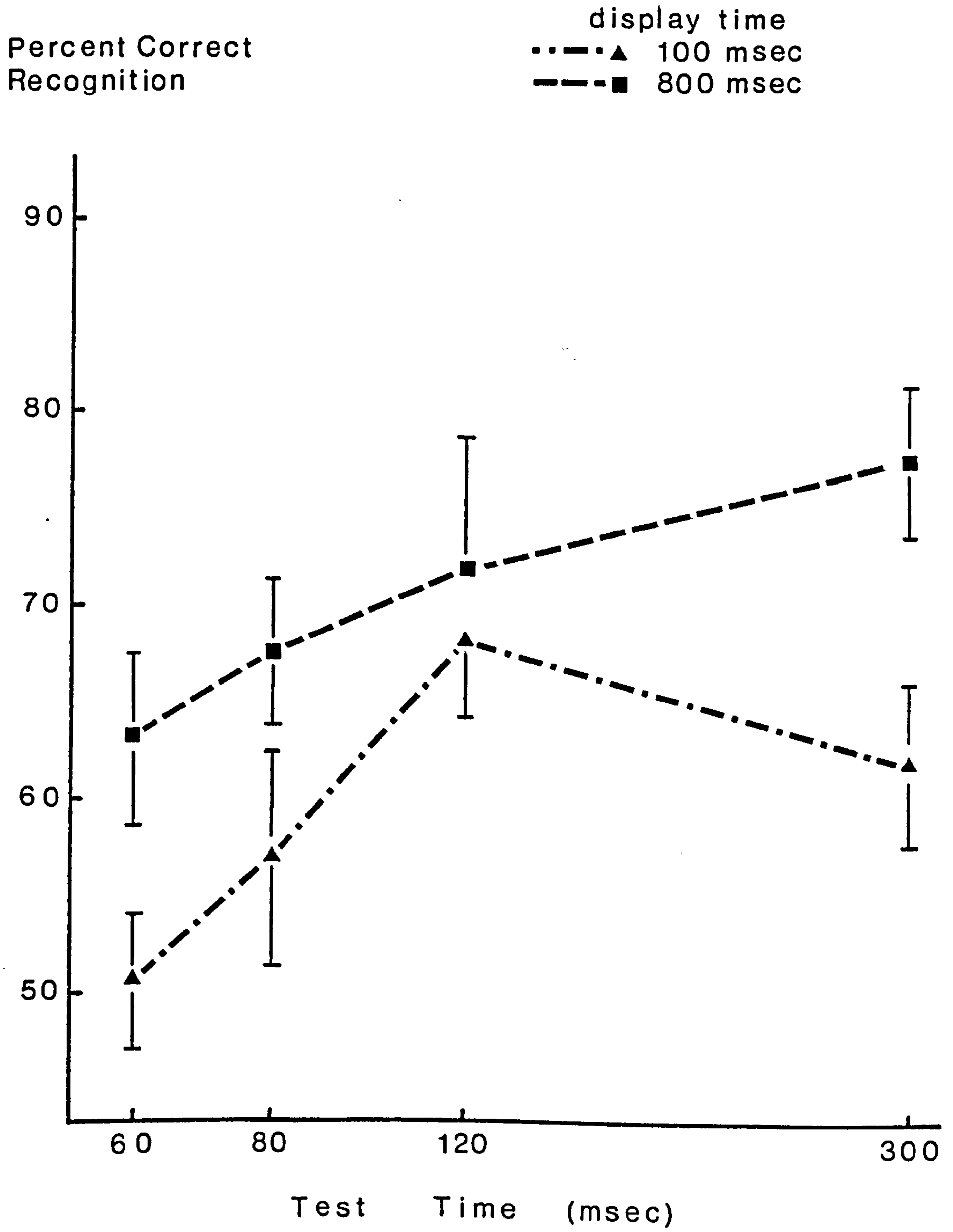


TABLE 8.4

Analysis of Variance Summary:Percent Correct Recognition as a Function of DisplayTime, Test Time and Interference.

Source	df	SS	MS	F	P
Subjects	7	3324.2			
Interference(A)	1	2363.3	2363.3	12.15	.0102
Error	7	1361.8	194.5		
Display Time(B)	1	1012.5	1012.5	9.61	.0171
Error	7	737.5	105.4		
Test Time(C)	3	5563.3	1854.4	11.44	.0001
Error	21	3405.5	162.2		
AxB	1	800	800	21.85	.0025
Error	7	256.3	36.7		
AxC	3	319.6	106.5	1.01	.407
Error	21	2205.4	105.0		
BxC	3	1692.2	564.1	4.33	.016
Error	21	2732.8	130.1		
AxBxC	3	479.7	159.9	1.63	.212
Error	21	2064.0	98.3		
Total Within	120	24993.8			

that can be made is that STVM and LTVM performance may show differences with respect to test time, but if so, these differences are relatively small.

The working hypothesis predicted that the increase in LTVM as a function of test time should be similar to the increase of STVM as a function of display time. For the LTVM₈₀₀ conditions, there was a progressive increase in recognition as a function of test time, similar to that predicted, but the increase was not significant ($F = 1.91$; $df = 3,21$; $p = .16$). A second prediction was that for STVM, the increase in performance with test time should take place at a faster rate than the increase of performance as a function of display time. If we consider the STVM₈₀₀ condition, this does not seem to be the case. First, there is no observable increase in performance as test time increases from 60 msec to 80 msec (compare Figure 8.2 with Figure 6.1). Secondly, there is a clear increase in recognition as test time is increased from 120 msec to 300 msec, and this difference is significant ($t = 2.998$; $df = 7$; $p < .05$; one-tailed.) Therefore the extraction of information at test is a process requiring test times longer than 120 msec. This result suggests that visualization has little (if any) facilitating effect on the rate at which information is utilised during the test pattern exposure.

An unexpected finding was that performance in the LTVM₁₀₀ and STVM₁₀₀ conditions was highest with test times of 120 msec. This anomaly shows in the significant interaction of display time and test time (Table 8.4). It suggests that recognition depends in part on the similarity of displayed events at presentation and at test. Thus with 100 msec display time, recognition is superior when the test pattern is shown for a similar brief duration (120 msec) than when it is longer, although this should allow a more complete description of the test pattern. This explanation may also account for the other surprising feature of the data, viz. that STVM₈₀₀ performance is lower than STVM₁₀₀ at shorter test times (60,80 and 120 msec). Statistical

confirmation of this was provided by a two-way analysis of variance with STVM display time as one factor, and the test times of 60, 80, 120 msec as the other. Significant effects of display time were found ($F = 9.31$; $df = 1,7$; $p = .018$), which are in the opposite direction to that predicted; for these test times, performance is superior with shorter display times.

To summarize, the results suggest that two effects are operating. Recognition increases as a function of test time, a result expected on the assumption that increasing the amount of information read from the test pattern improves the efficiency of the match to the memory trace. Also, there is evidence that recognition improves when test time approximates to the display time. This suggests that the recognition of a briefly presented pattern may depend on other factors besides the amount of information encoded at display time and available for comparison with the test pattern.

(ii) Mean response times.

The overall mean RTs and standard errors are plotted in Figure 8.3. Inspection of this figure reveals that LTVM response times are on the whole longer than in the STVM conditions, and that there is again a complex relationship between the effects of test time and display time. For the longest test time, shorter RTs are associated with long display times, but the reverse is true for short test times. With short test times there is also an effect of interference; as the test duration increases from 60 msec to 80 msec, LTVM response times increase, while the STVM response times decrease.

A three-way analysis of variance with repeated measures on all three factors was run on the RT data. A summary of this is given in Table 8.5. Of the three main variables, only interference approached significance. The interactions of interference and display time, interference

Figure 8.3 Mean response times for the same/different recognition test, as a function of test time. Both STVM and LTVM data are shown for each of two display time values.

Fig. 8.3

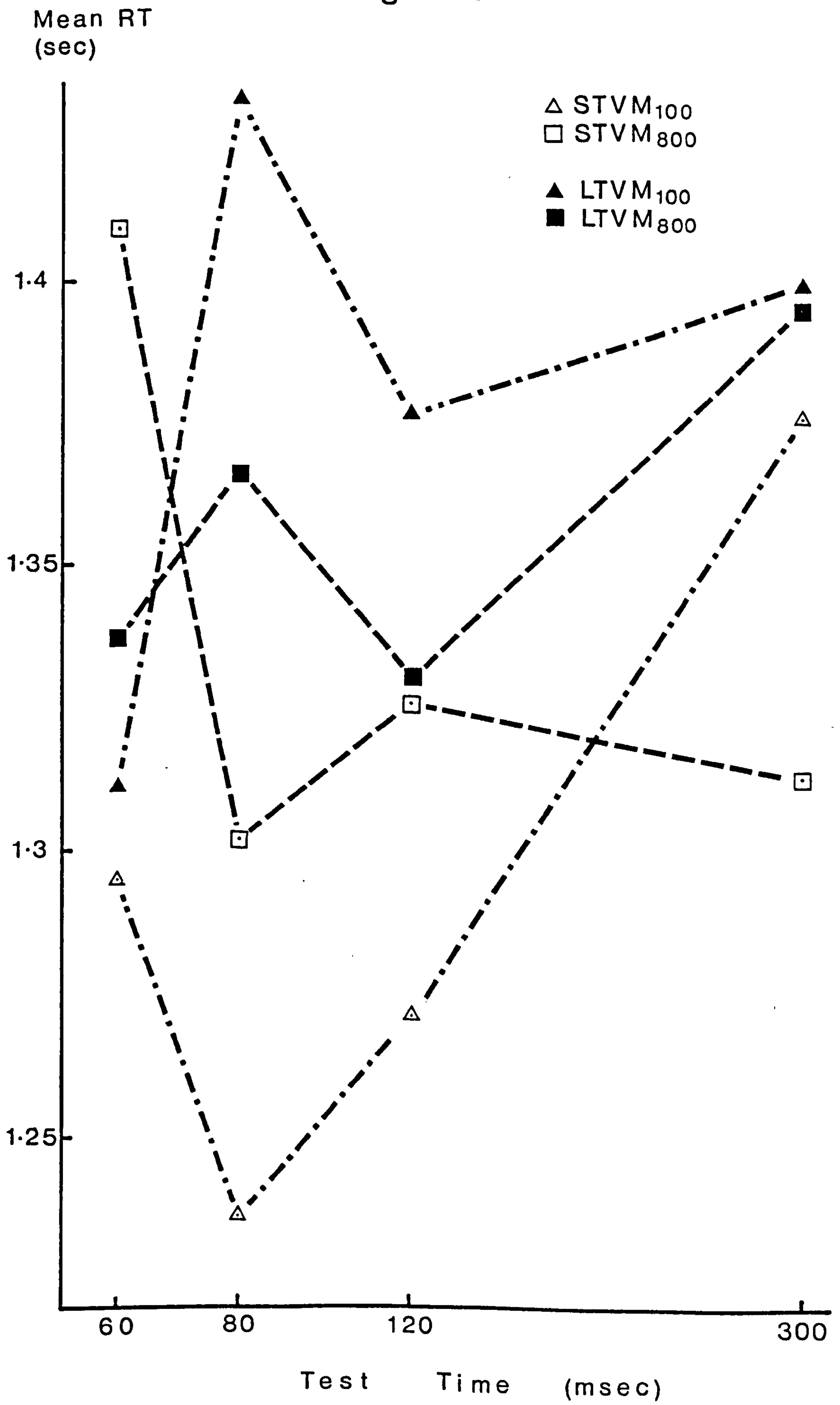


TABLE 8.5

Analysis of Variance Summary:Mean RT as a Function of Display Time,Test Time and Interference.

Source	df	SS	MS	F	P
Subjects	7	2.809			
Interference (A)	1	.088	.088	4.19	.078
Error	7	.146	.021		
Display Time (B)	1	.003	.003	.775	.59
Error	7	.031	.004		
Test Time (C)	3	.037	.012	.688	.57
Error	21	.378	.018		
AxB	1	.034	.034	5.75	.046
Error	7	.042	.006		
AxC	3	.100	.033	3.67	.028
Error	21	.190	.009		
BxC	3	.046	.015	1.70	.196
Error	21	.187	.009		
AxBxC	3	.044	.015	3.31	.0395
Error	21	.092	.004		
Total Within	120	1.418			

and test time, and the three-way interaction were significant. Together with the percent correct data these results argue against the interpretation that performance increases reflect the amount of information extracted from presentation and test displays. But the interaction of display time and test time (which was a prominent feature of the percent correct data) failed to reach significance.

(iii) Performance on the interference task.

The percentage of sums answered correctly in each LTVM condition and the corresponding mean solution times are listed in Table 8.6. The overall percentage of correct solutions was 86%, which shows that subjects were attending to the interference task. An analysis of variance with two factors within subjects showed that the percentage of correct solutions did not vary as a function of display time ($F < 1.0$) or test time ($F < 1.0$). A similar analysis run on the mean solution times showed no effect of display time ($F = 1.24$; $df = 3,21$; $p = .3$), but an effect of test time which was almost significant ($F = 2.75$; $df = 3,21$; $p = .07$). The interaction of display time and test time was highly significant ($F = 5.11$; $df = 3,21$; $p = .0083$). This result suggests that the distribution of interference was uneven across the display and test time conditions. However, the variation in mean solution times is relatively small, and it is unlikely that it could have much effect on LTVM performance. Moreover, the pattern of results does not help to explain the complex interactions found in the main task data. The finding that mean solution time on the interference task varies across display and test time conditions is probably a type I error, and therefore of little consequence.

8.4 General Discussion and Conclusions.

(i) Methodological problems.

These two experiments are first attempts to describe the

TABLE 8.6

Performance on the Mental Arithmetic
Interference Task for Each LTVM Condition.

Test Time	Display Time = 100 msec				Display Time = 800 msec			
	60	80	120	300	60	80	120	300
Percent Sums Correct								
Mean	80.0	89.4	86.3	86.3	88.	84.4	90.6	85.0
S.E.	7.79	5.38	4.41	5.96	4.60	4.95	3.71	4.09
Solution Times								
Mean	6.23	5.88	6.13	5.95	5.93	6.01	5.91	6.09
S.E.	0.23	0.13	0.19	0.20	0.14	0.17	0.15	0.14

effects of test time on STVM and LTVM. Although some significant and informative results were obtained, the data in general were noisy, and sometimes lacked the resolution necessary to draw firm conclusions. One particular problem was that large variations in response bias were found between conditions, especially in Experiment 8b. Three procedural changes should help to eliminate this. First, subjects should be given more practice, and informed that half the trials of each condition would be 'same' trials, the remainder 'different' trials. In conjunction with this, conditions should be blocked, rather than randomized. Thirdly, more trials should be given in each condition, and signal detection measures used. An additional point is that comparisons between display time and test time effects should be made using exactly the same type of recognition test, and for the same display and test time values. It was not possible to follow up these experiments adopting these changes, but the results obtained are sufficiently interesting to warrant further investigation.

(ii) The interaction of test time and display time.

The most surprising result of Experiment 8b was that with short display times, recognition was higher when the test times were also short. This violates the assumption that recognition for matrix patterns is based on knowledge of the target accumulated throughout the display time, and then compared with knowledge of the test pattern accumulated during the test exposure. If this were true then an increase in the information available at test should always result in increased recognition. Instead, as suggested above, the similarity of the events at display and test time may influence recognition. One way this could come about is through pattern/mask interactions. At short display and test times, the extent to which the pattern and mask fuse, or the mask selectively interferes with processing of one part of the pattern may make a large contribution to recognition. This idea has a counterpart in verbal memory where the

similarity of contexts for an item at presentation and test has a large effect on recognition (e.g. Tulving and Thomson, 1973).

(iii) Implications for LTVM recognition.

Experiment 8a showed that increasing the test time from 300 msec to 2.0 sec had little or no effect on STVM or LTVM. The shorter display time is long enough to allow the formation of an STVM description, but is not sufficient for the complex processing that is required to establish an LTVM representation. There are two possible accounts of the LTVM results: (a) that complex retrieval or encoding processes are not required at test or (b) that such processes are necessary, but are mediated by the construction of a short-term representation. This experiment rejects the theory that during test time subjects have to repeat the processing done during the initial presentation. It lends support to the theory that LTVM requires a large amount of processing during the initial presentation in order to overcome the effects of interference. Once constructed, the interference-resistant trace is easily and rapidly accessed by a subsequent recognition probe. A similar idea has recently been proposed by Craik and Jacoby (1979) who claim that elaborative encoding is required to make long-term representations distinctive.

Another possibility is that substantial processing during a long display makes the LTVM trace retrievable, so that at the time of test subjects are currently rehearsing a description of the target. This is conceivable under the conditions of these experiments, since there was an unfilled interval of at least one second before the recognition test, in which retrieval could occur. (The recall experiments have shown that retrieval of matrix patterns can occur, at least with moderately long display times.) This possibility could be investigated further by varying the time from the end of interference to the start of the recognition test. However, this explanation does not agree with subjective observations made while performing the task, and no subject reported

using this strategy. The significant interaction of interference and test time conditions in the response time data of Experiment 8b also argues against this interpretation.

(iv) The effects of visualization on recognition.

The results of Experiment 8b suggest that the extraction of useful information from a test pattern which is currently being visualized is not faster than the description of a novel pattern during its initial presentation. Although contrary to expectations, there are at least two reasons why this may be the case. The first is that visualization may involve some specific visual processing resources (as well as central processing capacity) and this may slow down the rate of test pattern description. It is known, for example, that visual imagery has a detrimental effect on signal detection (e.g. Segal and Fusella, 1971). Secondly, STVM recognition may involve matching operations as well as those describing the test pattern. Thus the amount of processing at initial presentation and test may not be equal. Some counter-evidence, a selective lowering of the visual threshold under visualization conditions is quoted by Zinchenko and Vergiles (1972). The question seems worthy of further investigation.

(v) The effects of familiarity on visual description rates.

One final point is that both experiments deal with novel visual patterns. At test, the patterns have been seen once before, and the descriptive processes which occur at test do not appear to be influenced by this single previous presentation. The situation may be quite different for highly overlearned visual forms. Phillips (personal communication) familiarised subjects with several 4x4 and 5x5 matrix patterns by repeated presentations. These patterns could be recognised, and discriminated from distractors differing by one randomly chosen cell, with display times as short as 70 msec. The effects of familiarity may

also be seen in the rapid alphanumeric readout functions for letters (e.g. Sperling, 1963) and words (cf. Allport, 1977).

CHAPTER NINE

Summary and Conclusions.

The central theme of this thesis has been the distinction between short-term and long-term visual memory. The starting point was the idea, empirically supported by a number of paradigms, that short-term visual memory is the consequence of an active process of visual rehearsal or visualization, extending from the stimulus offset to the retention test. In contrast to this, long-term visual memory was believed to depend on processes of memorization, long-term storage and retrieval, where continuous rehearsal was unnecessary. A large amount of evidence has been presented in this thesis which confirms the distinction of STVM and LTVM, and provides some insight into the nature of visualization, memorization and the relation between them. This chapter will present a summary of the main findings and the conclusions which can be drawn from them.

9.1 The Dissociation of STVM and LTVM.

Four new observations gathered from a number of experiments show a dissociation between STVM and LTVM, as follows:-

(1) Differential effects of display time on STVM and LTVM

When a post-stimulus mask is used to eliminate visual persistence, STVM for simple and complex patterns increases rapidly with display times of over 60 msec, reaching an asymptote at about 200-260 msec (Expts. 6a, 6b). In contrast, LTVM increases slowly and irregularly as display time is increased from 60 msec to at least 2.6 sec (Expts. 6a, 7a).

(2) The distribution of available information across trials

(i) Two recall experiments have shown that at least 4-5 cell placements can be made accurately on nearly all STVM trials. In contrast, the amount of information recalled is highly variable under LTVM conditions, and on a proportion of trials is at chance level

(Expts. 3a, 4a).

(ii) When STVM and LTVM recognition levels are equalized for one type of distractor (by manipulating display time), increasing the dissimilarity of targets and distractors has more effect on STVM than LTVM (Expt. 4b). This also suggests that the amount of information available to the subject is more variable under LTVM conditions.

(3) Coding in STVM and LTVM

When display time is manipulated to equalize performance under blocked STVM and LTVM conditions, there is evidence that STVM recognition is based on figural descriptions, while LTVM recognition relies more on semantic categorization and the registration of distinctive features (Expt. 5a).

(4) Response time differences in STVM, LTVM

STVM RTs in two-alternative forced-choice tests are shorter when responses are more accurate due to:

(a) longer display times (Expts. 4b, 6a, 6b, 8a, 8b)

(b) increased dissimilarity between target and distractor
(Expt. 4b)

or (c) differences in target encoding (Expts. 5a, 5b).

In contrast, LTVM response times are insensitive to differences in performance brought about by any of these manipulations.

Two other variables which were examined were expected to have differential effects on STVM and LTVM, but the results did not provide strong evidence for a dissociation. These were:-

(1) Recognition test time.

Decreasing the duration of a test pattern exposure from 2.0 to 0.3 sec has little or no effect on either STVM or LTVM (Expt. 8a). Further reductions in test time down to 60 msec give rise to qualitatively similar decreases in STVM and LTVM recognition performance (Expt. 8b). It is

possible that certain methodological improvements might reveal a dissociating effect of test time, but there is no evidence for such an effect in the present data.

(2) The effect of feedback on STVM and LTVM recall

It was anticipated that informative feedback provided during the recall of patterns should have beneficial effects under LTVM, but not STVM conditions. Although a significant interaction between feedback and interference conditions was obtained (Expt. 4a), the effects of feedback were not as predicted, and ceiling effects in STVM recall may have contributed to the interaction. Thus it is unclear if feedback has differential effects on STVM and LTVM.

We have seen that several original results of this thesis provide support for a dissociation between STVM and LTVM performance. In addition, some previous observations supporting the distinction have received confirmation:-

(1) Many experiments have shown that performance following an interference task lasting for only a few seconds is worse than performance after a short, unfilled retention interval. In a number of these experiments the retention interval was longer in the interference conditions. However, it is clear that interference is the important variable, since performance declines only very slowly over unfilled intervals (Phillips and Baddeley, 1971; Christie and Phillips, 1979), and clear differences are found when the filled and unfilled intervals are of equal duration (Expts. 3a, 4a).

(2) In recognition tests, STVM response times are typically shorter than LTVM RTs. This applies even when the mean recognition scores are the same under these two conditions (Expts. 4b, 5a, 6a, 7a, 8a, 8b).

(3) When items are presented in a series, followed by a probe recognition or completion test, there is a recency effect for the final item in the series. The recency effect is reflected in both accuracy and latency measures (Expts. 3d, 3e).

The dissociation of STVM and LTVM performance implies that there are distinct underlying mechanisms or processes. Consideration of the evidence provided in this thesis, and that reviewed in Chapter One leads to the view that STVM reflects an active maintenance process (visualization), while LTVM reflects acquisition processes enabling subsequent retrieval (memorization). The nature of these processes is discussed in the following sections. Other interpretations of the distinction of STVM and LTVM are possible, and some of these will be discussed in section 9.5.

9.2 The Nature of Visualization.

Several experiments reported here provide new information concerning the nature of visualization:

(1) The limited capacity of visualization.

(i) Two experiments made direct measures of the amount of information that can be recalled under STVM conditions. The estimated number of correct placements of filled cells in recall of a 4x4 pattern was 5.7 cells for relatively unpractised subjects (Expt. 3a), and 6.5 cells for highly practised subjects (Expt. 4a). These estimates must be qualified since (a) the display times were longer than required to form a visualized representation, (b) the retention intervals were relatively long (although this may not be critical for recall; cf. Christie and Phillips, 1979), and (c) the use of the light pen in recall may have generated considerable output interference. The number of correct placements varies considerably across patterns, but the results suggest that 4-5 cells can be recalled with high accuracy on almost every trial. Estimates of visualization capacity were also derived from asymptotic performance on recognition tests (Expt.6b), avoiding the objections raised against recall tests. For 4x4 patterns the estimated number of filled cells encoded was 5.0, and for 6x6 patterns the estimate was 5.27 cells. Although measures in terms of the number of cells

are specific to these materials, they suggest that there is a limit to the structural complexity of novel materials which can be visualized. This limit is reliable, and rather low - only simple patterns, or fragments of complex patterns, can be visualized.

(ii) A different limitation on visualization is the number of temporally discrete presentations that can be visualized at one time. All the evidence presented here (Expts. 3b, 3c, 3d, 3e) and elsewhere (e.g. Phillips and Christie, 1977a; Christie and Phillips, 1979) suggests that only the final attended item of a series can be visualized, irrespective of item complexity or spatial superposition. This appears contradictory to one role posited for visualization, namely that it integrates information over successive fixations. These studies suggest that it may be impossible to continue visualizing one aspect of a scene while engaging in close perceptual analysis of another part. In scene integration, other mechanisms may contribute, such as long-term knowledge in the form of schematic frames (Minsky, 1977). However, it is still possible that unrelated, serially presented patterns could be visualized together, given the appropriate incentives and conditions. More work is required in this area.

(2) Visualization as a voluntary control process.

Three observations from these experiments show that visualization is not a passive process which follows the stimulus offset, but is voluntary, occurring only when it is advantageous to do so, and dependent on the experimental context.

(i) When two items were presented in series, followed by probed recall of one item, recency effects were smaller than when a reverse serial order test was used (Expts. 3a, 3b).

(ii) STVM recognition of briefly exposed matrix patterns was lower in experiments involving complex procedures (Expts. 8a, 8b) than in simple tasks (e.g. Expt. 6b). This suggests that keeping track of the task

situation may compete for central processing resources that might otherwise be used for visualization.

(iii) There is a change in the degree of visualization, and/or in the type of information rehearsed, when interference may follow any presentation at random (Expt. 5b), compared to the case where presentation conditions are identical, but STVM trials are blocked (Expt. 5a). Strategies other than visualization may be more advantageous under randomized presentations, and these may be adopted to the exclusion of visualization.

(3) Coding in STVM.

Observations on the STVM recall of matrix patterns suggested that visualization was based on schematic descriptions, in agreement with a number of other experiments (e.g. Schnore and Partington, 1967). The experimental technique was intended to provide information about the grouping or 'chunking' of elements, but the method of recall used was unreliable. Subsequently, Bartram (1978) has shown that recall of matrix patterns is organized into 'chunks', determined largely by the proximity of elements.

Indirect evidence on coding comes from the experiments involving display time (Expts. 6a, 6b) and the consistency of performance over trials (Expts. 3a, 4a, 4b). These results show that visualized descriptions are computed rapidly, and have general application to all matrix patterns. This would be expected if low-level 'figural' descriptions are the basis of STVM performance. By 'figural', it is meant that the description specifies the stimulus configuration as a given spatial arrangement of shapes. This is similar to the usage of the term 'visual' coding (e.g. Posner, 1969). It does not imply that the code exists as persistent afferent information in the sensory pathways. (The contrasting idea of 'semantically' coded information involves a higher level of abstraction,

further removed from the physical parameters of the stimulus, and based on long-term knowledge.)

More direct evidence on STVM coding was provided by Experiment 5a. Patterns containing familiar shapes were recognized more accurately than patterns of equivalent complexity containing unfamiliar elements. This result suggests that familiar shapes may provide a schematic framework from which figural descriptions are constructed, the idea of schema-with-corrections. One implication of this is that visualization will be facilitated, and its capacity effectively increased if familiar materials are used. However, other interpretations of these results can be made, and more work is required to clarify the issue.

(4) Is visualizing an item equivalent to seeing the item displayed?

A recurrent question in psychology, which has recently been revived, concerns the relation between mental images and percepts. One viewpoint is that imagery constructs (or reconstructs) a picture which is then interpreted by the visual system in the same way that an external stimulus is perceived (cf. Pylyshyn, 1973; Anderson, 1978). The relation between mental imagery and visualization has not been discussed in this thesis, mainly for the pragmatic reason that performance on these tasks may not be closely related to phenomenological reports. However, some authors use the terms 'visualization' and 'imaging' interchangeably (e.g. Beech and Allport, 1978) and there is evidence that the same kinds of interference operate on both short-term visual memory and imagery tasks (e.g. Brooks, 1967; Margrain, 1967). It is therefore relevant to ask, within the context of this controversy, if visualization is equivalent to the extended perception of an event. If so, the effects of prolonging a display and the effect of extended visualization should be the same. Since LTVM increases significantly with increases of display time, but not with equivalent increases in time spent visualizing (Expt. 7a), this hypothesis

can be rejected. Visualizing an item is not the same as perceiving it.

9.3 Memorization.

(1) Coding.

Three results suggest that memorization of matrix patterns involves the construction of complex, semantically based representations:-

(i) LTVM recognition is sometimes based on the identity of a familiar element, rather than its precise configuration (Expts. 5a, 5b).

(ii) To obtain high LTVM performance, long display times are needed (Expts. 3d, 6a, 6b).

(iii) Subjects reported using strategies such as the interpretation of a matrix pattern as a scene, or the registration of informative details, both of which suggest a role for semantic information.

In addition, LTVM performance is more variable over trials than STVM (Expts. 4a, 4b). This is consistent with the hypothesis of semantic coding in LTVM, if it is assumed that some patterns are more amenable than others to this form of coding. For example, the familiar elements which occasionally are seen in matrix patterns may be readily encoded in LTVM.

No results presented in this thesis provide conclusive support for the view that purely figural descriptions can form the basis of LTVM recognition. Evidence from a number of other studies suggests that this is the case (e.g. Rock and Englestein, 1959; Bostrom, 1970; Rafnel and Klatzky, 1978). Figural descriptions may be less effective in the tasks used here, since these all used numerous presentations of matrix patterns with similar basic structures. Complex, semantic encodings may be necessary to create distinctive representations of such patterns in LTVM.

(2) Post-stimulus processing.

When display time is fixed and the onset of interference is

varied from 400 msec to 2.7 sec (Expt. 7a), LTVM does not vary with the available post-stimulus processing time. A similar absence of off time effects over the range 0.5 - 4.0 seconds was reported by Young (1974) and Phillips and Christie (1977a) using novel materials. In contrast, several experiments using natural scenes as materials have reported increased long-term recognition with post-stimulus processing (e.g. Tversky and Sherman, 1975).

From the results of Experiment 7a we cannot conclude that post-stimulus processing does not contribute to LTVM for matrix patterns. It is possible that any such processing is extremely slow, so that much longer off times would be required to show the effect. Another possibility is that some post-stimulus processing essential for LTVM takes place in a short interval after the stimulus offset.

Potter (1976), using natural scenes, proposed a 'consolidation' process requiring about 400 msec of additional processing time after scene identification. Her estimate of the time course of consolidation was based on indirect measurements, inferred from the growth of LTVM as a function of display time for strings of successive items. This estimate, therefore, refers to 'consolidation' occurring during the display time. More recent results by Intraub (1979, 1980) have shown that LTVM increases as a function of post-stimulus processing time when display time is fixed at 110 msec and the interval between successive items is increased from 0 msec to 1390 msec. Unfortunately, no post-stimulus mask was used in these experiments, so at least part of the increase may be attributed to visual persistence rather than post-stimulus processing. Both Potter (1976) and Intraub (1980) have compared memory for series of briefly presented pictures which are either (a) separated by relatively long (4.5 sec, 6.0 sec) mask-filled intervals, or (b) presented in immediate succession. Performance is much higher in the former condition, showing that some part of the inter-picture interval may be used for stimulus processing. Recent unpublished experiments

by Allan Mackenzie at Stirling have shown that LTVM increases when the mask-filled interval between pairs of briefly presented pictures varies between 50 msec and 500 msec. It is possible that a similar effect may also be found for novel materials, indicating post-stimulus processing for a short time after stimulus offset. If true, one plausible interpretation is that some refractoriness occurs in the processing of unrelated visual scenes. Once a description of the scene has been made, memorization requires a short period free from the interference provided by attention to a subsequent, to-be-remembered scene.

9.4 The Relation between Visualization and Memorization.

Several of the experiments carry implications for the relation between visualization and memorization. In particular, they show the contribution made by visualization to the acquisition of long-term visual memory, and also to long-term retrieval.

(1) Rejection of the modal model.

The essence of the modal model of memory is that there is a short-term store (STS) separate from the long-term store (LTS) and that information is transferred from STS to LTS. An explicit prediction is that transfer to LTS is linearly related to the length of time for which items are held in STS (Waugh and Norman, 1965; Atkinson and Shiffrin, 1968). Two results of this thesis reject the application of this model to visual memory.

(i) Display time has different, and quite unrelated effects on the performance levels of STVM and LTVM (Expt. 6a). In this instance it is possible to reconcile the data with the modal model, since the display time variable was confounded with total processing time. The modal model may be rescued by assuming that transfer from STVM to LTVM occurred partly during display time and partly during the interval from stimulus offset to

the start of interference. However, the second finding makes this explanation unlikely.

(ii) In Experiment 7a, patterns were shown for a duration long enough to establish an accurate STVM description, followed by an extended off time. Despite evidence that the visualized information was available up to 3.5 seconds after stimulus offset, no increase in LTVM was observed as a function of the duration of extended visualization, although equivalent increases in display time had large effects.

(2) Recoding of visualized information.

Atkinson and Shiffrin (1968) proposed that information transfer from STS to LTS could also come about by recoding of information. Such a theory can explain the differences in coding found between STVM and LTVM, but it cannot explain why prolonged visualization does not give rise to an increase in LTVM. Section 9.5 offers an explanation which accounts for both these findings.

(3) Do STVM descriptions mediate long-term recognition tests?

Although LTVM performance requires comparatively long display times, it is not disrupted when the duration of a recognition test pattern is reduced to 300 msec (Expts. 8a, 8b). This value is just sufficient for the construction of an STVM description (Expts. 6a, 6b). This finding, which requires confirmation, has two implications:-

(i) The encoding operations made during presentation do not have to be repeated in their entirety during recognition.

(ii) While visualization cannot provide the basis for constructing long-term representations, it may be useful for maintaining information during memory search.

However, the result is tentative, in view of (a) the methodological deficiencies of the experiments, and (b) the fact that only

performance correlates of test time were used to infer the nature of the test probe representation.

9.5 Information-processing Considerations: A Synthesis.

One aim of this thesis was to contribute towards an information-processing account of visual memory. Ultimately, this would describe the types of representation on which visual memory is based, and the sequence of operations acting on these representations. However, recent theoretical arguments advanced by J.R. Anderson (1976, 1978) maintain that it is in principle impossible to determine both representations and processes, based on purely behavioural (i.e. input and output) data. Despite this, progress can be made by eliminating some information-processing models that do not appear to hold. The modal and recoding models discussed in the previous section are two such examples.

The evidence reviewed in Chapter One, together with several findings of this dissertation (section 9.1), supports the functional dissociation of short-term and long-term visual memory. On this basis the one-component theory of memory, which interprets differences between STM and LTM as due to different stages or states in the history of a single trace, can be rejected. On the same grounds, the theory that STM is nothing more than a currently activated subset of nodes in LTM (e.g. Kroll, 1975) must also be rejected. If this were true, for example, we should expect a proportionate increase in the activated and deactivated (LTVM) nodes when a variable such as display time is manipulated.

However, this functional dissociation should not be taken to imply that there are two separate information stores, specific to STVM and LTVM. It shows that some independent structures, procedures or representations are involved in STVM and LTVM. These differences could originate during the storage, retrieval or encoding stages, or may result from interactions between these stages. The adequacy of models which account for the

STVM/LTVM distinction entirely in terms of storage, retrieval or encoding differences are discussed below.

(i) Storage. The difference between STVM and LTVM performance may be explained in terms of two passive stores with independent inputs. In this account, STVM depends on a labile, limited-capacity store with rapid input processes, whose contents are displaced by interference, and which may show spontaneous decay over long, unfilled intervals. In contrast, LTVM is a permanent store, capable of holding an indefinitely large amount of information, but with a slow rate of input. This view faces the problem that STVM performance does not seem to be governed by a fixed storage parameter, such as rate of decay, but depends on a control process. The differences in coding between STVM and LTVM also have to be accounted for.

(ii) Retrieval. There is prima facie evidence that retrieval differences exist between STVM and LTVM conditions. In the former case items are kept in mind by visualization and presumably do not need to be retrieved. This is supported by the fact that STVM response times are shorter than those found in LTVM. However, no evidence presented here unequivocally shows that the performance differences between STVM and LTVM arise from retrieval failure in LTVM. If anything, the correspondence between performance using recognition and recall tests, the similar effects of test time on STVM and LTVM performance, and the failure to improve LTVM recall by providing retrieval cues suggest that acquisition or storage is deficient in LTVM. Moreover, direct evidence against the idea that retrieval in LTVM is all-or-none was provided by Experiment 4a. This leads to the suggestion that visualization actively maintains novel visual information, it does not merely make it temporarily accessible.

(iii) Coding. The underlying assumption here is that there is a single store, and the durability of the stored information depends on the type of description used. Rapidly constructed, low-level descriptions

will decay quickly, and so contribute only to STVM; more complex, 'deeper' encodings may withstand the effects of interference and form the basis of LTVM. This theory accounts well for the observations on encoding strategies (Expts. 3d, 5a), which suggest that LTVM may rely to a large extent on 'semantic' or more elaborate encoding. In addition, if we assume that some deeper-level descriptions can be rapidly applied to some items then this accounts for differences in the distribution of information across trials in STVM and LTVM (Expts. 4a, 4b). However, not all the differences between STVM and LTVM performance can be satisfactorily explained in terms of coding alone. First, it has been repeatedly shown that low-level, figural descriptions may be relatively permanent (cf. section 9.3; also Kolers, 1977). Secondly, much evidence has been presented which shows that STVM does not have a fixed rate of decay, but can be maintained indefinitely in the absence of interference.

A recent revision of levels of processing theory claims that elaborated processing is required to increase the 'distinctiveness' of items recorded in episodic memory (Craik and Jacoby, 1979). This may explain why certain low-level encodings are stable over long periods for some kinds of presentation but not others. However, the notion of distinctiveness is vague, as indeed is the concept of 'levels' of processing, and independent measures of these constructs are difficult to obtain.

Final Synthesis.

The distinction between STVM and LTVM performance is not adequately explained in terms of differences arising at any one of the encoding, storage or retrieval stages. More complex interactions between these stages could account for the results, but an alternative approach emphasises what is known of the acquisition processes.

From the evidence presented here and elsewhere, visualization appears to involve active maintenance of what are essentially figural

descriptions of presented stimuli, in which elements are grouped into fragments of the total pattern, and familiar elements from long-term memory may provide a schematic framework. Such descriptions are rapidly constructed, up to a limit imposed by visualization capacity, and can be applied to all novel patterns. Since visualization is a voluntary process, performance which is based on it does not decline at a fixed rate, and is influenced by the type of task, the task context and the relative benefits of using this strategy. One such benefit, apart from increased accuracy, is the readiness to respond at test, which leads to short response times. In contrast, memorization of these patterns requires more complex and elaborate encoding processes, leading to performance which is more variable over trials, and has an extended requirement for display time.

After stimulus offset, visualization of an item may continue, but LTVM will show little, if any, improvement as a result of prolonged visualization. One plausible reason for this inability to construct memorized representations from STVM is that the elaborative encoding processes required for memorization compete for the central processing resources required for visualization.

The evidence presented in this dissertation suggests there are (at least) two classes of visual representation. One type consists of limited-capacity descriptions of general applicability, which are rapidly constructed, maintained throughout the immediate situation, and may only be available in that situation. The second type of representation takes longer to acquire, may be more elaborate, and more dependent on previous long-term knowledge, so that it is less generally applied to novel configurations. This type of representation does not have to be actively maintained, and can be retrieved from the psychological past.

TABLE 2.

Mean STVM Recall of 32 Randomly-Generated Matrix
Patterns. Data from Experiment 3a.

Odd Patterns (Group B)			Even Patterns (Group A)		
No.	Percent Cells Correct	S.E.	No.	Percent Cells Correct	S.E.
1	95.8	2.6	2	86.7	4.6
3	74.2	4.6	4	89.2	3.0
5	85.0	3.7	6	81.7	6.4
7	92.5	3.2	8	84.2	4.6
9	69.2	3.0	10	85.8	2.4
11	86.7	4.5	12	97.5	1.8
13	95.0	2.0	14	90.0	3.3
15	73.3	5.4	16	86.7	3.6
17	79.2	5.8	18	85.8	3.8
19	78.3	3.6	20	75.8	5.2
21	95.8	2.9	22	93.3	3.0
23	86.7	4.6	24	83.3	4.7
25	76.7	3.6	26	89.2	6.9
27	85.8	2.4	28	100	0
29	87.5	4.9	30	98.3	1.1
31	90.8	3.6	32	85.8	4.7

APPENDIX A

TABLE 3

Percent Correct Recognition as a Function of Interference,
Display Time and Test Time. Data of Experiment 8a.

Display Time (msec)	SHORT-TERM				LONG-TERM			
	80	80	600	600	80	80	600	600
Test Duration (msec)	300	2000	300	2000	300	2000	300	2000
Subject								
1	75	65	85	100	55	65	70	90
2	75	65	95	95	70	65	80	70
3	45	65	90	95	45	25	70	55
4	30	55	95	100	40	50	70	80
5	70	40	80	85	35	40	65	80
6	60	70	90	90	55	55	50	70
7	60	55	90	95	55	60	75	65
8	65	70	85	100	60	50	75	65
Mean	60	60.625	88.75	95	51.875	51.25	69.375	71.875
S.E.	5.51	3.59	1.83	1.89	4.00	4.79	3.19	3.89

APPENDIX A

Individual Subject Data Referred to in Text.

TABLE 1.

Percent Correct Recognition as a Function of Display

Condition and d. Data of Experiment 4b.

Display Condition	STVM ₁₀₀		STVM ₄₀₀		LTVM ₁₀₀		LTVM ₄₀₀	
	<u>d</u> 2	6	2	6	2	6	2	6
Subject								
1	75	85	95	100	45	35	70	70
2	75	95	90	100	50	55	65	70
3	80	90	95	100	50	75	80	80
4	90	95	100	100	70	75	75	75
5	70	100	95	100	55	55	85	80
6	95	100	95	100	75	80	80	95
7	70	60	95	95	40	50	70	85
8	75	90	95	100	75	60	90	85
Mean	78.8	89.4	95	99.4	57.5	60.6	76.9	80
S.E.	3.2	4.6	0.9	0.6	4.9	5.4	3.0	3.0

APPENDIX B

The Construction of the Stimulus Patterns for
Experiments 5a, 5b.

The aim in designing these materials was to create a set of targets and distractors where the visual properties (such as figural complexity and the target/distractor difference) were carefully controlled, and familiarity of one element in the pattern was varied independently. Letter shapes were used as the familiar elements since these are highly overlearned, and relatively simple.

(1) Construction of the critical shapes.

A number of upper- and lower-case letters were selected, and used to make up the critical shapes. These letters were those which could, to a first approximation be faithfully reproduced by filling the cells of a 6x6 matrix. Curvilinear letters in the main were excluded, as were closed letters, and letters like 'E' and 'S' which would occupy a large part of the matrix. The letters chosen to make up the critical shapes were C, F, H, h, J, L, n, T, t, u, Y and Z. Clearly some of these cannot be represented in a square cell matrix format without distortion, but it was hoped that all the shapes would resemble their parent letters closely enough to be readily identifiable.

The second stage involved the construction of families of matched critical shapes, V_1, V_2, N_1, N_2 , each based on one letter. From the original shape (V_1), the shapes V_2 and N_1 were constructed by the addition or deletion of a single cell, as outlined in the text. N_2 was constructed by changing N_1 by one cell, so that V_1 and N_2 had the same area. Thirty-two sets of critical shapes were made up in this way, with a number of constraints. For half the sets V_2 and N_1 had one more cell than V_1 and N_2 ; in the remainder, V_2 and N_1 were constructed from V_1 by the deletion of a cell. Thus, averaged over all the sets of patterns, the size and

complexity of the four types of critical shape did not vary. The sizes of these critical shapes varied between four and nine filled cells.

Thirty-two sets of critical shapes were made up in this way, each consisting of a V_1, V_2, N_1 and N_2 shape constructed by the above procedure. Some shapes occurred in more than one set; in all 114 different shapes were used.

(2) Construction of the pattern sets.

The final stage in the construction of the stimulus sets was to generate a set of unique matrix patterns containing them. This was done by embedding the critical shapes in a random background within the 6x6 matrix, so that the total number of filled cells varied between 17 and 19. Three factors were taken into account: the location of the critical shapes within the matrix, the complexity of the background, and the relation of the critical shape to the background. Each set of four critical shapes was used in two different locations within the 6x6 matrix. The precise locations depended to some extent on the shapes themselves, since they imposed severe limits on the possible backgrounds. Care was taken to ensure that over all the stimulus sets the critical shapes were distributed evenly in each quadrant of the pattern. The complexity of the background was determined by the number of separate blocks (areas of contiguous filled cells) within the patterns. The critical shapes themselves constituted one such block, and backgrounds were constructed such that the total number of blocks in the pattern varied from three to five. This procedure has the advantage that it restricts the complexity of the overall pattern, so that the memory load is not too far above visualization capacity; it also prevents a grossly uneven distribution of block sizes within the pattern. Finally, the relation between the critical shapes and the background was limited by three constraints: no cell of the background was contiguous with any cell of any of the critical shapes, no repetition of any critical shape or letter could occur within a

pattern, and no change of a critical shape should enclose an area within the pattern as a whole. The final constraint was imposed because enclosed areas within a pattern are very salient. Thus if the critical shape of one test alternative enclosed a part of the pattern which was not enclosed by the other, a judgment could be made on this basis. A decision of this kind could be made without describing the critical shape, so all instances of such enclosures were excluded from the pattern set.

Generation of the pattern set was accomplished with the aid of a computer program. Using the light pen facility, each critical shape of a set was drawn in a specified location of a blank 6x6 matrix. The union of these shapes was computed, and a background was generated which consisted of 2-4 blocks, and was not contiguous with any cells of the union of the critical shapes. Each pattern in the set (critical shape plus the common background) was then displayed, and the entire set was rejected or accepted according to the criteria listed above. If rejected, a new background was generated, and the test sequence began again. Two acceptable backgrounds were generated for each set of critical shapes drawn in one location within the matrix. The entire procedure was repeated with the critical shapes drawn in a different location. Thus the 32 original sets of critical shapes were expanded into 128 pattern sets, which were the stimuli used in Experiments 5a, 5b.

APPENDIX C

Validation of the Critical Shapes.

The critical shapes used in the experiments of Chapter Five were originally constructed by the author, but clearly the interpretation of the results depends on the interpretation of the shapes by the experimental subjects. A survey was conducted to find out how the critical shapes were interpreted by a sample of naive subjects drawn from a population similar to the experimental subjects. Ideally, this type of survey should have been used to improve the stimulus set. Unfortunately, lack of time would not allow this, and the survey data were obtained at the same time that the experiments were run. The purpose of the survey was to validate the stimulus materials used, by measuring the extent of the agreement between the experimenter's and subjects' classification of the critical shapes.

The questionnaire was distributed to two samples of subjects. Thirty-nine were third-year psychology undergraduates, most of whom had participated at some time in experiments involving memory for random matrix patterns. The remaining twenty-five subjects were recruited from the Part I subject panel, and were therefore drawn from the same source as the subjects in Experiments 5a and 5b. All subjects participating in the experiment were excluded from the survey.

The questionnaire presented subjects with all 114 critical shapes, in a random order, displayed in the form of outline drawings. Each critical shape was reproduced as an outline drawing with a unit cell size of 5mm. The shapes were arranged as an array of four columns and eight rows on sheets of white, A4 paper. Alongside each shape was a short, horizontal line, on which the subject wrote his response. Subjects were instructed to examine each shape briefly, and indicate if it looked like a letter of the alphabet by writing the capital form of the letter alongside,

or by writing a dash if it did not resemble any letter. All subjects were given the critical shapes in the same order. Some subjects were given the questionnaire in groups, and others were tested individually.

For each critical shape the percentage of subjects giving each type of response was calculated. The variability in responses was quite small. No shape elicited more than six different responses. Typically, only one or two common responses were observed for any shape, the remainder (if any) being aberrant classifications by a few subjects. Generally, there was good agreement between the subjects' ratings and the experimenter's intended classification, although there were discrepancies. Details of the agreement between the survey ratings and the experimenter's classification can be found in Tables 5.2 and 5.3 (pages 124 and 125).

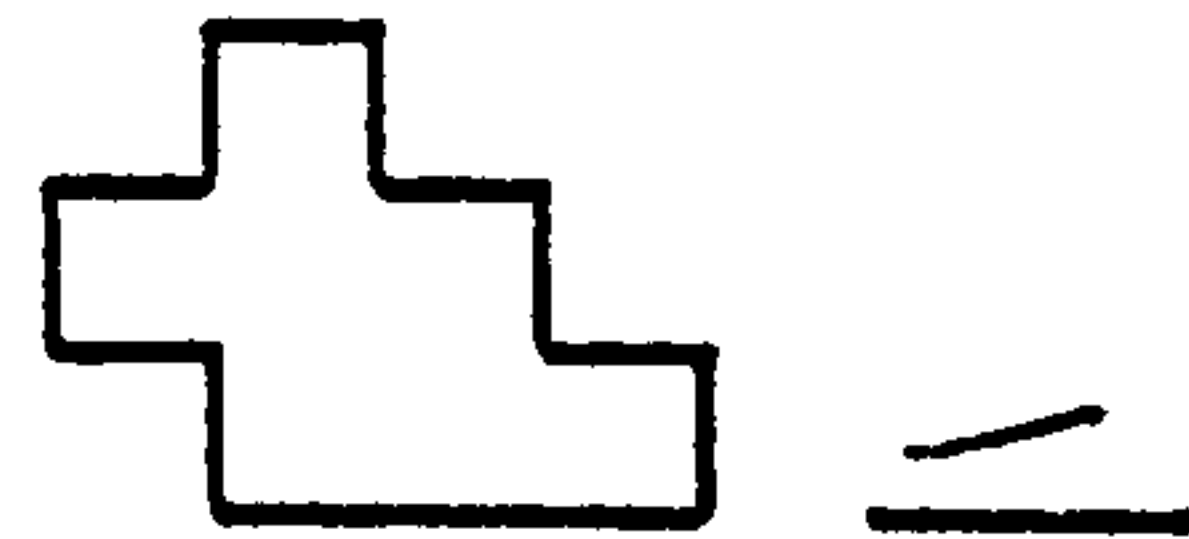
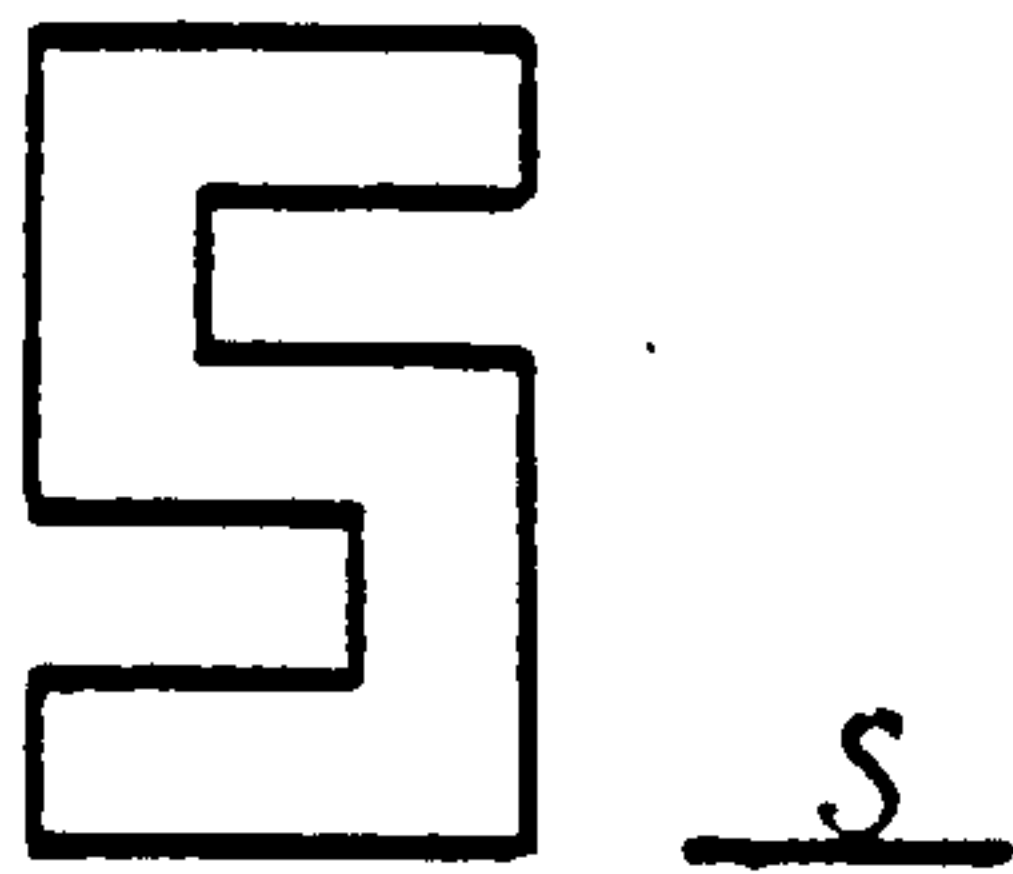
The instructions to the subjects and the layout of stimuli are given in the following facsimile of the questionnaire.

Instructions.

On each of the following pages there are a number of outline figures, and to the bottom right of each one there is a short line on which to write your answers. Your task is to decide quickly if each of the outline figures resembles a letter of the alphabet. If it does, then write the letter IN BLOCK CAPITALS on the line alongside the figure.

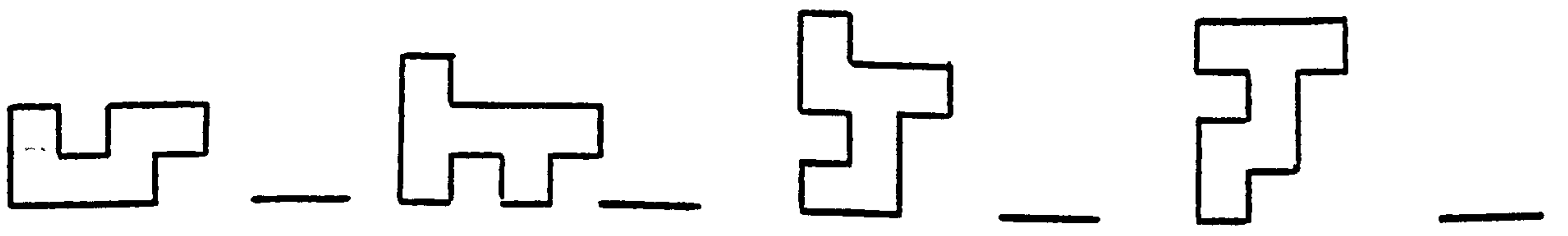
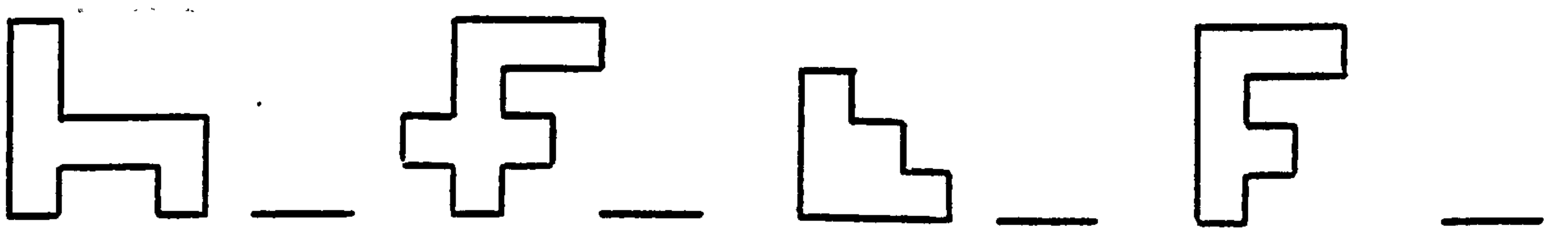
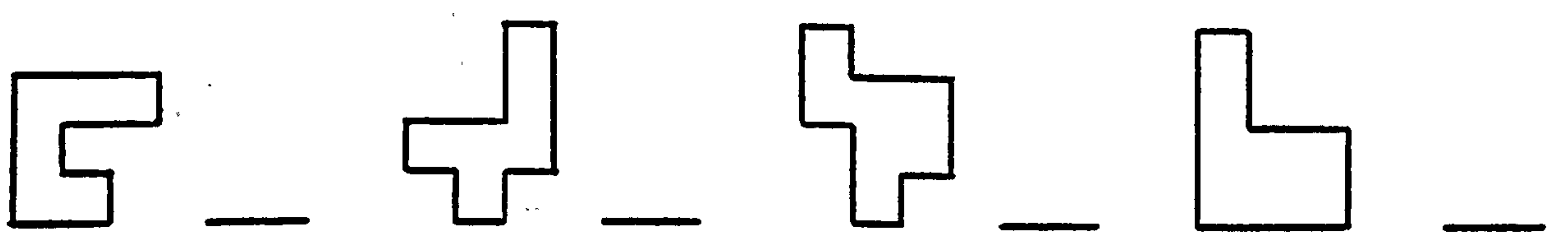
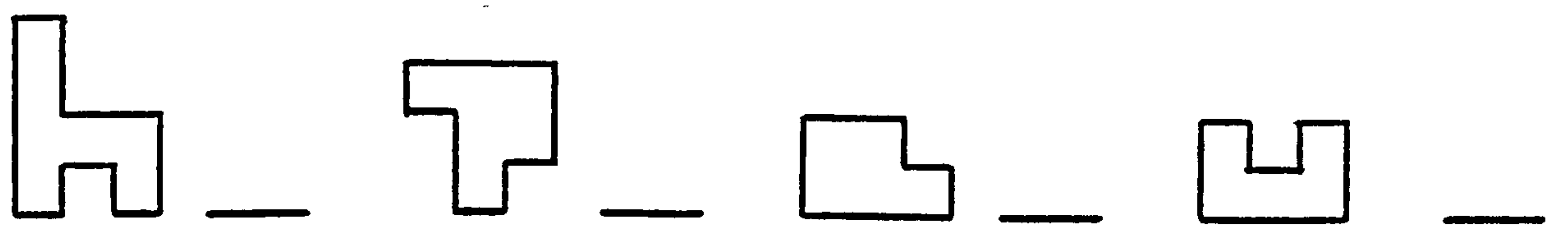
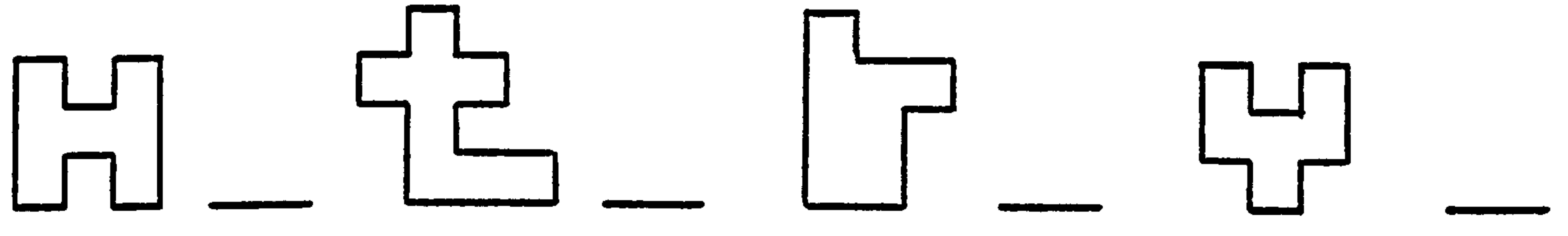
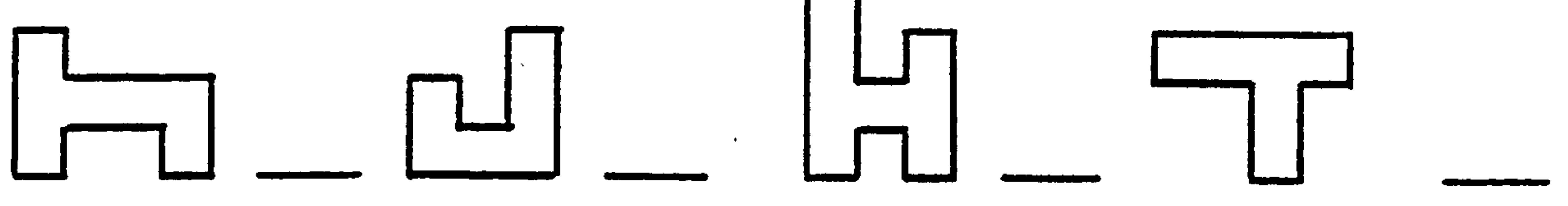
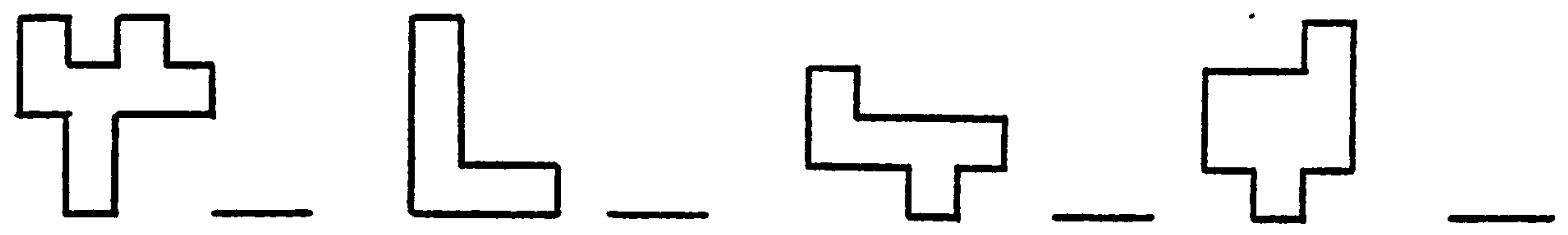
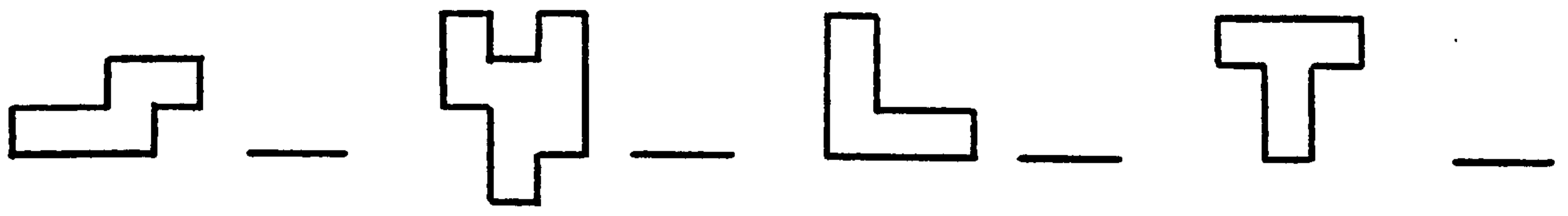
If it does not look like any letter of the alphabet, then put a dash alongside, so that I know you have examined that shape.

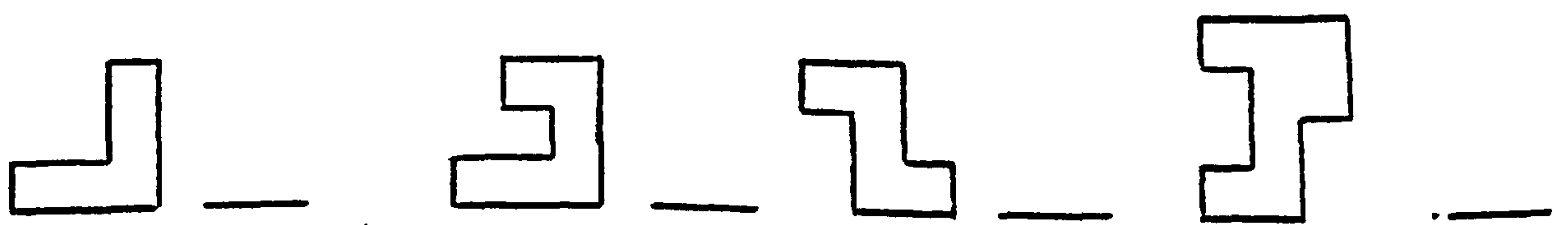
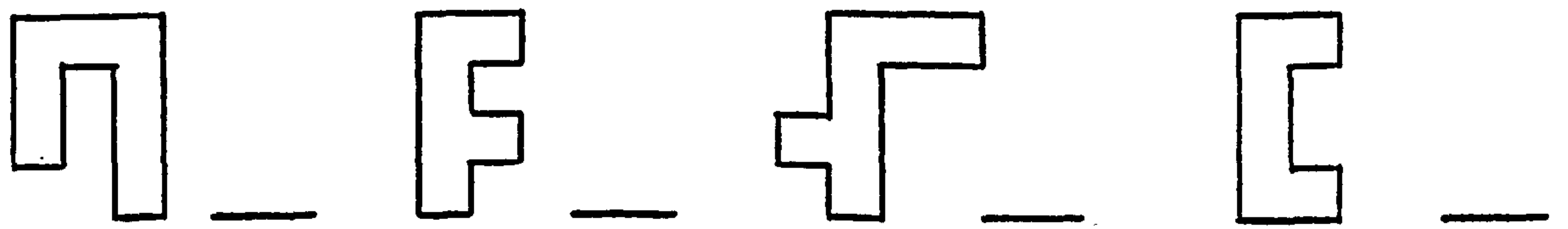
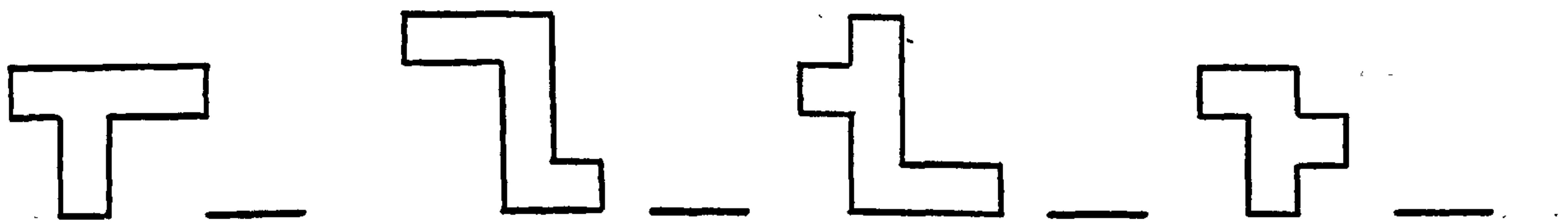
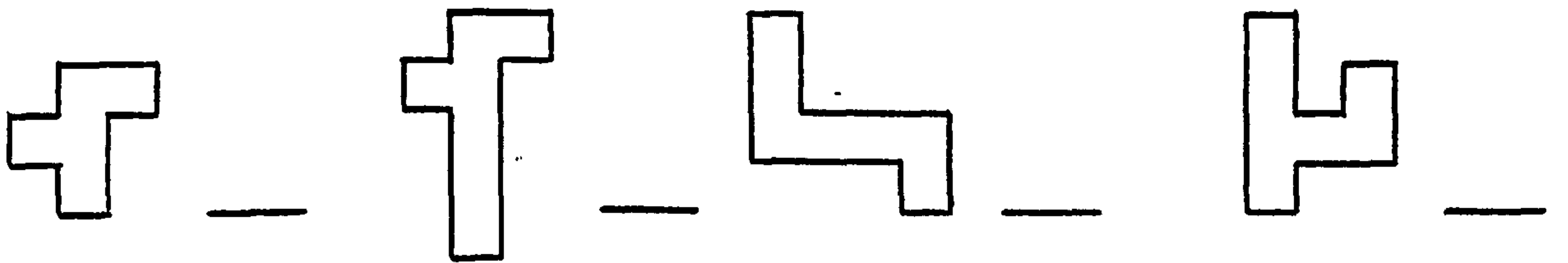
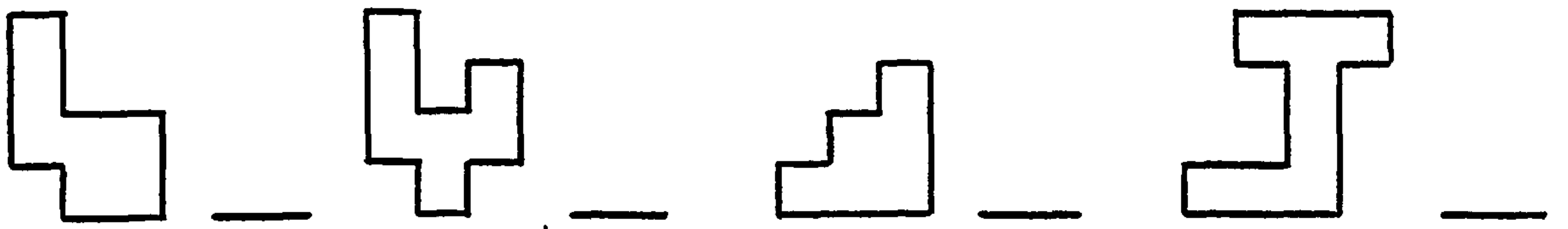
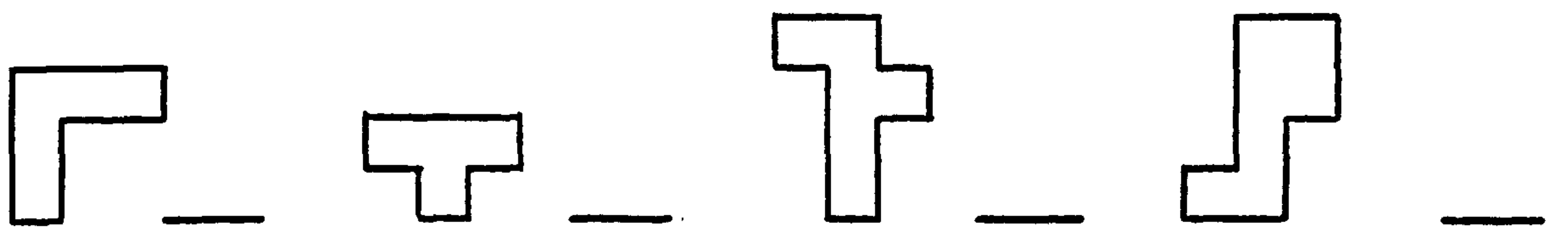
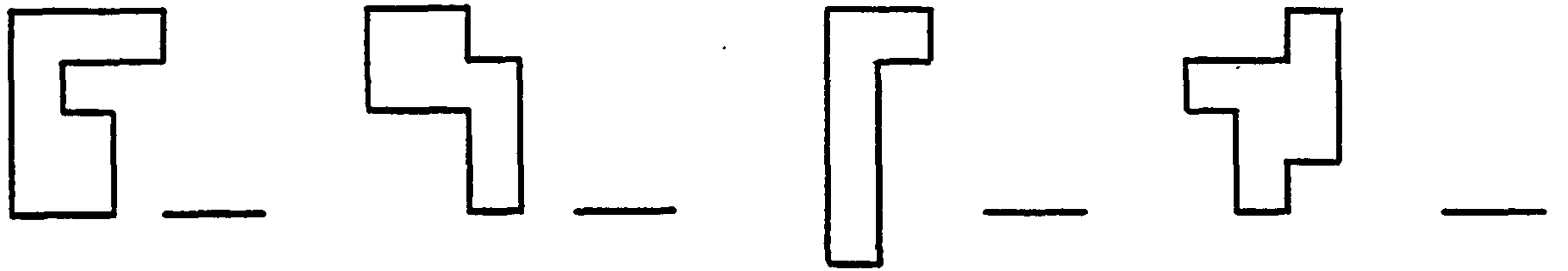
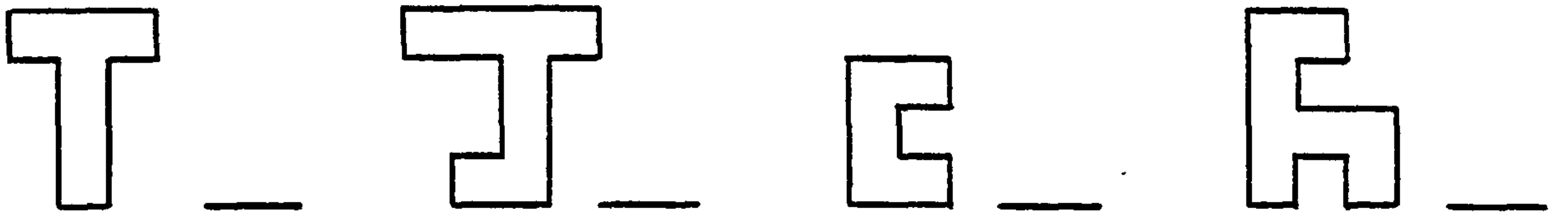
For example:



Please make sure that you look at each figure in the correct orientation. The page number should be at the top right, and you should look at each figure without tilting or rotating the page in any way. You can work along each row or down each column, the order does not matter so long as you do not miss any out. Do not look back or "correct" any of your previous answers. It is your first impressions that are important.

It is essential that you do this quickly. Look closely at each figure for about one second, and on no account for more than two seconds. If in that time the shape suggests a letter then write it in. If not, then put a dash, as in the examples above.





BIBLIOGRAPHY

- Adamowicz, J.K., & Hudson, B.R. (1978) Visual short-term memory, response delay, and age. Perceptual and Motor Skills, 46, 267-270.
- Allport, D.A. (1968) The rate of assimilation of visual information. Psychonomic Science, 12, 231-232.
- Allport, D.A. (1977) On knowing the meaning of words we are unable to report: the effects of visual masking. In Dornic, S. (Ed.). Attention and Performance VI. Hillsdale, NJ: Erlbaum.
- Anderson, J.R. (1976) Language, Memory and Thought. Hillsdale, NJ: Erlbaum.
- Anderson, J.R. (1978) Arguments concerning representations for mental imagery. Psychological Review, 85, 249-277.
- Anderson, R.E. (1976) Short-term retention of the where and when of pictures and words. Journal of Experimental Psychology: General, 105, 378-402.
- Atkinson, R.C. & Shiffrin, R.M. (1968) 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. New York: Academic Press.
- Attneave, F. (1954) Symmetry, information and memory for patterns. American Journal of Psychology, 68, 209-222.
- Baddeley, A.D. (1966a) The influence of acoustic and semantic similarity on long-term memory for word sequences. Quarterly Journal of Experimental Psychology, 18, 302-309.
- Baddeley, A.D. (1966b) Short-term memory for word sequences as a function of acoustic, semantic and formal similarity. Quarterly Journal of Experimental Psychology, 18, 362-365.
- Baddeley, A.D. (1976) The Psychology of Memory. New York: Basic Books.

- Baddeley, A.D. (1978) The trouble with levels: a re-examination of Craik and Lockhart's framework for memory research. Psychological Review, 85, 139-152.
- Baddeley, A.D. & Hitch, G. (1977) Recency re-examined. In Dornic, S. (Ed.), Attention and Performance VI. Hillsdale, NJ: Erlbaum.
- Baddeley, A.D., Grant, S., Wight, E. & Thomson, N. (1974) Imagery and visual working memory. In Rabbitt, P.M.A., & Dornic, S. (Eds.) Attention and Performance V. London: Academic Press.
- Baddeley, A.D., & Lieberman, K. (1978) Spatial working memory. In Requin, J. (Ed.). Attention and Performance VII, Hillsdale, NJ: Erlbaum.
- Baddeley, A.D., & Warrington, E.K. (1970) Amnesia and the distinction between long-term and short-term memory. Journal of Verbal Learning and Verbal Behavior, 9, 176-189.
- Baird, H.P. & Boucher, B. (1968) Retention of visual and verbal codes of the same stimuli. Journal of Experimental Psychology, 78, 417-422.
- Bartram, D.J. (1978) Post-iconic visual storage: chunking in the reproduction of briefly displayed visual patterns. Cognitive Psychology, 10, 324-355.
- Beech, J.R., & Allport, D.A. (1979) Visualization of compound scenes. Perception, 7, 129-138.
- Bernbach, H.A. (1975) Rate of presentation in free recall: a problem for two-stage memory theories. Journal of Experimental Psychology: Human Learning and Memory, 1, 18-22.
- Bevilacqua, L., Capitani, E., Luzzatti, C., & Spinnler, H.R. (1979) Does the hemisphere stimulated play a specific role in delayed recognition of complex abstract patterns? A tachistoscopic study. Neuropsychologia, 17, 93-97.
- Bisiach, E., & Faglioni, P. (1974) Recognition of random shapes by patients with unilateral lesions as a function of complexity, association value and delay. Cortex, 10, 101-110.

- Bjork, R.A., & Whitten, W.B. (1974) Recency-sensitive retrieval processes. Cognitive Psychology, 6, 173-189.
- Boies, S.J. (1969) Rehearsal of visual codes of single letters. Unpublished masters thesis, University of Oregon.
- Bostrom, A.G. (1970) Memory for form: the effects of memory for verbal labels and label quality. Unpublished Ph.D. thesis, Stanford University.
- Bower, G.H. (1967) A multi-component theory of the memory trace. In Spence, K.W., & Spence, J.T. (Eds.). The Psychology of Learning and Motivation: Advances in Research and Theory, Vol. 1. New York: Academic Press.
- Bower, G.H., & Glass, A.L. (1976) Structural units and the redintegrative power of picture fragments. Journal of Experimental Psychology: Human Learning and Memory, 2, 456-466.
- Bower, G.H., Karlin, M.B., & Dueck, A. (1975) Comprehension and memory for pictures. Memory and Cognition, 3, 216-221.
- Broadbent, D.E., (1958) Perception and Communication. London: Pergamon.
- Brooks, L.R. (1967) The suppression of visualization by reading. Quarterly Journal of Experimental Psychology, 19, 289-299.
- Brooks, L.R. (1968) Spatial and verbal components of the act of recall. Canadian Journal of Psychology, 22, 349-368.
- Bruce, V. (1977) Processing and remembering pictorial information. Unpublished Ph.D. thesis, Cambridge University.
- Cermak, G.W. (1971) Short-term recognition memory for complex free-form figures. Psychonomic Science, 25, 209-211.
- Cermak, G.W. (1977) Performance in a delayed comparison discrimination task as a function of stimulus interpretation. Perception and Psychophysics, 21, 69-76.
- Christie, D.F.M., & Phillips, W.A. (1979) Simple drawing and pattern completion techniques for studying visualization and long-term visual knowledge. Memory and Cognition, 7, 360-367.

- Clark, H.J. (1968) Random shape recognition at brief exposure durations. Psychonomic Science, 12, 245-6.
- Cohen, G. (1972) Serial position effects in the recall of picture sequences. Quarterly Journal of Experimental Psychology, 24, 41-47.
- Cohen, G. (1977) The Psychology of Cognition. London: Academic Press.
- Cohen, R.L., & Granstrom, K. (1970) Reproduction and recognition in short-term visual memory. Quarterly Journal of Experimental Psychology, 22, 450-457.
- Coltheart, M. (1972) Visual information processing. In Dodwell, P. (Ed.). New Horizons in Psychology: 2. Harmondsworth, Middlesex: Penguin.
- Conrad, R. (1964) Acoustic confusion in immediate memory. British Journal of Psychology, 55, 75-84.
- Cooper, L.A., & Podgorny, P. (1976) Mental transformations and visual comparison processes: Effects of complexity and similarity. Journal of Experimental Psychology: Human Perception and Performance, 2, 503-514.
- Cooper, L.A., & Shepard, R.N. (1973) Chronometric studies of the rotation of mental images. In Chase, W.G. (Ed.), Visual Information Processing. New York: Academic Press.
- Craik, F.I.M. (1968) Two components in free recall. Journal of Verbal Learning and Verbal Behavior, 7, 996-1004.
- Craik, F.I.M., & Jacoby, L. (1979) Elaboration and distinctiveness in episodic memory. In Nilsson, L.G. (Ed.). Perspectives on Memory Research. Hillsdale, NJ: Erlbaum.
- Craik, F.I.M., & Lockhart, R.S. (1972) Levels of processing: a framework for memory research. Journal of Verbal Learning and Verbal Behavior, 11, 671-684.
- Crowder, R.G. (1976) Principles of Learning and Memory. Hillsdale NJ: Erlbaum.
- Dale, H.C.A. (1973) Short-term memory for visual information. British Journal of Psychology, 64, 1-8.

- Dee, H.L., & Fontenot, D.J. (1973) Cerebral dominance and lateral differences in perception and memory. Neuropsychologia, 11, 167-173.
- De Luca, D., Cermark, L.S. & Butters, N. (1975) An analysis of Korsakoff patients' recall following varying types of distractor activity. Neuropsychologia, 13, 271-279.
- Den Heyer, K., Ryan, B., & MacDonald, J. (1976) The relationship between structural stimulus complexity and clarity of iconic storage under a backward masking paradigm. Acta Psychologica, 40, 189-198.
- Deregowski, J.B. (1978) The role of symmetry in pattern reproduction. British Journal of Psychology, 69, 217-224.
- De Renzi, E. (1968) Nonverbal memory and hemispheric side of lesion. Neuropsychologia, 6, 181-189.
- De Renzi, E., Faglioni, P., & Previdi, P. (1977) Spatial memory and hemispheric locus of lesion. Cortex, 13, 424-433.
- De Renzi, E., Faglioni, P. & Villa, P. (1977a) Sequential memory for figures in brain-damaged patients. Neuropsychologia, 15, 43-49.
- De Renzi, E., Faglioni, P., & Villa, P. (1977b) Topographical amnesia. Journal of Neurology, Neurosurgery and Psychiatry, 40, 498-505.
- De Renzi, E., & Nichelli, P. (1975) Verbal and non-verbal short-term memory impairment following hemispheric damage. Cortex, 11, 341-354.
- De Renzi, E., Spinnler, H. (1966) The influence of verbal and non-verbal defects on visual memory tasks. Cortex, 2, 322-335.
- Dimond, S.J., & Beaumont, J.G. (Eds.) (1974) Hemisphere Function in the Human Brain. London: Elek Books.
- Dricker, J., Butters, N., Berman, G., Samuels, I., & Carey, S. (1978) The recognition and encoding of faces by alcoholic, Korsakoff and right hemisphere patients. Neuropsychologia, 16, 683-695.
- Egan, D.E., & Schwartz, B.J. (1979) Chunking in recall of symbolic drawings. Memory and Cognition, 7, 149-158.

- Eichelman, W.H. (1970) Stimulus and response repetition effects for naming letters at two response-stimulus intervals. Perception and Psychophysics, 7, 94-96.
- Erdeiyi, M.H. (1970) Recovery of unavailable perceptual input. Cognitive Psychology, 1, 99-113.
- Feuge, R.L., & Ellis, H.C. (1969) Generalization gradients in recognition memory of visual form: The role of stimulus meaning. Journal of Experimental Psychology, 79, 288-294.
- Fontenot, D.J. (1973) Visual field differences in the recognition of verbal and nonverbal stimuli in man. Journal of Comparative and Physiological Psychology, 85, 564-569.
- Frith, C.D. (1978) The subjective properties of complex visual patterns. In Leenwenberg, E.L.J., & Buffart, H.F.J.M. (Eds.). Formal Theories of Visual Perception. New York: Wiley.
- Frost, N. (1972) Encoding and retrieval in visual memory tasks. Journal of Experimental Psychology, 95, 317-326.
- Gaffan, D. (1978) Measurement of trace strength in memory for pictures. Quarterly Journal of Experimental Psychology, 30, 263-281.
- Gainotti, G., Caltagirone, C., & Miceli, G. (1978) Immediate visual-spatial memory in hemisphere damaged patients: Impairment of verbal coding and of perceptual processing. Neuropsychologia, 16, 501-507.
- Garner, W.R. (1974) The Processing of Information and Structure. Hillsdale, NJ: Erlbaum.
- Gazzaniga, M.S. (1970) The Bisected Brain. New York: Appleton-Century Crofts.
- Glanzer, M., & Clark, W.H. (1963) The verbal loop hypothesis: Binary numbers. Journal of Verbal Learning and Verbal Behavior, 2, 301-309.
- Glanzer, M., & Clark, W.H. (1964) The verbal loop hypothesis: Conventional figures. American Journal of Psychology, 77, 621-626.

- Glanzer, M. & Cunitz, A. (1966) Two storage mechanisms of free recall. Journal of Verbal Learning and Verbal Behavior, 5, 351-360.
- Goldstein, A.G. & Chance, J. (1974) Some factors in picture recognition memory. Journal of General Psychology, 90, 69-86.
- Gombrich, E.H. (1977) Art and Illusion. Oxford: Phaidon.
- Gould, J.D. (1976) Looking at pictures. In Monty, R.A., & Senders, J.W. (Eds.), Eye Movements and Psychological Processes. Hillsdale, NJ: Erlbaum.
- Growney, R. (1978) Metacontrast as a function of the spatial frequency composition of the target and mask. Vision Research, 18, 1117-1123.
- Gruneberg, M.M. (1970) A dichotomous theory of memory - unproved and unprovable? Acta Psychologica, 34, 489-496.
- Haber, R.N. & Standing, L. (1970) Direct estimates of the apparent duration of a flash. Canadian Journal of Psychology, 24, 216-229.
- Haber, R.N. & Erdelyi, M.H. (1967) Emergence and recovery of initially unavailable perceptual material. Journal of Verbal Learning and Verbal Behavior, 6, 618-628.
- Healy, A.F. (1975) Coding of temporal-spatial patterns in short-term memory. Journal of Verbal Learning and Verbal Behavior, 14, 481-495.
- Henderson, L. (1972) Visual and verbal codes: Spatial information survives the icon. Quarterly Journal of Experimental Psychology, 24, 439-447.
- Herrick, R.M. (1956) Foveal luminance discrimination as a function of the duration of the decrement or increment in luminance. Journal of Comparative and Physiological Psychology, 49, 437-443.
- Hiles, D.R. (1973) Visual encoding in short-term memory. Unpublished Ph.D. thesis, McGill University.
- Hines, D. (1975) Immediate and delayed recognition of sequentially presented random shapes. Journal of Experimental Psychology: Human Learning and Memory, 1, 634-639.
- Hines, D. (1978) Task difficulty and visual similarity increase a distractor's effects on random shapes. Perceptual and Motor Skills, 46, 235-248.

- Hines, D. & Smith, S. (1977) Recognition of random shapes followed at varying delays by attended or unattended shapes, digits and line grids. Journal of Experimental Psychology: Human Learning and Memory, 3, 29-36.
- Hintzman, D.L. & Summers, J.F. (1973) Long-term visual traces of visually presented words. Bulletin of the Psychonomic Society, 1, 325-327.
- Hitch, G. (1974) Short-term memory for spatial and temporal information. Quarterly Journal of Experimental Psychology, 26, 503-513.
- Hochberg, J.E. (1968) In the mind's eye. In Haber, R.N. (Ed), Contemporary Theory and Research in Visual Perception. London: Holt, Rinehart and Winston.
- Hulme, M.R. & Merikle, P.M. (1976) Processing time and memory for pictures. Canadian Journal of Psychology, 30, 31-38.
- Huppert, F.A. & Piercy, M. (1977) Recognition memory in amnesic patients: a defect of acquisition? Neuropsychologia, 15, 643-652.
- Intraub, H. (1979) The role of implicit naming in pictorial encoding. Journal of Experimental Psychology: Human Learning and Memory, 5, 78-87.
- Intraub, H. (1980) Presentation rate and the representation of briefly glimpsed pictures in memory. Journal of Experimental Psychology: Human Learning and Memory, 6, 1-12.
- James, W. (1890) The Principles of Psychology. New York: Holt.
- Jones, G.V. (1979) Multirate forgetting. Journal of Experimental Psychology: Human Learning and Memory, 5, 98-114.
- Kelter, S., Cohen, R., Engel, D., List, G., & Strohner, H. (1977) Verbal coding and visual memory in aphasics. Neuropsychologia, 15, 51-60.
- Klatzky, R.L., & Rafnel, K. (1976) Labelling effects on memory for nonsense pictures. Memory and Cognition, 4, 717-720.
- Kolers, P.A. (1977) Pattern-analyzing memory. Science, 191, 1280-1281.

- Kolers, P.A., Ostry, D.J. (1974) Time course of loss of information regarding pattern analyzing operations. Journal of Verbal Learning and Verbal Behavior, 13, 599-612.
- Kroll, N.E.A. (1975) Visual short-term memory. In Deutsch, D., & Deutsch, J.A. (Eds.), Short-term Memory. New York: Academic Press.
- Kroll, N.E.A. & Parks, T.E. (1978) Interference with short-term visual memory produced by concurrent central processing. Journal of Experimental Psychology: Human Learning and Memory, 4, 111-120.
- Lashley, K.S. (1951) The problem of serial order in behavior. In Jeffress, L.A. (Ed.), Cerebral Mechanisms in Behavior. New York: Wiley.
- Leeuwenberg, E.L.J. (1971) A perceptual coding language for visual and auditory patterns. American Journal of Psychology, 84, 307-349.
- Levin, H.S., Grossman, R.G. & Kelly, P. (1976) Short-term recognition memory in relation to severity of head injury. Cortex, 12, 175-182.
- Levy, B.A. (1971) The role of articulation in auditory and visual short-term memory. Journal of Verbal Learning and Verbal Behavior, 10, 123-132.
- Lichtenstein, E.H., & Keren, G. (1979) Effects of perception versus imagery on later recognition of visual patterns. Acta Psychologica, 43, 145-155.
- Liss, P. (1968) Does backward masking by visual noise stop stimulus processing? Perception and Psychophysics, 4, 328-330.
- Loftus, G.R. (1972) Eye fixations and recognition memory for pictures. Cognitive Psychology, 3, 525-551.
- Loftus, G.R. (1974) Acquisition of information from rapidly presented verbal and nonverbal stimuli. Memory and Cognition, 2, 545-548.
- Loftus, G.R. (1976) A framework for a theory of picture recognition. In Monty, R.A., & Senders, J.W. (Eds.), Eye Movements and Psychological Processes. Hillsdale, NJ: Erlbaum.

- Loftus, G.R. & Bell, S.M. (1975) Two types of information in picture memory. Journal of Experimental Psychology: Human Learning and Memory, 2, 103-113.
- Loftus, G.R. & Kallman, H.J. (1979) Encoding and use of detail information in picture recognition. Journal of Experimental Psychology: Human Learning and Memory, 5, 197-211.
- Lutz, W.J. & Scheirer, C.J. (1974) Coding processes for pictures and words. Journal of Verbal Learning and Verbal Behavior, 13, 316-320.
- Mackworth, J.F. (1963) The duration of the visual image. Canadian Journal of Psychology, 17, 62-81.
- Madigan, S., McCabe, L., & Itatani, E. (1972) Immediate and delayed recall with words and pictures. Canadian Journal of Psychology, 26, 407-414.
- Marcel, A.J. (1980) Conscious and unconscious reading: the effects of visual masking on word perception. Cognitive Psychology, in press.
- Margrain, S.A., (1967) Short-term memory as a function of input modality. Quarterly Journal of Experimental Psychology, 19, 109-114.
- Melton, A.W. (1963) Implications of short-term memory for a general theory of memory. Journal of Verbal Learning and Verbal Behavior, 2, 1-21.
- Meudell, P.R. (1972) Short-term visual memory: Comparative effects of two types of distraction on the recall of visually presented verbal and nonverbal material. Journal of Experimental Psychology, 94, 244-247.
- Meudell, P.R. (1977) Effects of length of retention interval on proactive interference in short-term visual memory. Journal of Experimental Psychology: Human Learning and Memory, 3, 264-269.
- Miller, L.K. (1972) Letter recognition: effects of inter-item similarity and report requirements. Perception and Psychophysics, 11, 252-256.
- Minsky, M. (1977) Frame-system theory. In Johnson-Laird, P.N., & Wason, P.C. Thinking: Readings in Cognitive Science. Cambridge University Press.

- Modigliani, V. (1976) Effect on a later recall by delaying initial recall. Journal of Experimental Psychology: Human Learning and Memory, 2, 609-622.
- Moscovitch, M., Scullion, D. & Christie, D. (1976) Early versus late stages of processing and their relation to functional hemispheric asymmetries in face recognition. Journal of Experimental Psychology: Human Perception and Performance, 2, 401-416.
- Murdock, B.B. (1962) The serial position effect of free recall. Journal of Experimental Psychology, 64, 482-488.
- Navon, D. (1977) Forest before trees: the precedence of global features in visual perception. Cognitive Psychology, 9, 353-383.
- Nickerson, R.S. (1968) A note on long-term recognition memory for pictorial material. Psychonomic Science, 11, 58.
- Paivio, A. (1975) Imagery and long-term memory. In Kennedy, A., & Wilkes, A. (Eds.), Studies in long-term memory. London: Wiley.
- Paivio, A., & Bleasdale, F. (1974) Visual short-term memory: a methodological caveat. Canadian Journal of Psychology, 28, 24-31.
- Paivio, A., Rogers, R.B. & Smythe, P.C. (1968) Why are pictures easier to recall than words? Psychonomic Science, 11, 137-138.
- Parks, T.E., & Kroll, N.E.A. (1975) Enduring visual memory despite forced verbal rehearsal. Journal of Experimental Psychology: Human Learning and Memory, 1, 648-654.
- Parks, T.E., Kroll, N.E.A., Salzberg, P.M. & Parkinson, S.R. (1972). Persistence of visual memory as indicated by decision time in a matching task. Journal of Experimental Psychology, 92, 437-438.
- Pellegrino, J.W., Siegel, A.W. & Dhawan, M. (1976) Short-term retention of pictures and words as a function of type of distraction and length of delay interval. Memory and Cognition, 4, 11-15.
- Phillips, W.A. (1974) On the distinction between sensory storage and short-term visual memory. Perception and Psychophysics, 16, 283-290.

- Phillips W.A. & Baddeley, A.D. (1971) Reaction time and short-term visual memory. Psychonomic Science, 22, 73-74.
- Phillips, W.A. & Christie, D.F.M. (1977a) Components of visual memory. Quarterly Journal of Experimental Psychology, 29, 117-133.
- Phillips, W.A. & Christie, D.F.M. (1977b) Interference with visualization. Quarterly Journal of Experimental Psychology, 29, 637-650.
- Posner, M.I. (1969) Abstraction and the process of recognition. In Bower, G.H. & Spence, J.T. (Eds.); The Psychology of Learning and Motivation (Vol. 3). New York: Academic Press.
- Posner, M.I., Boies, S.J., Eichelman, W.H. & Taylor, R.L. (1969) Retention of visual and name codes of single letters. Journal of Experimental Psychology, 79; Monograph Suppl. 1, 1-16.
- Posner, M.I. & Keele, S.W. (1967) Decay of visual information from a single letter. Science, 158, 137-139.
- Posner, M.I. & Konick, A.F. (1966) Short-term retention of visual and kinaesthetic information. Organizational Behavior and Human Performance, 1, 71-86.
- Posner, M.I. & Taylor, R.L. (1969) Subtractive method applied to separation of visual and name components of multiletter arrays. Acta Psychologica, 30, 104-114.
- Postman, L. (1975) Verbal learning and memory. Annual Review of Psychology, 26, 291-335.
- Potter, M.C. (1975) Meaning in visual search. Science, 187, 965-966.
- Potter, M.C. (1976) Short-term conceptual memory for pictures. Journal of Experimental Psychology: Human Learning and Memory, 2, 509-522.
- Potter, M.C. & Levy, E.I. (1969) Recognition memory for a rapid sequence of pictures. Journal of Experimental Psychology, 71, 10-15.
- Price, R.H. & Slive, A.B. (1970) Verbal processes in shape recognition. Journal of Experimental Psychology, 83, 373-379.
- Proctor, R.W. (1978) Attention and modality-specific interference in visual short-term memory. Journal of Experimental Psychology: Human Learning and Memory, 4, 239-245.

- Pylyshyn, Z.W. (1973) What the mind's eye tells the mind's brain: A critique of mental imagery. Psychological Bulletin, 80, 1-24.
- Rafnel, K.J. & Klatzky, R.L. (1978) Meaningful-interpretation effects on codes of nonsense pictures. Journal of Experimental Psychology: Human Learning and Memory, 4, 631-646.
- Reeve, R.A. & Hall, R. (1976) The storage of physical and name properties in short-term visual memory. Memory and Cognition, 4, 6-10.
- Rock, I. & Englestein, P. (1959) A study of memory for visual form. American Journal of Psychology, 72, 221-229.
- Rodieck, R.W. (1973) The Vertebrate Retina. San Francisco: W.H. Freeman & Co.
- Rollins, H.A. & Thibadeau, R. (1973) The effect of auditory shadowing on recognition of information received visually. Memory and Cognition, 1, 164-168.
- Rothkopf, E.Z. (1971) Incidental memory for location of information in text. Journal of Verbal Learning and Verbal Behavior, 10, 608-613.
- Roufs, J.A.J. (1972) Dynamic properties of vision-I. Experimental relationships between flicker and flash thresholds. Vision Research, 12, 261-278.
- Rowe, E.J. & Rogers, T.B. (1975) Effects of concurrent auditory shadowing on free recall and recognition of pictures and words. Journal of Experimental Psychology: Human Learning and Memory, 1, 415-422.
- Rundus, D. (1971) Analysis of rehearsal processes in free recall. Journal of Experimental Psychology, 89, 63-77.
- Salthouse, T.A. (1975) Simultaneous processing of verbal and spatial information. Memory and Cognition, 3, 221-225.
- Scarborough, D.L. (1972) Memory for brief visual displays of symbols. Cognitive Psychology, 3, 408-429.
- Schnore, M.M. & Partington, J.T. (1967) Immediate memory for visual patterns: symmetry or amount of information. Psychonomic Science, 8, 421-422.

- Shaffer, W.O. & Shiffrin, R.M. (1972) Rehearsal and storage of visual information. Journal of Experimental Psychology, 92, 292-296.
- Shepard, R.N. (1967) Recognition memory for words, sentences and pictures. Journal of Verbal Learning and Verbal Behavior, 6, 156-163.
- Shepard, R.N. & Podgorny, P. (1978) Cognitive processes that resemble perceptual processes. In Estes, W.K. (Ed.), Handbook of Learning and Cognitive Processes, Vol. 5. Hillsdale, NJ: Erlbaum.
- Shiffrin, R.M. (1973) Visual free recall. Science, 180, 980-982.
- Sperling, G. (1963) A model for visual memory tasks. Human Factors, 5, 19-31.
- Sperling, G. (1967) Successive approximations to a model for short-term memory. Acta Psychologica, 27, 285-292.
- Standing, L. (1973) Learning 10000 pictures. Quarterly Journal of Experimental Psychology, 25, 207-222.
- Standing, L., Conezio, J. & Haber, R.N. (1970) Perception and memory for pictures: single-trial learning of 2500 visual stimuli. Psychonomic Science, 19, 73-74.
- Swanson, H.L. (1977) Nonverbal visual STM as a function of age and dimensionality in learning disabled children. Child Development, 48, 51-55.
- Tabachnick, B. & Brotsky, S.J. (1976) Free recall and complexity of pictorial stimuli. Memory and Cognition, 4, 466-470.
- Tolhurst, D.J. (1975) Reaction times in the detection of gratings by human observers: a probabilistic mechanism. Vision Research, 15, 1143-1149.
- Tulving, E. & Thomson, D.M. (1973) Encoding specificity and retrieval processes in episodic memory. Psychological Review, 80, 352-373.
- Turvey, M.T. (1973) On peripheral and central processes in vision: inferences from an information-processing analysis of masking with patterned stimuli. Psychological Review, 80, 1-52.

- Tversky, B. & Sherman, T. (1975) Picture memory improves with longer on time and longer off time. Journal of Experimental Psychology: Human Learning and Memory, 1, 114-118.
- Tzeng, O.J.L. (1973) Positive recency effect in delayed free recall. Journal of Verbal Learning and Verbal Behavior, 12, 436-439.
- Walker, P. (1978) Short-term visual memory: the importance of the spatial and temporal separation of successive stimuli. Quarterly Journal of Experimental Psychology, 30, 665-679.
- Warrington, E.K. & James, M. (1967) Disorders of visual perception in patients with localised cerebral lesions. Neuropsychologia, 5, 253-266.
- Weaver, G.E. (1974) Effects of post stimulus study time on the recognition of pictures. Journal of Experimental Psychology, 103, 799-801.
- Weaver, G.E. & Stanny, C.J. (1978) Short-term retention of pictorial stimuli as assessed by a probe recognition technique. Journal of Experimental Psychology: Human Learning and Memory, 4, 55-65.
- White, B.J. (1957) Complexity and heterogeneity in the visual recognition of two-dimensional forms. In Wulfeck, J.W. & Taylor, J.H. (Eds.), Form Discrimination as Related to Military Problems. Washington, D.C.: National Academy of Sciences.
- White, C.W. & Lorber, C.M. (1976) Spatial frequency specificity in visual masking. Perception and Psychophysics, 19, 281-284.
- Wicklegren, W.A. (1975) The long and the short of memory. In Deutsch, D., & Deutsch, J.A. (Eds.), Short-term Memory. New York: Academic Press.
- Williams, M. & Owen, G. (1977) Word vs. picture recognition in amnesic and aphasic patients. Neuropsychologia, 15, 351-354.
- Wiseman, S. & Neisser, U. (1974) Perceptual organization as a determinant of visual recognition memory. American Journal of Psychology, 87, 675-681.
- Wolford, G. & Hollingsworth, S. (1974) Evidence that STM is not the limiting factor in the tachistoscopic full report procedure. Memory and Cognition, 2, 796-800.

Woodworth, R.S. & Schlosberg, H. (1954) Experimental Psychology.

New York: Holt.

Wyant, S., Banks, W.P., Berger, D. & Wright, P.W. (1972) Verbal and pictorial similarity in recognition of pictures. Perception and Psychophysics, 12, 151-153.

Young, M.A. (1974) Short-term storage and the rehearsal of pictorial material. Unpublished Ph.D. thesis, Adelphi University.

Yuille, J.C. & Fox, C. (1973) Proactive inhibition in short-term retention of pictures. Journal of Experimental Psychology, 101, 388-390.

Yuille, J.C. & Ternes, W. (1975) Attention and modality specific interference as determinants of short-term verbal and visual retention. Canadian Journal of Psychology, 29, 360-374.

Zinchenko, V.P. & Vergiles, N.Y. (1972) Formation of visual images: studies of stabilized retinal images. New York: Plenum.