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Short-Term Memory for Temporal and Spatial Order Information

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SHORT-TERM MEMORY FOR TEMPORAL AND SPATIAL ORDER INFORMATION

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PREFACE

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ABSTRACT

The present investigation includes theoretical and experimental comparisons of short-term memory for temporal and spatial order information. Two questions are of central interest: whether short-term memory for letter sequences is limited to a verbal-acoustic coding process and whether the loss of information from short-term memory results from interference or from a mere decay with time.

The basic experimental paradigm employed in the present study was the Brown-Peterson design. The items to be recalled were sequences of four consonants presented visually in varying temporal and spatial arrangements. On each trial the to-be-remembered sequence of consonants was followed by an intervening task which in general consisted of digit shadowing. At the end of the retention interval the subject recalled the consonants in the order in which they were presented on the given trial.

Two experiments were conducted which dealt exclusively with memory for temporal order information. These studies provided an experimental separation of item and order information. In one experiment, the subject was required to learn only order information, and in the other, he was required to learn only item information. Two Markov models were proposed to describe behavior in these experiments as well as in an experiment by Bjork and Healy (1970) where both item and order information had to be learned. The models provided good fits to the data of the Bjork and Healy experiment and of the experiment where the subject had to learn only order information. This result supports the notions that in these situations acoustic coding is employed, item and order information are lost independently, and each item is independently represented in memory.

In five additional experiments, temporal and spatial order information were varied independently. These studies revealed a considerable difference between short-term memory for temporal and spatial order information. There was no evidence for acoustic coding in the spatial

order recall case as there had been in the case of temporal order recall. In addition, the time course of forgetting in spatial order recall was much flatter than in temporal order recall. The latter finding was explained in terms of the intervening task. Similarity of the processes involved in the intervening and recall tasks, rather than similarity of the items involved in the two tasks, was found to be the essential determinant of intervening task effectiveness.

A probabilistic model was proposed to account for the spatial order recall situations and provided a good fit to the data. The model incorporates the notion that in spatial order recall the basic memory unit is the temporal spatial pattern of item presentations, rather than a representation of each separate item as in temporal order recall.

These studies ruled out the notion that short-term memory for letter sequences is limited to a verbal-acoustic coding system. Evidence was found instead for a flexible coding system. Although the present results could not settle the question of whether forgetting is due to interference or decay, they do suffice to put restrictions on the form of an acceptable decay or interference theory. It is concluded that an acceptable decay theory must postulate different types of rehearsal, and that an acceptable interference theory must postulate process similarity as well as item similarity as a source of interference.

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

Figure | Page

I. INTRODUCTION

The aim of the present research is to understand the nature of short-term memory for letter sequences. Two questions are of central interest. One question concerns how information is stored and maintained in memory and the other question concerns how information is lost from memory.

In the past these questions about short-term memory have been variously answered. As for the first question, some psychologists (e.g., Atkinson & Shiffrin, 1968; Sperling & Speelman, 1970) argue that, despite variations in the to-be-remembered material, all items are coded in short-term memory in a given form and are maintained in memory by a given form of rehearsal. However, other investigators (e.g., den Heyer & Barrett, 1971; Kroll, Parks, Parkinson, Bieber, & Johnson, 1970) have provided evidence for a more flexible coding process. Their studies have shown that the type of coding employed depends on the type of material to be learned and on its method of presentation. The second question concerning the nature of forgetting is also controversial. On the one hand are psychologists (e.g., Broadbent, 1963; Brown, 1958) who conceive of forgetting as a decay of information during time when no rehearsal is permitted. On the other hand are psychologists (e.g., Reitman, 1971; Waugh & Norman, 1965) who contend that items are forgotten only if they are interfered with by other items.

By and large, the experimental situation employed to attack these questions has been the Brown-Peterson paradigm (Brown, 1958; Peterson & Peterson, 1959). In this situation a sequence of items to be remembered is presented to the subject followed by an intervening task designed to be so difficult that the subject is unable to rehearse the to-be-remembered sequence. Substantial forgetting is then observed after only a few seconds of the intervening activity.

Consideration of such a situation enables one to rephrase the controversial questions discussed above in more specific terms. For example, it is known that if no intervening task is included, so that the

subject is able to rehearse the items, and the number of items in the sequence is within the subject's short-term memory span (Miller, 1956), then no forgetting occurs (e.g., Brown, 1958). The question then arises: What is it about the intervening task that causes forgetting? Is the intervening task effective merely because it prevents rehearsal, or is it effective rather because it consists of items that are similar to the to-be-remembered items? This question clearly relates to the aspect of the controversy concerning whether forgetting is due to interference or a mere decay with time.

Specific questions about this experimental situation also bear on that aspect of the controversy concerning the form of information stored in memory. One may ask whether the items of the sequence are separately represented in memory or whether the sequence as a unit is represented in memory. Similarly, one may be led to question whether the information about the specific items that make up the sequence is lost separately from information about the order of the items in the sequence.

Coding of Information

Although, for the most part, these questions have not been resolved, advances have been made. With regard to the question of the form of information stored in short-term memory, a large body of evidence has been accumulating which suggests that acoustic information is employed even when the items are presented visually (e.g., Conrad, 1964). Conrad showed that a large proportion of the errors on to-be-remembered items are instances in which the correct item is replaced by another item with which it is acoustically confusable. More specifically, studies have indicated that when consonants are incorrectly recalled, consonants substituted for the correct ones have either a vowel or a consonant phoneme in common with the correct ones (Wickelgren, 1965a). Later studies where degree of vocalization (Murray, 1965) and amount of subvocalization (Glassman, 1972) of the to-be-remembered items were manipulated, as well as studies where items other than those to be remembered were vocalized upon presentation of the critical items (Estes, 1973; Murray, 1967; Peterson & Johnson, 1971), have demonstrated that phonemic

encoding depends upon auditory presentation or articulation of the critical items. Furthermore, it has been shown (Adams, Thorsheim, & McIntyre, 1969) that such acoustic coding occurs only when items are presented successively, not simultaneously.

The question then arises: In these cases where phonemic coding is not possible, is an alternative form of coding employed? While some investigators (e.g., Levy, 1971) have found that memory for items neither articulated nor heard is close to the chance level, other investigators have found evidence for alternative forms of coding. For example, in a series of experiments by Kroll, Parkinson, and their colleagues (Kroll, Parks, Parkinson, Bieber, & Johnson, 1970; Parkinson, 1972; Parkinson, Parks, & Kroll, 1971) retention of letters presented visually with no articulation possible because of an auditory shadowing requirement was in fact superior to retention of letters both heard and articulated after a fairly long retention interval. At first glance this divergence in findings seems to be attributable to differences in the task intervening between presentation and recall. In Levy's experiment items that intervened between the presentation of a to-be-remembered item and its recall were auditorily presented only when the to-be-remembered item was presented auditorily, whereas in the Kroll and Parkinson series all intervening items were presented auditorily. However, in other studies also employing acoustic intervening tasks, visual presentation was not found to be superior (Cooley & McNulty, 1967; Grant & McCormack, 1969) as it had been in the Kroll and Parkinson series. Scarborough (1972a) attempts to resolve this discrepancy by proposing that in the experiments by Cooley and McNulty and by Grant and McCormack, the visually presented items were not accurately perceived. He demonstrated that when this problem was alleviated, visually presented items did show superior retention at the longer intervals.

Other researchers have manipulated the intervening task variable to show that visual as well as acoustic coding is employed in short-term memory and that the two types of coding are differentially affected by changes in the intervening task. For example, Margrain (1967) showed

that interpolated written and verbal recall differentially affected retention depending on whether the to-be-remembered items were presented auditorily or visually. Similarly, den Heyer and Barrett (1971), using intervening tasks comprising either orally presented digits or visually presented dot patterns, showed that retention of letter identity and of letter spatial position in an array were differentially affected by the intervening tasks. In a similar experiment, Meudell (1972), using an intervening task consisting of either backward counting or eye movements, also showed that memory for letter identity and for letter spatial position were differentially affected by the intervening tasks. Furthermore, Atwood (1971) showed that an intervening task where digits were presented visually interfered more with retention of high-imagery phrases than did an intervening task where the same digits were presented auditorily; the relative interfering effects of the two intervening tasks were reversed for the retention of abstract phrases.

Evidence for various types of short-term memory coding also comes from quite different paradigms. Brooks (1968) showed that information about a visually presented line diagram held in memory is easier to give vocally than by spatially monitored output; but the reverse holds for an auditorily presented sentence. Another interesting series of experiments (Sanders & Shroots, 1969; Scarborough, 1972b; Henderson, in press), suggests that auditorily presented items do not compete with visually presented items for short-term memory capacity. One item of evidence for this conclusion is the observation that the number of auditorily presented consonants recalled is unaffected when a number of spatial locations are additionally held in memory (Sanders & Shroots, 1969).

Independence of Item and Order Information

The specific question of whether item and order information are lost independently also has been given considerable attention. Conrad (1965) argued that the order errors he observed in his experiment were a by-product of acoustic confusion errors and completely dependent on them. However, Bjork and Healy (in press) pointed out that there

are problems with Conrad's analysis which result from his considering only a subset of his data and from his particular error classification scheme. Murdock and vom Saal (1967) also concluded that item and order information are interdependent on the basis of a study employing word trigrams which revealed that item errors increased with increasing order errors. Again however, Bjork and Healy found a problem with their analysis. Murdock and vom Saal failed to present their analysis separately for each retention interval, and consequently their findings could result merely from the fact, already demonstrated, that order and item errors both increase with increasing retention interval. Bjork and Healy further noted that, in fact, Murdock and vom Saal's study could be considered to lend some support to the concept of independent loss of item and order information since their subjects made more order errors but fewer item errors in recall of same-category trigrams than different-category trigrams. Another quite different experiment by Wickelgren (1965b) also demonstrated that item and order errors are differentially affected by item similarity. This experiment involved the recall of strings of letters that were either acoustically similar or different; ordered recall was poorer in the acoustically confusable strings, but item recall either did not discriminate between the two types of strings or was superior in the confusable strings.

Thus item similarity seems to be the type of variable Conrad (1965) was seeking when he remarked, "What would be crucial is a variable that ... could be shown to affect order of items differentially from the items themselves (p.169)." Additional variables have been found to affect retention of item and order information differentially. In a series of short-term memory experiments Wickelgren (1964, 1967) imposed limitations on the size of rehearsal groups or chunks. He found that although both recall of items and recall of correct serial positions of the items increased similarly from rehearsal group size one to size three, recall of positions declined much more sharply than recall of items from size three to size five. And in an experiment involving the probed recall of words in strings of length five, order errors yielded

a bow-shaped serial position curve, whereas item errors yielded no such function (Fuchs, 1969). Similar results were found by McNicol (1971) in an experiment involving the probed recall of digit strings of length five and by Aaronson (1968) in a serial recall experiment involving seven-digit sequences.

Decay vs. Interference

Along with these advances in determining the form of information stored in memory, advances have been made towards answering the question whether forgetting of such information is due to a mere decay with time or to a specific interference from intervening items which are similar to the to-be-remembered items. Various arguments have been made to support the notion of decay of information with time (*e.g.*, Broadbent, 1963; Conrad, 1967); yet perhaps the most insistent argument (see Brown, 1958) is that in short-term memory experiments variations in the intervening task do not affect the amount of forgetting; as long as rehearsal is prohibited, forgetting takes place despite the specific nature of the intervening task. Differences in intervening task effectiveness have been shown, but in a great number of cases these differences have been attributed to the fact that different tasks allow different amounts of rehearsal. For example, Posner and his colleagues (Posner & Konick, 1966; Posner & Rossman, 1965) have found that intervening task effectiveness varies with task difficulty in terms of the amount of information reduction required. They attributed this variation to the use of the same limited capacity information processing system by rehearsal and intervening task processes. Presumably rehearsal processes can coexist to a greater degree with tasks that require a smaller amount of this capacity. From studies using various key-pressing tasks as interpolated activities, Crowder (1967a, 1967b) drew a similar conclusion that the extent of rehearsal in a short-term memory task may be controlled by variations in the filler task. Here evidence for rehearsals came from key-pressing scores which were lower on memory trials than on control trials where no items were to be recalled.

Those who are opposed to decay theory have argued, however, that not all variations in intervening task difficulty are attributable to differences in the amount of rehearsal permitted. Reitman (1971) claimed to have found an intervening task that successfully prevented rehearsal but caused no forgetting. She had subjects learn word trigrams and then perform an interpolated signal detection task. No forgetting was evidenced across the fifteen seconds of intervening activity. Reitman contended that no rehearsal occurred since no decrement was observed on the detection task when it was compared to a control condition where no recall was involved. However, it is conceivable that rehearsal could be carried out without detriment to the performance on the detection task. In an extended replication of Reitman's study, Shiffrin (1972) tried to overcome such objections by including a condition where subjects were specifically told to rehearse and by finding a superiority for this condition.

Nevertheless, it is possible that the signal detection task Reitman used was not difficult enough to prevent rehearsal. If a task could be found that is known to prevent rehearsal but that produces no forgetting, a stronger case could be made against decay theory. In fact there are instances where an intervening task has been found that causes a large decrement in the recall of one type of material but not of another type. In these cases it could be argued that since the intervening task caused forgetting of one type of material, the task was difficult enough to prevent rehearsal. If that argument is granted, decay theory could not explain why the same task did not cause forgetting of the other type of material. On the other hand, interference theory could simply account for the results by explaining that the intervening task was similar to the one type of material and thus caused interference with it but not with the other type of material. In another series of studies by Wickelgren (1965c, 1966) four-letter strings were to be recalled after an intervening task which involved letters that were either acoustically similar or dissimilar to the letters to be recalled. Wickelgren found that acoustically similar items produced much more

interference than did dissimilar items. Similar results come from an experiment by Tell (1971) where consonant trigrams, either voiced or not, were to be recalled after an interpolated task that involved responding either verbally or manually to a series of digits. Tell found that both intervening tasks depressed recall considerably when voicing of the consonants was suppressed; however little forgetting occurred in the voiced condition with the manual interpolated task. Similarly, in the experiments discussed above by Meudell (1972), Margrain (1967) and den Heyer and Barrett (1971), intervening task effectiveness was shown to vary depending upon whether the recall material was acoustically or visually coded. For example, Meudell found that recall of verbal material (letters) was hardly affected by an eye-movement task but was considerably affected by a task involving backward counting. On the other hand, the nonverbal material (spatial positions) evidenced considerable forgetting during both of the intervening tasks.

These experiments, though, constitute a refutation of decay theory only if it can be assumed that a given intervening task prevents rehearsal to the same extent despite variations in the nature of the to-be-learned material. This is a reasonable contention if rehearsal is defined in the manner of Reitman (1971) as "conscious purposeful subvocal repetition of the items to be retained." However, it may be that there are several kinds of rehearsal. For example, rehearsal of verbal material may be very different from the rehearsal of a sequence of tones (_e.g._, Deutsch, 1972). A given intervening task that prevents one type of rehearsal but not another would be expected to cause forgetting of one type of material but not of another. If such arguments are made, then whenever confronted with an intervening task that caused no forgetting of a certain type of material, proponents of decay theory could claim that the intervening task allowed the specific type of rehearsal necessary to remember that type of material.

If rehearsals themselves could be monitored such claims could be verified. With that goal in mind consider the experiment by Kroll and Kellicutt (1972) where they specifically measured the extent of rehearsal

during interpolated activity by asking subjects to report rehearsals via button pressing. They found different intervening tasks to vary considerably in the number of rehearsals observed. However, what is more interesting is their finding that a given intervening task that allows a given number of rehearsals produces different amounts of forgetting depending on the recall task. An auditory shadowing task that allowed five rehearsals resulted in 100% recall when the to-be-remembered material was presented visually. On the other hand, the same task, even when it allowed as many as six rehearsals, yielded only 50% recall when the to-be-remembered material was presented auditorily. This last experiment seems to provide just the evidence necessary to refute decay theory. Yet even this last experiment has its problems. One could argue that for some reason or other subjects are able to report only certain types of rehearsals, or that rehearsals of auditory material are easier to detect than rehearsals of visual material. Therefore, it seems that present techniques offer no way of discriminating decisively between interference and decay theories. Nevertheless, the present techniques may allow one to put restrictions on the acceptable form of decay or interference theories. For example, the preceding arguments suggest that an acceptable decay theory must postulate different types of rehearsals. This conclusion suggests that the two controversial questions discussed at the start are not entirely independent. Decay theory must be linked with a flexible coding process in order to be viable.

Present Study

The aim of the present study is to provide further insights into these questions of how information is stored in memory and what causes this information to be lost from memory. The literature provides clear evidence for an abundance of acoustic confusion errors; yet there is not a clear picture of how these errors change during the retention interval. The present study attempts to answer this question as well as the related question of whether these confusion errors reflect imperfect storage (input coding) of information or a loss of information

during the retention interval.

It is recognized that acoustic coding may not be the only form available to a subject who is given a particular kind of input. Thus an attempt will be made to determine whether the manner in which a set of items is coded depends on the manner in which the given set of items is to be recalled.

Finally, the present study includes a detailed consideration of the possible interdependence of item and order information in memory and the question whether each item in a sequence is independently represented in memory or whether the sequence of items is stored as a unit. Attention will be given to the possibility that the answers to these questions about independence depend on the specific experimental situations considered.

The present study seeks to achieve these various goals by means of a two-stage approach. Firstly, a number of variations on the experimental paradigm developed by Conrad (1967) are employed in order to trace the forgetting of item and order information separately and in combination throughout a retention interval. Secondly, short-term memory for temporal and spatial order information are compared in the same basic experimental situation.

Various aspects of the method used here to compare memory for temporal and spatial order have been anticipated by other investigators (Lundberg & Böök, 1969a, 1969b; Mandler & Anderson, 1971; Murdock, 1969; Slamecka, 1967). The present study differs from all of those previously reported in utilizing the particular combination of conditions required to generate evidence bearing on the theoretical questions at issue. These essential conditions include (1) control of subjects' vocalization and preclusion of rehearsal both during item presentation and during the retention interval; (2) testing of memory at a series of retention intervals by an ordered recall procedure (rather than an item or position probe); and (3) assessment of memory for temporal and spatial order of items following identical conditions of item presentation.

The present report is divided into two sections. The first section (Chapters II and III) presents an analysis of memory for temporal order. In the second section (Chapters IV and V) memory for temporal order is compared with memory for spatial order. In each case mathematical models describing subjects' behavior in these tasks are proposed in order to test specific hypotheses about the form of information stored in short-term memory and the manner in which information is lost from memory.

II. TWO MODELS OF ITEM AND ORDER INFORMATION

The immediate impetus to the present research was a series of experiments conducted in the Mathematical Psychology Laboratory at Rockefeller University and based on an experiment by Conrad (1967). The first experiment in the series was reported by Estes (1970). A Brown-Peterson design was employed with four successively presented consonants comprising the items to be recalled and digit-shadowing constituting the intervening task. The five different retention intervals employed were filled with sequences of 3, 6, 12, 18 or 30 digits. The presentation rate of the consonants and digits was sufficiently rapid (one item/400 msec.) that rehearsal was greatly inhibited. On every trial the character displayed, whether consonant or digit, appeared in the same location of the display screen (see Figure 1). The subject read aloud the items as they appeared and then attempted to write down the four consonants seen on that trial in the order shown. The subject was permitted to leave blanks for the letters he could not recall. The four consonants of each trial were drawn from a population of ten consonants which, on the basis of acoustic confusion matrices (Conrad, 1964; Morgan, 1973), can be subdivided into three confusion sets of consonants -- BCPTV FSX MN. The members of each subset are acoustically confusable with each other and relatively nonconfusable with other letters in the population (see Appendix A).

The recall errors made on this experiment were classified into four exhaustive categories -- confusion-transposition errors, confusion-nontransposition errors, nonconfusion-transposition errors, and nonconfusion-nontransposition errors. Confusion errors are made whenever the subject substitutes for the correct letter another letter in its confusion set; transposition errors occur whenever the subject substitutes for the correct letter one of the other three letters shown on that trial (regardless of the subset of the substituted letter). Thus, for example, if the stimulus string of consonants displayed to the subject was BPSX and he made the response PTBN, his response would be scored as a confusion-transposition error for the first letter, a confusion-

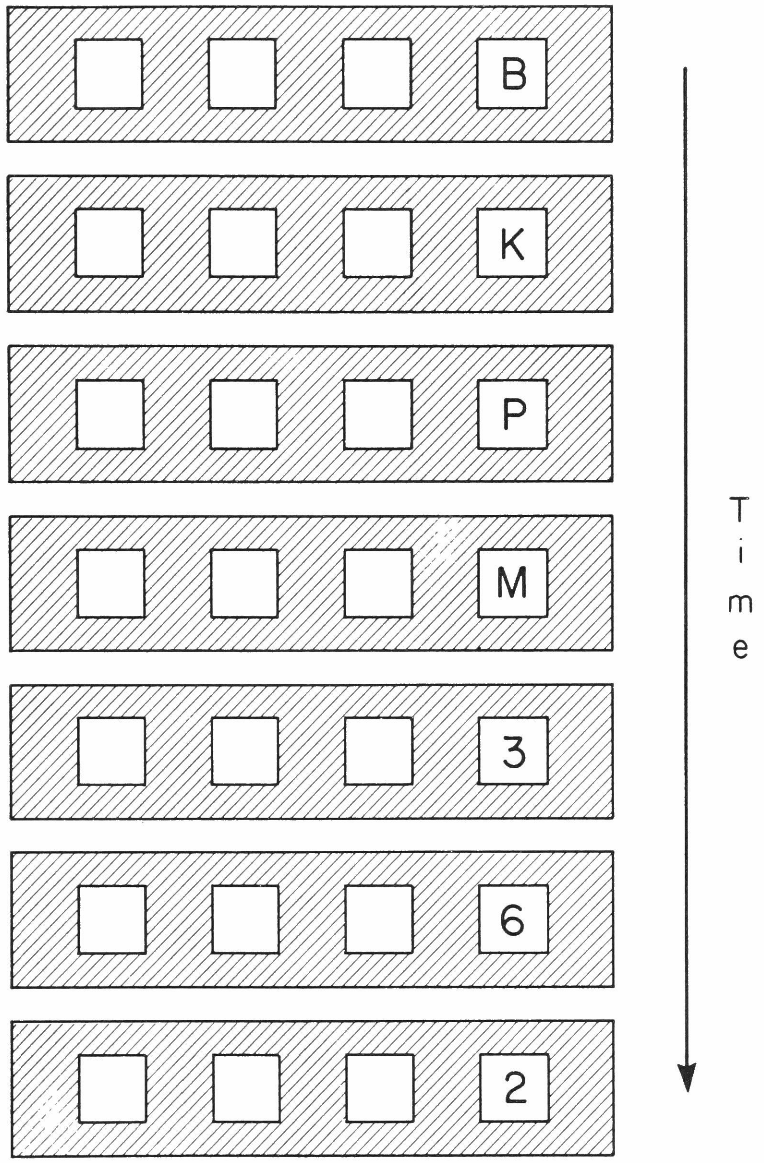

Figure 1. Sample experimental display from Item + Order, Order Only, and Item Only Experiments, including views of the display screen that the subject sees at seven successive instants in time.

nontransposition error for the second letter, a nonconfusion-transposition error for the third letter, and a nonconfusion-nontransposition error for the fourth letter.

The experiment was primarily concerned with the relative proportions of these types of errors as a function of retention interval. The interesting finding in this regard was that the different types of errors showed different courses of change during the retention interval. For instance, while the proportion of confusion errors and the proportion of nonconfusion errors both increased and then declined during the retention interval, the two types of errors peaked at very different times.

Preliminary attempts to formulate a model to describe subjects' behavior during this experimental situation were fruitful (Estes, 1970) but pointed out the necessity of redesigning the experiment to provide additional controls. The indicated follow-up experiment was carried out by Bjork and Healy (1970). In this new experiment the population of consonants was modified to include four confusion sets with three consonants in each set. The first two sets each consisted of three letters that were acoustically confusable -- BPV and FSX. The other two sets -- KMR and HLQ -- were control sets, including consonants none of which are highly confusable acoustically with any consonant in the entire population of twelve (see Appendix A).

In addition, in order to assess the magnitude of the interaction between confusion and transposition errors, a constraint was imposed upon the context of each particular consonant. Only two types of context were permitted -- the "paired context" and the "all-different context". A string of letters in the paired context included two consonants from one of the two acoustic confusion sets and two letters from one of the two control sets. For example, BKPM would be a string of consonants in the paired context. The all-different context included one letter from each of the four confusion sets. Therefore, BKFH would be a string in the all-different context. In this experiment, the

number of digits that intervened between the last consonant of a string and recall was restricted to 3, 8, or 18, yielding the three retention intervals 1.2, 3.2, and 7.2 seconds, respectively.

Moreover, the experimental design of the Bjork and Healy study insured that across subjects each letter appeared equally often in each of the two context types, at each of the three retention intervals, and in each of the four serial positions. Bjork and Healy also modified the subjects' task. The subjects were no longer permitted to leave blanks on their response cards for any letters they could not recall. They were rather forced to make a response for every consonant on every trial. In addition, the subjects gave confidence ratings from one to three for each of the four response consonants on a trial.

Twelve subjects were run in the Bjork and Healy study in two replications with six subjects in each replication. Each subject participated in two hour-long sessions. Table I summarizes the important experimental findings.

Several important features of this table should be mentioned. Each row of the table must add to 1.00 since the classification of the subjects' responses into five categories is exhaustive and nonoverlapping. Furthermore, when a subject sees a letter from a control confusion set and makes an error by responding with another letter in that set, his error is scored as a confusion error even though no acoustic confusion was made. For instance, if the subject saw a _K_ and recalled it as an _M_, he would be scored as making a confusion error since _K_ and _M_ are in the same confusion set although they are not acoustically confusable. The information about confusion errors in the control confusion sets thus acts as a baseline with which to compare the more interesting information about confusion errors in the acoustic confusion sets. It should be noted further that confusion-transposition errors are not possible in the all-different context; thus their entries are absent from Table I.

Two striking features of the data of the Bjork and Healy study are

Table I

Proportions of Response Types for Item + Order Study by Retention Interval, Context, and Confusable vs. Control Letter Category

Context, Letter Category	No. of Digits	Correct Responses	Errors			
			Conf. Trans.	Conf. Nontrans.	Nonconf. Trans.	Nonconf. Nontrans.
Paired, Confusable	3	.77	.10	.02	.07	.03
	8	.56	.10	.05	.16	.12
	18	.35	.11	.04	.18	.31
Paired, Control	3	.90	.03	.00	.05	.02
	8	.62	.09	.02	.13	.13
	18	.39	.09	.03	.16	.34
All-Different, Confusable	3	.86	---	.03	.09	.02
	8	.64	---	.10	.18	.08
	18	.40	---	.09	.29	.22
All-Different, Control	3	.85	---	.01	.11	.03
	8	.65	---	.05	.19	.11
	18	.40	---	.08	.28	.24

revealed by Table I. First, confusion errors are greater for the confusable letters than for the control letters at the shortest retention interval, but little difference remains at the longest interval. It thus seems, considering the questions discussed earlier, that the subject makes use of acoustic information at first, but that this information decays rapidly and is no longer available after a few seconds of intervening activity. Second, transposition errors are a large source of error at each of the three retention intervals, although their conditional probability given an error was made decreases, like that of the confusion errors, with increasing retention interval. The high frequency of transposition errors suggests that when forgetting occurs the string is not lost as a unit but rather the information about the identity of the consonants is lost independently from the information about the order of the consonants.

Description of the Two Models

The data from the Bjork and Healy experiment gave clear answers to the questions just discussed, but at the same time generated new problems. For example, the preponderance of acoustic confusion errors at the shortest retention interval coupled with the relatively small number of such errors at the longest interval suggested to Bjork and Healy that "confusion errors may be primarily the product of storage or input coding errors occurring at or shortly after presentation. Such errors would then be subject to loss in the same manner as information not misstored. (Bjork and Healy, 1970, p.15)." Alternatively, as Conrad (1967) proposed, confusion errors may arise during the retention interval rather than at storage. More specifically, Conrad felt that the subject's memory about the different features of a given string decays with time so that as more and more digits intervene to lengthen the retention interval, more and more distinguishing features or items of information are dropped out of memory.

With the existing data it seems impossible to determine directly whether confusion errors arise from imperfect storage or from loss of information during the retention interval. However one method to attack

this problem is to devise alternative models which incorporate these conflicting hypotheses. Then a close fit of one of the models to the data would give support to the hypothesis which it incorporates.

Therefore, two simple Markovian models were developed which were quite similar in all respects except that one model, Model 1, includes the assumption that confusion errors occur as a result of information loss during the retention interval, whereas the other model, Model 2, includes the assumption that confusion errors occur as a result of a failure to store complete information about an item.

The two models were also designed to provide tests for the three hypotheses discussed earlier about how information is stored in memory. Both models incorporate each of these three hypotheses so that a close fit of either or both models to the data would give support to these hypotheses. The first hypothesis is that acoustic information is coded about the items. The second is that this information about identity of the items is lost independently from information about the order of the items, and the third is that the string of consonants is not coded as a unit but rather each consonant is coded in memory independently. In order to incorporate the first of these hypotheses, both models make use of a simplifying assumption proposed by Sperling and Speelman (1970) and employed by Estes (1970) in his early attempts to formulate a model. Sperling and Speelman proposed that each consonant can be represented by exactly two critical acoustic features, one of which is common to all those letters in its acoustic confusion set and one which is unique to the specific consonant. Although Sperling and Speelman identified these critical features as phonemes, work by Conrad (1964) and Morgan (1973) seems to indicate that while consonants with common phonemes are confusable, a phonemic classification cannot completely account for the observed confusion matrices. Therefore, for the present analysis, the exact nature of these critical features is left unspecified.

In any case, considering only the consonants in the experimental population used in the present study, each consonant in an acoustic confusion set has one unique feature and one feature shared with the other

two members of its confusion set. Thus, considering the letter B for example, the vowel phoneme /i/ is its common feature which it shares with the letters P and V; the consonant phoneme /b/ is its unique feature. On the other hand, it is assumed that each consonant in a control confusion set has two features that are unique in that they are not shared with any other letter in the population. For these consonants in the control sets, one feature is arbitrarily denoted as the "common" feature and one as the "unique" feature. It should be noted here that while these control letters may be confusable with letters not included in the population of twelve, such confusions need not be considered since the Bjork and Healy study, as well as previous studies, shows that subjects rarely respond with a letter from outside the experimental population.

In order to incorporate the hypothesis that item and order information are lost independently, both models include a simplifying assumption with respect to the subject's knowledge about the position of a given consonant. It is assumed that the subject can be in one of two conditions -- either he recalls the exact serial position of the given consonant or he remembers nothing about the position of the given consonant. *

Finally, in order to incorporate the hypothesis that each consonant is represented independently in memory, both models include the assumption that the subject's knowledge about a given consonant on a given trial is independent of his knowledge about the other three consonants on that trial. It is further assumed that the subject's response to a given consonant is not affected by his responses to the other consonants shown on the same trial.

Keeping in mind the various assumptions, the subject's memory for

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* Alternatively, it could be assumed that the subject may have partial information about position. Probably such an assumption is more accurate than the simpler all-or-none assumption made by the model; however such an assumption is not necessary for the present purposes.

a given stimulus item can be characterized as being in one of the following five Markovian states, which are defined in terms of the particular type of information held in memory about the given item:

State 1: Subject knows unique feature and position.

State 2: Subject knows unique feature but not position.

State 3: Subject knows "common" feature only and position.

State 4: Subject knows "common" feature only and not position.

State 5: Subject knows neither feature.

Two peculiarities about this classification should be made clear. First, if the subject knows the unique feature of a given consonant, he immediately knows which consonant he is dealing with since no two consonants in the experimental population share a unique feature. Therefore, it is a matter of indifference whether a subject in states 1 or 2 is characterized as knowing the unique feature or knowing both features. Furthermore, common is put in quotation marks since the common feature for letters in either of the acoustic confusion sets is shared with the two other letters in its set, but the "common" feature for letters in the control sets is as unique with respect to the given population of consonants as is the so-called unique feature. Therefore, when a subject's knowledge about a given consonant that is a member of a control confusion set is in state 3 or 4, he will behave as though it were in state 1 or 2, respectively, since he has enough information to specify exactly which of the twelve consonants he has just seen.

To give an illustration, if the subject is shown consonant B in position 1, he will have the following knowledge, depending on which of the five states he is in:

State 1: He knows consonant B occurred in position 1.

State 2: He knows consonant B occurred but he does not know when it occurred.

State 3: He knows consonant B, P, or V occurred in position 1.

State 4: He knows consonant B, P, or V occurred but he does not know when it occurred.

State 5: He does not know which of the 12 consonants occurred.

According to the model based on Conrad's notion, Model 1, it is assumed that immediately following the presentation of a letter its representation in the subject's memory starts off in state 1 so that the initial vector has a 1 in the first row, the row representing state 1, and 0's in the other 4 rows. In addition the model assumes that during successive intervals of time or successive digit presentations, there may be a transition to one of the other four states. (Note, as it stands this assumption is neutral with respect to the controversy of whether forgetting is due to a mere decay with time or to interference during the retention interval.) The probabilities for such transitions are not determined in advance but are rather left as free parameters in the model, their values being assumed to depend on characteristics of the individual and the material.

There are three free parameters in Model 1 corresponding to the three types of information postulated that a subject can have about each particular consonant that he is shown -- information about the unique feature, information about the common feature, and position or order information. The three parameters are as follows:

T is the probability of losing the unique feature during the presentation of one intervening digit.

P is the probability of losing the common feature during the presentation of one intervening digit.

S is the probability of losing position information during the presentation of one intervening digit.

Thus, according to Model 1, as each digit occurs, each of these memory losses takes place with the given probability. It is then possible to write the probability of a subject's memory for an item going from any one state into another during the presentation of a digit; these probabilities are the cell entries of the transition matrix L shown on Figure 2.

The rows of the transition matrix represent the state of a subject's memory for an item before the given digit, whereas the columns

$$L = \begin{array}{c} \\ S1 \\ S2 \\ S3 \\ S4 \\ S5 \end{array} \begin{array}{c} \begin{array}{ccccc} \underline{S1} & \underline{S2} & \underline{S3} & \underline{S4} & \underline{S5} \end{array} \\ \left[\begin{array}{ccccc} (1-T)(1-S) & (1-T)S & T(1-P)(1-S) & T(1-P)S & T(P) \\ 0 & 1-T & 0 & T(1-P) & T(P) \\ 0 & 0 & (1-P)(1-S) & (1-P)S & P \\ 0 & 0 & 0 & 1-P & P \\ 0 & 0 & 0 & 0 & 1 \end{array}\right] \end{array}$$

Figure 2. Transition matrix for Model 1. The rows and columns of this matrix correspond to memory states S1 to S5.

represent the state of a subject's memory for an item after the digit has been presented. Thus, for example, if a subject's memory is in state 3 where he knows only the common phoneme and the position information, with probability (1-S)(1-P) he retains both of these types of information and stays in state 3. With probability S(1-P) he loses the position information but retains the common phoneme so goes to state 4, and with probability P he loses the common phoneme and goes to state 5.

By raising the transition matrix to successive powers, the following probabilities of being in the five states after n intervening digits are computed:

$$P_n(S_1) = (1-T)^n(1-S)^n$$
$$P_n(S_2) = (1-T)^n[1-(1-S)^n]$$
$$P_n(S_3) = (1-P)^n[1-(1-T)^n](1-S)^n$$
$$P_n(S_4) = (1-P)^n[1-(1-T)^n][1-(1-S)^n]$$
$$P_n(S_5) = [1-(1-P)^n][1-(1-T)^n]$$

In order to facilitate a comparison of the two models, Model 2, the alternative model incorporating the notion of storage errors, was also given three free parameters to account for transitions from one state to another. As in Model 1, these parameters correspond to the probabilities of losing certain types of information:

A is the probability of losing the unique feature at storage.

B is the probability of losing item information during the presentation of one intervening digit.

C is the probability of losing position information during the presentation of one intervening digit.

If the subject loses item information, as he will with probability B upon the presentation of each intervening digit, he will lose any knowledge that he has about both features. Therefore, after the item is stored, it is impossible for the subject of Model 2 to lose information about the unique feature alone. Thus during the presentation of the intervening digits, the subject can never make the transitions from states 1 and 2 to states 3 and 4 as can the subject of Model 1. This situation becomes more obvious upon inspection of Figure 3 which shows

$$M = \begin{bmatrix} 1-A \\ 0 \\ A \\ 0 \\ 0 \end{bmatrix}$$

$$N = \begin{bmatrix} (1-B)(1-C) & (1-B)C & 0 & 0 & B \\ 0 & (1-B) & 0 & 0 & B \\ 0 & 0 & (1-B)(1-C) & (1-B)C & B \\ 0 & 0 & 0 & 1-B & B \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Figure 3. Initial vector and transition matrix for Model 2. The rows and columns correspond to memory states S1 to S5.

the initial vector and the transition matrix that apply to Model 2. The initial vector M applies at the time of storage of each consonant; while the matrix N applies once with every intervening digit.

After raising the transition matrix N to successive powers, the following probabilities of being in the five states after n intervening digits are computed:

$$P_n(S_1) = (1-A)(1-B)^n(1-C)^n$$
$$P_n(S_2) = (1-A)(1-B)^n[1-(1-C)^n]$$
$$P_n(S_3) = A(1-B)^n(1-C)^n$$
$$P_n(S_4) = A(1-B)^n[1-(1-C)^n]$$
$$P_n(S_5) = [1-(1-B)^n]$$

Next to be considered is how a subject responds depending on his state of knowledge. As indicated earlier, both models include the assumption that the subject's knowledge about a given consonant on a given trial as well as his response to that consonant are independent of his knowledge about and his response to the other three consonants on that trial. Because of this assumption, both an experimental subject and a hypothetical subject (one who behaves according to the models) make four responses, but subjects in the experiment are forced to put exactly one consonant in each of the four serial positions; while it is possible for the hypothetical subject to put two, three, or four consonants in one serial position. Similarly, although the experiment does not explicitly constrain the experimental subjects from putting any one consonant in two, three, or four serial positions on a given trial, subjects do this extremely infrequently. Yet the hypothetical subject is not forbidden to repeat a given consonant on any trial. Although this simplifying assumption of independence permits the hypothetical subject to deviate from observed behavior in the two ways described, it does not bias the hypothetical subject to increase or decrease his responses of any specific type or category.

This assumption of response independence was employed since it greatly simplifies the calculation of the conditional probabilities of

responses given the state of knowledge. For example, it allows one to assume that if the subject does not know when a given item was shown, he will place it at random in one of the four serial positions. In this way, the independence assumption allows one to specify exactly the response probabilities of a subject who sees, say, a B in the first position, to use the earlier example. If a subject is shown consonant B in position 1 and acts according to his memory of the given consonant, he will respond as follows depending on which of the five states he is in:

State 1: He puts consonant B in position 1.

State 2: He puts consonant B in position 1, 2, 3, or 4, selected at random.

State 3: He puts consonant B, P, or V, selected at random, into position 1.

State 4: He puts consonant B, P, or V, selected at random, into position 1, 2, 3, or 4, selected at random.

State 5: He selects at random one of the 12 consonants and either places it into position 1 or places it into positions 1, 2, 3, or 4, selected at random.

It should be clear that although the subject can act in one of two ways if he is in state 5, depending on whether he knows the position of the given consonant or not, both ways of acting are equivalent with respect to the probability of his making a response of a given type or category.

With such an analysis, it is simple to compute the probability that a subject in a given state of knowledge will make either a correct response or one of the four types of errors. For example, if a subject is in state 2 and sees B in the first position, then the model implies, as indicated above, that he chooses randomly one of the four positions and places B in that position. In that case 1/4 of the time the subject will put B in position 1 and make a correct response and 3/4 of the time he will put B in positions 2, 3, or 4 and make a transposition error. By considering also the nature of the other three letters shown on that trial and the fact that B is from an acoustic confusion set, the

probability of a confusion error can be similarly determined. Thus the various response probabilities associated with the five states of knowledge were computed and are shown in Table II. In this classification, the consonants are separated into four categories depending on whether they were shown in the paired or all-different context and whether they were in the acoustic confusion sets or the control sets.

In order to determine whether the conditional probabilities shown on Table II were accurate, a simulation of the two models was conducted (see Appendix B) which did not employ the information in Table II but rather generated responses in the manner of the illustration on page 26 and then scored those responses against the input string of consonants.

Comparison of Models 1 and 2

A comparison of Models 1 and 2 was accomplished by means of a computer program which aided both in estimating for the two models those values for the parameters that give the best fit to the data and in comparing the ability of the two models to fit the data. This program was written in Fortran for the PDP-8/I computer.

The computer program is centered around a routine which computes the chi-square values for each set of parameters of each model. The program reads into the computer the experimentally observed frequencies of responses of each type. These response frequencies are the proportion values shown in Table I multiplied by 576, the total number of stimuli of each of the twelve types. The program determines the expected frequencies predicted by a given model with a given set of parameter values by combining the model's statement of the probability of a subject's being in each of the five states with its statement of the conditional probability of a subject's responding in a given way depending on the state of his knowledge.

The computer program calculated for each model a series of chi-square values based on different sets of parameters. While the program was being run in the computer, the operator selected for one of the models at a time the number of values each of the three parameters was

Table II

Response Probabilities Associated with Memory States in Models 1 and 2 for Item + Order Experiment, by Context and Confusable vs. Control Letter Category

Context, Letter Category	State	Correct Responses	Errors: Conf. Trans.	Conf. Nontrans.	Nonconf. Trans.	Nonconf. Nontrans.
Paired, Confusable	1	1	0	0	0	0
	2	1/4	1/4	0	1/2	0
	3	1/3	1/3	1/3	0	0
	4	1/6	1/6	1/6	1/3	1/6
	5	1/12	1/12	1/12	1/6	7/12
Paired, Control	1	1	0	0	0	0
	2	1/4	1/4	0	1/2	0
	3	1	0	0	0	0
	4	1/4	1/4	0	1/2	0
	5	1/12	1/12	1/12	1/6	7/12
All-Different, Confusable	1	1	---	0	0	0
	2	1/4	---	0	3/4	0
	3	1/3	---	2/3	0	0
	4	1/12	---	1/6	1/4	1/2
	5	1/12	---	1/6	1/4	1/2
All-Different, Control	1	1	---	0	0	0
	2	1/4	---	0	3/4	0
	3	1	---	0	0	0
	4	1/4	---	0	3/4	0
	5	1/12	---	1/6	1/4	1/2

to take on as well as the range of these values. For example, when working with Model 1, the operator started by specifying that the first parameter was to take on five values between .02 and .06, the second parameter was to take on five values between .02 and .06 and the third parameter was to take on five values between .08 and .12. The program calculated a chi-square value for every combination of the specified values of the three parameters. After a given chi-square was calculated, the program determined whether it was the smallest chi-square computed thus far and if so printed the values of chi-square and of the three parameters which yielded it. After determining chi-square for every specified set of parameter values, the program printed the frequencies of the different response types expected according to the set of parameter values that yielded the minimum chi-square.

In order to avoid finding local minima the first specification of the set of parameter values had quite a large range. The program was then rerun in order to further "zero in" on the set of parameters giving the best fit by basing new specifications of parameter values on those that just yielded the minimum chi-square. The program was rerun with different specifications of parameter values until it was clear that those parameter values had been found for a given model that yielded the closest fit to the experimental data.

Both models have the same number of parameters and thus their predictions have the same number of degrees of freedom, 39. Therefore, the ability of the two models to fit the data could be compared simply by examining the final minimum chi-squares for each model.

Model 1 was found to have a slight advantage over Model 2. Model 1 generated a final minimum chi-square of 122.9 for the parameter values T=.0420, S=.0367, and P=.1429, whereas the minimum chi-square for Model 2 was 161.7 using the parameter values A=.1000, B=.0325, and C=.0350. Table III compares the observed results to the results expected according to each of the models with the parameters that yielded the minimum chi-squares.

Table III

Comparison of Observed and Expected Proportions of Response Types by Retention Interval, Context and Confusable vs. Control Letter Category, for Models 1 and 2 with Item + Order Results and Parameters That Yield Best Fit

		Letter Category					
	No. of	Confusable			Control		
Context	Digits	Obs.	Mod.1	Mod.2	Obs.	Mod.1	Mod.2
	Correct Responses						
Paired	3	.77	.84	.79	.90	.88	.85
	8	.56	.61	.60	.62	.66	.64
	18	.35	.34	.37	.39	.36	.39
All-Different	3	.86	.84	.79	.85	.88	.85
	8	.64	.61	.60	.65	.66	.64
	18	.40	.34	.37	.40	.36	.39
	Confusion-Transposition Errors						
Paired	3	.10	.05	.06	.03	.03	.03
	8	.10	.09	.09	.09	.07	.07
	18	.11	.11	.11	.09	.10	.10
All-Different	3	--	--	--	--	--	--
	8	--	--	--	--	--	--
	18	--	--	--	--	--	--
	Confusion-Nontransposition Errors						
Paired	3	.02	.03	.04	.00	.00	.01
	8	.05	.04	.04	.02	.02	.02
	18	.04	.05	.05	.03	.04	.04
All-Different	3	.03	.05	.07	.01	.01	.02
	8	.10	.08	.08	.05	.03	.04
	18	.09	.10	.10	.08	.08	.07
	Nonconfusion-Transposition Errors						
Paired	3	.07	.06	.06	.05	.06	.06
	8	.16	.13	.13	.13	.14	.13
	18	.18	.20	.20	.16	.20	.20
All-Different	3	.09	.08	.09	.11	.09	.09
	8	.18	.19	.19	.19	.20	.20
	18	.29	.30	.30	.28	.31	.31
	Nonconfusion-Nontransposition Errors						
Paired	3	.03	.03	.06	.02	.03	.06
	8	.12	.12	.14	.13	.12	.14
	18	.31	.30	.27	.34	.30	.26
All-Different	3	.02	.03	.05	.03	.02	.05
	8	.08	.11	.12	.11	.10	.12
	18	.22	.26	.24	.24	.25	.22

It should be noted here that in both cases significant chi-squares were obtained so that it seems proper to conclude that the observed data deviate significantly from the predictions of both models. However, experience has shown that with such a large number of degrees of freedom nonsignificant chi-squares are quite rare, so that they may not be a realistic goal to seek when evaluating a given model. Furthermore, Table III reveals a fit of the model and the data which appears close to the eye. In addition, on the basis of correlation coefficients comparing the observed data and the models' predictions, it can be concluded that approximately 99% of the variance in the data can be accounted for by either of the two models (Model 1, $r = .99$; Model 2, $r = .99$). It therefore seems reasonable to accept the models as a fair representation of subjects' behavior in this experiment.

The question then arises whether Model 1 is significantly better than Model 2 at fitting the data. There are tests which enable one to compare the fit of two models by means of comparing their chi-square values. However, the present models are not appropriate for these tests (see Young, 1971, pp. 67-68). In any event, since both models do show similar chi-square values and similar close fits to the data, it does not seem appropriate to conclude on the basis of this analysis alone that Model 1 is superior to Model 2.

Conclusions

The interesting question of whether confusion errors are due to information misstorage or loss during the retention interval is therefore left unresolved. Since the given experiment is inconclusive on this important issue, later experiments in this series were designed to provide additional means of comparing and differentiating the two models.

Despite the fact that the two models could not be successfully differentiated with the given data, their close fit to the data has important implications since it provides support for the critical hypotheses incorporated in the models concerning how information is stored in short-term memory. Thus, the close fit to the data lends support to the

notions that in a short-term recall situation like the Bjork and Healy experiment (1) each item is represented independently in the subject's memory, (2) such item information is lost independently from order information, and (3) even though the subjects were presented the letters visually, they recoded them and stored them in memory in an acoustic form.

III. SEPARATING ITEM FROM ORDER INFORMATION

Subjects in the Bjork and Healy experiment had to remember both the identity and the order of the consonants they saw on a given trial. The two models proposed to describe behavior in the Bjork and Healy situation therefore implied that the subject codes information both about the identity of the consonants and about their order of presentation and that he loses these two different types of information independently. In order to gain a better understanding of how these two types of information are represented and lost from short-term memory, the next two experiments in this series dealt with each type of information separately. In the first experiment the subject had to learn only the order of the consonants so that order information was the focal point of interest in that study. In the second study the subject had to learn only the identity of the consonants so that in that case item information was the focal point of interest.

Order Only Experiment

Although evidence of acoustic coding was found in the Bjork and Healy study, it is not appropriate to conclude at this point that the same coding process is employed in all situations despite variations in the task. Therefore, the present experiment as well as the later experiments in this series were conducted to see whether there would be evidence for employment of the same processes despite variations in the task. More specifically, the present study was aimed at determining whether the two mathematical models proposed to account for the Bjork and Healy study could make accurate predictions of behavior in a similar situation where only order information rather than both item and order information had to be learned.

Given that the models could fit the data of this new situation, one might expect no difference in the parameter values yielding the best fit to the data from the new experiment and to the Bjork and Healy data since the experimental situations are very similar. On the other hand, since subjects in the new situation would not be required to code

item information as they were in the Bjork and Healy situation, one might expect the parameter values representing loss of item information to be different in the two situations. Furthermore, removing the constraint to code item information might throw light on the question of whether confusion errors are caused at the time of storage or during the retention interval. Model 1, the model attributing confusion errors to information loss during the retention interval, provided a slightly better fit to the data of the Bjork and Healy study than did Model 2, the model incorporating the notion of information misstorage. However, the fits of the two models did not differ enough to warrant rejecting either model. It was hoped that the data of the present experiment would be able to discriminate between the two models more satisfactorily.

The experimental situation of the present study was strictly analogous to that of the Bjork and Healy experiment except for one substantial modification. Whereas subjects in the Bjork and Healy experiment (hereafter referred to as the Item + Order Experiment) had to remember both the identity and the order of the items shown on a given trial, subjects in the present experiment (referred to as the Order Only Experiment) had to remember only the order of the items. In this case the same four letters were shown on every trial of a given subject's session.

Method

Subjects Twenty-four male and female young adults who had responded to advertisements in local newspapers served as subjects in this experiment. They were paid at the rate of $2.00 per hour.

Apparatus As in the Item + Order Experiment, one cell of a four-cell Iconix Bina-view display device was used to present the stimuli visually to each subject. The Bina-view was operated by means of a Digitronics paper tape reader. Three clocks were included in the system. The first clock timed the stimulus duration at 400 msec. per item, the second timed the inter-trial interval at 16 sec., and the third clock timed the inter-stimulus interval at approximately 2 msec. Once the

paper tape reader was started, all trials proceeded automatically until the reader was manually stopped by the experimenter.

Subjects sat approximately 3 ft. in front of the Bina-view display unit which was located about eye level. Each character appeared individually on the one cell of the Bina-view screen in use. Each character was approximately 1-3/8 in. high and 7/8 in. wide. All letters were upper case. (See Figure 1 for sample experimental display.)

Materials Six different paper control tapes, each containing 72 experimental trials and two initial practice trials, were constructed. As in the Item + Order Experiment, each experimental trial consisted of a four consonant stimulus followed by a retention interval including either 3, 8, or 18 intervening digits.

In this experiment, unlike the Item + Order Experiment, the same four consonants appeared on each trial of a given tape. The 24 permutations of the four letters each appeared three times, once at each of the three retention intervals. The presentation order of the trials was quasi-random and determined with the aid of a table of random numbers. The only constraint imposed was that in every block of twelve trials, there were four instances of each of the three retention intervals.

The intervening digits displayed on each trial were also quasi-random and selected from the digits one to nine with the aid of a random number table. The one constraint imposed here in order to avoid perceptual confusions was that no digit immediately succeed itself. The retention intervals and digits were identically placed on each of the six tapes; the tapes differed only in the four consonants displayed on each trial.

Four of the six tapes included consonants drawn from the same twelve-letter population as in the Item + Order Experiment. The population was divided into four confusion sets, two acoustic confusion sets -- BPV and FSX -- and two control sets -- KMR and HLQ. In the Item + Order Experiment the four consonants in each stimulus appeared in one of

the two contexts, the paired context and the all-different context. Similarly, in the present experiment two of the six tapes consisted of four consonants in the paired context -- BPKM and FSHL -- and two of the six tapes consisted of four consonants in the all-different context -- BKFH and PMSL. In this way only eight of the twelve letters, two letters from each of the four confusion groups, were used in the first four tapes. Each of these eight letters appeared in both a paired context and an all-different context tape.

The last two of the six tapes in the present experiment consisted of consonants in a new type of context, the all-same context. The all-same context stimuli included four letters that were all acoustically confusable with each other. Since the acoustic confusion sets in the twelve-letter population consisted of only three consonants each, one consonant was added to one of these sets to form a four-consonant acoustic confusion set -- BPVD. In addition, another four consonant acoustic confusion set -- CTGZ (American pronunciation of Z) -- was constructed. (See Appendix A.) Each of the last two tapes included the four members of one of the four-consonant acoustic confusion sets -- BPVD and CTGZ.

Thus, in the present experiment, two of the six tapes used included no letters which were acoustically confusable (the all-different context tapes); two of the six tapes included two letters which were acoustically confusable and two letters which were not acoustically confusable (the paired context tapes), and two of the six tapes included four letters all of which were acoustically confusable with each other (the all-same context tapes).

<u>Procedure</u> Subjects were tested individually in one-hour sessions. Each of the 24 subjects was assigned to one of the six tapes depending on his time of arrival for testing. Four subjects were shown the same tape. The instructions and procedure for all 24 subjects were otherwise identical.

As in the Item + Order Experiment, on each of the 72 experimental

trials in a session, the subject saw four consonants followed by 3, 8, or 18 successive digits displayed in one cell of the Bina-view screen. The subject was instructed to shadow or read aloud the consonants and digits as they appeared. At the end of each sequence of consonants and digits, the screen became blank and the subject was given 16 seconds to write down the four consonants he saw on that trial in the same order as they appeared. The subject wrote his responses on 3 x 5 in. cards on which four boxes had been printed, one box for each of the four consonants. The subject was to write the first consonant seen in the first box on the card, the second consonant in the second box, and so on. He was not required to fill in the boxes in any particular order. Within the 16 second inter-trial interval, the subject was also to circle one of the three numbers -- 1, 2, and 3 -- printed underneath each box. The number he chose depended on how confident he was that the consonant he placed in a given box was in fact the consonant displayed in that position. The subject was instructed to circle the number 3 if he was certain of his response, the number 1 if he was just guessing, and the number 2 if he was neither certain of his response nor just guessing. The subject recalled all four consonants shown on a trial before he gave his four confidence ratings.

After eight seconds of the inter-trial interval had elapsed, a double click was sounded by the tape reader which warned the subject that he should finish responding and get ready for the next trial. At the beginning of each trial, the tape reader clicked twice and the screen blinked with each click. At the end of the first 36 experimental trials, the experimenter turned off the tape reader and the subject was given a short rest period.

The two practice trials at the start of each tape consisted of a series of digits. No consonants appeared on these trials. The subject was instructed to read aloud the digits as they occurred on these practice trials but to make no written response at the end of the trials. The practice trials were included to give the subject a feeling for the quick reading pace required of him in this experiment.

The instructions read to the subject were identical to those given in the Item + Order Experiment with one addition: the subject was given full information concerning the four consonants which would be presented in varying orders during his session. The experimenter also repeated this information to the subject immediately before turning on the tape reader. These instructions were sufficient to insure that the subject knew the four consonants that were shown on every trial of his session. (See Appendix C for a complete record of the instructions to the subject.)

Results and Discussion

The results of the present experiment are summarized in Table IV in terms of proportions of correct responses. Two multifactorial analyses of variance (ANOVAs) with repeated measures (Winer, 1971, pp. 514-603) were computed for these data, one to assess the contribution of the between-subjects factor of context and the within-subjects factor of retention interval and the other to assess the contribution of these same factors with the additional within-subjects factor of confusion set; however, here only the paired and all-different contexts were included. Since similar ANOVAs were performed throughout the present series of experiments, in order to provide a sample, the summary of the ANOVA results of the first analysis is presented in Table V. The analyses were performed in part in order to obtain estimates of the standard error of the means. By employing the error mean squares from the ANOVA, the standard error of the means were computed. (See Cochran and Cox, 1957, pp. 70-73.) In this manner the second ANOVA yielded .03 as the standard error of the Table IV entries for the paired and all-different contexts, and the first ANOVA yielded .06 as the standard error of the Table IV entries for the all-same context.

Time Course of Forgetting The time course of forgetting for the paired and all-different context conditions of the present experiment is shown in the upper panel of Figure 4 in contrast with that from the Item + Order Experiment. The all-same context condition is excluded from this analysis since no comparable condition was included in the Item + Order Experiment. While the time course is relatively shallow

Table IV

Proportions of Correct Responses for Order Only Experiment, by Retention Interval, Context, and Confusable vs. Control Letter Category

	Context				
	Paired		All-Different		All-Same
No. of Digits	Confusable	Control	Confusable	Control	Confusable
3	.83	.89	.90	.82	.55
8	.69	.75	.76	.68	.48
18	.57	.56	.61	.56	.36

Table V

Analysis of Variance Summary Table for Order Only Experiment

Source	df	Mean Square	F
Between Subjects	23		
Context	2	1204.8	14.3*
Subj. W. Groups	21	84.4	
Within Subjects			
Interval	2	883.9	58.5*
Interval X Context	4	16.9	1.1
Error 1	42	15.1	
Serial Position	3	356.9	39.8*
Position X Context	6	20.4	2.3**
Error 2	63	9.0	
Interval X Position	6	2.7	1.1
Interval X Position X Context	12	7.4	2.8*
Error 3	126	2.6	

* $p < .01$

**$p < .05$

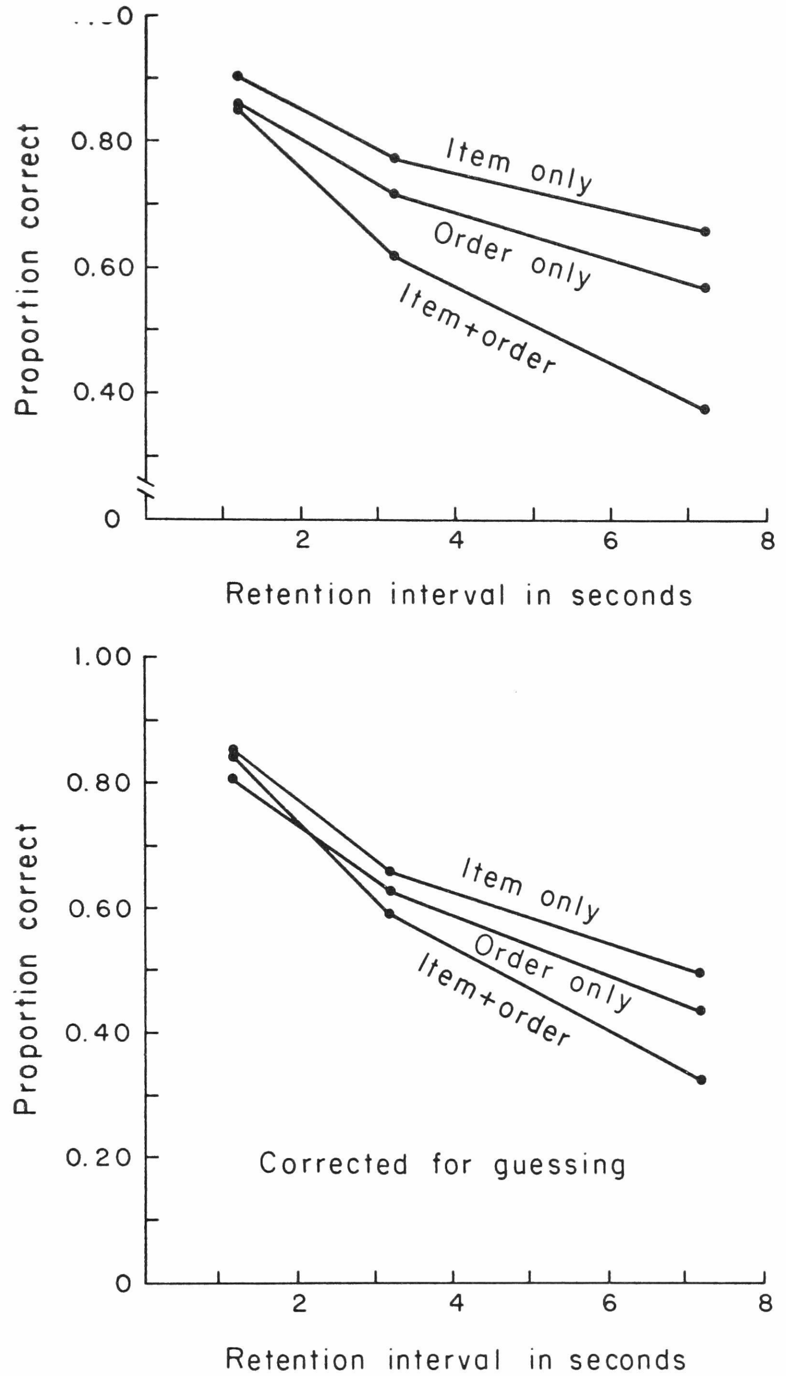

Figure 4. Time course of forgetting in terms of proportion of correct responses in the Item + Order, Order Only, and Item Only Experiments. Only Paired and All-Different context conditions are included for the Order Only Experiment and only Restricted and All-Different context conditions are included for the Item Only Experiment. Raw proportions are shown in the upper panel and the same data replotted after corrections for guessing in the lower panel.

compared to the earlier Item + Order Experiment, the difference in slope may be due to unequal guessing probabilities in the two experiments. Therefore, corrections were made for guessing. To correct for guessing it is assumed that the subject either remembers the item (with probability X) or he cannot remember the item (with probability 1-X) and is forced to guess. The observed proportion of correct responses is then equal to X + (1-X)G where G is the probability that the subject will be correct when he is guessing. In the Item + Order Experiment, if a subject has no memory for a given item, he will guess by choosing randomly from the population of 12 consonants. Therefore, on the average, 1/12 of the time he will be correct when he is guessing so G equals 1/12. However, in the Order Only Experiment, since the same four letters appear on every trial, if a subject has no memory for a given item, he will guess by choosing randomly from the four letters. Here, on the average, 1/4 of the time he will be correct when he is guessing so G equals 1/4. The lower panel of Figure 4 plots the value of X for the two conditions and therefore presents the time courses after they have been corrected for guessing. Even with the correction, the Order Only curve is somewhat less steep than the curve for Item + Order; although the two experiments show comparable proportions correct at the shortest retention interval, they differ considerably at the longer retention intervals. This apparent difference in slope of the time courses of forgetting in the two experiments seems to point to a difference in the rate of loss of information during the retention interval. Therefore, in terms of the two models proposed to handle behavior in this situation, it would be expected that the parameters representing information losses during the retention interval would take on different values in the two experimental situations. On the other hand, the parameter in Model 2 representing information misstorage would be expected to remain constant across the two experimental situations.

Table IV also allows a comparison of the time courses of forgetting in the three context conditions of the present experiment. Unlike the Item + Order Experiment, here there is no difference in proportion correct between the paired and all-different contexts at any of the three

retention intervals. The ANOVA revealed that the factor of context is not significant when only the paired and all-different contexts are considered ($F = .004$, $p > .05$, $df = 1,14$). This failure to find a context difference in the present experiment is surprising in view of the fact that confusion errors, found to be a considerable source of errors in the Item + Order Experiment, are impossible in the all-different context condition of the present experiment. For the same reason, an even smaller proportion of correct responses is expected on stimuli in the all-same context where all errors are confusion errors. However, in this case the expectations are achieved; there is a considerable drop in proportion correct in the all-same context. In fact, the ANOVA reveals that the factor of context is significant when all three contexts are included ($F = 14.28$, $p < .01$, $df = 2,21$).

Although no difference in overall proportion correct was observed between the paired and all-different contexts, a more detailed analysis reveals results which are consonant with the notion that acoustic confusability is an important source of errors. Acoustic confusability would be expected to cause a larger number of errors on confusable letters than on control letters in the paired context; while no such result is expected in the all-different context. Similarly, acoustic confusability would be expected to cause a larger number of errors in the paired context than in the all-different context on confusable letters; while no such difference is expected on control letters. In fact, as expected, at each retention interval, there are more errors made on confusable letters in the paired context than in the all-different context; while the same is not true for control letters. In accordance with these observations, the ANOVA reveals that the factor of confusion set is not significant ($F = 1.78$, $p > .05$, $df = 1,14$) but the interaction of confusion set and context is significant ($F = 20.70$, $p < .01$, $df = 1,14$). In addition, a comparison of the proportion of correct responses made in the paired context on confusable and control letters reveals more correct responses on the control letters at the shorter retention intervals; but no comparable advantage for control letters appeared at any retention

interval in the all-different context. The ANOVA found a significant three-way interaction between the factors context, confusion set, and retention interval ($F = 3.97$, $p < .05$, $df = 2,28$).

Confusion Errors Since by design in the present experiment all errors are confusion errors in the all-same context and no errors are confusion errors in the all-different context, only the paired context condition gives interesting data with respect to confusion errors. Table VI summarizes the error data for the paired context condition. A multifactorial ANOVA with repeated measures was conducted with these data for the factors error type, confusion set, and retention interval. The standard error of the points in Table VI was thus found to be .01. A more complete understanding of the confusion errors can be gathered by considering the conditional proportions of confusion errors. Figure 5 presents the conditional proportions of confusion errors given that an error was made at the three retention intervals in the paired context condition. The conditional proportions are substantially greater for the confusable letters than for the control letters at the shorter retention intervals, but no difference is seen at the longest interval. An ANOVA was conducted on these data considering the factors of confusion set and interval. (Note that Figure 5 presents the more reliable pooled group means although, by necessity, the ANOVA was conducted using the means of the individuals' scores. This convention will be employed throughout this paper.) The standard error of the means was found to be .05. The factor of confusion set was found to be significant ($F = 14.80$, $p < .01$, $df = 1,7$); the factor of interval was not found to be significant ($F = 0.62$, $p > .05$, $df = 2,14$), but the interaction of confusion set and interval was also found to be significant ($F = 5.45$, $p < .05$, $df = 2,14$). This finding is similar to that seen in the Item + Order Experiment as is clear from Figure 5 where a comparison of the two conditions is made.

The high proportion of acoustic confusion errors is curious in this situation where only order information must be learned. If subjects were coding only order information, these acoustic confusion errors would not

Table VI

Proportions of Confusion and Nonconfusion Errors in Paired Context of Order Only Experiment by Retention Interval and Confusable vs. Control Letter Category

	Errors			
No. Of	Confusion		Nonconfusion	
Digits	Confusable	Control	Confusable	Control
3	.09	.02	.08	.08
8	.12	.07	.19	.19
18	.15	.17	.28	.28

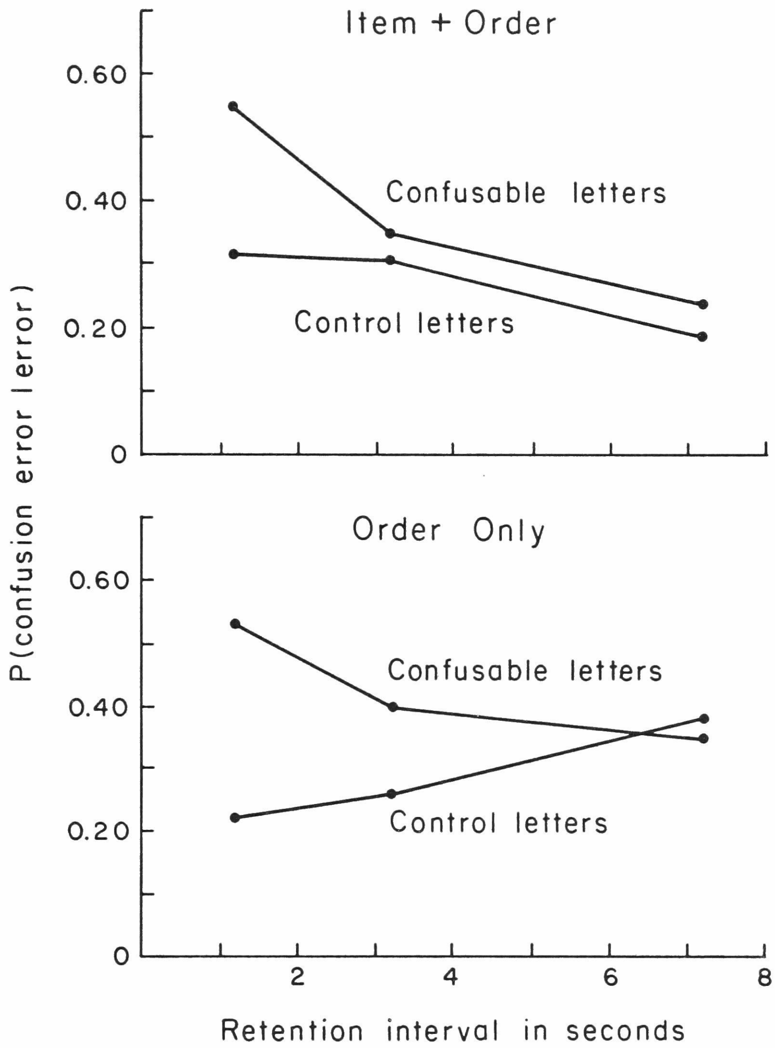

Figure 5. Proportions of errors which reflect intra-set confusions at each of the three retention intervals for letters in the acoustic confusion sets and in the control sets of the Item + Order and the Order Only Experiments (Paired Context).

be expected. This result seems to indicate that subjects are coding item information as well as order information in this situation. However, an alternative explanation is that representations of the positions of the two acoustic features of a given letter are lost from memory independently. This question will be considered below in more detail.

Evaluation of the Two Proposed Models As discussed earlier, it was planned to determine whether the two models proposed to describe behavior in the Item + Order Experiment could also account for the data of the present Order Only Experiment. A close fit of the models to the present data would support the notion that despite the considerable modification of the experiment, the subjects made use of the same coding and filtering processes that were employed in the earlier study. A close fit would add further support to the various hypotheses incorporated into the models -- independent loss of item and order information, independent representation of each item, and acoustic coding of the items. It was further hoped that the data of the present experiment would differentiate between the two proposed models.

In order to compute the predictions of the models for the present experiment all that must be recalculated are the conditional probabilities of the subject's making responses of the various types given his state of knowledge. These probabilities differ from those calculated for the Item + Order Experiment since the population of stimulus letters was of size twelve for subjects in the Item + Order Experiment but only of size four for each subject in the present experiment. Also the all-same context used in the present experiment was not employed in previous research. The various response probabilities associated with the five states of knowledge are presented in Table VII for subjects in the present experiment.

The computer program described earlier was modified to include these new conditional probabilities so that it could compute the set of parameters for each of the two models that yielded the minimum chi-square

Table VII

Response Probabilities Associated with Memory States in Models 1 and 2 for Order Only Experiment, by Context and Confusable vs. Control Letter Category

Context	Letter Category	State	Correct Responses	Errors: Confusion	Errors: Nonconfusion
Paired	Confusable	1	1	0	0
		2	1/4	1/4	1/2
		3	1/2	1/2	0
		4	1/4	1/4	1/2
		5	1/4	1/4	1/2
	Control	1	1	0	0
		2	1/4	1/4	1/2
		3	1	0	0
		4	1/4	1/4	1/2
		5	1/4	1/4	1/2
All-Different	Confusable	1	1	---	0
		2	1/4	---	3/4
		3	1	---	0
		4	1/4	---	3/4
		5	1/4	---	3/4
	Control	1	1	---	0
		2	1/4	---	3/4
		3	1	---	0
		4	1/4	---	3/4
		5	1/4	---	3/4
All-Same	Confusable	1	1	0	---
		2	1/4	3/4	---
		3	1/4	3/4	---
		4	1/4	3/4	---
		5	1/4	3/4	---

fit to the present results. Although the Item + Order results did not differentiate the two models, Model 2 was found to be superior to Model 1 in its ability to fit the data of the present experiment. However, neither model fit the present data as well as the data of the Item + Order Experiment. Model 1 generated a minimum chi-square of 289 with 18 degrees of freedom for the parameter values of T = .1125, S = .0525, and P = .0000. Model 2 generated a minimum chi-square of 159, also with 18 degrees of freedom, for the parameter values A = .4500, B = .0000, and C = .0525. Table VIII compares the observed results with the results expected according to Model 1 using its parameters that yielded the minimum chi-square and with the results expected according to Model 2 using its parameters that yielded the best fit. It is interesting to note that the same value of chi-square is obtained when the value of parameter A remains constant and the values of parameters B and C are interchanged so that A = .4500, B = .0525, and C = .0000. In fact, identical chi-square values are obtained whenever the value of parameter A is constant and the values of parameters B and C are interchanged as long as either B or C equals 0.0. This finding is peculiar to the present experimental situation. Because the same four letters appear on every trial of the present experiment, the situation when a subject knows the serial position of an item (the order information) but forgets all the information about the item's features (the item information) is equivalent to the situation when the subject maintains the item information but loses the order information; in each case the subject's probability of a correct response for that item is at chance.

It is further interesting to note that the values of two of the three parameters that give the best fit for Model 1 are equal to the values of the corresponding parameters for Model 2. As a result the two models yield identical predictions for all but twelve cells of Table VIII. (There are asterisks beside these twelve cells in Table VIII.) This finding can be understood also because of the peculiarity of the present experiment that the same four letters appear on every trial. For all control set letters and for letters in the all-different context from

Table VIII

Comparison of Observed and Expected Proportions of Response Types, by Retention Interval, Context, and Confusable vs. Control Letter Category, for Models 1 and 2 With Order Only Results and Parameters that Yield Best Fit.

		Letter Category					
	No. of	Confusable			Control		
Context	Digits	Obs.	Mod.1	Mod.2	Obs.	Mod.1	Mod.2
	Correct Responses						
Paired	3	.83*	.76*	.70*	.89	.89	.89
	8	.69*	.55*	.59*	.75	.74	.74
	18	.57*	.37*	.45*	.56	.53	.53
All-Different	3	.90	.89	.89	.82	.89	.89
	8	.76	.74	.74	.68	.74	.74
	18	.61	.53	.53	.56	.53	.53
All-Same	3	.55*	.70*	.60*	---	---	---
	8	.48*	.46*	.52*	---	---	---
	18	.36*	.28*	.41*	---	---	---
	Confusion Errors						
Paired	3	.09*	.16*	.23*	.02	.04	.04
	8	.12*	.27*	.23*	.07	.09	.09
	18	.15*	.32*	.24*	.17	.16	.16
All-Different	3	---	---	---	---	---	---
	8	---	---	---	---	---	---
	18	---	---	---	---	---	---
All-Same	3	.45*	.30*	.40*	---	---	---
	8	.52*	.54*	.48*	---	---	---
	18	.64*	.72*	.59*	---	---	---
	Nonconfusion Errors						
Paired	3	.08	.08	.08	.08	.08	.08
	8	.19	.17	.17	.19	.17	.17
	18	.28	.31	.31	.28	.31	.31
All-Different	3	.10	.11	.11	.18	.11	.11
	8	.24	.26	.26	.32	.26	.26
	18	.39	.47	.47	.44	.47	.47
All-Same	3	---	---	---	---	---	---
	8	---	---	---	---	---	---
	18	---	---	---	---	---	---

* Cells where Model 1 and Model 2 differ.

the acoustic confusion sets and the control sets, the subject's losing the unique feature does not affect his behavior since the common feature is not shared by any other letter in the set of four. Therefore, the parameters A (Model 2) and T (Model 1) are irrelevant to these cases. In the cases where A and T are irrelevant, Model 1 with S = .0525, and P = .0000 is equivalent to Model 2 with either B = .0000 and C = .0525 or B = .0525 and C = .0000 since in all three instances the subject has probability .0525 of losing a particular item of information; if the subject loses that information, his probability of a correct response is at chance, whereas if the subject retains that information, his probability of a correct response is unity.

Examination of Table VIII reveals that the large chi-square values obtained are due mainly to the poor fit of the twelve cells with asterisks beside them. These cells include the letters in the all-same context. Since the all-same context was the only context not present in the Item + Order Experiment and since good fits by both models were found for the data of the Item + Order Experiment, a second minimum chi-square fit was computed for all the data excluding those of the all-same context condition. The fit of the data was greatly improved for both models by eliminating the all-same context condition. Model 1 generated a minimum chi-square of 63 with 15 degrees of freedom for the parameter values T = .0150, S = .0525, and P = .0000; Model 2 generated a minimum chi-square of 48 with 15 degrees of freedom for both the set of parameter values A = .1100, B = .0000, and C = .0525 and the set of values A = .1100, B = .0525, and C = .0000. Here again Model 2 was found to be superior to Model 1, although only slightly. Table IX compares the observed results with the results expected by Models 1 and 2 using the parameters which yield the minimum chi-square fits. As in the Item + Order Experiment, although significant chi-square values were obtained, the fit of the models to the data of the present experiment seems close by inspection. Furthermore, correlation coefficients comparing the predictions and the observed data reveal that approximately 98% of the variance in the data can be accounted for by Model 1 (r = .99) and approximately 98%

Table IX

Comparison of Observed and Expected Proportions of Response Types, by Retention Interval, Context, and Confusable vs. Control Letter Category, for Models 1 and 2 With Order Only Results and Parameters that Yield Best Fit (All Data Except for All-Same Context)

		Letter Category					
	No. of	Confusable			Control		
Context	Digits	Obs.	Mod.1	Mod.2	Obs.	Mod.1	Mod.2
	Correct Responses						
Paired	3	.83*	.87*	.84*	.89	.89	.89
	8	.69*	.71*	.70*	.75	.74	.74
	18	.57*	.49*	.51*	.56	.53	.53
All-Different	3	.90	.89	.89	.82	.89	.89
	8	.76	.74	.74	.68	.74	.74
	18	.61	.53	.53	.56	.53	.53
	Confusion Errors						
Paired	3	.09*	.06*	.08*	.02	.04	.04
	8	.12*	.12*	.12*	.07	.09	.09
	18	.15*	.20*	.18*	.17	.16	.16
All-Different	3	---	---	---	---	---	---
	8	---	---	---	---	---	---
	18	---	---	---	---	---	---
	Nonconfusion Errors						
Paired	3	.08	.08	.08	.08	.08	.08
	8	.19	.17	.17	.19	.17	.17
	18	.28	.31	.31	.28	.31	.31
All-Different	3	.10	.11	.11	.18	.11	.11
	8	.24	.26	.26	.32	.26	.26
	18	.39	.47	.47	.44	.47	.47

* Cells where Model 1 and Model 2, Table VIII and Table IX differ.

of the variance in the data can be accounted for by Model 2 ($r = .99$). It therefore seems appropriate to conclude that both models provide accurate descriptions of subjects' behavior in this task.

It is interesting to note that the values of the parameters S and P from Model 1 and B and C from Model 2 that give the minimum chi-square fits for the data without the all-same context condition are the same as those that give the minimum chi-square fits for the complete experiment, whereas the values of A (Model 2) and T (Model 1) differ in the two situations. Furthermore, all but six cells of Table IX match the corresponding cells of Table VIII. The six deviant cells (which are marked by asterisks in Table IX) represent the acoustic confusion set letters in the paired context. These findings are understandable in light of the above analysis which showed that parameters A and T were irrelevant to all but the acoustic confusion set letters in the paired context and the all-same context.

The parameter values computed using the present data can be compared with those from the Item + Order Experiment. The parameter values yielding the best fit in the two experiments differ considerably; however, no interesting pattern of differences seems to emerge. The only value which remains fairly stable across the two experiments is the value of parameter A of Model 2, the parameter representing loss of the unique feature information at storage. In the Item + Order Experiment $A = .1000$; in the present study $A = .1100$. As was discussed earlier, the coincidence in proportion correct at the shortest retention interval of the two experiments is compatible with this finding. As far as the other two parameters of Model 2 are concerned, it seems that both loss of item information (B) and loss of order information (C) occur in the Item + Order Experiment during the retention interval, while only one type of information loss occurs during the retention interval of the present Order Only Experiment.

Three State Model The close fit of the models to the paired and all-different context conditions of the present experiment suggest that

the same coding process was used by subjects in the present experiment as in the Item + Order Experiment. This finding is especially peculiar when one recalls that in the Item + Order Experiment the subject had to remember which items he saw on every trial as well as their order; while in the present study the subject knew which items would be shown on a given trial; all he had to learn was their serial order. The two models imply that the subject codes item information as well as order information about each consonant even in this case when the items are already known. As far as the two models are concerned, the subject makes use of his knowledge about the four consonants shown on every trial only to limit his responses (his conditional probabilities of responses given his state of knowledge) not to adjust his coding strategy.

Finding a close fit of the models to the present Order Only Experiment supports this unintuitive coding strategy; nevertheless, it seems worthwhile to see whether a model employing a more intuitive coding strategy could be found to fit the data. In fact a simple model of this type was found to give a reasonable fit to the data. The model in this case is a three-state Markovian model, quite similar in most respects to the earlier models. The main difference between this three-state model and the two earlier models is that according to the three-state model only order information, not item information, is coded and lost from memory. In order to account for the effects of acoustic confusability, the additional assumption is made that information about the positions of the two features of a given letter may be lost independently. The three states of a subject's memory then follow:

State 1: The subject knows the position of the unique feature.

State 2: The subject knows the position of the common feature only.

State 3: The subject knows the position of neither feature.

As in Model 1, it is assumed that immediately following the presentation of a letter, its position information is represented in the subject's memory in state 1 and then, during successive digit presentations, there may be a transition to one of the other two states. The probabilities for such transitions are left as free parameters in the model.

There are two such parameters, corresponding to the two types of information postulated that a subject codes about each consonant -- information about the position of the unique feature and information about the position of the common feature. The parameters are as follows:

D is the probability of losing the position of the unique feature during one digit presentation.

E is the probability of losing the position of the common feature during one digit presentation.

The transitions from one of the three states to another at each digit presentation then occur with the probability shown in the transition matrix R on Figure 6.

By raising the transition matrix R to successive powers, one can compute the following probabilities of being in the three states after n intervening digits:

$$P_n(S_1) = (1-D)^n$$
$$P_n(S_2) = [1-(1-D)^n](1-E)^n$$
$$P_n(S_3) = [1-(1-D)^n][1-(1-E)^n].$$

Next to be considered is the probability that the subject will make a response of a specific type depending on his state of knowledge. These conditional probabilities are calculated only for the paired and all-different contexts since the previous modeling showed the all-same context condition to be deviant. The various response probabilities associated with the three states of knowledge are given in Table X.

The parameters that yielded the best fit of the three state model to the Order Only data were determined by means of a computer program similar to that used for Models 1 and 2. A minimum chi-square of 88.6 was found for the parameter values D = .05 and E = .99 with 16 degrees of freedom. What is interesting about these values is that E comes as close to the value 1.00 as the program will permit so that the probability of being in state 2 is negligible at these values. It is also true that using these parameter values no difference is predicted for confusion errors on acoustically confusable and control letters. This

$$R = \begin{bmatrix} (1-D) & D(1-E) & DE \\ 0 & 1-E & E \\ 0 & 0 & 1 \end{bmatrix}$$

Figure 6. Transition matrix for three-state model. The rows and columns correspond to memory states S1 to S3.

Table X

Response Probabilities Associated with Memory States in 3-State Model for Order Only Experiment, by Context and Confusable vs. Control Letter Category

Context	Letter Category	State	Correct Responses	Errors: Confusion	Errors: Nonconfusion
Paired	Confusable	1	1	0	0
		2	1/2	1/2	0
		3	1/4	1/4	1/2
	Control	1	1	0	0
		2	1	0	0
		3	1/4	1/4	1/2
All-Different	Confusable	1	1	---	0
		2	1	---	0
		3	1/4	---	3/4
	Control	1	1	---	0
		2	1	---	0
		3	1/4	---	3/4

prediction as well as the other predictions of the model using these optimal parameter values are shown in Table XI where they are compared with the observed data. A correlation coefficient comparing the observed data and the predictions of the model reveals that over 98% of the variance in the data can be accounted for by the model ($r = .99$). But, although the three-state model does have parameter values which give a reasonable fit to the data of the Order Only Experiment, this model must be considered inadequate since in its present form an important and statistically reliable aspect of the data is not accounted for by the model. It seems appropriate to conclude that the assumptions of the other two models are necessary. Although it may be unintuitive, subjects code information about the items as well as the order of the items even when they have to remember only the order of the items. The coding process used by subjects in the Item + Order Experiment is not strictly limited to the original experimental situation but occurs despite considerable changes in the experiment.

Serial Position Curves Serial position effects are not interpretable by any of the three models. The models treat items at the four serial positions identically. One may wonder, however, since the models postulate information losses at the presentation of each intervening digit, whether such information losses would also occur at the presentation of each consonant which succeeds the consonant in question. If information losses do occur during successive consonant presentations as well as during successive digit presentations, an asymmetrical serial position curve with marked recency and no primacy would be expected.

The serial position curves at each of the three retention intervals in the present experiment are shown in Figure 7. These curves are not separated by context or confusion set since no significant interactions were found in the ANOVA for these factors and that of serial position except for a significant interaction of serial position and context when the three contexts were included ($F = 2.28$, $p < .05$, $df = 6, 63$). In any case, quite contrary to the predictions, all three serial position curves are bowed and symmetrical. The proportions of correct responses

Table XI

Comparison of Observed and Expected Proportions of Response Types, by Retention Interval, Context, and Confusable vs. Control Letter Category, for 3-State Model With Results of Order Only Experiment and Parameters that Yield Best Fit (All Data Except for All-Same Context)

Context	No. of Digits	Letter Category: Confusable Obs.	Confusable Exp.	Control Obs.	Control Exp.
	Correct Responses				
Paired	3	.83	.89	.89	.89
	8	.69	.75	.75	.75
	18	.57	.55	.56	.55
All-Different	3	.90	.89	.82	.89
	8	.76	.75	.68	.75
	18	.61	.55	.56	.55
	Confusion Errors				
Paired	3	.09	.04	.02	.04
	8	.12	.08	.07	.08
	18	.15	.15	.17	.15
All-Different	3	---	---	---	---
	8	---	---	---	---
	18	---	---	---	---
	Nonconfusion Errors				
Paired	3	.08	.07	.08	.07
	8	.19	.17	.19	.17
	18	.28	.30	.28	.30
All-Different	3	.10	.11	.18	.11
	8	.24	.25	.32	.25
	18	.39	.45	.44	.45

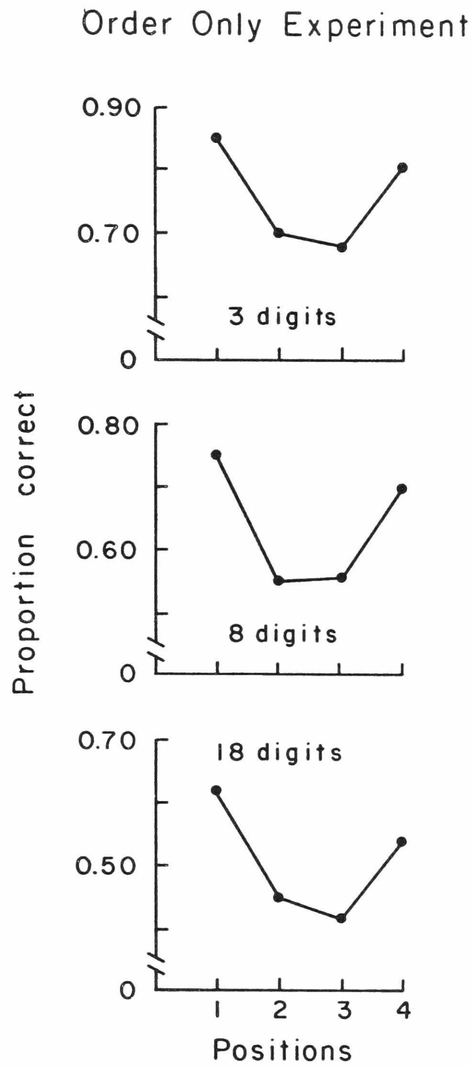

Figure 7. Serial position functions in terms of proportions of correct responses at each of the three retention intervals of the Order Only Experiment.

are highest and roughly equal at the first and fourth serial positions and lower but roughly equal at the second and third serial positions at each retention interval. The ANOVA allowed calculation of the standard error of the means for these curves which was found to be .01.

The fact that relatively symmetrical serial position curves were obtained, with any skewness being in the direction of primacy, appears to refute the notion that information is being lost during successive consonant presentations in a manner similar to that during successive digit presentations. Clearly then a model based on the notion of retroactive interference, where succeeding similar items interfere with the to-be-remembered items (see Keppel, 1968), would be incompatible with the observed results. By that notion interference should, if anything, be greater for succeeding consonants than for succeeding digits because of greater similarity with the to-be-remembered items. An attempt to explain these serial position effects is beyond the scope of the present paper. However, the reader is referred to Estes (1972) who was able to account for these results by relying on the notion that later material interferes with recall of the critical items, not by means of unlearning or competition in recall, but rather by making it harder to locate critical items in memory.

Distance Functions The symmetrical bow-shape of the serial position curve further suggests that transposition errors might be generated by some process in which the likelihood of a given pair of letters being transposed would depend upon the distance between the two letters in the pair. If the two letters were immediate neighbors more transpositions would be expected than if they were separated by one or more letters. It would seem to follow that in any such process, more transposition errors would be found for those letters with more letters close to them or more immediate neighbors, and positions 2 and 3 have two neighbors each, whereas positions 1 and 4 have only one neighbor each.

In order to test the above hypothesis, an analysis of the response data was performed which considered the stimulus position of a given

letter in the display as well as the stimulus position of the response letter substituted for that correct letter by the subject. Figure 8 summarizes these "distance functions." It plots the probability that an item put into a given serial position (marked C on the figure) will come from a given serial position. It is clear that the farther away a letter is from another letter in the stimulus display, the less likely one will be substituted for the other. Also interesting is the observed symmetry of the distance gradients. The curves for serial positions 3 and 4 look like mirror images of those for positions 1 and 2, which is consistent with the symmetry observed in the serial position curves. For example, a letter in position 1 is most often replaced by a letter from position 2, its immediate neighbor, then by a letter from position 3, and then by a letter from position 4. In mirror image fashion, a letter in position 4 is most often replaced by a letter from its immediate neighbor, position 3, then by a letter from position 2, and then by a letter from position 1. These findings are generally weaker with increasing retention interval. Furthermore, another form of symmetry is observed here. It seems that for each pair of serial positions, the probability of putting an item from a given serial position into another serial position is equal to the probability of putting an item from the latter position into the former.

Although it is upheld by the data, the simple hypothesis that the error frequencies on letters presented at the different serial positions are due to the number of neighboring letters that provide opportunities for transpositions is not sufficient to explain all the features of Figure 8. One especially striking feature of the figure is left unaccounted for -- the great tendency to interchange letters in positions 2 and 3. Consistently, at all retention intervals, subjects show a much larger tendency to substitute a letter in position 2 with one from position 3 than with one from position 1. In like manner, subjects show a larger tendency to substitute a letter in position 3 with one from position 2 than with one from position 4. While the simple model cannot account for these results, the more sophisticated model by Estes (1972),

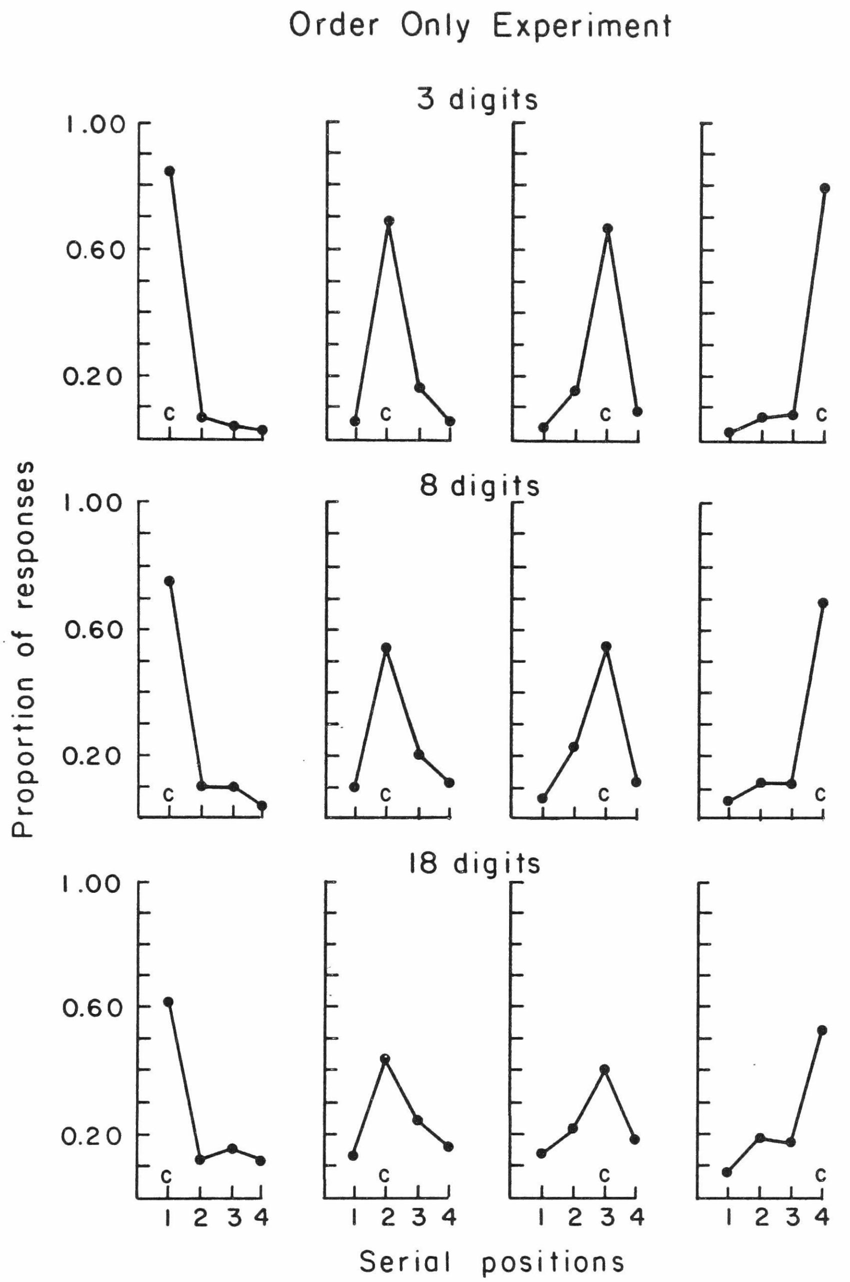

Figure 8. Distance functions for Order Only Experiment. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

referred to earlier, can account for the observed distance functions as well as the serial position curves. Estes' model is phrased in terms of a reverberatory loop mechanism such that successively displayed items are reactivated in a reverberatory loop at successive instants in time. Transpositions are then attributed to perturbations in the timing of the item reactivations.

Item Only Experiment

Subjects learning only order information seem to use the same coding processes as those who learn item and order information. The question then arises whether subjects who learn only item information will employ the same processes as well. The present experiment (hereafter referred to as the Item Only Experiment) was designed to examine this possibility. More specifically, the present study, like the previous Order Only Study, was aimed at determining whether the two mathematical models proposed to handle the Item + Order Experiment by Bjork and Healy could make accurate predictions of behavior in a similar situation where only one of the two types of information had to be learned. Given that the models could fit the data of the Item Only Experiment as they were able to fit the data of the Order Only Experiment, one might expect no difference in the parameter values yielding the best fit to the data from the Item Only and Item + Order Experiments since the experimental situations are so similar. On the other hand, since order information is not required in all conditions of the Item Only Experiment as it was in the Item + Order Experiment, one might expect the parameter values representing loss of order information to differ in the two situations.

Model 1, the model attributing confusion errors to information loss during the retention interval, provided a slightly better fit to the data of the Item + Order Experiment; but Model 2, the model attributing confusion errors to information loss at the time of storage, provided a slightly better fit to the data of the Order Only Experiment. Therefore, the two models could not be differentiated on the basis of the previous experiments. The two models differ only in their assumptions about memory for item information; their assumptions about memory for order

information are identical. However, memory for order information played a large role in the previous experiments which may have made it more difficult to get a clear picture of memory for item information. Since memory for order information plays only a minor role in the Item Only Experiment, it was hoped the data from this experiment would be able to give conclusive evidence in favor of one of the models.

The experimental situation of the present study was therefore strictly analogous to that of the Item + Order Experiment except for one substantial modification. The order of the letters shown to a given subject was restricted and the subject was made aware of these restrictions. For each subject the letters that could appear in a given serial position were restricted to a set of three, and the subject was told the identity of these three letters for each of the four serial positions. Therefore on each trial the subject had only to recall which letter in each of the four sets had appeared in the display.

Method

Subjects Twenty-four male and female young adults served as subjects in the present experiment. There were three conditions in this experiment with eight subjects in each condition. No subject had participated previously in a short-term memory experiment in this laboratory. Subjects were recruited in the same manner as in the Order Only Experiment and were similarly paid at the rate of $2.00 per hour.

Apparatus The same apparatus was employed in the present experiment as had been employed in the Order Only Experiment.

Materials Twelve different tapes were employed in the present experiment. Each tape contained 81 experimental trials and two practice trials. Each experimental trial consisted of a four-consonant stimulus followed by a retention interval including either 3, 8, or 18 digits. Only digits appeared on the two initial practice trials.

As in the Order Only Experiment, the intervening digits displayed on each trial were quasi-random and selected from the digits from one to nine with the aid of a table of random numbers. The one constraint

imposed here in order to avoid perceptual confusions was that no digit immediately succeed itself. The digits, and thus the retention intervals, were identically placed on the twelve tapes.

The four consonants in each stimulus were chosen from the population of twelve consonants which contained the four confusion sets of letters -- BPV, FSX, KMR, and HLQ. (See Appendix A.) In the Order Only Experiment stimulus tapes consisted of these consonants in the paired, all-different, and all-same contexts. Similarly, in the present experiment eight of the twelve experimental tapes consisted of stimuli in the paired context, and four of the twelve experimental tapes consisted of stimuli in the all-different context. No all-same context tapes were employed in the present experiment. In the present experiment, as in the Order Only Experiment, context was thus a between-subjects variable, whereas it was a within-subjects variable in the Item + Order study.

Four of the eight tapes with paired context stimuli were in the Repetitions Condition and four were in the Restricted Condition. The four tapes with all-different context stimuli were in the All-Different Context Condition. Since they were to be similar in structure, the eight tapes in the Repetitions Condition and the All-Different Context Condition were constructed from a master tape in the latter condition. On every trial of this master tape only letters from the confusable set BPV appeared in the first serial position; only letters from the confusable set FSX appeared in the second serial position; only letters from the control set KMR appeared in the third serial position; and only letters from the control set HLQ appeared in the fourth serial position. There are 81 permutations of the twelve letters allowed with these constraints. Each of these 81 permutations was employed once in the 81-experimental-trial tape. Twenty-seven of these 81 trials were shown with 3-digit retention intervals, 27 were shown with 8-digit retention intervals, and 27 were shown with 18-digit intervals. The presentation order of the trials was quasi-random and determined with the aid of a table of random numbers. The only constraint imposed was that in every block of nine trials there were three trials at each of the

three retention intervals.

The remaining seven tapes from either the Repetitions Condition or the All-Different Context Condition were constructed from the master tape by a series of mappings. For instance, the second tape was constructed by changing every B to K, P to M, V to R, F to H, S to L, X to Q, and vice versa. If the four sets of letters are designated 1 for BPV, 2 for FSX, 3 for KMR, and 4 for HLQ, then the first tape has consonants from set 1 in the first serial position, set 2 in the second serial position, set 3 in the third serial position, and set 4 in the fourth serial position. The first tape can be identified as 1234. Similarly, the second tape has consonants from set 3 in the first serial position, set 4 in the second, set 1 in the third, and set 2 in the fourth. The second tape can be identified as 3412. The other six tapes can then be identified as 2143, 4321, 1331, 3113, 2424, and 4242. In these eight tapes each confusion set is represented at each serial position once in the paired context and once in the all-different context. It should be noted that in some trials in the Repetitions Condition it will be true that the same letter will occur in two different serial positions. For instance, on the first tape in that condition, the string BKMB occurs. This form of repetition had not occurred in previous experiments.

The four tapes in the Restricted Condition were constructed to be parallel to those in the Repetitions Condition except that no such repetitions of consonants were permitted. Therefore, while 81 permutations of the twelve consonants were shown in any one of the four tapes in the Repetitions Condition, only 36 permutations were shown in any one of the four tapes in the Restricted Condition. Each of these 36 permutations was shown either two or three times, each time at a different one of the three retention intervals. The further constraint was imposed that for a given tape each letter appeared equally often so that across the nine permutations that were shown three rather than two times, each of the three letters allowed in a given serial position was shown there three times.

Like the eight tapes in the Repetitions and All-Different Context

Conditions, the four tapes in the Restricted Condition were constructed using one of the tapes as a master tape and performing a series of mappings to form the other three tapes. For example, whenever B, P, or V appeared in the first serial position of the master tape, it was replaced by F, S, or X, respectively, to form tape 3. Similarly, K, M, or R in the second position of the master tape was replaced by H, L, or Q; K, M, or R in the third position of the master tape was replaced by F, S, or X, and B, P, or V in the fourth position of the master tape was replaced by H, L, or Q to form tape 3.

The four tapes in the Restricted Condition were otherwise similar to the four tapes in the Repetitions Condition since the same confusion sets were allowed at the serial positions of the Restricted Condition tapes as were allowed at the serial positions of the Repetitions Condition tapes. The four tapes in each case can be represented as 1331, 3113, 2424, and 4242. Furthermore, the presentation order of the three retention intervals as well as the specific intervening digits displayed at each retention interval in the Restricted Condition tapes were the same as in the Repetitions Condition and All-Different Context Condition tapes.

Procedure Each subject was tested individually in an hour-long session. The 24 subjects were assigned to the twelve experimental tapes according to their time of arrival for testing. Each of the twelve experimental tapes was shown to two subjects so that there were eight subjects in each condition.

The testing sessions in the present experiment were conducted in the same manner as in the Order Only Experiment.

The instructions read to subjects in the present experiment (see Appendix C) were identical to those read to subjects in the Item + Order Experiment. However, one additional statement was included at the end of the instructions. The subject was given full information concerning the three consonants that would be presented at each of the four serial positions on every trial of his session. For example, a subject seeing

the first tape in the All-Different Context Condition was told that on every trial the first letter he would see would always be either B, P, or V; the second letter he would see would always be either F, S, or X; the third letter he would see would always be either K, M, or R; and the fourth letter he would see would always be either H, L, or Q. The subject was given a card with this information on it, and this card was kept in front of him throughout his experimental session. The subject was instructed to refer to this card whenever he needed help during the recall period.

Results and Discussion

The results of the present experiment are summarized in Table XII in terms of proportions correct. A multifactorial ANOVA was computed with these data to assess the contribution of the between-subjects factor of context condition and the within-subjects factors of confusion set and retention interval. The standard error of the values in this table, estimated from the error mean square of the ANOVA, is .02.

Time Course of Forgetting The time course of forgetting for the Restricted and All-Different Context Conditions of the present experiment is shown in the upper panel of Figure 4 in contrast with that from the Item + Order and Order Only Experiments. The Repetitions Condition was excluded from this comparison since no similar condition was included in the previous experiments. While the time course is relatively shallow compared to the earlier experiments, the difference in slope may be due to unequal guessing probabilities in the three experiments. Therefore, corrections were made for guessing in the same manner as described earlier. It is assumed that in the present experiment, if a subject has no memory for a given item, he will guess by choosing randomly from the three letters specified for that serial position. On the average, 1/3 of the time in this situation the subject will be correct when he is guessing so G equals 1/3. The lower panel of Figure 4 presents the time courses from the three experiments after they have been corrected for guessing. Even with the correction, the Item Only curve is somewhat less steep than the curves for the other two

Table XII

Proportions of Correct Responses for Item Only Experiment by Retention Interval, Condition, and Confusable vs. Control Letter Category

No. of Digits	Condition: Restricted		Repetitions		All-Different	
	Confusable	Control	Confusable	Control	Confusable	Control
3	.72	.93	.76	.94	.94	.99
8	.59	.78	.72	.78	.83	.89
18	.62	.60	.60	.61	.66	.75

experiments; although the three experiments show similar proportions correct at the shortest retention interval, they differ considerably at the longer retention intervals.

When considering the time courses of forgetting, it is further interesting to compare the two Paired Context Conditions of the present experiment (see Table XII). If, as the two models imply, the subject's knowledge about a given consonant on a given trial is independent of his knowledge about the other three consonants on that trial, the two conditions should show similar proportions of correct responses. However, if independence does not hold, then proportion correct on the Repetitions Condition should fall below that for the Restricted Condition since the latter condition places considerable restrictions on the permutations that are allowed. In fact, consistent with the independence notion, at each retention interval the proportion correct for the Repetitions Condition was greater than or approximately equal to that for the Restricted Condition. An ANOVA conducted for just the two Paired Context Conditions did not find the factor of context to be significant ($F = .0004$, $p > .05$, $df = 1,14$).

<u>Confusion Errors</u> In this experiment by design all errors made were necessarily confusion errors so that it is not profitable to compare the conditional proportions of confusion errors given an error was made for confusable and control letters. However, confusion errors can be studied by comparing the proportion of errors on confusable and control letters, obtainable by subtracting the entries in Table XII from unity. Here, as in the previous experiments, the proportion of confusion errors is considerably greater for confusable letters than for control letters at the shortest retention interval, but there is no difference in error proportions at the longest interval. The ANOVA reveals that the factor of confusion set is significant ($F = 8.40$, $p < .01$, $df = 1,21$) as is the interaction of the factors confusion set and retention interval ($F = 9.08$, $p < .01$, $df = 2,42$).

<u>Transposition Errors</u> Although no transposition errors are possible

in the All-Different Context Condition of the present experiment, they are possible in both Paired Context Conditions. A summary of the error data in the Paired Context Conditions is presented on Table XIII; it provides a comparison of transposition and nontransposition errors. An ANOVA was computed for these data considering the between-subjects factor of condition and the within-subjects factors of error type, interval, and confusion set. The ANOVA allowed computation of the standard error of the means shown in the table which was found to be .02. As in the Item + Order Experiment, a more complete understanding of the transposition errors can be gathered by considering the conditional proportions of transposition errors. The conditional proportions of transposition errors given that an error was made at each of the three retention intervals is presented in Figure 9. In Figure 9 the two paired context conditions are not separated since the ANOVA described above found no significant interaction of context and error type ($F = 1.02$, $p > .05$, $df = 1,14$). An ANOVA was then computed on these data in order to get an estimate of the standard error of the means which was found to be .06.

The observed conditional proportions of transposition errors shown in Figure 9 may be compared to the chance value expected if subjects were guessing randomly from the possible letters for a given position. In the Restricted Condition, for each letter presented there is one letter in the stimulus from the same confusion set and another letter not shown on that trial from the same confusion set. Therefore, if subjects are guessing randomly from the three possible letters for a given position when they make an error, the probability of their making a transposition error is 1/2. In the Repetitions Condition no comparable calculation of a chance value can be made since, for those trials where there are repeats of a given letter, no error made on a repeated letter will be a transposition error. While .50 is used as the estimate for the chance conditional proportion for the combined paired context conditions, it should be understood that it is exaggerated. In any case, this value of .50 can be compared to the observed conditional

Table XIII

Proportions of Errors in Paired Context of Item Only Experiment by Retention Interval, Condition, and Confusable vs. Control Letter Category

		Condition			
	No. of	Restricted		Repetitions	
Error Type	Digits	Confusable	Control	Confusable	Control
	3	.22	.05	.18	.06
Transposition	8	.26	.15	.18	.16
	18	.19	.23	.17	.21
	3	.06	.02	.06	.01
Nontransposition	8	.15	.07	.11	.06
	18	.19	.17	.23	.18

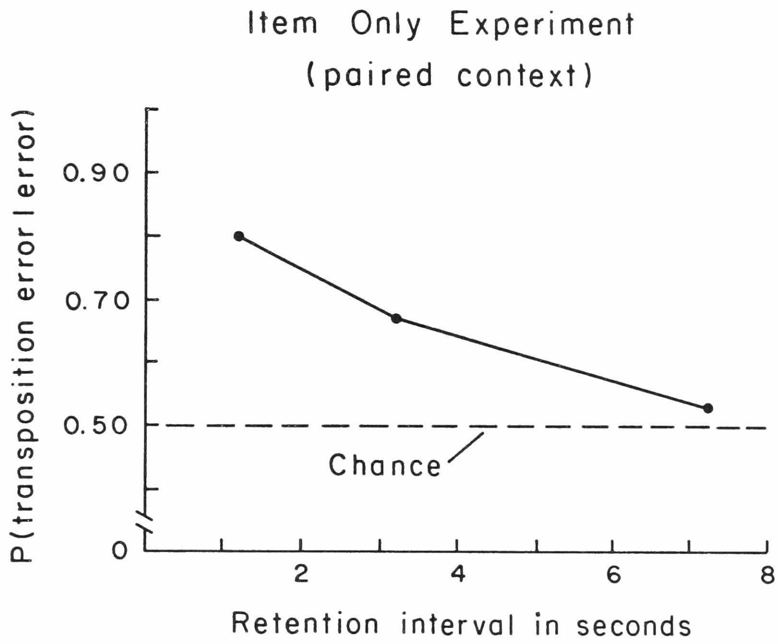

Figure 9. Proportions of overt errors which were transpositions in combined paired context conditions of the Item Only Experiment. See text for explanation of the chance calculation.

proportions of transposition errors given an error was made. At each retention interval the observed value is greater than the chance value although it approaches the chance value at the longest retention interval. Hence the ANOVA demonstrates that retention interval is a significant factor ($F = 12.01$, $p < .01$, $df = 2,28$). As in the Item + Order Experiment, transpositions are a considerable source of errors at each retention interval. This finding is consonant with the notion, incorporated in the two models, that order information is lost independently from item information.

Evaluation of the Two Proposed Models As discussed above, it was planned to determine whether the two models found earlier to fit the data of the situations where the subjects had to learn item and order information or only order information could also fit the data of the present experiment where only item information had to be learned. It was hoped that the two models, one attributing confusion error to information loss during the retention interval and one to information misstorage, could be differentiated on the basis of their ability to fit the present data.

In order to compute the predictions of the model for the present experiment all that must be recalculated are the conditional probabilities of the subject's making responses of the various types given his state of knowledge. These probabilities differ from those computed for the Item + Order Experiment since it is assumed that in the present situation the subject will make responses which are consistent with his knowledge about which three consonants will appear at each of the four serial positions. The various response probabilities associated with the five states of knowledge are shown in Table XIV for subjects in the present experiment.

The computer program described earlier was modified to include these new conditional probabilities so that it could compute the set of parameters for each of the two models that yielded the minimum chi-square fit to the present results. However, the fit of the models to

Table XIV

Response Probabilities Associated with Memory States in Models 1 and 2 for Item Only Experiment, by Condition and Confusable vs. Control Letter Category

Condition	Letter Category	State	Correct Responses	Errors: Transposition	Errors: Nontransposition
Paired, Restricted	Confusable	1	1	0	0
		2	1/2	1/2	0
		3	1/3	1/3	1/3
		4	1/3	1/3	1/3
		5	1/3	1/3	1/3
	Control	1	1	0	0
		2	1/2	1/2	0
		3	1	0	0
		4	1/2	1/2	0
		5	1/3	1/3	1/3
Paired, Repetitions	Confusable	1	1	0	0
		2	2/3	1/3	0
		3	1/3	2/9	4/9
		4	1/3	2/9	4/9
		5	1/3	2/9	4/9
	Control	1	1	0	0
		2	2/3	1/3	0
		3	1	0	0
		4	2/3	1/3	0
		5	1/3	2/9	4/9
All-Different	Confusable	1	1	---	0
		2	1	---	0
		3	1/3	---	2/3
		4	1/3	---	2/3
		5	1/3	---	2/3
	Control	1	1	---	0
		2	1	---	0
		3	1	---	0
		4	1	---	0
		5	1/3	---	2/3

the data of the present experiment was not as good as it was to the data of the previous studies. Furthermore, once again the two models provided comparable fits to the data and thus could not be differentiated. Model 1 generated a minimum chi-square of 241 with 27 degrees of freedom for the parameter values T = .04525, S = .0650, P = .0775, and Model 2 generated a minimum chi-square of 232 with 27 degrees of freedom for the parameter values A = .1725, B = .0250, and C = .0525. Table XV compares the observed results with the results expected according to Model 1 using its parameters that yielded the minimum chi-square and with the results expected according to Model 2 using its parameters that yielded the best fit.

The optimal parameter values computed for the present experiment may be compared to those from the previous experiments. Recall that in Model 1, T and P are parameters representing loss of item information and S is the parameter representing loss of order information; while in Model 2, A and B are parameters representing loss of item information and C is the parameter representing loss of order information. Since item information must be retained in the Item Only Experiment and in the Item + Order Experiment, one might expect parameters T, P, A, and B to have the same values in these two experiments. Furthermore, since order information must be retained in all three experiments (however, only in the paired context conditions of the present experiment), one might expect parameters S and C to have the same values in all three experiments. The parameter values for Model 1 are T = .0420, .0150, and .0425 in the Item + Order, Order Only, and Item Only Experiments, respectively. Similarly, S = .0367, .0525, and .0650; P = .1429, .0000, and .0775. Likewise for Model 2, A = .1000, .1100, and .1725; B = .0325, .0000 or .0525, and .0250; C = .0350, .0525 or .0000, and .0525. (Recall that in the Order Only Experiment the values A = .1100, B = .0000, C = .0525 and the values A = .1100, B = .0525, and C = .0000 gave equally good fits to the data.) No consistent pattern emerges, except that the parameters representing loss of order information during the retention interval (S and C in Models 1 and 2, respectively) show

Table XV

Comparison of Observed and Expected Proportions of Response Types, by Retention Interval, Condition, and Confusable vs. Control Letter Category, for Models 1 and 2 With Item Only Results and Parameters That Yield Best Fit

Condition	No. of Digits	Confusable Obs.	Confusable Mod.1	Confusable Mod.2	Control Obs.	Control Mod.1	Control Mod.2
	Correct Responses						
Paired Restricted	3	.72	.84	.79	.93	.89	.88
	8	.59	.66	.66	.78	.73	.73
	18	.62	.48	.52	.60	.52	.56
Paired Repetitions	3	.76	.87	.81	.94	.92	.90
	8	.72	.71	.71	.78	.79	.78
	18	.60	.53	.57	.61	.59	.62
All-Different	3	.94	.92	.84	.99	.98	.95
	8	.83	.80	.78	.89	.91	.88
	18	.66	.64	.68	.75	.72	.76
	Transposition Errors						
Paired Restricted	3	.22	.12	.13	.05	.10	.09
	8	.26	.25	.23	.15	.22	.20
	18	.19	.34	.32	.23	.34	.32
Paired Repetitions	3	.18	.08	.09	.06	.06	.06
	8	.18	.16	.15	.16	.15	.14
	18	.17	.23	.22	.21	.23	.21
All-Different	3	---	---	---	---	---	---
	8	---	---	---	---	---	---
	18	---	---	---	---	---	---
	Nontransposition Errors						
Paired Restricted	3	.06	.04	.08	.02	.01	.03
	8	.15	.10	.11	.07	.05	.06
	18	.19	.18	.16	.17	.14	.12
Paired Repetitions	3	.06	.05	.10	.01	.01	.03
	8	.11	.13	.14	.06	.06	.08
	18	.23	.24	.21	.18	.19	.16
All-Different	3	.06	.08	.16	.01	.02	.05
	8	.17	.20	.22	.11	.09	.12
	18	.34	.36	.32	.25	.28	.24

comparable values in the Order Only and Item Only Experiments and not very much smaller values in the Item + Order Experiment. The fact that neither model was able to fit the present data as successfully as the data from the previous experiments suggests that somewhat different processes are being employed in the present task. The poor fits may also be due to the fact that only one set of parameter values was employed to fit the data from all three conditions of the present experiment. It may be, though, that different coding strategies are used in the different conditions. For example, in the All-Different Context no order information need be coded but such order information is required in the Paired Context Conditions. In any case, it is beyond the scope of the present paper to suggest alternative models for this situation.

Serial Position Curves The previous Order Only Experiment yielded the initially puzzling finding, which cannot be handled by the two models, that serial position curves were bow-shaped and symmetrical. Similarly, analysis of the serial position effects in the Bjork and Healy study revealed bow-shaped serial position curves. In addition, Bjork and Healy (in press) found that these curves were attributable solely to transposition errors which showed a bow-shaped serial position curve while the serial position curve for nontransposition errors was flat. This finding by Bjork and Healy is consistent with that of other experimenters (Aaronson, 1968; Fuchs, 1969; McNicol, 1971) who found a bowed serial position curve for order errors but not for item errors. While all errors in the Order Only Experiment were necessarily transposition errors, no transposition errors were possible in the All-Different Context Condition of the present experiment. Therefore, that condition provided an interesting test of the serial position effect. Figure 10 presents the serial position curves at each of the three retention intervals for the All-Different Context Condition and compares them to the curves for the Paired Context Conditions where transposition errors were possible and, as was clear from the transposition error analysis above, quite prevalent. An ANOVA was computed on these data in order to obtain an estimate of the standard error of these points which was found to be

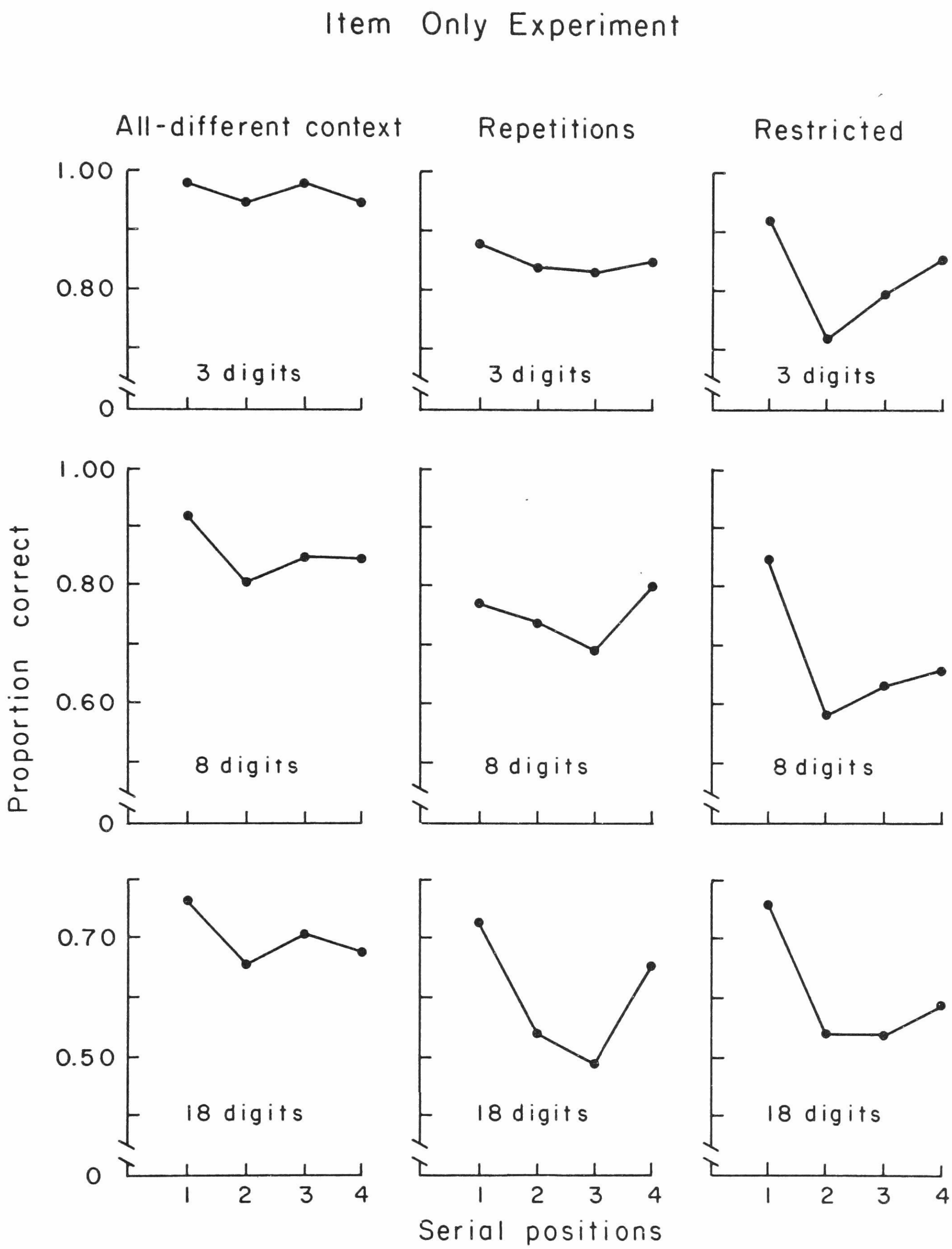

Figure 10. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the three context conditions of the Item Only Experiment.

.03. Although a slight primacy effect seems to be evident at the longer retention intervals of the All-Different Context Condition, the serial position curves are quite flat for that condition. On the other hand, the usual bow shape is noticeable for the Paired Context Conditions although there is considerable irregularity there. This irregularity may account for the failure to find a significant interaction of context and serial position ($F = 1.66$, $p > .05$, $df = 6,63$). In any case, these findings are consonant with the notion that order errors are solely responsible for the bow-shape of the serial position curve.

IV. MEMORY FOR SPATIAL ORDER

Temporal Spatial Experiment

In the earlier experiments in this series, each of the four items on a trial appeared in the same spatial location -- the right-most cell of the Bina-view screen so the four consonants were ordered only by their temporal sequence. In many situations involving visual information processing, items are arranged both spatially and temporally. For instance, when one reads a word, its letters will be arranged spatially from left to right on the line, and since one reads from left to right, its letters will also be ordered temporally, and the temporal order will correspond exactly to the spatial order. One would first read the left-most letter, next the letter just to its right, and so on.

In this chapter the spatial factor is put back into the picture. However, when temporal and spatial order coincide exactly, as they usually do, one cannot separate and compare their effects. Therefore, an experimental situation was adopted in which the temporal and spatial orders of the consonants are independent. The situation was not unlike those studied by Lundberg and Böök (1969a, 1969b), Mandler and Anderson (1971), Murdock (1969), Shiffrin (personal communication), and Slamecka (1967). In the present case, four Bina-view cells were employed to present four consonants in rapid succession on every trial. Each consonant appeared in a different one of the four cells. A sample experimental display is shown in Figure 11, where four successive views of the Bina-view screen are shown, views that the subject sees at successive instants in time. The subject first sees B in the third cell of the screen; he then sees K in the second cell; P in the fourth cell; and M in the first cell. The temporal order of the consonants in this case is BKPM; the spatial order is MKBP.

A comparison of memory for temporal and spatial orders was intended to provide an additional test of the notion that the same coding process is always employed in short-term memory despite variations in the task. If the models proposed earlier for the Bjork and Healy study could fit

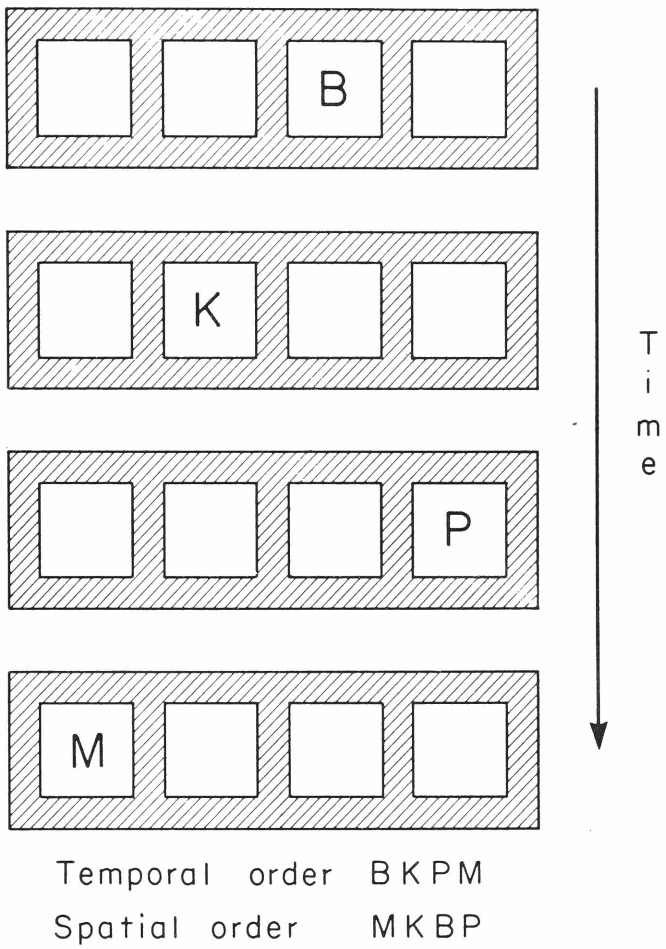

Figure 11. Sample experimental display of consonants shown during the Temporal Spatial Experiment, including views of the display screen that the subject sees at four successive instants in time. In this example, the temporal order of the consonants is BKPM and the spatial order of the consonants is MKBP.

the data for the recall of both temporal and spatial order, an inflexible coding process would be implicated. On the other hand, clear differences in the recall of temporal and spatial order would support the notion of an active filtering and coding process that can select different types of information to be coded and stored depending on the specific recall task.

It was also hoped that a comparison of memory for temporal and spatial order would help to discriminate among the more general models proposed to handle serial order. Models based on the position hypothesis (see Jensen & Rohwer, 1965) clearly imply that memory for spatial order should show properties similar to those of memory for temporal order. According to a model based on the position hypothesis, associations are formed between the code for each consonant and the code for the consonant's serial position. It seems reasonable to assume that forming associations between the code for a given consonant and a code for its temporal position would be similar to forming associations between the code for the same consonant and a code for its spatial position. Thus if differences are found between the recall of temporal and spatial order in such statistics as the time course of forgetting, the conditional proportion of acoustic confusion errors, or the serial position and distance functions, then these models must be considered inadequate.

On the other hand, the simple chaining or sequential hypothesis based on item-to-item associations (see Jensen & Rohwer, 1965) or the synchrony model proposed by Estes (1972) do not imply that the memory for temporal and spatial order should be similar. In fact, these models have little to say at present about memory for spatial order, since they are formulated exclusively in terms of temporal factors. However, the synchrony model implies that temporal order is primary so that memory for spatial order would be dependent on or mediated by memory for temporal order. According to this model, even if a subject is asked to recall the spatial order of a given set of items, he would pay attention to their temporal order as well. It also follows from the synchrony model that memory for temporal order would be superior to that for

spatial order.

Method

Subjects Sixteen male and female young adults served as subjects in the present experiment. No subject had previously participated in a short-term memory experiment at Rockefeller. Subjects were recruited in the same manner as in the previous experiments and were similarly paid at the rate of $2.00 per hour.

Apparatus The same apparatus was employed in the present experiment as in the previous experiments; however, all four cells of the Bina-view display device were employed.

Materials Sixteen different experimental paper tapes were employed, a different one for each of the sixteen subjects. Each tape contained 72 experimental trials. In addition, two practice paper tapes were employed with six practice trials on each tape. Each experimental and each practice trial consisted of a four letter stimulus followed by a retention interval including either zero, four, or twelve intervening digits.

The four consonants in a trial were presented successively, each consonant in a different one of the four cells of the screen. In this way the temporal and spatial order of the consonants were varied independently. As each consonant was displayed in one of the four cells, the other three cells were left blank. Each of the digits in the retention interval, however, was displayed simultaneously in all four cells of the Bina-view screen.

In this experiment, as in the Order Only Experiment, the same four consonants appeared on each trial of a given experimental tape. The 24 permutations of the four letters each appeared three times as the spatial ordering of the consonants, once at each of the three retention intervals. In addition, the 24 permutations of the four letters each appeared three times as the temporal ordering of the consonants, once at each of the three retention intervals. Furthermore, the temporal and spatial ordering of the consonants never coincided so that no letter

appeared in the same temporal and spatial serial position on a trial. For each of the sixteen experimental tapes the correct recall ordering of the consonants coincided with the correct recall ordering of the consonants on the corresponding tapes of the Order Only Experiment. For half of the 72 trials on a tape, this correct recall ordering was equivalent to the temporal order of the consonants and for half of the trials this correct recall ordering was equivalent to the spatial order of the consonants. The presentation order of these correct recall orderings corresponded exactly to that in the Order Only Experiment. The only new constraints imposed were that in every block of twelve trials there were four instances of each of the three retention intervals, two of which had consonants that were to be recalled according to their spatial order and two of which had consonants that were to be recalled according to their temporal order.

The order, either temporal or spatial, which determined the correct recall ordering of the consonants was cued either two seconds before the presentation of the consonants (Precue Condition) or immediately following the last digit of the retention interval (Postcue Condition). The cue for temporal order recall was the presentation of the vowel I simultaneously in all four cells of the Bina-view screen. The cue for spatial order recall was the presentation of the vowel O simultaneously in all four cells of the Bina-view screen. In the Precue Condition, each trial was begun with the screen showing blanks in all four cells for the first 400 msec., then the recall cue for the next 400 msec., and then blanks again for 2 sec. or five successive 400 msec. displays. Next the four consonants were presented successively at the rate of 400 msec. per item, followed by either 0, 4, or 12 successive digits, also presented at the rate of 400 msec. per item. Finally the recall cue was again displayed for 400 msec. In the Postcue Condition all displays were identical to those in the Precue Condition except that in place of the initial recall cue, the vowel U was displayed for 400 msec. Eight experimental tapes and one practice tape were in the Precue Condition, and eight experimental tapes and one practice tape were in the Postcue Condition so that cueing condition was a between-subjects variable.

The intervening digits displayed on each trial were quasi-random

and selected from the digits 1 to 9 with the aid of a random number table. The one constraint imposed here in order to avoid perceptual confusions was that no digit immediately succeed itself. The digits, and thus the retention intervals, were identically placed on each of the sixteen tapes.

As in the Order Only Experiment, the consonants displayed in the present experiment were drawn from the population -- BPFSKMHL. (See Appendix A.) The eight letter population was divided into four confusion sets, two acoustically confusable sets -- BP and FS -- and two control sets -- KM and HL. In the Order Only Experiment these consonants appeared in one of two contexts -- paired and all-different. Similarly, in the present experiment eight of the sixteen experimental tapes consisted of stimuli in the paired context, and eight of the sixteen experimental tapes consisted of stimuli in the all-different context. In fact, the paired context tapes of the present experiment corresponded to the paired context tapes in the Order Only Experiment so that either the consonants BKPM were displayed on every trial or the consonants FHSL were displayed on every trial. Similarly, the all-different context tapes in the present experiment corresponded to the all-different context tapes in the Order Only Experiment so that either the consonants BKFH or the consonants PMSL were displayed on every trial. No all-same context tapes were employed in the present experiment. In the present experiment context was thus a between-subjects variable as it was in the Order Only and Item Only Experiments, whereas it was a within-subjects variable in the Item + Order Experiment.

The sixteen experimental tapes then included four tapes with the consonants BKPM, four with the consonants FHSL, four with the consonants BKFH, and four with the consonants PMSL. The four sets of tapes were identical except for the difference in the letters displayed. Whenever B occurred on the first set of tapes, F appeared on the second, B on the third, and P on the fourth. Similarly, K on the first was replaced by H, K, and M respectively; P was replaced by S, F, and S respectively; and M was replaced by L, H, and L respectively on the second, third, and

fourth tapes.

The four tapes showing the same consonants included one pair in the Precue Condition and one corresponding pair in the Postcue Condition. The two pairs of tapes were identical except for the presence or absence of the initial recall cue. In addition, the two tapes in each pair were identical except that for every trial the spatial order of the consonants on one tape was the temporal order on the other tape and the temporal order of the consonants on one tape was the spatial order on the other. Furthermore, the cues shown on each trial of the two tapes in a given pair were reversed so that for a given trial one tape had the cue for spatial order recall and the other the cue for temporal order recall. The correct recall ordering of the consonants on a given trial was thus the same for each member of a pair of tapes and was equivalent to the correct recall ordering on the corresponding trial of the corresponding tape in the Order Only Experiment. A sample trial from each member of such a pair of tapes is shown on Figure 12. In each case the correct recall order is PBMK. (Note that the .'s on Figure 12 stand for blank cells, the subject does not see .'s.)

The letters shown on the two practice tapes were ABCD. Each practice tape included six different temporal orderings paired with six different spatial orderings of the letters ABCD, two of these trials at each of the three retention intervals, one of which was cued as temporal order recall and one of which was cued as spatial order recall. The order of the trials and the digits that comprised the intervening task were quasi-random and were the same for both tapes. One of the practice tapes was in the Precue Condition and one was in the Postcue Condition; otherwise the two practice tapes were identical.

<u>Procedure</u> Each subject was tested individually in an hour-long session. The sixteen subjects were assigned to the sixteen experimental tapes depending on their time of arrival for testing. Each session began with the experimenter's reading the instructions to the subject and then conducting the six practice trials. All subjects in the Precue Condition were shown the Precue Condition practice tape, and all subjects

Temporal Spatial Experiment

Sample Trials

Temporal Order Recall	Spatial Order Recall
....	....
IIII	0000
....	....
....	....
....	....
....	....
....	....
..P.	...K
...B	..M.
.M..	P...
K...	.B..
3333	3333
9999	9999
7777	7777
4444	4444
IIII	0000

TIME ↓   TIME ↓

Temporal Order PBMK	Temporal Order KMPB
Spatial Order KMPB	Spatial Order PBMK

Figure 12. Sample trial sequences in the Precue Condition of the Temporal Spatial Experiment. Sixteen views of the display screen are shown for each trial in the order seen by the subject. In the sample trial shown on the left, the subject sees the letters in the temporal order PBMK and in the spatial order KMPB, and he is told to recall the letters in their temporal order. In the sample trial shown on the right, the subject sees the letters in the temporal order KMPB and in the spatial order PBMK, and he is told to recall the letters in their spatial order. The .'s represent blank cells of the display screen.

in the Postcue Condition were shown the Postcue Condition practice tape.

The testing sessions were conducted in the same manner as in the previous experiments. The instructions read to subjects in the present experiment were identical to those read to subjects in the Order Only Experiment except for additional descriptions of the temporal and spatial properties of the consonant displays, the recall cues, and the practice trials. (See Appendix C.) As in the Order Only Experiment, the subject was given full information concerning the four consonants that would be presented in varying orders during his session. The experimenter also repeated this information to the subject immediately before starting the experimental trials.

Results and Discussion

The results of the present experiment are summarized in Table XVI in terms of proportions correct. A multifactorial ANOVA was computed with these data to assess the contribution of the between-subjects factor of cue condition and the within-subjects factors of temporal vs. spatial order recall, interval, and serial position. The standard error of the values in Table XVI was found to be .07. In their study of memory for temporal and spatial order, Mandler and Anderson (1971) found a striking similarity between the pattern of results in a precue and a postcue condition which suggested to them that subjects process both temporal and spatial orders whether or not they are aware of the required recall mode prior to input. In the present experiment also the Precue and Postcue Conditions show similar patterns of results. Furthermore, although Mandler and Anderson found a significant advantage in terms of proportion correct for the precue condition, here there is only a slight advantage for the Precue Condition over the Postcue Condition. In fact, the ANOVA did not find this factor significant ($F = 1.22$, $p > .05$, $df = 1,14$).

Time Course of Forgetting Table XVI allows one to compare the time courses of forgetting for the temporal and spatial order recall conditions. Little difference is seen between the functions for the two cueing

Table XVI

Proportions of Correct Responses for Temporal Spatial Experiment, by Retention Interval, Cue Condition, and Temporal vs. Spatial Order Recall Condition

	Condition			
	Precue		Postcue	
No. of Digits	Temporal	Spatial	Temporal	Spatial
0	.94	.80	.90	.72
4	.82	.62	.72	.57
12	.61	.44	.55	.42

conditions. The ANOVA did not find a significant interaction between the cueing factor and the factor of retention interval ($F = 0.15$, $p > .05$, $df = 2,28$). Clearly recall of temporal order is superior to recall of spatial order; however, similar decay functions are seen in the two cases. Thus the curves for temporal and spatial order recall are parallel. The ANOVA finds the temporal vs. spatial factor significant ($F = 44.55$, $p < .01$, $df = 1,14$) but the interaction of the temporal vs. spatial factor and retention interval insignificant ($F = 0.11$, $p > .05$, $df = 2,28$).

Confusion Errors As in the Order Only Experiment, only the paired context was considered for the analysis of confusion errors, since no confusion errors are possible in the all-different context. The conditional probability of a confusion error, given that an error was made, was considered for both the confusable and the control letters. As in the earlier experiments, in the case of temporal order recall, confusion errors are greater between letters in the confusable sets than between letters in the control sets at the shortest retention interval, whereas there is no difference between confusable and control letters at the longest interval. It may be concluded that acoustic information is employed in the temporal order case, much as in the experiments which involved only temporal order recall. Again this information decays rapidly and is no longer available after a few seconds of intervening activity. On the other hand, there is no such evidence for acoustic coding in the case of spatial order recall. Here little difference is seen in the proportions of confusion errors for confusable and control letters at any of the three retention intervals. However, an ANOVA performed on the data does not yield a significant interaction between the factors temporal vs. spatial, interval and confusion set ($F = 2.10$, $p > .05$, $df = 2,12$).

Serial Position Curves Symmetrical bowed serial position curves were found in the Order Only study which could not be accounted for by the Item + Order models but were understandable in terms of Estes (1972) synchrony model. However, the synchrony model explains the curves solely

in terms of temporal factors. Therefore one might predict that in the present experiment similar curves would be seen in the case of temporal order recall but not in the case of spatial order recall.

Serial position curves for the present experiment are plotted in Figure 13. Note that the four serial positions in the case of temporal order recall are the four temporal positions, whereas the four serial positions in the spatial order case are the four spatial positions. The curves are not separated by cue group since the first ANOVA described above did not find a significant interaction between serial position and cue group ($F = 0.79$, $p > .05$, $df = 3,42$). The same ANOVA yielded an estimate of .02 for the standard error of the points in this figure. The serial position curves for temporal order recall are clearly similar to those seen in the Order Only Experiment, being bowed and symmetrical at each retention interval. In fact the ANOVA reveals no significant interaction between the factors serial position and interval ($F = 1.91$, $p > .05$, $df = 6,84$). As predicted, the curves for spatial order recall show no orderly pattern. The ANOVA found a significant interaction between the temporal vs. spatial factor and the factor of serial position ($F = 20.05$, $p < .01$, $df = 3,42$).

In his study of spatial order recall Murdock (1969) found a bowed serial position curve when he plotted error proportions as a function of temporal position. Apparently, the recall of an item's spatial position depended on the position of the item in the temporal sequence. Therefore, although no regularity is seen in the serial position curves in the present experiment for spatial order recall when the spatial positions are considered, possibly here, as in Murdock's case, some regularity will be discovered if the temporal positions are considered. In fact, such a finding would be compatible with a model such as that of Estes (1972) where temporal order is assumed to be primary so that temporal factors affect recall even when spatial order is required. In addition, it is possible that the spatial positions of the consonants affect their probability of being correctly recalled in the temporal order recall situation.

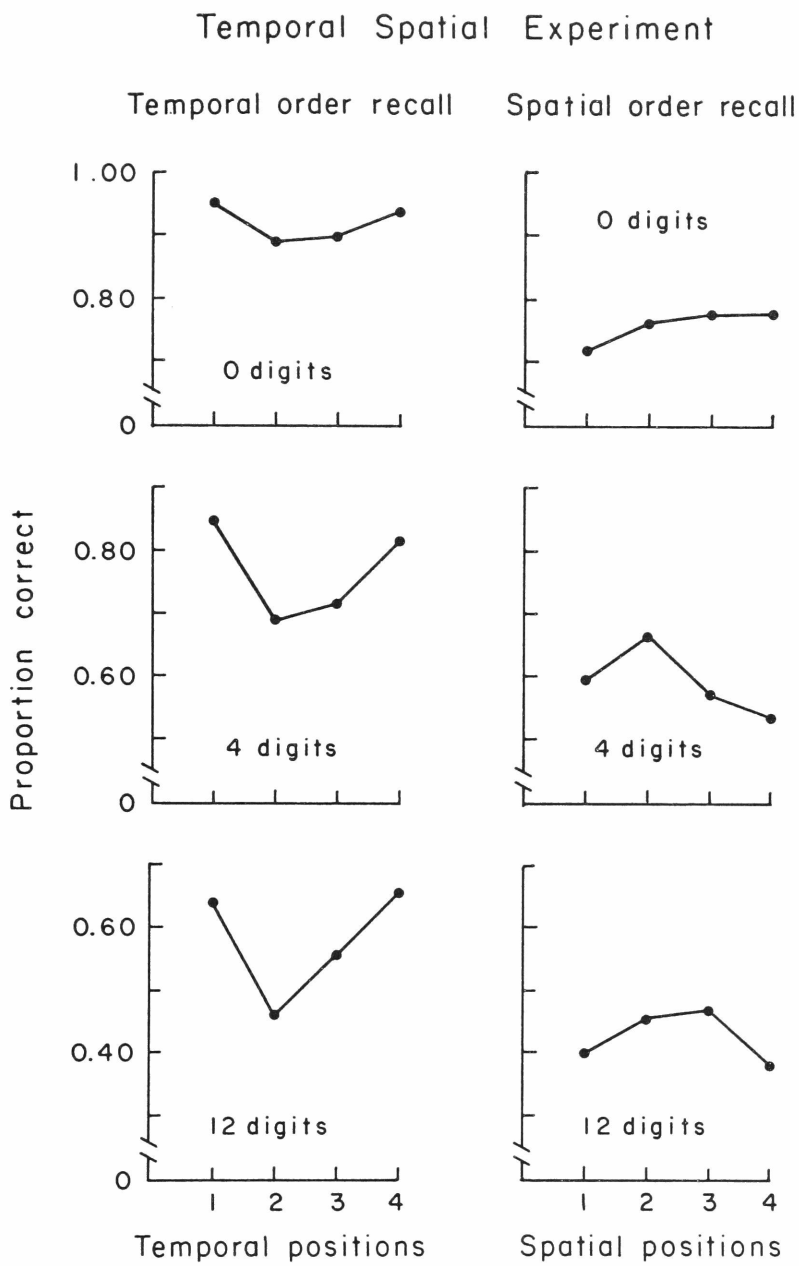

Figure 13. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the Temporal Order and Spatial Order Recall situations of the Temporal Spatial Experiment. The serial positions represented are the temporal positions in Temporal Order Recall and the spatial positions in Spatial Order Recall.

Figure 14 then presents the serial position curves for temporal and spatial order recall plotted as a function of spatial position for the case of temporal order recall and as a function of temporal position for the case of spatial order recall. In the temporal order recall case, the curves denote the proportion of correct responses on items presented in each of the four spatial positions. For example, consider the case when a subject was shown the temporal sequence BKPM with the letters in the spatial order PMBK (P in the first cell, M in the second cell, B in the third and K in the fourth). Then, if the subject responded when asked for the temporal order with KBPM, he made errors on letters B and K which came from temporal positions 1 and 2. Yet, in order to construct the serial position curves with the spatial positions, the spatial not the temporal positions of the letters must be considered. Letters B and K, the incorrect letters, came from spatial positions 3 and 4. Therefore, in this case the subject would be scored with one error each from spatial positions 3 and 4 and one correct response each from spatial positions 1 and 2. An ANOVA computed with these data yielded .03 as the standard error of the points in Figure 14. The analysis revealed that with the spatial positions, the serial position curves for temporal order recall, like those for spatial order recall, show no orderly pattern. However, as predicted, with the temporal positions, the serial position curves for spatial order recall, like the serial position curves with the temporal positions for temporal order recall, are bow-shaped except that here they are asymmetrical. The primacy portion of the serial position curves is greater than the recency portion. The ANOVA found a significant interaction between the temporal vs. spatial factor and the factor of serial position ($F = 16.83$, $p < .01$, $df = 3,45$).

These asymmetrical curves suggest that the subjects in the spatial order recall situation are employing some coding strategy which makes reference to the first letter of a string regardless of its spatial position. In any case these serial position curves demonstrate that the temporal position of a consonant affected its probability of being recalled in the proper spatial order. This finding is reasonable in view

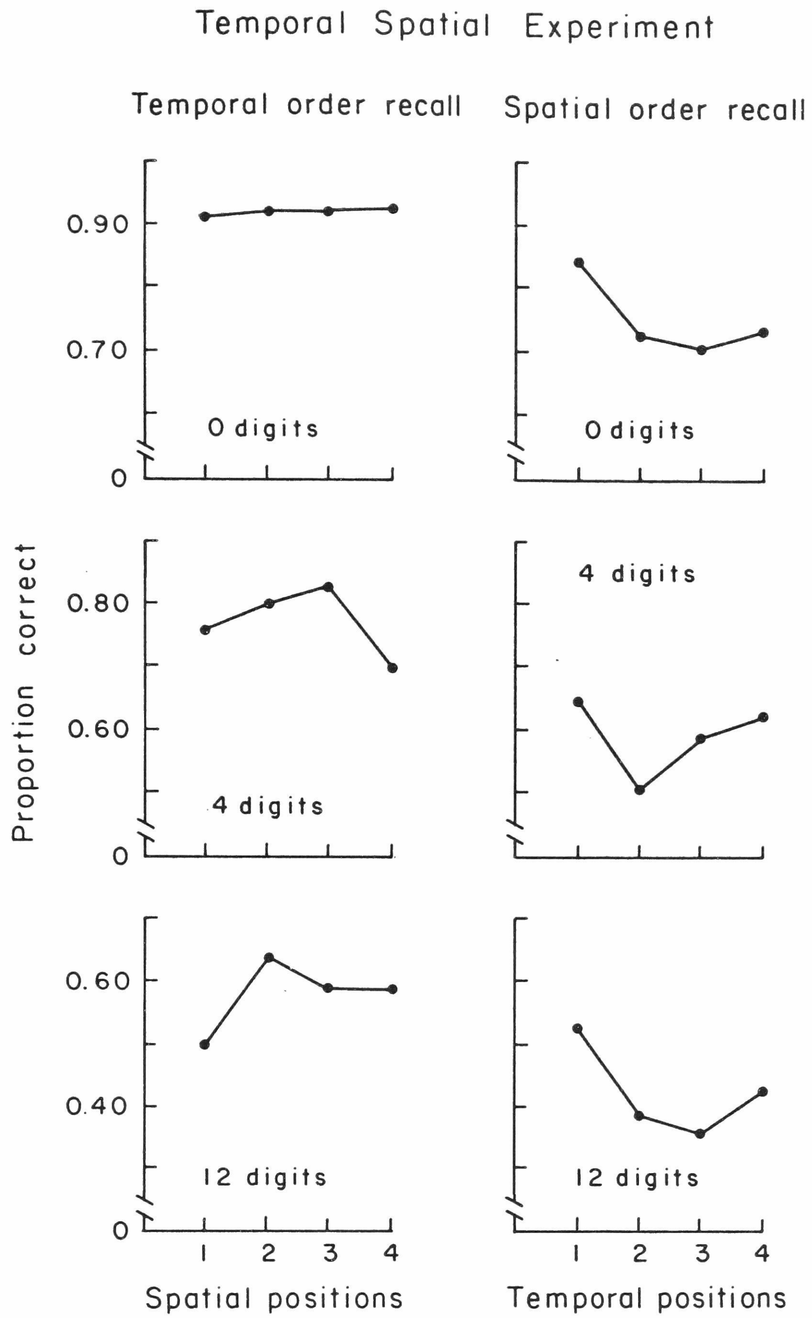

Figure 14. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the Temporal Order and Spatial Order Recall Situations of the Temporal Spatial Experiment. The serial positions represented are the spatial positions in Temporal Order Recall and the temporal positions in Spatial Order Recall.

of an observation by the experimenter that subjects often, when recalling the spatial order of the consonants, filled in the boxes on the response card according to the temporal order of consonant presentation. Therefore, for instance, if the first item shown to the subject on a given trial was a B in the third cell, then the first response the subject would make for that trial would be to write a B in the third box on the response card.

Distance Functions In the Order Only Experiment it proved useful to consider the distance between the serial position where a consonant was placed on the response card and the serial position where it had been shown in the stimulus display. It was found that incorrect items most often came from neighboring serial positions. These distance functions like the serial position curves were accounted for by Estes'(1972) model by implicating temporal factors. Therefore, one would expect to find similar distance functions for temporal order recall, but not necessarily for spatial order recall.

Distance functions were plotted for the present data and are shown in Figure 15 for the case of temporal order recall. In this case, as is usual for temporal order recall, the serial positions considered are the temporal positions. Thus, for instance, if the subject were given the stimulus in the temporal order BKPM and he responded with BPKM when asked for the temporal order, for this analysis there will be scored one case where he put an item into position 1 from position 1, one case where he put an item into position 2 from position 3, one case where he put an item into position 3 from position 2, and one case where he put an item into position 4 from position 4. On the whole, as expected, these curves for temporal order recall are quite similar to those seen in the Order Only Experiment. The distance functions show that incorrect responses are most likely to come from neighboring temporal positions. Furthermore, the curves for positions 3 and 4 look like mirror images of those for positions 1 and 2, which is consistent with the symmetry observed in the serial position curves. In addition, it seems that items from positions 2 and 3 are more often substituted for each other than are any other

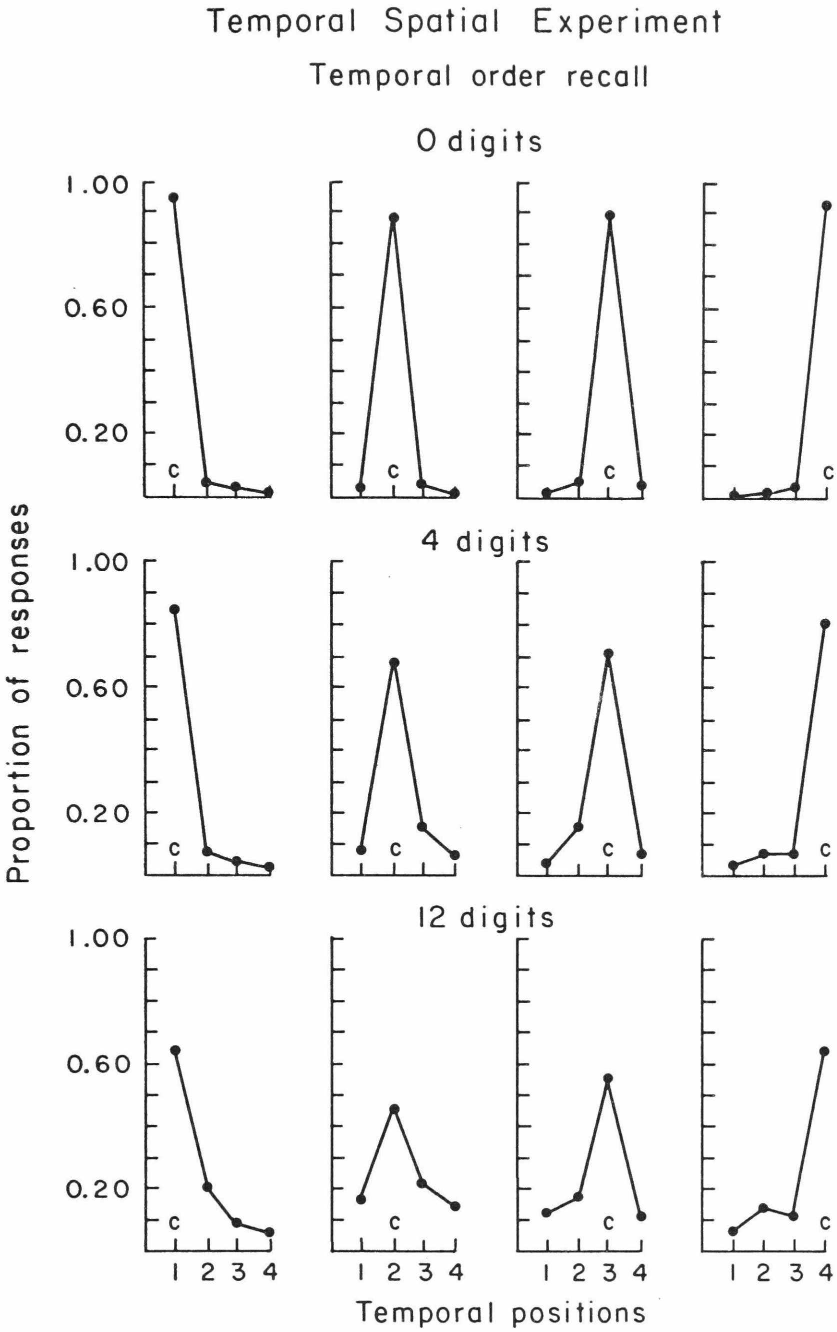

Figure 15. Distance functions for Temporal Order Recall in the Temporal Spatial Experiment. The serial positions represented are the temporal positions. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

pair of items. Moreover, for each pair of serial positions, the probability of recalling an item from a given serial position in another position is equal to the probability of recalling an item from the latter position in the former.

Similar distance functions for the recall of spatial order as a function of the spatial serial positions are presented in Figure 16. However, as with the serial position curves, there is little regularity. (Here and in other similar instances, a distance function with no regularity is one where there is no obvious relationship between the position where a subject enters a letter on his response card and the position of the same letter in the stimulus display. Such distance functions are described as "flat" because errors at any given response position are equally likely to come from any one of the stimulus positions. In these cases the actual curves do not look flat because information about correct responses is included along with the information about the errors.) These flat functions for spatial order recall are like those found by Murdock (1969) when he looked at similar gradients in his data. On the other hand, when Murdock performed the same analysis with temporal positions rather than spatial positions he found the characteristic sharp adjacency effects.

Therefore, as in the serial position curves, it seemed worthwhile to consider the distance functions with the temporal positions for the spatial order recall situation and similarly with the spatial positions for the temporal order recall situation. The distance functions for the recall of temporal order plotted as a function of spatial position are shown on Figure 17. The distance functions here represent the probability that the response for an item that was shown in a given spatial position will be an item from another spatial serial position. For instance, if the subject received the stimuli in the temporal order BKPM and in the spatial order PBMK, and if he responded that the temporal order had been MKPB, then his response transposed consonants B and M; in order to score the accuracy of temporal recall as a function of spatial position, there would be scored one case where he gave for a stimulus in spatial

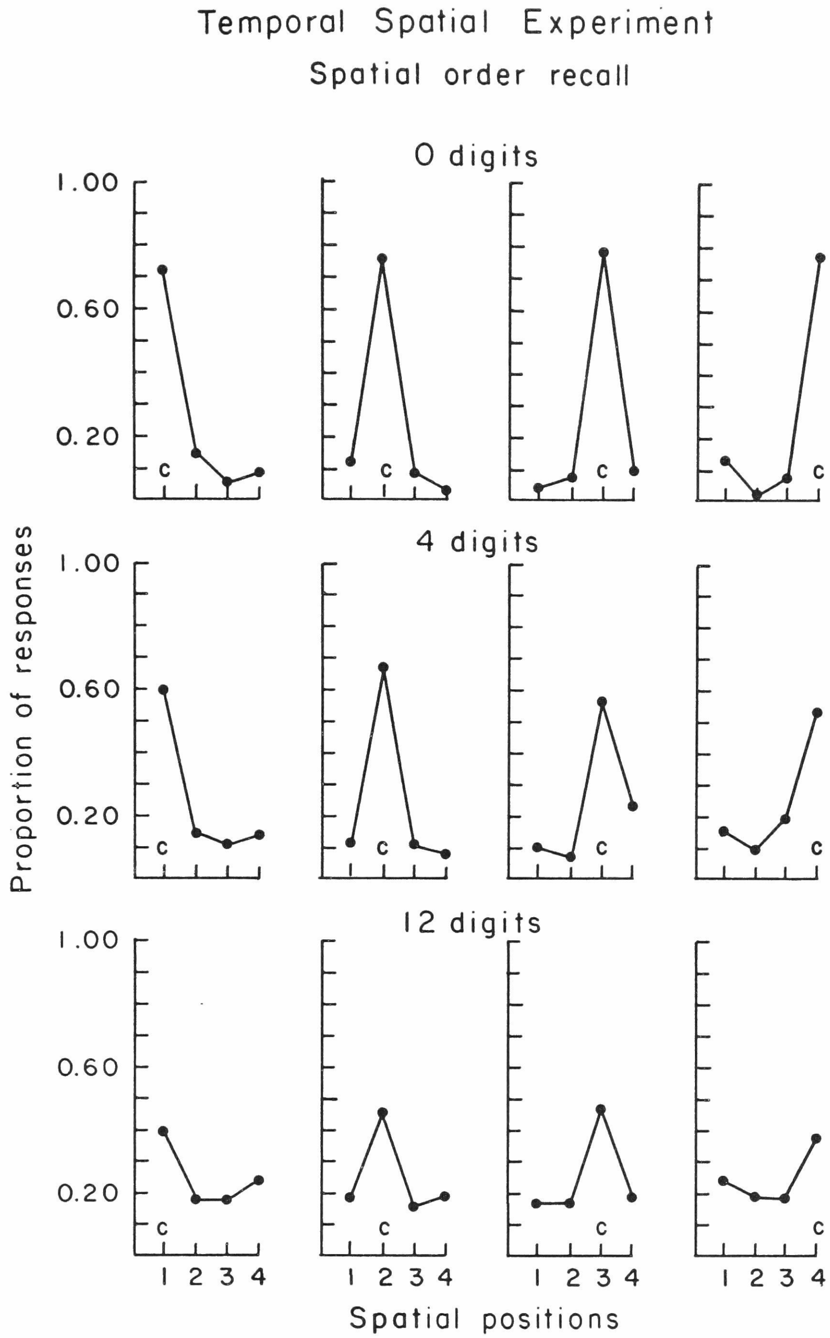

Figure 16. Distance functions for Spatial Order Recall in the Temporal Spatial Experiment. The serial positions represented are the spatial positions. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

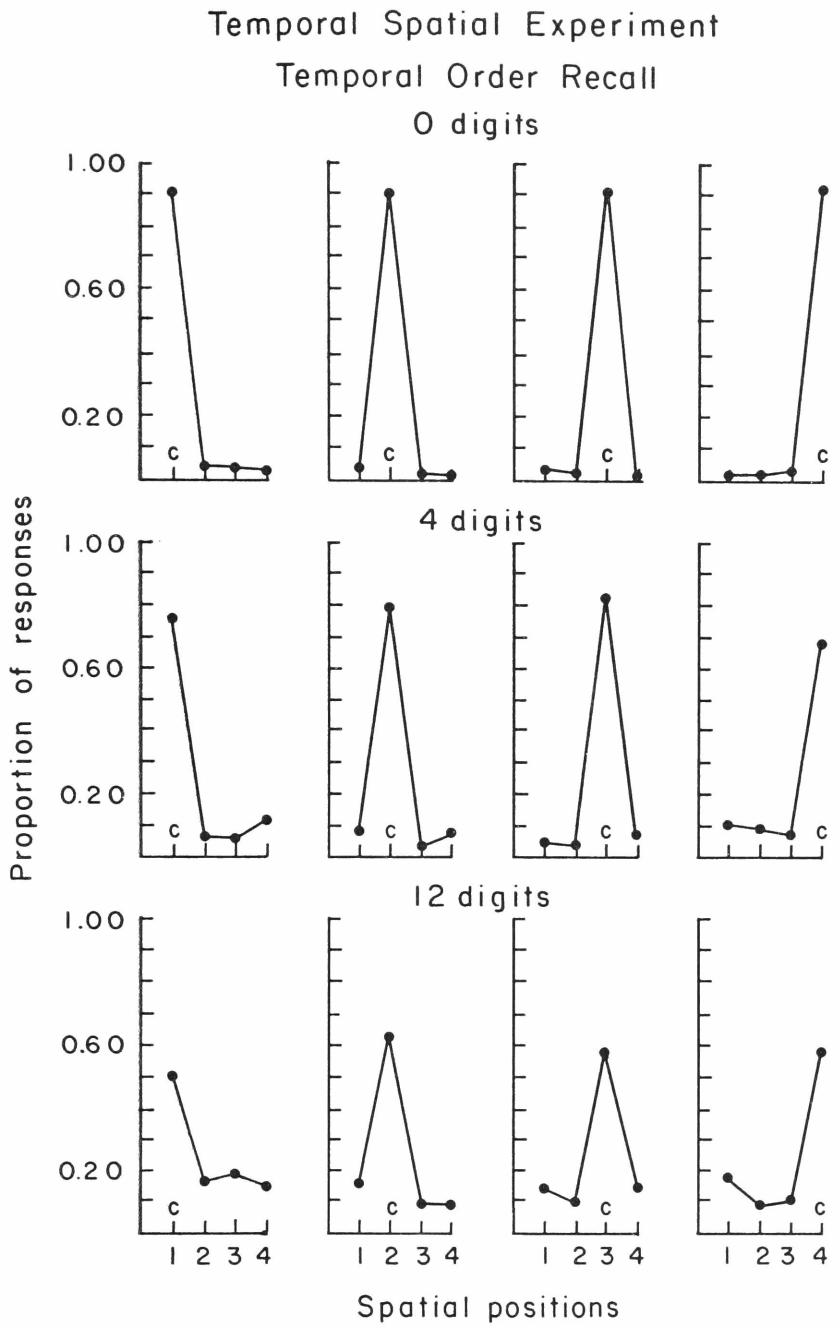

Figure 17. Distance functions for Temporal Order Recall in the Temporal Spatial Experiment. The serial positions represented are the spatial positions. The point plotted for position i of any panel represents the proportion of instances in which the letter that was shown in the spatial position marked C was replaced in the subject's protocol by the letter that was shown in spatial position i on the given trial.

position 2 a response presented in spatial position 3, one case where he gave for a stimulus presented in spatial position 4, a response from spatial position 4, one case where he gave for a stimulus presented in spatial position 1 a response from spatial position 1, and one case where he gave for a stimulus presented in spatial position 3 a response from spatial position 2. These distance functions, with the spatial serial positions for temporal order recall, like those for spatial order recall, are not orderly. Finding no orderly distance functions when the spatial positions are considered is consonant with a model like that of Estes (1972) which attributes these functions to temporal factors.

The distance functions for spatial order recall plotted as a function of temporal serial position are shown on Figure 18. Here, as in the case of temporal order recall, there is some regularity. There seems to be a greater probability that the response for an item shown in a given temporal position will be an item from a neighboring temporal position. Again it seems that items in temporal positions 2 and 3 are most often substituted for each other, but here items in temporal positions 3 and 4 are also substituted for each other quite often, especially at the shortest and longest retention intervals. The large number of cases where the last two items are interchanged suggests that in the recall of spatial order the subject employs some coding strategy that chunks these last two items. In any case, as a result of the large number of errors in positions 3 and 4, the curves for positions 3 and 4 are not quite mirror images of those for positions 1 and 2 as they were in the case of temporal order recall. However, in Figure 18 the other form of symmetry is observed as it was for temporal order recall. For each pair of serial positions, the probability of putting an item from a given serial position into another serial position is approximately equal to the probability of putting an item from the latter of the two serial positions into the former. Once again, then, the temporal position of an item affects the response for that item when its spatial order is being recalled. Murdock (1969) explains his similar finding by hypothesizing that spatial information is extracted through a temporally mediated reconstruction, just as

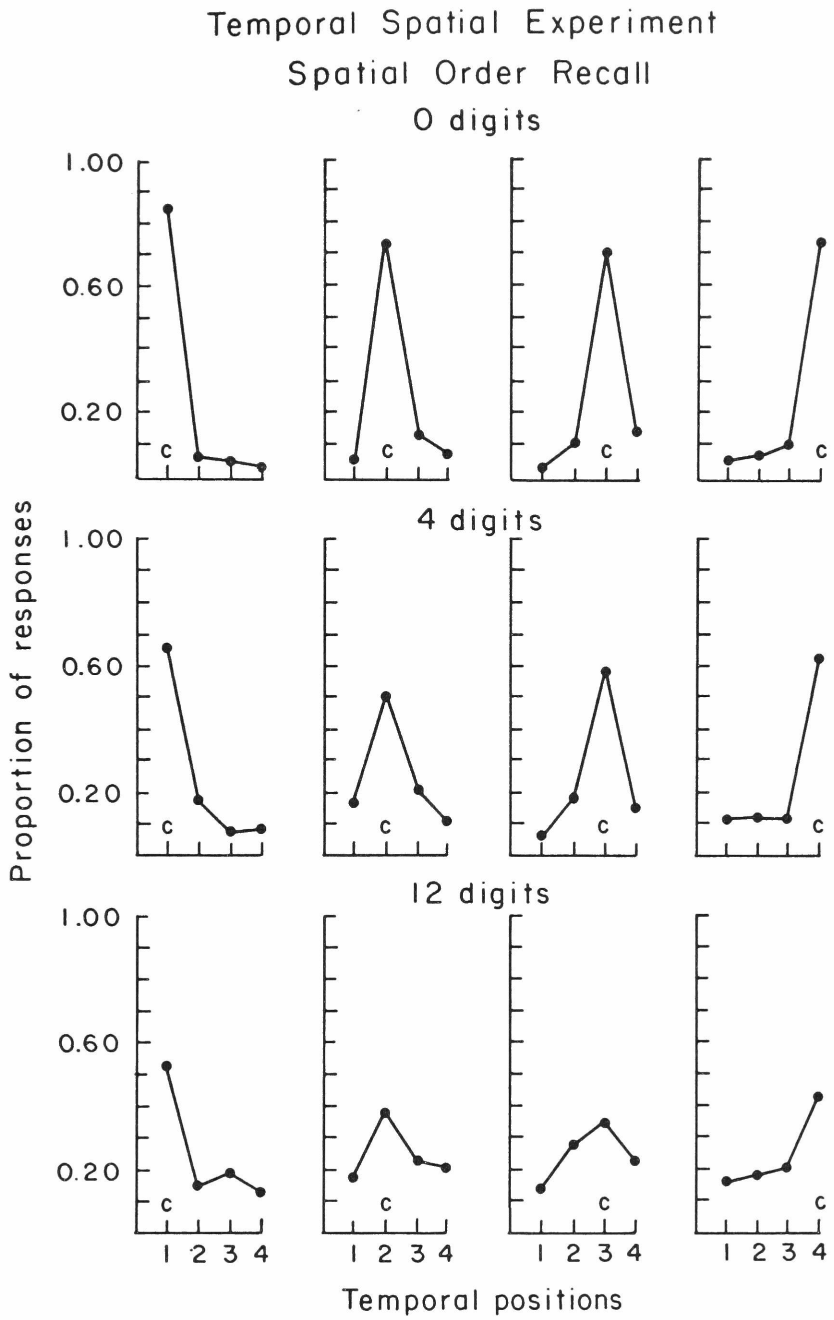

Figure 18. Distance functions for Spatial Order Recall in the Temporal Spatial Experiment. The serial positions considered are the temporal positions. The point plotted for position i of any panel represents the proportion of instances in which the letter that was shown in the temporal position marked C was replaced in the subject's protocol by the letter that was shown in temporal position i on the given trial.

Estes (1972) model would imply.

Constant Temporal Spatial Experiment

The Temporal Spatial Experiment led to the conclusion that spatial information is extracted through a temporally mediated reconstruction. However, there is an alternative explanation for the results of the Temporal Spatial Experiment which is compatible with the position hypothesis. It can be argued that during the Temporal Spatial Experiment, when the subject was to learn either the temporal or the spatial order of the consonants, he had to learn in effect a list of paired associates; each of the four consonants had to be associated with its respective position code. However, in the case of temporal order recall, the subject was always given the four position code members of the paired associate list in a constant order -- 1, 2, 3, 4 -- while in the case of spatial order recall, neither the four consonant members of the paired associate list nor the four position code members of the list were shown in a constant order. For that reason it was felt that the Temporal Spatial Experiment did not provide a fair comparison of temporal and spatial order recall. In fact, this same criticism can be leveled against the other experiments comparing temporal and spatial recall (Lundberg & Böök, 1969a, 1969b; Mandler & Anderson, 1971; Murdock, 1969; Shiffrin, personal communication; and Slamecka, 1967). The present experiment was designed to make possible a fair comparison of temporal and spatial order recall.

The design of the present experiment was strictly parallel to that of the Temporal Spatial Experiment except that type of order was a between-subjects variable here rather than a within-subjects variable so that no cueing was necessary. In addition, for all subjects who had to learn the spatial order of the consonants, the temporal order was held constant throughout the entire session. Similarly, for all subjects who had to learn the temporal order of the consonants, the spatial order was held constant throughout the entire session. Therefore, if the paired associate analogy is made, for each group of subjects one of the members of the paired associate list to be learned was always given in a constant order. For the temporal order recall group, the position code

members of the list were given in a constant order, and for the spatial order recall group, the consonant members of the list were given in a constant order.

Method

Subjects Twenty-four male and female young adults served as subjects in the present experiment. There were two conditions with twelve subjects in each condition. No subject had participated previously in a short-term memory experiment at Rockefeller. Subjects were recruited in the same manner as in the previous experiments and were similarly paid at the rate of $2.00 per hour.

Apparatus The apparatus was the same as in the previous experiments.

Materials Eight different experimental paper tapes were employed; 72 experimental trials were included on each tape. In addition, two practice paper tapes were employed with six practice trials on each tape. Each experimental and each practice trial consisted of a four-letter stimulus followed by a retention interval including either 3, 8, or 18 intervening digits.

As in the Temporal Spatial Experiment, the four consonants were presented successively, each consonant in a different one of the four cells of the screen. As each consonant was displayed in one of the four cells, the other three cells were left blank. Each of the digits in the retention interval, however, was displayed simultaneously in all four cells of the Bina-view screen.

In this experiment, as in the Order Only and Temporal Spatial Experiments, the same four consonants appeared on each trial of a given experimental paper tape. For four of the eight experimental paper tapes, each of the 24 permutations of the four letters appeared three times as the temporal ordering of the consonants, once at each of the three retention intervals (Temporal Order Recall Condition). In addition, for the remaining four of the eight experimental paper tapes, each of the 24 permutations of the four letters appeared three times as the spatial ordering of the consonants, once at each of the three retention intervals (Spatial Order Recall Condition). In the Temporal Order Recall Condition

the temporal order of the consonants corresponded trial-by-trial to the order of the consonants in the Order Only Experiment. Similarly, in the Spatial Order Recall Condition the spatial order of the consonants corresponded trial-by-trial to the order of the consonants in the Order Only Experiment. Furthermore, in the Temporal Order Recall Condition the spatial order of the four consonants was constant throughout the 72-trial experimental tapes. Thus, for example, on the tape where the letters BKPM were shown on every trial, the letters were always shown in the spatial order B in the first Bina-view cell, K in the second, P in the third, and M in the fourth. All that varied from trial to trial was the temporal order of the consonants. Likewise, in the Spatial Order Recall Condition the temporal order of the four consonants was constant throughout the 72-trial experimental tapes so that, for example, in the case where the letters BKPM were shown on every trial, the letters were always shown in the temporal order B first, then K, then P, and then M. All that varied from trial to trial was the spatial order of the consonants.

The presentation order of the trials corresponded exactly to that employed in the Order Only and Temporal Spatial Experiments. The intervening digits displayed on each trial corresponded exactly to those shown in the Order Only Experiment. The digits, and thus the retention intervals, were identically placed on each of the eight tapes.

The consonants displayed in the present experiment were drawn from the same eight-letter population employed in the Order Only and Temporal Spatial Experiments. (See Appendix A.) Further, as in the Temporal Spatial Experiment, four of the eight experimental tapes consisted of stimuli in the paired context and four of the eight experimental tapes consisted of stimuli in the all-different context. Thus, here, as in the Order Only, Item Only, and Temporal Spatial Experiments, context was a between-subjects variable. In fact, the paired context tapes of the present experiment corresponded to paired context tapes in the Order Only and Temporal Spatial Experiments so that either the consonants BKPM or the consonants FHSL were displayed on every trial. Similarly, the

all-different context tapes in the present experiment corresponded to the all-different context tapes in the Order Only and Temporal Spatial Experiments so that either the consonants BKFH or the consonants PMSL were displayed on every trial.

The eight experimental tapes included two tapes with the consonants BKPM, two with the consonants FHSL, two with the consonants BKFH, and two with the consonants PMSL. The sets of two tapes were identical except for the differences in the letters displayed. Whenever B occurred on the first set of tapes, F appeared on the second, B on the third, and P on the fourth. Similarly, K on the first set of tapes was replaced by H, K, and M; P was replaced by S, F, and S; and M was replaced by L, H, and L, respectively on the second, third, and fourth set of tapes.

The two tapes showing the same consonants included one tape in the Temporal Order Recall Condition and one in the Spatial Order Recall Condition. Thus, each pair of tapes was identical except that for every trial the spatial order of the consonants on one tape was the temporal order on the other tape and the temporal order of the consonants on one tape was the spatial order on the other. The constant spatial order of the consonants in the Temporal Order Recall Condition and the constant temporal order of the consonants in the Spatial Order Recall Condition was BKPM, FHSL, BKFH, or PMSL for the four pairs of tapes respectively.

As in the Temporal Spatial Experiment, the letters ABCD were shown on the two practice tapes. The two practice tapes were identical except that one of the tapes was assigned to the Temporal Order Recall Condition and one to the Spatial Order Recall Condition. In the case of the Temporal Order Recall Condition, the spatial order of the letters was always ABCD, and six different permutations of the letters were employed for the temporal order, two at each of the three retention intervals. In the case of the Spatial Order Recall Condition the temporal order of the letters was always ABCD, and the spatial order corresponded trial-by-trial to the temporal order in the Temporal Order Recall Condition. The order of the six trials and the digits that comprised the intervening tasks were quasi-random and were the same for both tapes.

Procedure Each subject was tested individually in an hour-long session. The 24 subjects were assigned to the eight different experimental tapes according to their time of arrival for testing. Each of the eight tapes was shown to four subjects so that there were twelve subjects in each recall condition. Note that recall condition is therefore a between-subjects variable in the present experiment whereas it was a within-subjects variable in the Temporal Spatial Experiment. All subjects in the Temporal Order Recall Condition were shown the practice tape for that condition, and all subjects in the Spatial Order Recall Condition were shown the practice tape for that condition.

The testing sessions were conducted in the same manner as in the previous experiments except that no confidence ratings were required of the subject in the present experiment so that no numbers appeared on the response cards.

The instructions read to subjects in the present experiment (see Appendix C) were identical to those read to subjects in the Temporal Spatial Experiment except that the previous instructions regarding the confidence ratings were omitted as were the instructions regarding the recall cues. In addition, subjects in the Temporal Order Recall Condition were told that the spatial order of the letters would be constant and were informed of the constant spatial order for their session. Furthermore, they were told to recall the consonants in their temporal order. Similarly, subjects in the Spatial Order Recall Condition were told that the temporal order of the consonants would be constant and were informed of the constant temporal order for their session. They were further told to recall the consonants in their spatial order. The experimenter also repeated the constant order of the consonants immediately before starting the experimental trials.

Results and Discussion

Time Course of Forgetting The time course of forgetting for the Temporal Order Recall Condition of the present experiment is shown on Figure 19 where it is compared with the time course of forgetting of the

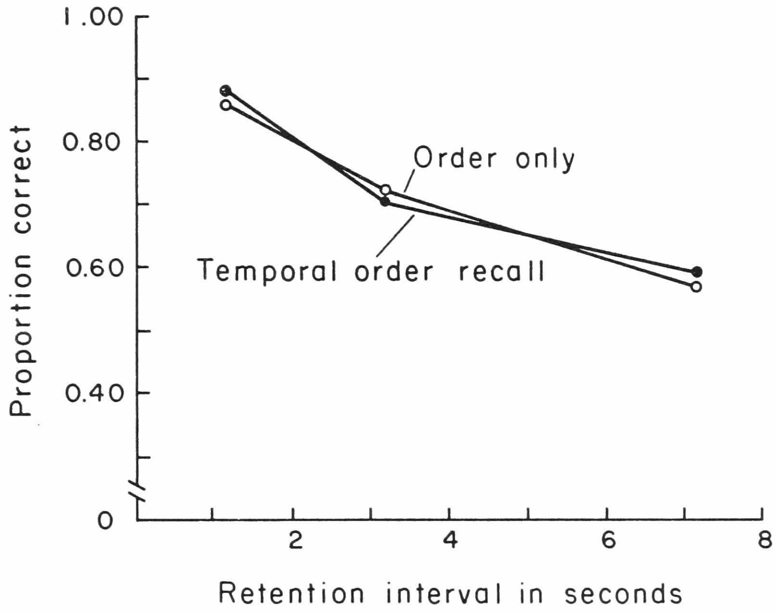

Figure 19. Time course of forgetting in terms of proportion of correct responses at each of the three retention intervals in the Paired and All-Different Context Conditions of the Order Only Experiment and in the Temporal Order Recall Condition of the Constant Temporal Spatial Experiment. Solid circles stand for temporal order recall; unfilled circles stand for Order Only recall.

Order Only Experiment (pooled data for the paired and all-different context conditions). The two curves are remarkably similar. The addition of the spatial factor does not seem to have modified the time course of forgetting of temporal order. However, Figure 20 reveals a marked difference in the time course of forgetting for the Temporal and Spatial Order Recall Conditions. Although the curve for the temporal order case is quite steep, the spatial order curve is very flat. An ANOVA was conducted for these data to assess the contribution of the between-subjects factor of temporal vs. spatial order recall and the within-subjects factor of retention interval. The ANOVA yielded an estimate of .05 for the standard error of the points on Figure 20. The effects of temporal vs. spatial recall ($F = 4.56$, $p < .05$, $df = 1,22$), retention interval ($F = 26.32$, $p < .01$, $df = 2,44$), and the interaction of the two factors ($F = 15.61$, $p < .01$, $df = 2,44$) were all significant. In addition t tests revealed that the proportions correct for the temporal and spatial cases were not different at the shortest retention interval ($t = .69$, $p > .05$, $df = 22$, two-tailed test), but were significantly different at the longer retention intervals ($t = 2.53$, $p < .05$, at 8 digits and $t = 3.11$, $p < .01$ at 18 digits; $df = 22$, two-tailed tests in each case). The earlier conclusion, based on the results of the Temporal Spatial Experiment, that temporal order recall is superior to spatial order recall is now seen to be unwarranted.

Confusion Errors The former confusion error analysis comparing the conditional probabilities of confusion errors given that an error was made on confusable and control letters is not applicable to the present situation because of the constant order constraint. In the Spatial Order Recall Condition the confusable letters come from temporal positions 1 and 3 and the control letters come from temporal positions 2 and 4. Similarly, in the Temporal Order Recall Condition confusable letters come from spatial positions 1 and 3 and the control letters come from spatial positions 2 and 4. Therefore a new confusion error analysis was devised.

For all the subjects in the Spatial Order Recall Condition letters in temporal positions 1 and 3 were from the acoustically confusable sets.

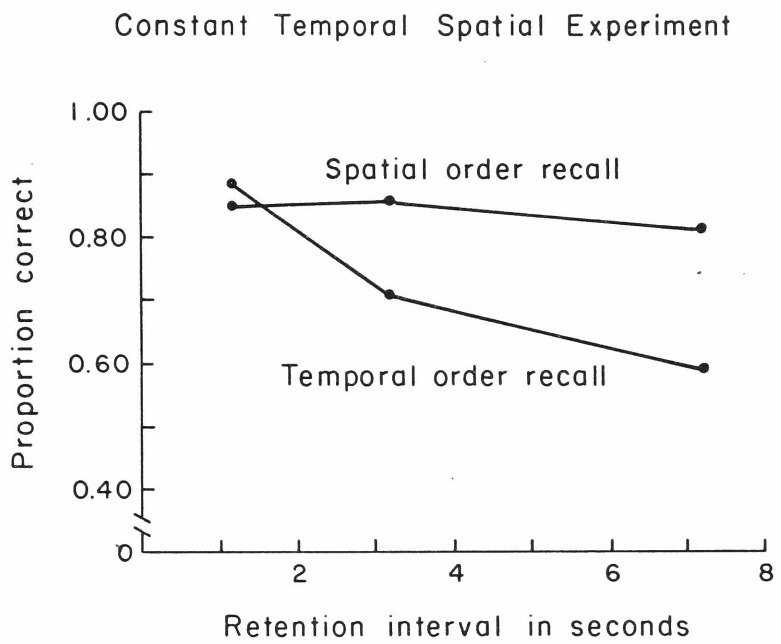

Figure 20. Time course of forgetting in terms of proportion of correct responses at each of the three retention intervals in the Temporal Order and in the Spatial Order Recall Conditions of the Constant Temporal Spatial Experiment.

However, for the half of these subjects who saw paired context displays, the letters in temporal positions 1 and 3 were from the same acoustic confusion set, and for the half of the subjects who saw all-different context displays, the letters in temporal positions 1 and 3 were from different acoustic confusion sets. Similarly, for subjects in the Temporal Order Recall Condition, half the subjects, those seeing paired context displays, saw confusable letters in spatial positions 1 and 3, and half the subjects, those seeing all-different context displays, saw in positions 1 and 3 letters which were from the acoustic confusion sets but which were not confusable with each other. Let us define confusion-set error as an error on a letter from one of the two acoustic confusion sets when the subject substitutes an incorrect letter which comes from either of the two acoustic confusion sets.

A confusion-set error is identical to a confusion error for letters in the paired context, since confusable letters are involved, but it differs from a confusion error for letters in the all-different context since nonconfusable letters are involved. Therefore, if acoustic coding is being employed, one should find a difference in the proportion of confusion-set errors on confusable letters, always in the paired context, and on nonconfusable letters, always in the all-different context. Note that this confusion-set error comparison does not have the same problems as the confusion error comparison although the two comparisons are otherwise quite similar. In the confusion-set case, both the confusable and nonconfusable letters come from the serial positions 1 and 3. The conditional proportions of confusion-set errors given that an error was made on a letter from the acoustic confusion sets is shown in Figure 21. Confusion-set errors for confusable and nonconfusable letters are compared as are confusion-set errors for temporal and spatial order recall. An ANOVA on these data yielded an estimate of .08 for the standard error of the means. Acoustic coding is evident in the Temporal Order Recall Situation, confusion-set errors being greater on confusable than on nonconfusable letters at the shorter retention intervals. Here, as in the earlier experiments dealing with temporal order recall, there is a decline in confusion-set errors on confusable letters as the retention

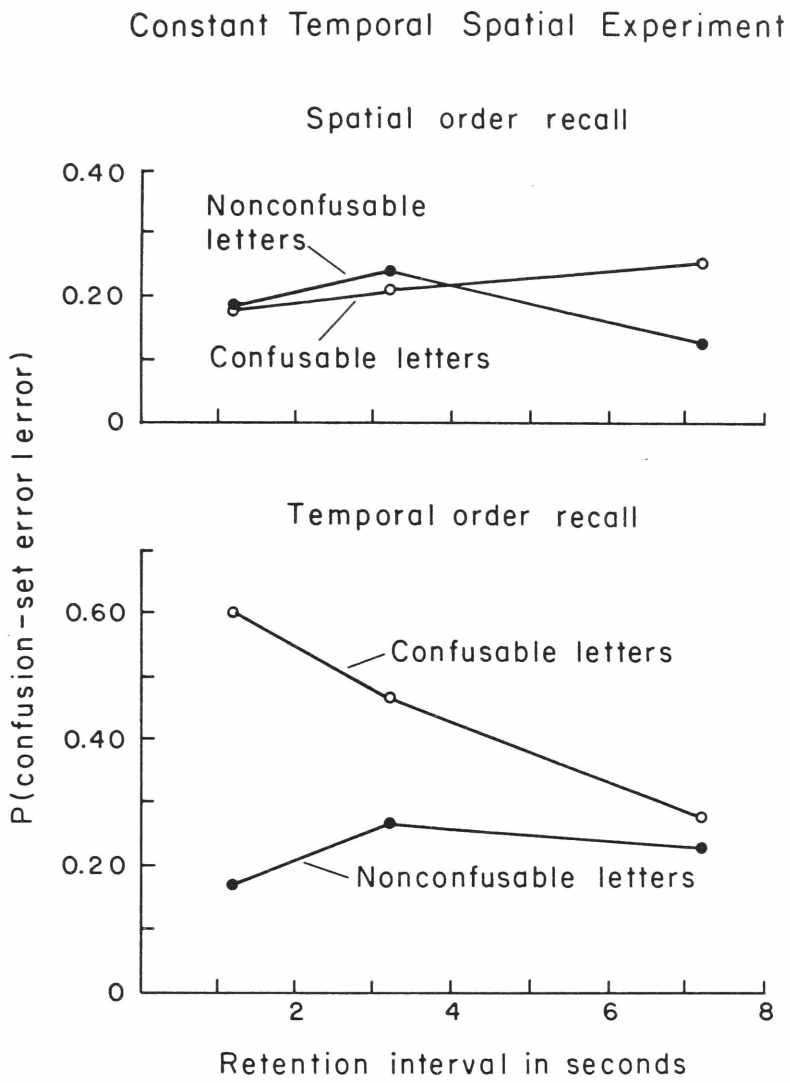

Figure 21. Conditional proportions of confusion-set errors given that an error was made at each of the three retention intervals for letters from the paired context strings (confusable letters) and letters from the all-different context strings (nonconfusable letters) in the Spatial Order and Temporal Order Recall Conditions of the Constant Temporal Spatial Experiment. Solid circles stand for nonconfusable letters; unfilled circles stand for confusable letters.

interval increases. Therefore it seems appropriate to conclude that acoustic information is employed in temporal order recall but that this information decays rapidly and is no longer available after several seconds of intervening activity. However, in the spatial order case, there is no evidence for acoustic coding since there is no difference between confusion-set errors on the confusable and the nonconfusable letters. In accordance with these observations, the ANOVA found both between-subjects factors of temporal vs. spatial order recall ($F = 13.41$, $p < .01$, $df = 1,20$) and context (confusable vs. nonconfusable letters) ($F = 10.36$, $p < .01$, $df = 1,20$) significant and the interaction between the two factors marginally significant ($F = 4.12$, $.10 > p > .05$, $df = 1,20$).

Serial Position Curves Symmetrical bowed serial position curves were found for temporal order recall in the Temporal Spatial Experiment, whereas flat curves were found for spatial order recall. It seems reasonable to assume that subjects in the temporal order recall situations of both the present experiment and the preceding Temporal Spatial Experiment do not pay attention to the spatial locations of the items. In that case, one would not expect that holding the spatial locations of the items constant rather than varying them would change the serial position curves for temporal order recall. Therefore, bowed serial position curves are expected for the temporal order recall condition of the present experiment. However, since temporal factors have been shown to influence spatial order recall, the constant temporal order constraint is expected to affect the spatial order recall situation. In fact, the time course of forgetting in the Spatial Order Recall Condition of the present experiment was very different from that in the spatial order recall situation of the Temporal Spatial Experiment. Therefore, one might expect that the serial position curves for spatial order recall would also differ in the two experiments.

Serial position curves for the Temporal and Spatial Order Recall Conditions at each of the three retention intervals are presented in Figure 22. The serial positions employed in the Temporal Order Recall

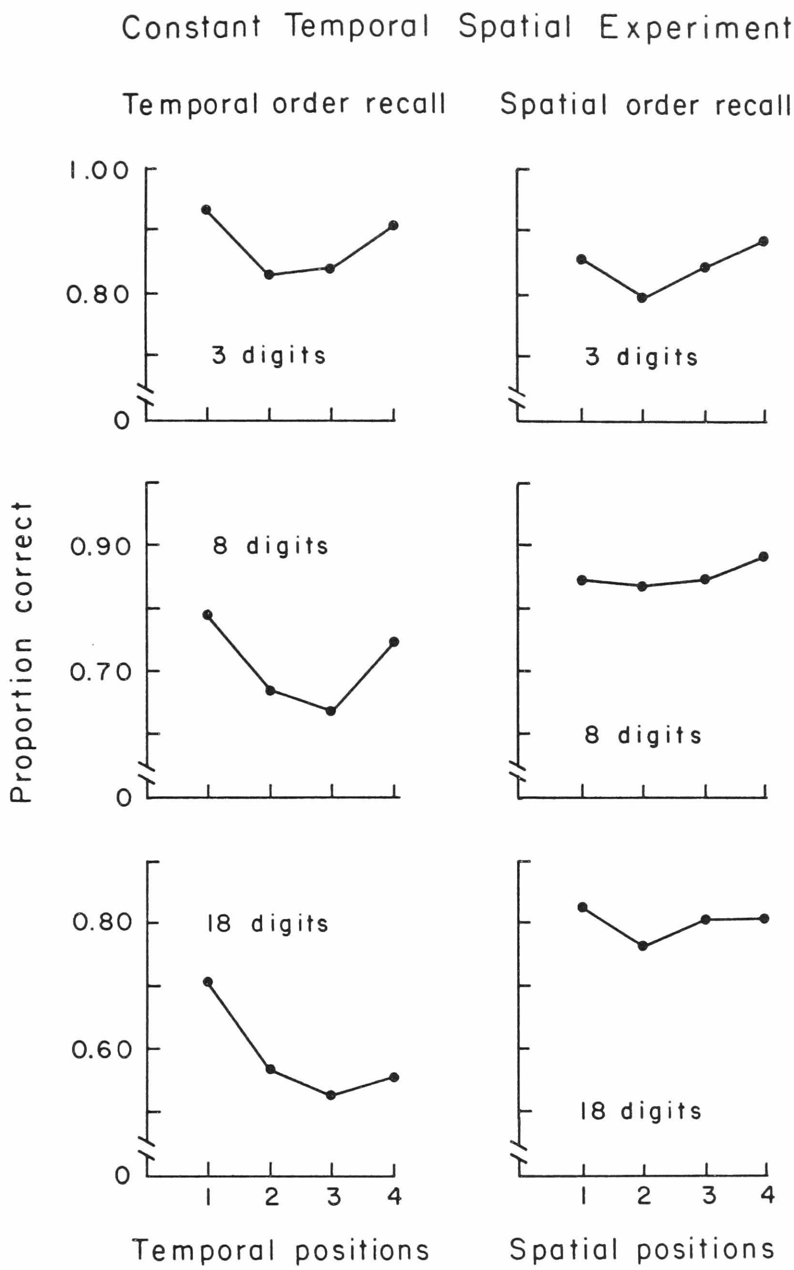

Figure 22. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the Temporal Order and Spatial Order Recall Conditions of the Constant Temporal Spatial Experiment. The serial positions represented are the temporal positions in the Temporal Order Recall Condition and the spatial positions in the Spatial Order Recall Condition.

Condition are the temporal positions, and the serial positions used in the Spatial Order Recall Condition are the spatial positions. An ANOVA performed with these data yielded an estimate of .02 for the standard error of the points in Figure 22. As in the Temporal Spatial Experiment, the serial position curves for the Temporal Order Recall Condition are bowed and symmetrical except for a loss of recency at the longest retention interval. The curves for spatial order are also similar to those in the Temporal Spatial Experiments; they show only a slight tendency toward a bow-shape. The ANOVA found to be significant the factors serial position ($F = 17.73$, $p < .01$, df = 3,66) and the interaction of the factors temporal vs. spatial and serial position ($F = 8.02$, $p < .01$, df = 3,66).

The Temporal Spatial Experiment demonstrated that the temporal position of a consonant influences its probability of correct recall even during spatial order recall. This finding led to the conclusion that spatial order recall is mediated by temporal factors. Temporal factors, however, may be less influential in the present experiment where the items are shown in a constant temporal order on every trial. Therefore, one might predict little effect of temporal position on spatial order recall. In any case, since spatial position did not affect temporal order recall in the Temporal Spatial Experiment, spatial position is not expected to affect temporal order recall in the present experiment.

The serial position curves for temporal and spatial order recall plotted as a function of spatial position for the Temporal Order Recall Condition and as a function of temporal position for the Spatial Order Recall Condition are shown in Figure 23. An ANOVA computed with these data yielded .02 as the standard error of the points in Figure 23. As predicted, the serial position curves for the Temporal Order Recall Condition show little regularity and only a slight tendency toward a bow-shape. The serial position curves for the Spatial Order Recall Condition, contrary to predictions, are similar to those in the Temporal Spatial Experiment. The ANOVA found that the factor of serial position was significnat ($F = 11.62$, $p < .01$, df = 3,66) as was the interaction

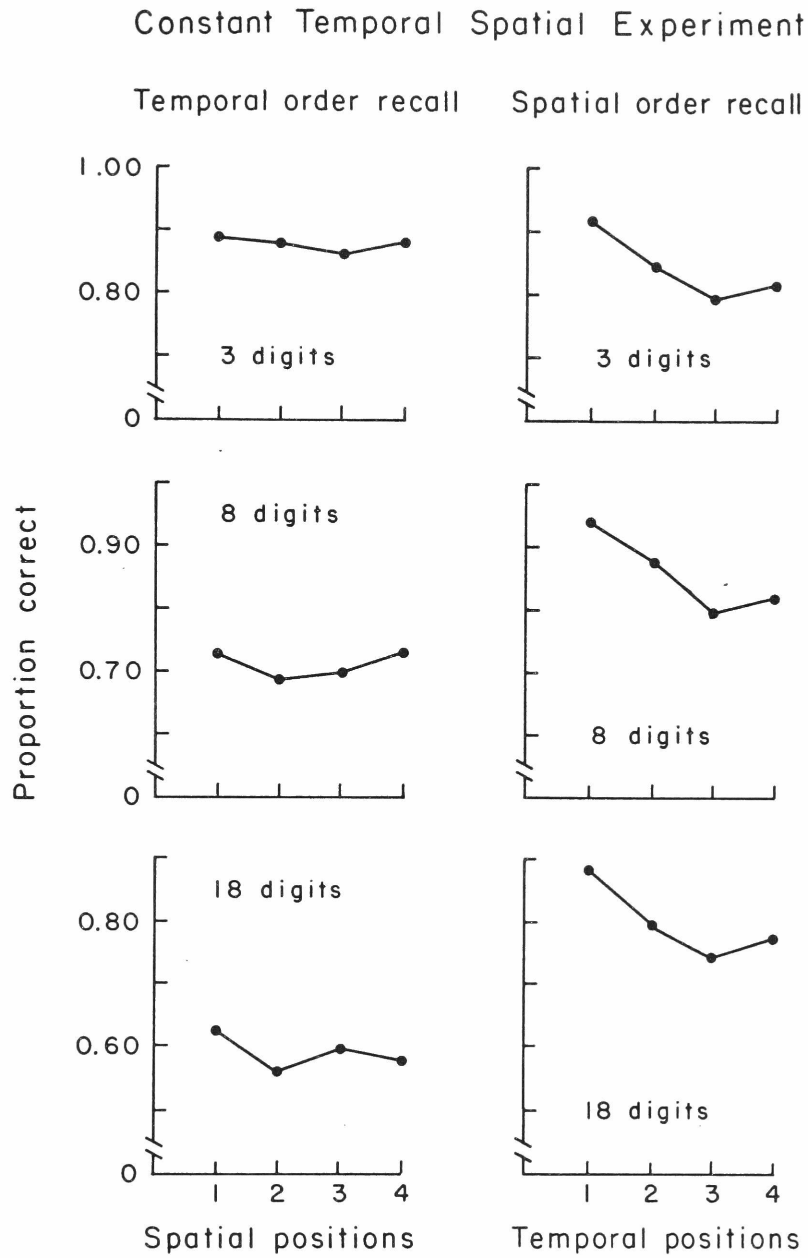

Figure 23. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the Temporal Order and Spatial Order Recall Conditions of the Constant Temporal Spatial Experiment. The serial positions represented are the spatial positions in the Temporal Order Recall Condition and the temporal positions in the Spatial Order Recall Condition.

between the temporal vs. spatial factor and the factor of serial position ($F = 5.29$, $p < .01$, $df = 3,66$). The curves for spatial order recall like those for temporal order recall are bow-shaped when the temporal positions are used in each case. However, in the Spatial Order Recall Condition the curves are more asymmetrical than in the Temporal Order Recall Condition, the primacy effect being larger than the recency effect. A similar observation was made in connection with the Temporal Spatial Experiment.

Since the temporal order of the consonants is constant in the spatial order recall task, all that the subjects had to remember is the temporal order of the spatial positions. The spatial order recall situation is therefore quite similar to an experimental situation devised by Sanders (1968) where subjects learned the temporal order of spatial positions. Sanders employed five spatial positions and lists of length three to seven. For each list length, Sanders found asymmetrical serial position curves for temporal positions which were very similar to those found in the present study. Sanders' curves also show considerable evidence for a primacy effect but not for a recency effect. These asymmetrical curves suggest that subjects in these situations use a coding strategy which makes reference to the first letter of a string regardless of its spatial location.

In any case, despite the fact that the temporal order of the consonants was constant in the Spatial Order Recall Condition, the temporal position of an item affected its probability of being recalled in the correct spatial position.

<u>Distance Functions</u> In the Temporal Spatial Experiment the distance functions revealed that in the case of both temporal and spatial order recall incorrect items most often came from neighboring temporal positions. However, the spatial position of an item did not affect the response for that item even in the case of spatial order recall. One may wonder whether the same conclusions can be reached on the basis of the data from the present Constant Temporal Spatial Experiment. In fact, the distance functions in the two experiments do lead to similar conclusions.

The distance functions for each of the three retention intervals in the Temporal Order Recall Condition are presented in Figure 24. In this case the serial positions considered are the temporal positions. With a few irregularities, the distance functions show that incorrect responses are most likely to come from neighboring serial positions. In addition, the probability of putting an item from serial position 2 into serial position 3 is especially large as is the probability of putting an item from serial position 3 into serial position 2. At the longest retention interval, it is also the case that the probability of putting an item from serial position 4 into serial position 3 is very large as is the probability of putting an item from serial position 3 into serial position 4. Therefore, at the earlier retention intervals, the curves for serial positions 3 and 4 look like mirror images of those for positions 1 and 2, which is consistent with the symmetry observed in the serial position curves at those intervals. However, at the longest retention interval, the symmetry is marred by the larger probability of interchanging items in positions 3 and 4 than in 1 and 2. This asymmetry in the distance functions is reminiscent of the asymmetry observed in the serial position curves at the same retention interval. The other form of symmetry of the distance function, though, is evident at each of the three retention intervals: the probability of putting an item from a given serial position into another serial position is roughly equal to the probability of putting an item from the latter of the two serial positions into the former.

The distance functions at each of the three retention intervals for the Spatial Order Recall Condition plotted as a function of spatial serial position are presented in Figure 25. Here, as with the serial position curves, the functions are much flatter than in the temporal order case, showing a tendency toward an equal probability of putting an item from a given serial position into any one of the other serial positions. Furthermore, the distance functions for the Temporal Order Recall Condition plotted as a function of spatial serial position are similar to those for the Spatial Order Recall Condition as a function of spatial serial

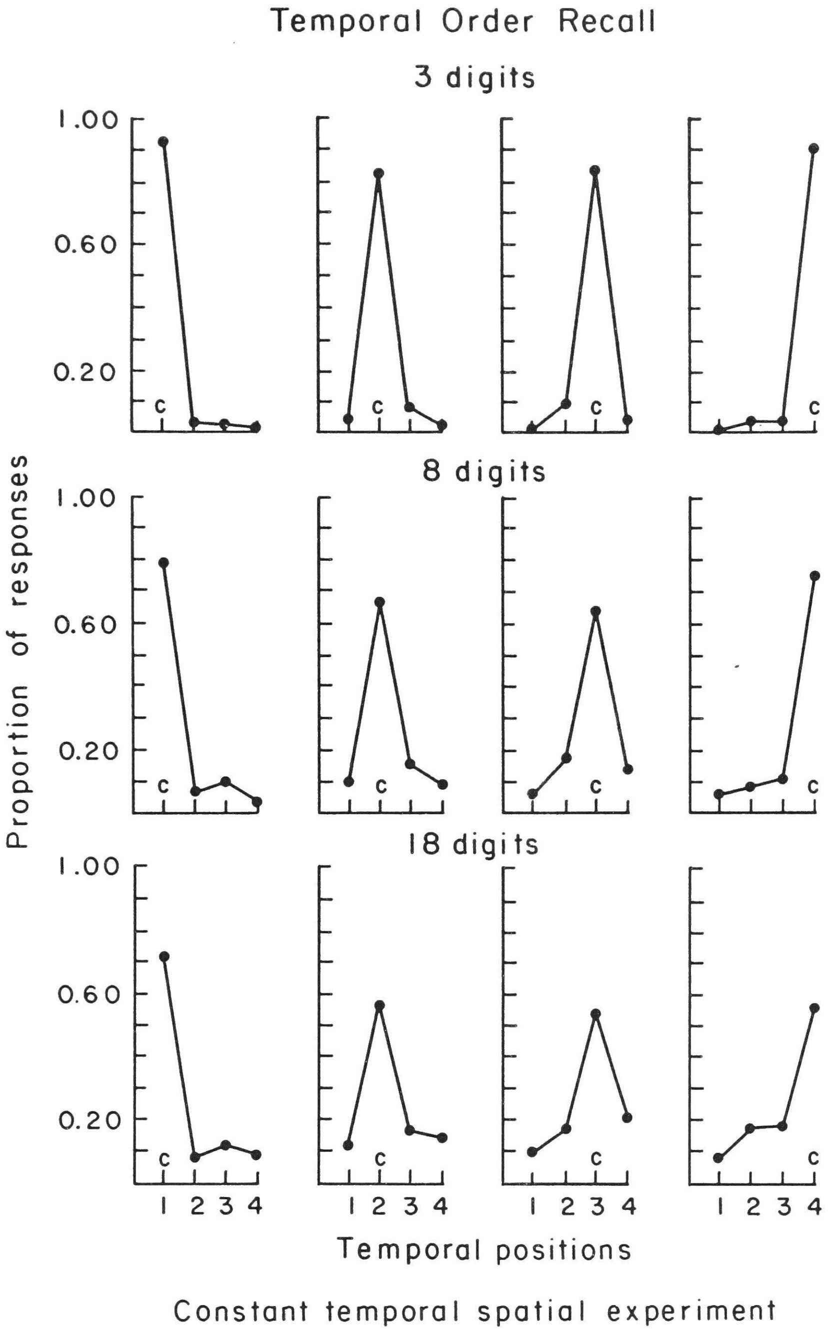

Figure 24. Distance functions for the Temporal Order Recall Condition of the Constant Temporal Spatial Experiment. The serial positions represented are the temporal positions. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

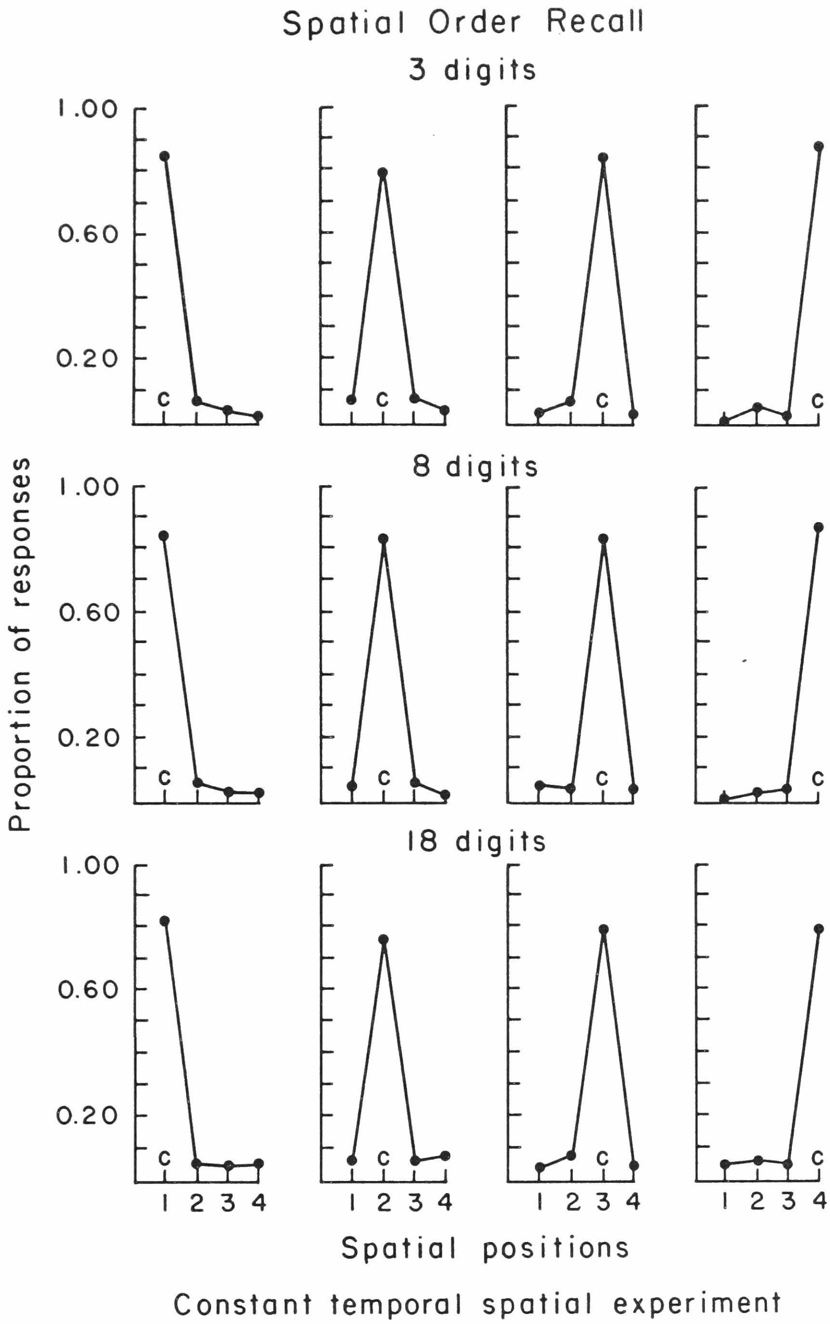

Figure 25. Distance functions for the Spatial Order Recall Condition of the Constant Temporal Spatial Experiment. The serial positions represented are the spatial positions. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

position. These curves which are quite flat are presented in Figure 26.

On the other hand, regularity is again observed when the temporal serial positions are considered, this time for the Spatial Order Recall Condition (see Figure 27). It seems here that items from neighboring temporal positions are most often substituted for the correct item. In addition, it seems that items from temporal positions 3 and 4 are most often interchanged and more often than are items from temporal positions 2 and 3 and 1 and 2, which is consistent with the marked asymmetry in the serial position curves. Furthermore, again it seems that for each pair of serial positions, the probability of putting an item from a given serial position into another serial position is equal to the probability of putting an item form the latter of the two serial positions into the former. These findings for the distance functions, like those for the serial position functions, are consonant with the notion that temporal factors influence spatial order recall. In this way additional support is given to Murdock's notion that spatial order information is extracted through a temporally mediated reconstruction.

Pattern Analysis Temporal factors have been shown to influence the recall of spatial order. At this point, though, the specific role of the temporal factors is not clear. One obvious possibility is that the subject is paying attention, not to each consonant independently, but rather to the temporal spatial pattern of consonant presentations. These patterns are shown in Figure 28. There are 24 possible temporal spatial patterns, and, because of the manner in which the stimulus tapes were constructed, every subject saw each one of these patterns once at each of the three retention intervals. Some of these temporal spatial patterns were included in the studies of temporal and spatial order recall of Lundberg and Böök (1969a, 1969b).

Distance functions for the temporal serial positions are shown in Table XVII for each of the 24 patterns in the Temporal Order Recall Condition. The distance functions for the spatial serial positions are similarly presented in Table XVIII for each of the 24 patterns in the Spatial Order Recall Condition. It is clear from these tables that the

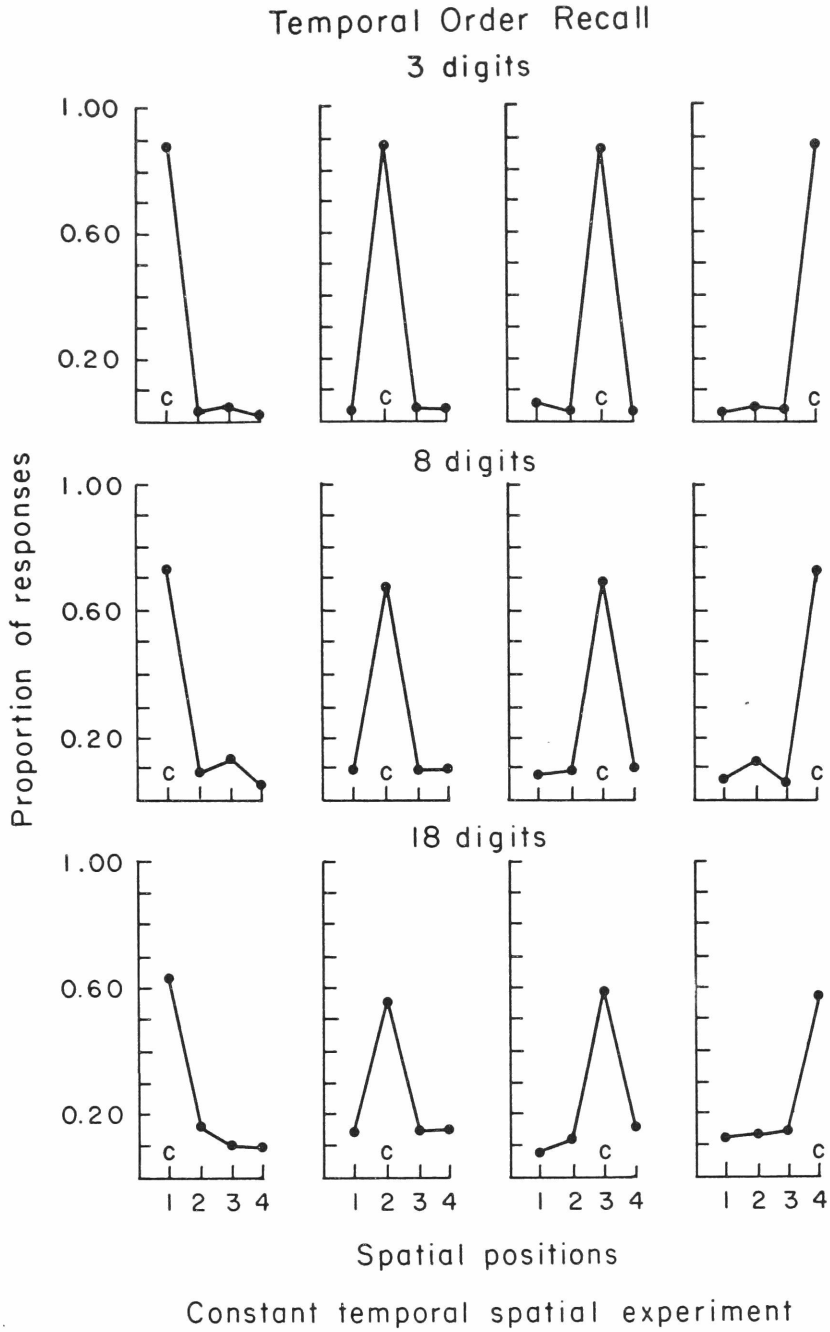

Figure 26. Distance functions for the Temporal Order Recall Condition of the Constant Temporal Spatial Experiment. The serial positions represented are the spatial positions. The point plotted for position i of any panel represents the proportion of instances in which the letter that was shown in the spatial position marked C was replaced in the subject's protocol by the letter that was shown in spatial position i on the given trial.

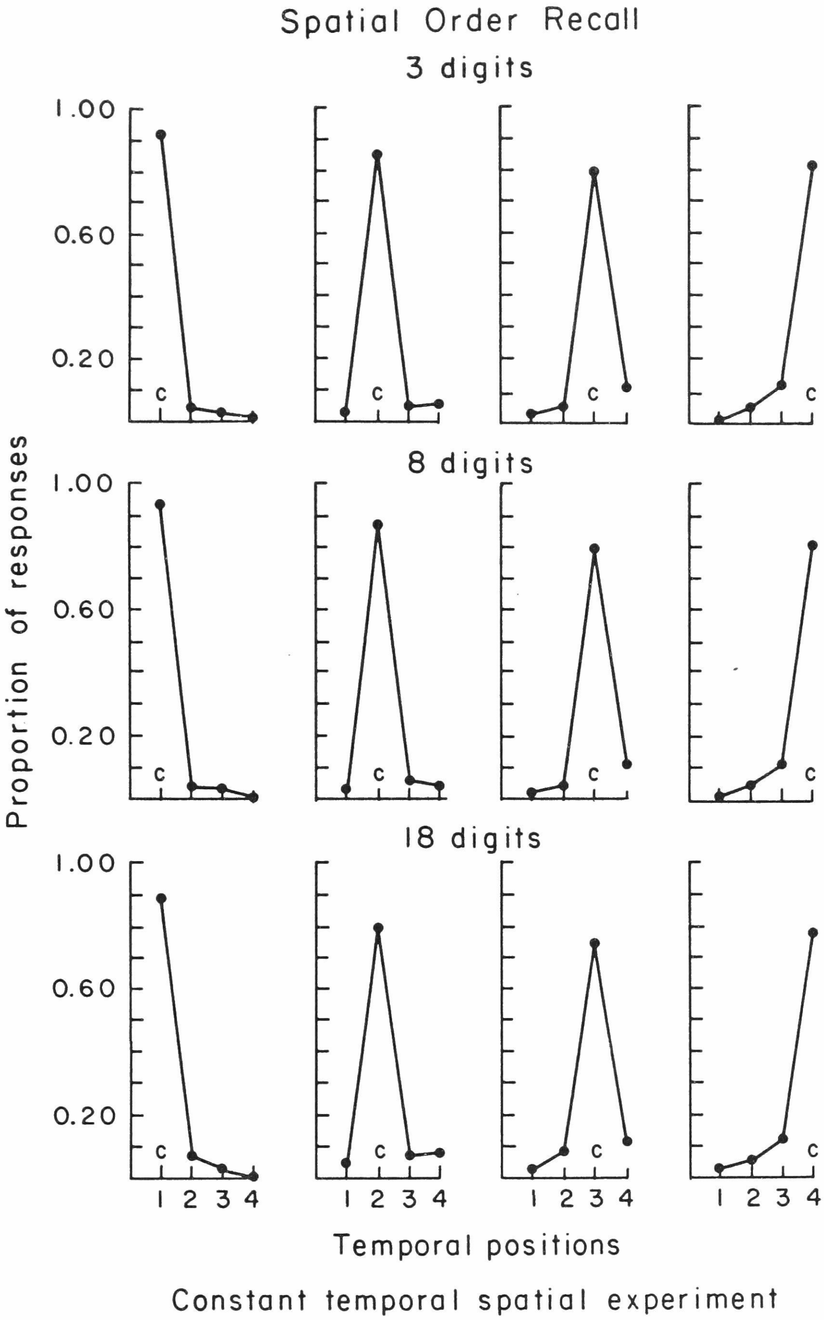

Figure 27. Distance functions for the Spatial Order Recall Condition of the Constant Temporal Spatial Experiment. The serial positions represented are the temporal positions. The point plotted for position i of any panel represents the proportion of instances in which the letter that was shown in the temporal position marked C was replaced in the subject's protocol by the letter that was shown in temporal position i on the given trial.

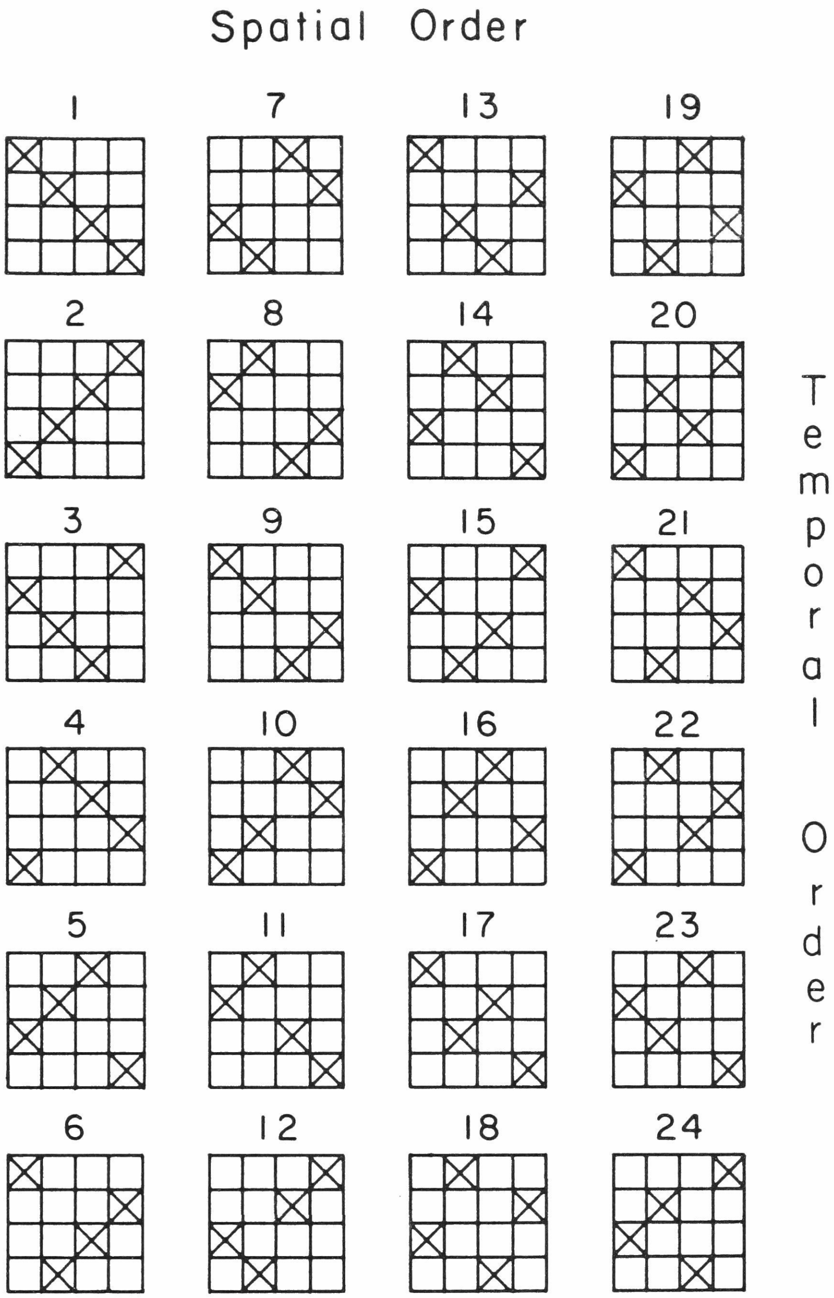

Figure 28. Temporal spatial patterns of consonant presentations. The spatial positions are shown horizontally, and the temporal positions are shown vertically. For example, in pattern number 7, the subject first sees a consonant in the third cell, then one in the fourth cell, then one in the first cell, and then one in the second cell.

Table XVII

Temporal Distance Functions for Temporal Order Recall Condition of Constant Temporal Spatial Experiment

Pattern No.	Distance Function (Response Position, Stimulus Position)															
	1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
1	36	0	0	0	0	32	4	0	0	3	31	2	0	2	1	33
2	31	0	4	1	3	27	6	0	1	7	25	3	1	2	1	32
3	26	5	3	2	4	26	5	1	3	4	25	4	3	1	3	29
4	29	2	4	1	2	29	2	3	3	2	28	3	2	3	2	29
5	22	3	9	2	8	20	3	5	3	10	21	2	3	3	3	27
6	33	0	1	2	1	24	7	4	0	8	21	7	2	4	7	23
7	31	1	3	1	3	23	5	5	1	9	23	3	1	3	5	27
8	30	2	3	1	2	27	4	3	2	6	21	7	2	1	8	25
9	34	0	2	0	1	29	4	2	1	4	27	4	0	3	3	30
10	29	4	1	2	3	25	4	4	2	3	25	6	2	4	6	24
11	27	5	3	1	4	26	4	2	5	2	27	2	0	3	2	31
12	32	1	2	1	4	26	3	3	0	7	24	5	0	2	7	27
13	29	0	4	3	5	19	8	4	1	8	21	6	1	9	3	23
14	27	4	3	2	3	20	9	4	4	8	23	1	2	4	1	29
15	28	1	4	3	5	23	5	3	1	6	26	3	2	6	1	27
16	26	3	2	5	6	20	6	4	2	6	24	4	3	7	3	23
17	32	1	3	0	0	25	8	3	3	7	23	3	1	3	2	30
18	29	2	4	1	3	26	2	5	2	0	27	7	2	8	3	23
19	27	6	1	2	3	25	6	2	0	3	22	11	6	2	7	21
20	24	7	4	1	8	23	1	4	3	3	24	6	1	3	7	25
21	33	1	0	2	1	27	6	2	1	6	25	4	1	2	5	28
22	26	2	6	2	4	22	3	7	4	9	20	3	2	3	7	24
23	30	3	3	0	2	26	4	4	2	3	23	8	2	4	6	24
24	29	0	3	4	2	27	5	2	1	7	24	4	4	2	4	26

Table XVIII

Spatial Distance Functions for Spatial Order Recall Condition of Constant Temporal Spatial Experiment

Pattern No.	Distance Function (Response Position, Stimulus Position)															
	1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
1	35	1	0	0	1	35	0	0	0	0	36	0	0	0	0	36
2	35	1	0	0	1	34	1	0	0	1	34	1	0	0	1	35
3	32	2	2	0	2	32	1	1	2	1	33	0	0	1	0	35
4	33	0	0	3	0	31	4	1	0	5	30	1	3	0	2	31
5	30	4	0	2	4	24	7	1	0	5	29	2	2	3	0	31
6	31	1	0	4	0	25	11	0	2	8	23	3	3	2	2	29
7	33	2	0	1	3	33	0	0	0	0	36	0	0	1	0	35
8	29	2	3	2	2	32	1	1	3	1	28	4	2	1	4	29
9	36	0	0	0	0	32	0	4	0	2	34	0	0	2	2	32
10	27	9	0	0	9	27	0	0	0	0	35	1	0	0	1	35
11	30	0	4	2	0	33	2	1	4	3	29	0	2	0	1	33
12	28	5	3	0	5	29	2	0	3	2	27	4	0	0	4	32
13	33	2	0	1	1	31	4	0	2	2	29	3	0	1	3	32
14	35	0	0	1	0	36	0	0	1	0	34	1	0	0	2	34
15	29	4	2	1	3	21	12	0	1	11	22	2	3	0	0	33
16	28	1	0	7	6	28	0	2	0	0	35	1	2	7	1	26
17	33	0	3	0	0	34	0	2	3	0	33	0	0	2	0	34
18	25	4	3	4	7	27	2	0	3	5	24	4	1	0	7	28
19	28	4	0	4	4	27	0	5	0	1	34	1	4	4	2	26
20	32	2	2	0	3	32	1	0	1	2	33	0	0	0	0	36
21	34	0	1	1	0	16	3	17	2	4	28	2	0	16	4	16
22	25	1	8	2	1	28	4	3	7	5	21	3	3	2	3	28
23	30	5	0	1	3	23	4	6	1	3	31	1	2	5	1	28
24	22	6	8	0	5	26	4	1	8	1	24	3	1	3	0	32

patterns differ considerably in their overall probability of correct recall; also it is clear that the distribution of errors made on these 24 patterns is far from random. It seems that certain patterns show characteristic distance functions. This finding is especially interesting for the Spatial Order Recall Condition in light of the observation that the same distance functions grouped across patterns were flat. For example, in the Spatial Order Recall Condition, patterns #6 and 15 show a tendency to interchange items in serial positions 2 and 3; pattern #10 shows a tendency to interchange items in serial positions 1 and 2, and pattern #21 shows a tendency to interchange items in serial positions 2 and 4. Furthermore, in each of these cases, letters in temporal positions 3 and 4 were interchanged, and these two interchanged letters had been presented from right to left spatially. Thus there seems to be a tendency to recall letters in the last two temporal positions as though they were presented from left to right spatially.

A correlation of .35 was found between proportion correct at each of these 24 patterns in the Temporal Order Recall Condition and the proportion correct at each of the same 24 patterns in the Spatial Order Recall Condition. This coefficient is positive but not significant at the .05 level with 22 degrees of freedom. (Here and in other similar instances the reader is referred to Snedecor and Cochran, 1967, p. 557.) The nonsignificant correlation coefficient indicates that subjects in the Temporal Order Recall Condition did not code the temporal spatial patterns in the same manner as did subjects in the Spatial Order Recall Condition.

1234 Experiment

The Constant Temporal Spatial Experiment revealed substantial differences between temporal and spatial order recall. Most impressive were the differences in the time course of forgetting and in the effects of acoustic confusability. Temporal order recall showed the typical steep time course of forgetting, whereas spatial order recall showed a much flatter function. Furthermore, temporal order recall, but not spatial order recall, showed evidence for coding in terms of acoustic information.

The distinction between temporal and spatial order recall is therefore confounded with a distinction between acoustic and nonacoustic coding. One wonders then whether eliminating acoustic coding would eliminate the other differences between temporal and spatial order recall. The present experiment sought to answer this question by determining whether the time course of forgetting in temporal and spatial order recall differ when acoustic information is eliminated.

This experiment was therefore a direct follow-up of the Constant Temporal Spatial Experiment. All materials of the experiment as well as the design were identical to that of the preceding experiment; all that differed in the two cases was the subject's task. In the present experiment the subject was required to say aloud the digits "1, 2, 3, 4" as the four consonants appeared successively, rather than to read aloud the four consonants. In this way the present experiment eliminated the use of acoustic information by requiring the subject to pronounce irrelevant items rather than the consonants themselves. The technique is similar to that employed by Estes (1973), Murray (1967), Tell (1971) and others.

Method

Subjects Twenty-four male and female young adults served as subjects in the present experiment, half assigned to the Temporal Order Recall Condition and half to the Spatial Order Recall Condition. No subject had participated previously in a short-term memory experiment at Rockefeller. Subjects were recruited in the same manner as in the previous experiments and were similarly paid at the rate of $2.00 per hour.

Apparatus The same apparatus was employed in the present experiment as had been employed in the previous experiments.

Materials The identical eight experimental and two practice paper tapes from the Constant Temporal Spatial Experiment were employed in the present experiment.

Procedure The procedure employed in the present experiment was identical to that employed in the Constant Temporal Spatial Experiment with one exception. Although the subject was instructed to read aloud every

one of the 3, 8, or 18 digits as they appeared during the retention interval, he was not instructed to read aloud the letters as they appeared at the beginning of a trial. Rather, the subject was told to say aloud "one" as the first consonant appeared, "two" as the second consonant appeared, "three" as the third consonant appeared, and "four" as the fourth consonant appeared. (See Appendix C.) In addition, the subject was told the constant order of the consonants and a card was placed in front of him that had printed on it the constant order.

Results and Discussion

Time Course of Forgetting The time course of forgetting for the Temporal and Spatial Order Recall Conditions of the present experiment are compared in Figure 29. An ANOVA performed on these data yielded .03 as the value of the standard error of the points on Figure 29. Whereas in the Constant Temporal Spatial Experiment the proportions correct at the shortest retention interval were not different for temporal and spatial recall but were significantly different at the longer retention intervals, in the present experiment the proportions correct for temporal and spatial order recall differ at all three retention intervals. Furthermore, whereas in the Constant Temporal Spatial Experiment the time course of forgetting was quite steep in the case of temporal order recall, in the present experiment the time course of forgetting for Temporal Order Recall is flat just as for the Spatial Order Recall Condition. The ANOVA finds the temporal vs. spatial factor marginally significant ($F = 3.54$, $.05 < p < .10$, $df = 1,22$), the factor of retention interval significant ($F = 14.57$, $p < .01$, $df = 3,66$), but the interaction of the two factors not significant ($F = 0.78$, $p > .05$, $df = 2,44$). The fact that the time courses of forgetting in the two recall conditions are parallel supports the hypothesis that the same form of coding was employed in the two tasks.

Confusion Errors Now that acoustic information has been eliminated, no evidence is expected for acoustic coding in either recall condition. Therefore no difference is expected in proportion of confusion-set errors on confusable and nonconfusable letters in either the Temporal or the

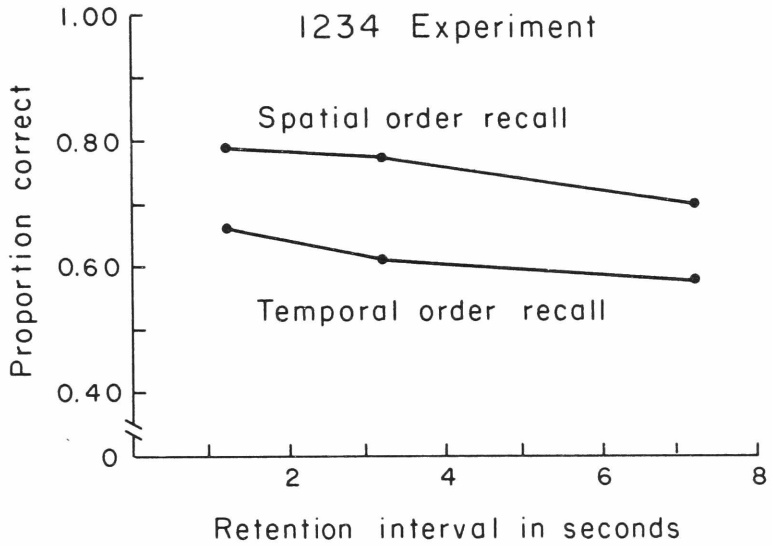

Figure 29. Time course of forgetting in terms of proportion of correct responses at each of the three retention intervals in the Temporal Order and Spatial Order Recall Conditions of the 1234 Experiment.

Spatial Order Recall Conditions. The conditional proportions of confusion-set errors given that an error was made on a letter from one of the two acoustic confusion sets are shown on Figure 30. The conditional proportions for confusable and nonconfusable letters are compared as are the conditional proportions for the Temporal and Spatial Order Recall Conditions. An ANOVA yielded .06 as the standard error of the means. Here, as expected, no difference is seen between confusion-set errors on confusable and nonconfusable letters in either recall condition. This finding is consonant with the contention that acoustic information is not being employed in the present experiment. In accordance with these observations, the ANOVA did not find the factor of context (confusable vs. nonconfusable letters) to be significant ($F = 1.49$, $p > .05$, $df = 1,20$) nor the interaction of the factors temporal vs. spatial order recall and context ($F = 2.34$, $p > .05$, $df = 1,20$).

Serial Position Curves In the Constant Temporal Spatial Experiment the serial position curves for temporal positions were very similar for temporal and spatial order recall except that less recency was noted for the spatial order case. Furthermore, in the Constant Temporal Spatial Experiment, the serial position curves with the spatial positions were very similar for temporal and spatial recall. Therefore, in the present experiment, where it is supposed that temporal and spatial order recall involve the same coding mechanism, little difference is expected between temporal and spatial order recall in the serial position curves either when both are plotted for temporal or when both are plotted for spatial positions. These predictions are upheld by the data.

Serial position curves are shown in Figure 31 for the Temporal and Spatial Order Recall Conditions at each of the three retention intervals. The serial positions used for the analysis in the Temporal Order Recall Condition are the temporal positions; whereas the serial positions used for the analysis in the Spatial Order Recall Condition are the spatial positions. As in the Constant Temporal Spatial Experiment, the serial position curves for the Temporal Order Recall Condition are bowed with a loss of recency especially at the longest retention interval. However,

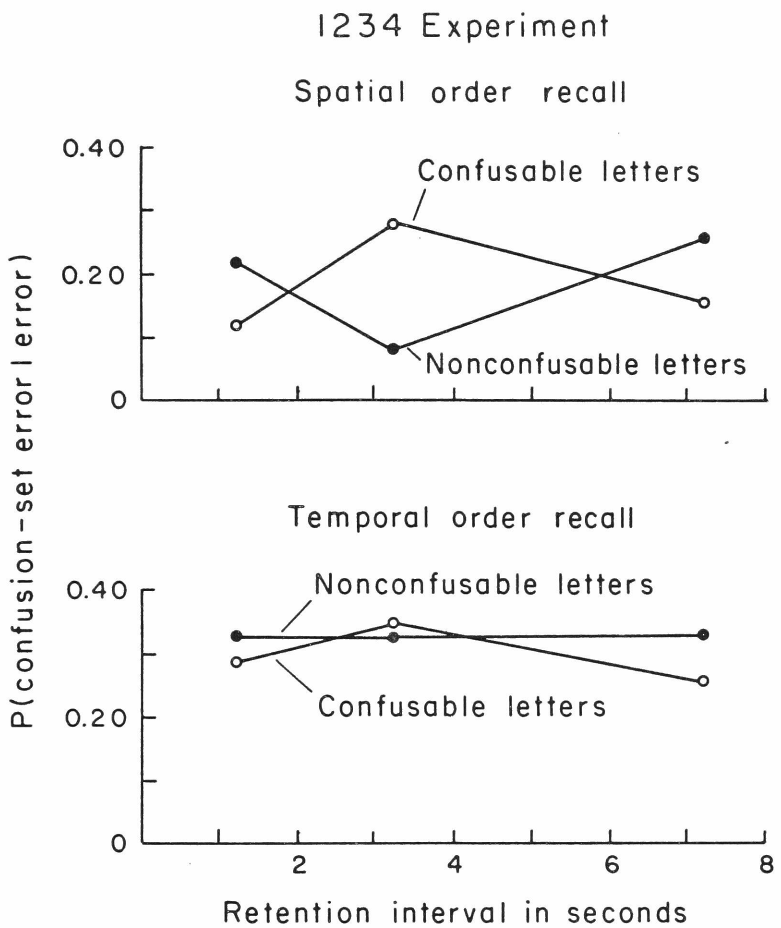

Figure 30. Conditional proportions of confusion-set errors given that an error was made at each of the three retention intervals for letters from the paired context strings (confusable letters) and letters from the all-different context strings (nonconfusable letters) in the Spatial Order and Temporal Order Recall Conditions of the 1234 Experiment. Solid circles stand for nonconfusable letters; unfilled circles stand for confusable letters.

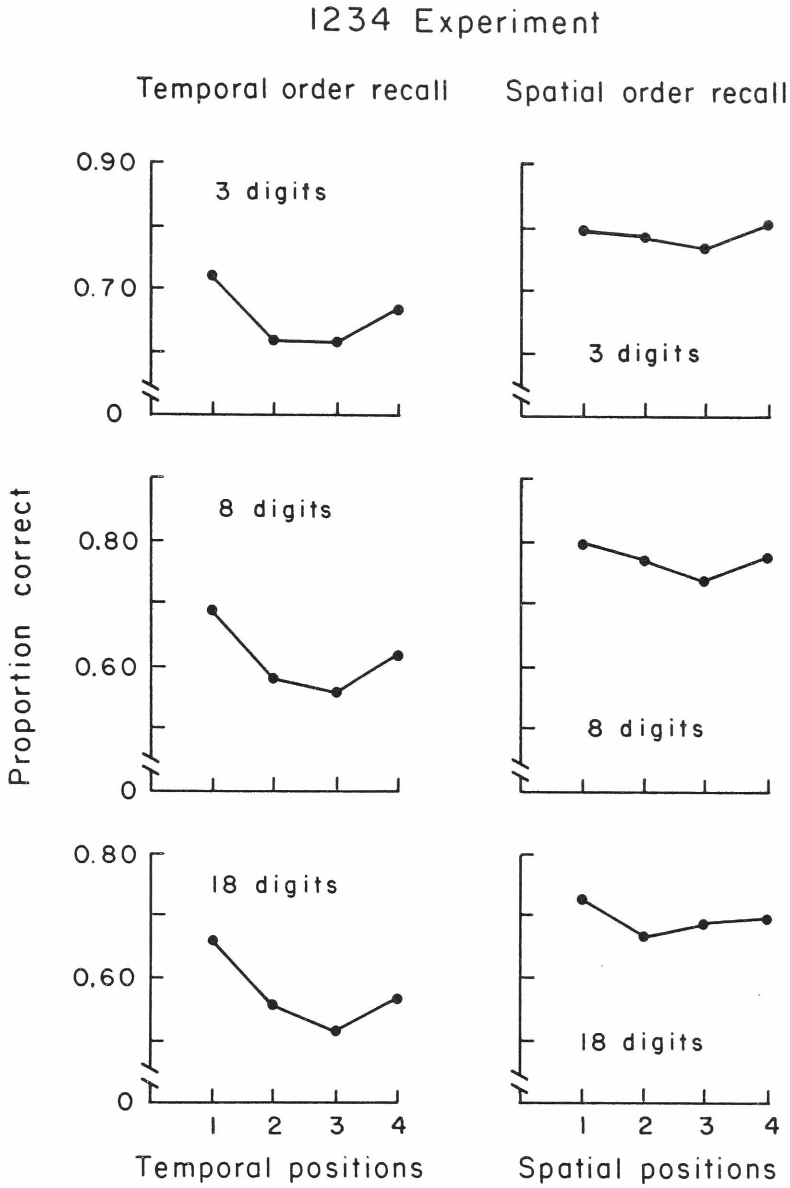

Figure 31. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the Temporal Order and Spatial Order Recall Conditions of the 1234 Experiment. The serial positions represented are the temporal positions in the Temporal Order Recall Condition and the spatial positions in the Spatial Order Recall Condition.

the curves for the Spatial Order Recall Condition, also as in the Constant Temporal Spatial Experiment, show only a slight tendency toward a bow shape. An ANOVA yielded .02 as the standard error of the points in Figure 31. The ANOVA found both the factor of serial position ($F = 14.74$, $p < .01$, $df = 3,66$) and the interaction of the factors serial position and temporal vs. spatial order recall ($F = 3.76$, $p < .05$, $df = 3,66$) significant.

The serial position curves for the Temporal and Spatial Order Recall Conditions are presented on Figure 32 as a function of spatial position for the Temporal Order Recall Condition and as a function of temporal position for the Spatial Order Recall Condition. As predicted, the serial position curves for the Temporal Order Recall Condition are like those for the Spatial Order Recall Condition both when the spatial positions and when the temporal positions are considered. In the former case, the curves show little regularity; in the latter, the curves are bow-shaped and asymmetrical with primacy but little recency. An ANOVA computed with these data yielded .02 as the standard error of the points in Figure 32. The ANOVA found the factor of serial position to be significant ($F = 15.71$, $p < .01$, $df = 3,66$) as well as the interaction of the factor of serial position and the temporal vs. spatial factor ($F = 12.15$, $p < .01$, $df = 3,66$).

Distance Functions As with the serial position curves, in the Constant Temporal Spatial Experiment little difference was observed between the distance functions for temporal and spatial order recall, either when the temporal positions or when the spatial positions were employed. Therefore, little difference between the distance functions in the two conditions is expected in the present experiment where presumably the same coding mechanisms are being employed in the two recall conditions. These predictions for the distance functions, like those for the serial position curves, are upheld by the data. In fact, the distance functions for the present experiment are strikingly similar to those in the Constant Temporal Spatial Experiment just as were the serial position curves. These distance functions for Temporal Order Recall are shown in Figure 33

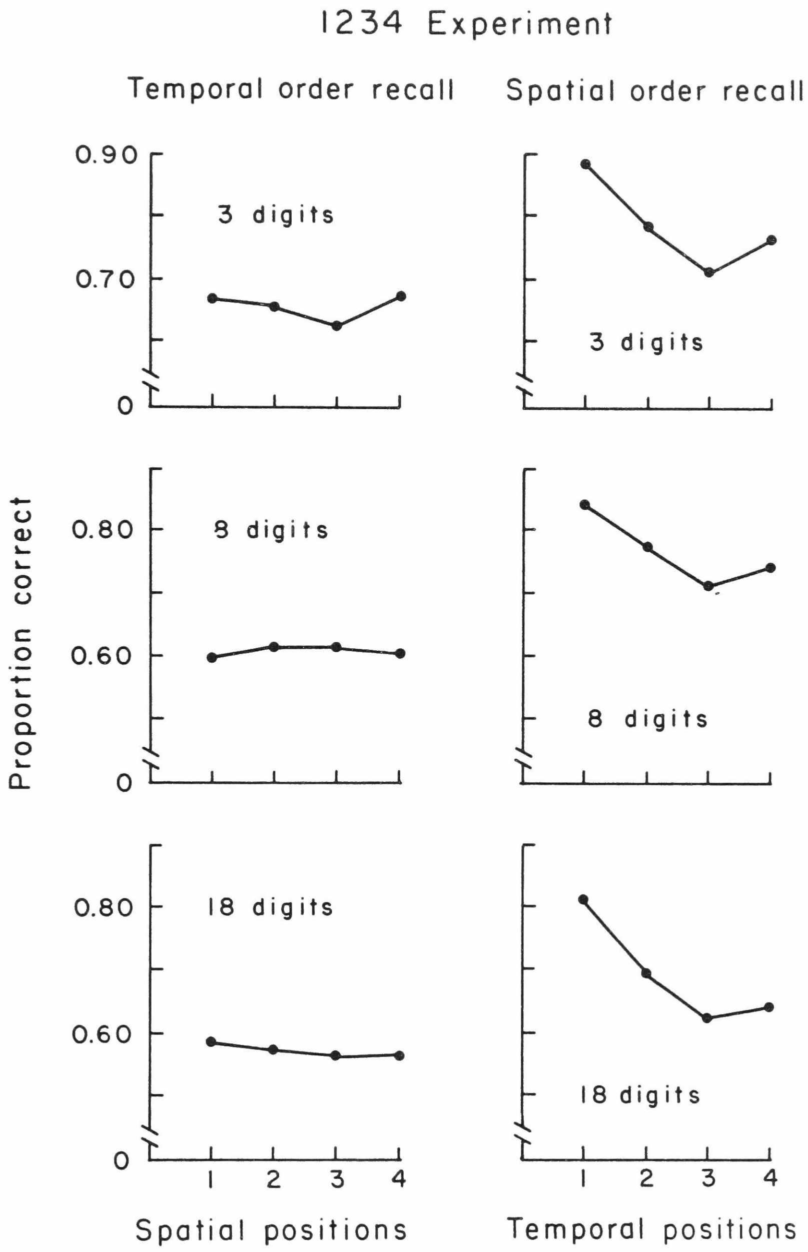

Figure 32. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the Temporal Order and Spatial Order Recall Conditions of the 1234 Experiment. The serial positions represented are the spatial positions in the Temporal Order Recall Condition and the temporal positions in the Spatial Order Recall Condition.

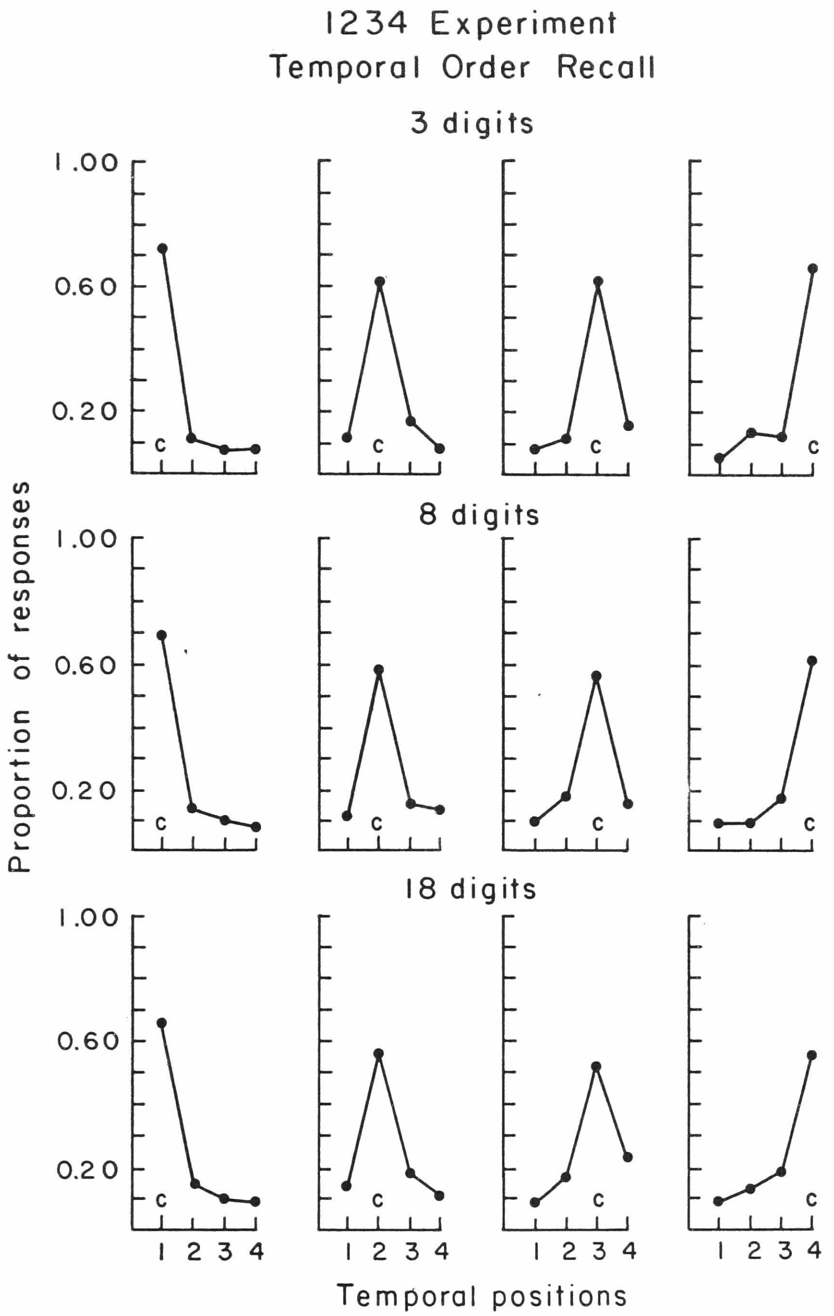

Figure 33. Distance functions for the Temporal Order Recall Condition of the 1234 Experiment. The serial positions represented are the temporal positions. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

plotted as a function of temporal position. The functions for Spatial Order Recall are shown in Figure 34 plotted as a function of spatial position; the curves for Temporal Order Recall are shown in Figure 35 plotted as a function of spatial serial position; and the curves for Spatial Order Recall are shown on Figure 36 plotted as a function of temporal serial position.

These distance functions revealed that temporal and spatial factors have similar effects whether the subjects are recalling the temporal or the spatial order of the items. It therefore seems that the subjects are employing the same coding strategies in the Temporal and Spatial Order Recall Conditions of the present experiment.

Pattern Analysis Distance functions with the temporal positions are shown for each of the 24 patterns in the Temporal Order Recall Condition in Table XIX. Similarly the distance functions with the spatial positions are shown for the 24 patterns in the Spatial Order Recall Condition in Table XX. The picture in each case is similar to that observed in the Constant Temporal Spatial Experiment. The patterns differ in the overall probability correct, and for the most part, the patterns show the same characteristic distance functions observed in the Constant Temporal Spatial Experiment.

The proportion correct at each of the 24 patterns in the Temporal Order Recall Condition of the present experiment was compared with the proportion correct at each of the 24 patterns in the Spatial Order Recall Condition. The correlation coefficient was found to be .66. Furthermore, the correlation coefficient for the proportion correct at each of the 24 patterns in the Temporal Order Recall Condition of the present experiment and the Temporal Order Recall Condition of the Constant Temporal Spatial Experiment was found to be .69, and a correlation coefficient of .84 was found between the proportions correct in the Spatial Order Recall Conditions of the two experiments. In each case the correlation coefficient was significant at the .01 level. There is, therefore, considerable consistency across conditions in the effect of temporal spatial patterns on probability correct. This finding gives support

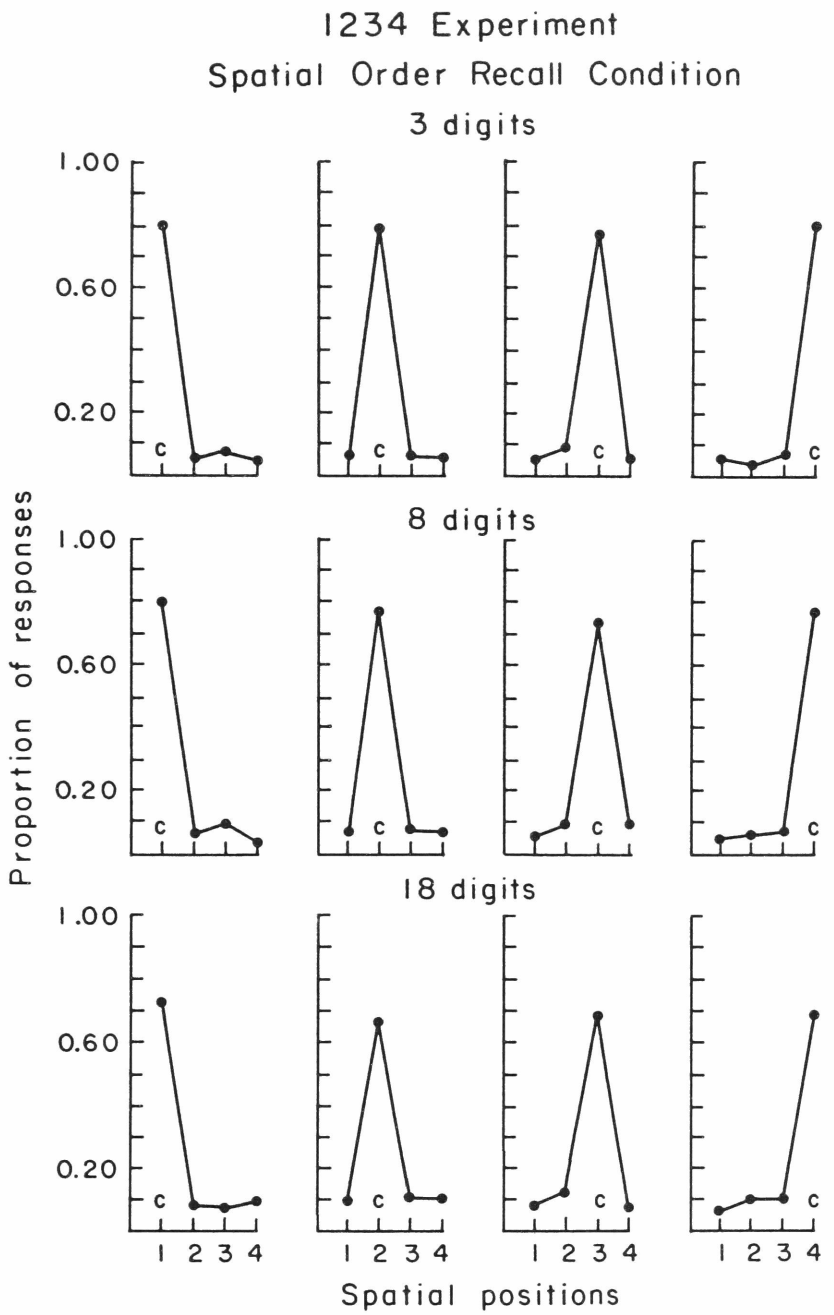

Figure 34. Distance functions for the Spatial Order Recall Condition of the 1234 Experiment. The serial positions represented are the spatial positions. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

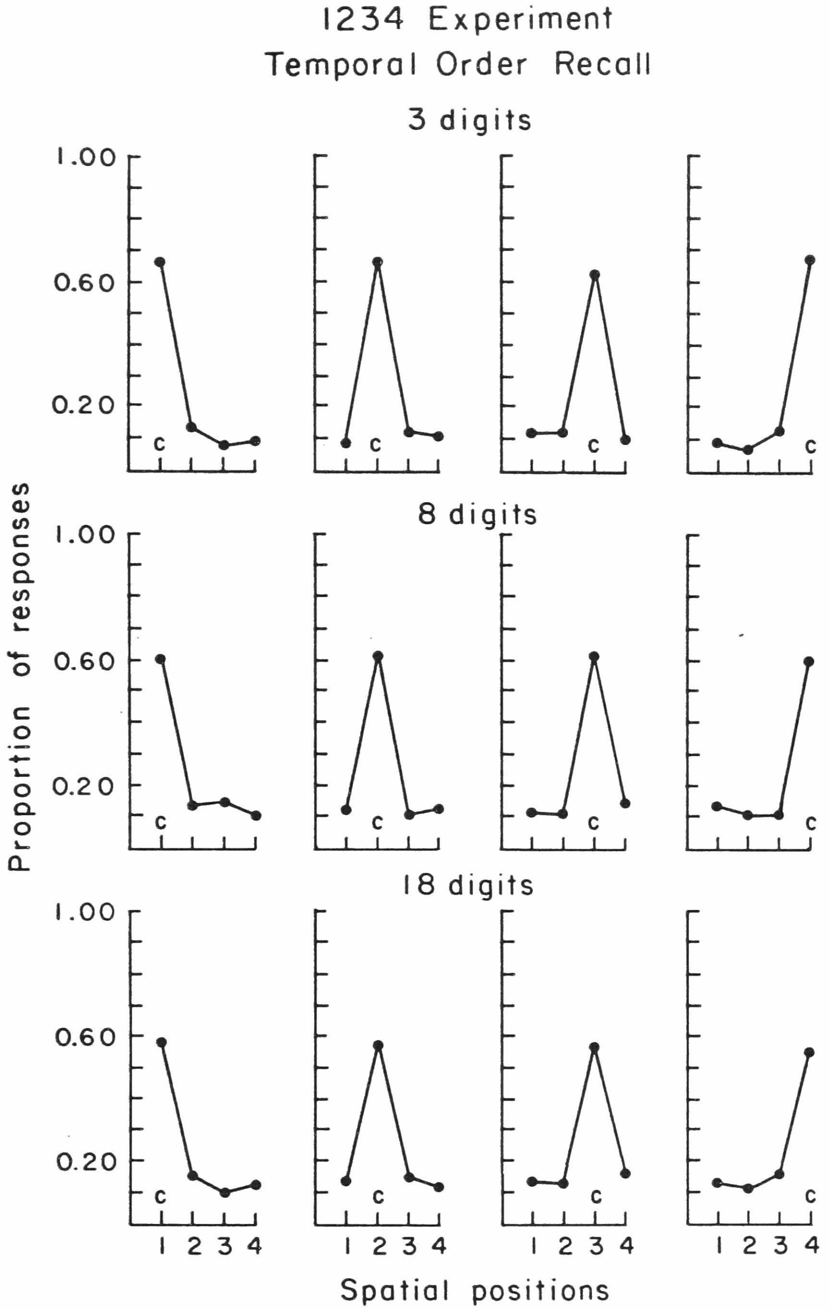

Figure 35. Distance functions for the Temporal Order Recall Condition of the 1234 Experiment. The serial positions represented are the spatial positions. The point plotted for position i of any panel represents the proportion of instances in which the letter that was shown in the spatial position marked C was replaced in the subject's protocol by the letter that was shown in spatial position i on the given trial.

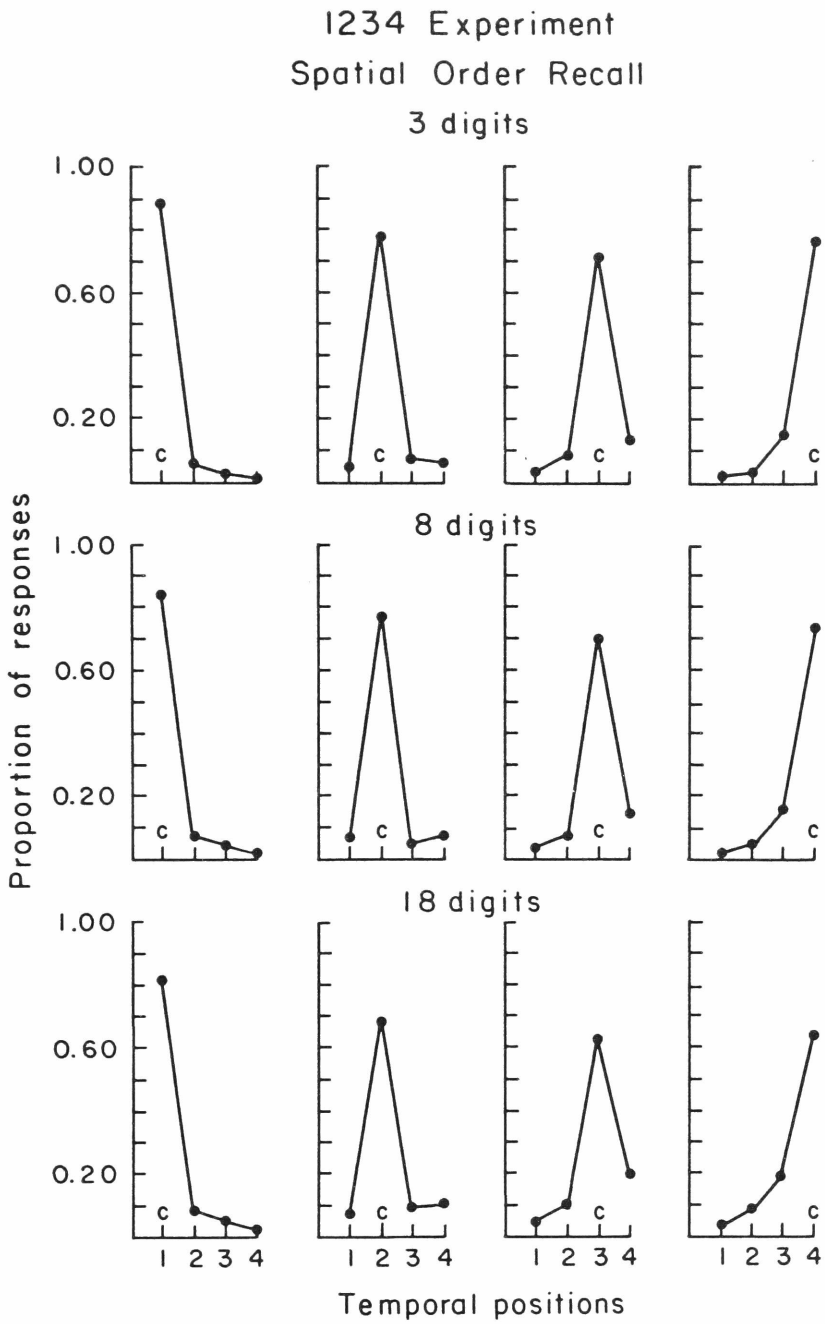

Figure 36. Distance functions for the Spatial Order Recall Condition of the 1234 Experiment. The serial positions represented are the temporal positions. The point plotted for position i of any panel represents the proportion of instances in which the letter that was shown in the temporal position marked C was replaced in the subject's protocol by the letter that was shown in temporal position i on the given trial.

Table XIX

Temporal Distance Functions for Temporal Order Recall

Condition of 1234 Experiment

Pattern No.	Distance Function (Response Position, Stimulus Position)															
	1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
1	31	3	1	1	3	25	5	3	1	6	25	4	1	1	5	29
2	28	3	0	5	3	28	3	2	1	1	33	1	4	4	0	28
3	21	8	2	5	3	22	8	3	6	4	21	5	6	2	5	23
4	30	1	2	3	2	30	3	1	2	4	26	4	2	1	5	28
5	26	4	3	3	5	19	5	7	2	10	19	5	3	3	9	21
6	31	3	1	1	3	23	9	1	1	6	14	15	1	4	12	19
7	25	3	5	3	3	24	6	3	4	6	22	4	4	3	3	26
8	23	5	2	6	6	22	4	4	4	3	27	2	3	6	3	24
9	31	3	1	1	3	28	3	2	1	3	28	4	1	2	4	29
10	24	5	1	6	5	21	8	2	4	5	18	9	3	5	9	19
11	25	6	4	1	5	21	6	4	4	6	19	7	2	2	7	25
12	23	7	5	1	6	18	6	6	4	4	21	7	3	7	4	22
13	21	4	6	5	8	14	5	9	4	8	20	4	4	9	5	18
14	19	6	10	1	5	19	5	7	7	6	16	7	5	5	5	21
15	25	7	3	1	5	18	8	5	3	5	16	12	3	5	9	19
16	24	4	4	4	5	23	6	2	4	4	20	8	3	5	6	22
17	29	3	4	0	5	23	6	2	2	6	24	4	0	4	2	30
18	21	3	8	4	6	14	7	9	6	8	15	7	2	11	8	15
19	24	6	3	3	7	17	5	7	2	7	19	8	3	6	9	18
20	24	3	4	5	5	22	6	3	4	7	20	5	3	4	6	23
21	30	3	1	2	3	21	10	2	2	8	16	10	1	4	9	22
22	20	5	6	5	3	18	9	6	4	7	15	10	9	6	6	15
23	22	10	3	1	5	16	9	6	5	6	16	9	4	4	8	20
24	19	7	4	6	6	21	7	2	4	6	19	7	6	2	7	21

Table XX

Spatial Distance Functions for Spatial Order Recall Condition of 1234 Experiment

Pattern	Distance Function (Response Position, Stimulus Position)															
No.	1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
1	35	0	0	1	0	34	2	0	1	1	33	1	0	1	1	34
2	33	2	1	0	3	32	1	0	0	2	33	1	0	0	1	35
3	32	2	2	0	2	29	5	0	1	5	29	1	1	0	0	35
4	28	0	2	6	3	30	2	1	1	6	29	0	4	0	3	29
5	25	5	1	5	4	21	5	6	3	3	29	1	4	7	1	24
6	28	1	3	4	1	23	11	1	2	9	21	4	5	3	1	27
7	32	2	0	2	2	32	0	2	1	0	35	0	1	2	1	32
8	29	2	2	3	2	32	1	1	2	2	25	7	3	0	8	25
9	34	0	2	0	1	30	0	5	1	3	30	2	0	3	4	29
10	21	14	1	0	12	19	0	5	1	2	30	3	2	1	5	28
11	24	3	5	4	4	30	2	0	8	3	23	2	0	0	6	30
12	29	4	3	0	3	30	3	0	3	2	23	8	1	0	7	28
13	32	1	1	2	2	30	3	1	0	4	27	5	2	1	5	28
14	29	1	3	3	1	33	2	0	2	2	28	4	4	0	3	29
15	27	2	4	3	1	22	12	1	4	11	19	2	4	1	1	30
16	25	3	0	8	3	29	2	2	0	3	32	1	8	1	2	25
17	32	3	1	0	1	29	1	5	3	4	26	3	0	0	8	28
18	23	2	5	6	5	23	4	4	4	9	19	4	4	2	8	22
19	24	2	3	7	3	23	0	10	2	1	29	4	7	10	4	15
20	24	0	12	0	6	26	2	2	6	5	22	3	0	5	0	31
21	32	0	3	1	4	16	3	13	0	4	23	9	0	16	7	13
22	21	2	13	0	4	23	4	5	6	9	18	3	5	2	1	28
23	25	5	3	3	5	21	4	6	4	2	28	2	2	8	1	25
24	27	4	5	0	2	27	6	1	6	2	24	4	1	3	1	31

to the hypothesis that subjects are specifically attending to these temporal spatial patterns when trying to recall the consonants in their proper order.

The data from the Temporal and Spatial Order Recall Conditions of the present experiment are similar in every respect considered. The time courses of forgetting in the two conditions are parallel and relatively flat. The confusion-set analyses are similar in the two conditions, there being no difference between confusion-set errors on confusable and control letters in either case. The serial position curves and distance functions for the two conditions are similar when the temporal positions are considered in each case, and the serial position curves and distance functions for the two conditions are similar when the spatial positions are considered in each case. Moreover, the proportion of correct responses at each of the 24 patterns are similar in the two conditions. Therefore, removing acoustic coding has removed the substantial differences which had obtained between the temporal and spatial order recall situations in the Constant Temporal Spatial Experiment.

Pattern Interference I

In both the Constant Temporal Spatial and the 1234 Experiments, subjects in the Spatial Order Recall Condition showed a high level of performance at each of the three retention intervals. The time course of forgetting was nearly flat in each case. The contrast between the flat function for spatial order recall and the relatively steep decline for temporal order recall calls for some explanation.

The most probably locus of the difference appears to be the intervening task, reading digits aloud. Clearly from the previous experiments and from the Temporal Order Recall Condition of the Constant Temporal Spatial Experiment, reading digits aloud at the rapid rate required is a difficult enough task to produce forgetting. Yet the subject does not show evidence of forgetting the spatial order of the consonants, only their temporal order. Why is this? Decay theory might attempt to explain this finding by postulating several types of rehearsal. Reading aloud

digits might prevent the type of rehearsal necessary for temporal order recall but allow the type of rehearsal necessary for spatial order recall. This finding could also be explained by interference theory. Reading digits aloud might be considered more similar to the temporal order recall task than to the spatial order recall task and therefore would be expected to produce more interference in the former situation than in the latter. The first step toward testing these possible explanations empirically must be to determine more specifically the role of the intervening task in relation to spatial order recall.

The present experiment sought to test the hypothesis that similarity was the essential determiner of intervening task effectiveness by replicating the Spatial Order Recall Condition of the Constant Temporal Spatial Experiment and manipulating the intervening task. Two different intervening tasks were employed. The intervening items were the same in both tasks; the subjects were shown digits which, like the to-be-remembered consonants, appeared in only one of the four cells of the Bina-view screen. However, the subjects' response to these digits differed from task to task. In one task, as in the previous experiments, the subjects merely read aloud each digit as it appeared and were not required to pay attention to the spatial arrangements of the digits. In the other task, which was designed to be more interfering with spatial order recall, the subjects, who were trying to remember the spatial order of the consonants, were forced to process the spatial order of the digits. In this task the subjects said aloud the Bina-view cell number where each digit appeared, the cells being numbered from left to right.

Method

Subjects Twenty-four male and female young adults served as subjects in the present experiment. There were two conditions in this experiment with twelve subjects in each condition. No subject had participated previously in a short-term memory experiment at Rockefeller. Subjects were recruited in the same manner as in the previous experiments. The first 10 subjects (5 subjects in each condition) were paid at the rate of $2.00 per hour; the last 14 subjects (7 in each condition) were

paid at the rate of $2.50 per hour.

Apparatus The same apparatus was employed in the present experiment as had been employed in the previous experiments.

Materials Four experimental and one practice paper tape were employed, all identical to those employed in the Spatial Order Recall Condition of the Constant Temporal Spatial and 1234 Experiments with one exception involving the intervening digits. Trial-by-trial the same digits were employed in the present experiment as in the previous experiments; however the digits in the retention interval were not displayed simultaneously in all four cells of the Bina-view screen. Rather, like the consonants, each digit was displayed in only one of the four cells of the screen, while the other three cells were left blank. The cell location where each digit appeared varied from digit to digit; the location was quasi-random and was determined with the aid of a table of random numbers. The one constraint imposed was that no two successive digits appeared in the same cell location.

Procedure Each subject was tested individually in an hour-long session. The 24 subjects were assigned to the four different experimental tapes according to their time of arrival for testing. Each of the four tapes was shown to six subjects, three subjects in one condition (Digit Name Condition) and three subjects in the other condition (Digit Position Condition). Each session was begun with the experimenter's reading of the instructions to the subject and then conducting the six practice trials from the practice tape.

The testing sessions of the present experiment were conducted in the same manner as in the Spatial Order Recall Condition of the Constant Temporal Spatial Experiment.

The instructions read to subjects in the Digit Name Condition of the present experiment (see Appendix C) were identical to those read to subjects in the Spatial Order Recall Condition of the Constant Temporal Spatial Experiment except for the explanation concerning the location of each digit on the Bina-view screen. Furthermore, the instructions read

to subjects in the Digit Position Condition were identical to those read to subjects in the Digit Name Condition with the exception of the instructions involving the intervening digits. Subjects in the Digit Name Condition were instructed, as in the Constant Temporal Spatial Experiment, to read aloud every item as it appeared on the Bina-view screen. However, subjects in the Digit Position Condition, although they were told to read aloud the consonants as they appeared, were not told to read aloud the digits as they appeared. Rather they were told to say aloud the cell number where each digit appeared, assuming that the cells were numbered from left to right. Thus, if a digit, any digit, appeared in the cell closest to the left, the subject was to say "one" as it appeared; if a digit appeared in the cell second from the left, he was to say "two" as it appeared; if a digit appeared in the cell third from the left, he was to say "three" as it appeared; and if a digit appeared in the cell closest to the right, he was to say "four" as it appeared. (See Figure 37 for sample intervening tasks in the two conditions.)

Results and Discussion

Time Course of Forgetting The time course of forgetting for the Digit Name and Digit Position Conditions of the present experiment are compared on Figure 38. The two time courses are almost parallel, and in each case the time course is quite flat. The curve for the Digit Name Condition is very similar to that observed in the Spatial Order Recall Condition of the Constant Temporal Spatial Experiment. In fact, the difference between proportions correct in the two conditions was not significant at any of the three retention intervals ($t = 0.80$, $p > .05$; $t = 1.95$, $p > .05$; $t = 1.17$, $p > .05$; at 3, 8, and 18 digits respectively, using a two-tailed test with $df = 22$ in each case). However, the proportion correct for the Digit Position Condition is significantly lower than that for the Digit Name Condition at each retention interval ($t = 2.94$, $p < .01$; $t = 4.00$, $p < .01$; $t = 3.54$, $p < .01$ at 3, 8, and 18 digits respectively, a two-tailed test with $df = 22$ in each case). An ANOVA was also conducted on these data to assess the contribution of the between-subjects factor of condition and the within-subjects factor of

SAMPLE INTERVENING TASKS

Temporal Spatial, Constant Temporal Spatial, and 1234 Experiments

Subject Sees:

2	2	2	2
6	6	6	6
8	8	8	8

Subject Says: '2', '6', '8'

Pattern Interference I Experiment

Subject Sees:

2	.	.	.
.	.	6	.
.	8	.	.

Digit Name Condition

Subject Says: '2', '6', '8'

Digit Position Condition

Subject Says: '1', '3', '2'

Pattern Interference II Experiment

Zero Position Condition

Subject Sees:

0	.	.	.
.	.	0	.
.	0	.	.

Subject Says: '1', '3', '2'

Successor Name Condition

Subject Sees:

2	.	.	.
.	.	6	.
.	8	.	.

Subject Says: '3', '7', '9'

Figure 37. Sample intervening tasks for Temporal Spatial, Constant Temporal Spatial, 1234, Pattern Interference I, and Pattern Interference II Experiments. In each example, three different views of the display screen are shown in the order seen by the subject. The .'s represent blank cells.

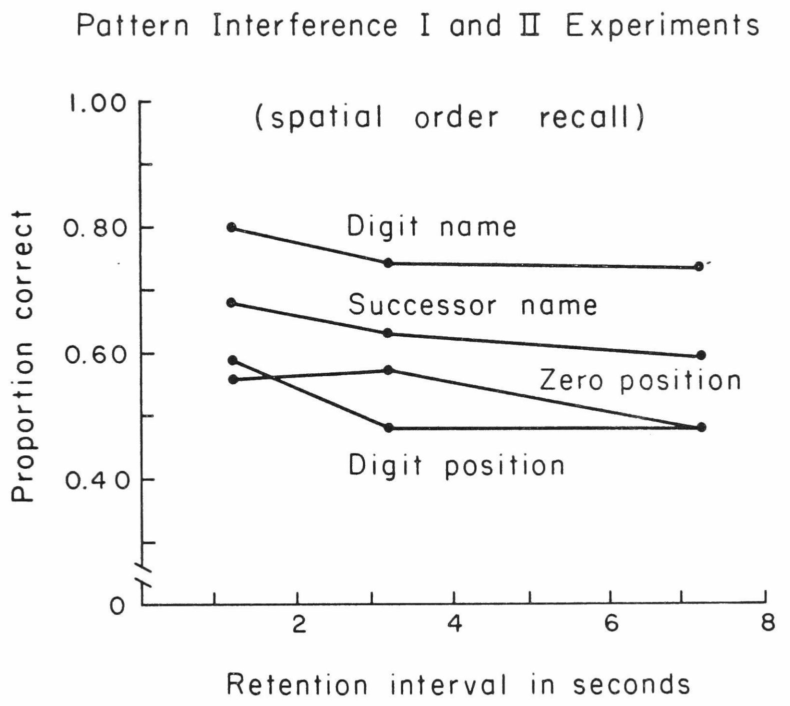

Figure 38. Time course of forgetting in terms of proportion of correct responses at each of the three retention intervals in the Digit Name and Digit Position Conditions of the Pattern Interference I Experiment and the Zero Position and Successor Name Conditions of the Pattern Interference II Experiment.

retention interval. The ANOVA yielded an estimate of .04 for the standard error of the points on Figure 38 representing the data from the present experiment. In accordance with the observations described above, the ANOVA found the factor of condition significant ($F = 13.18$, $p < .01$, $df = 1,22$) but not the interaction of condition and retention interval ($F = 1.10$, $p > .05$, $df = 2,44$). Even though the time courses are relatively flat in each condition, there is some decay across the retention intervals. In fact, the ANOVA did find the factor of retention interval to be significant ($F = 18.08$, $p < .01$, $df = 2,44$).

Confusion Errors In the Spatial Order Recall conditions of the preceding experiments, no evidence was found for acoustic coding. Therefore no such evidence is expected in the present experiment. In order to assess the evidence for acoustic coding, because of the constant temporal order of the consonants, the confusion-set analysis was applied to the data from the present experiment. The conditional proportions of confusion-set errors given that an error was made on a letter from one of the two acoustic confusion sets are presented on Figure 39. These conditional proportions are compared for confusable and nonconfusable letters and for the Digit Name and Digit Position Conditions. An ANOVA on these data yielded .05 as the standard error of the means. Here, as expected, no significant difference is seen between confusion-set errors on confusable and nonconfusable letters in either recall condition ($F = 0.18$, $p > .05$, $df = 1,20$). This finding is consonant with the hypothesis that acoustic coding is not being used in the present experiment.

Serial Position Curves The serial position curves with the spatial positions were found to be quite flat in the preceding Spatial Order Recall Situations. Similar flat curves were therefore expected in both conditions of the present experiment. Serial position curves are shown in Figure 40 for the Digit Name and Digit Position Conditions at each of the three retention intervals. The serial positions used for the analyses of these spatial order recall tasks are the spatial positions. As in the earlier Spatial Order Recall Conditions, the curves are irregular with a slight tendency toward a bow-shape in the Digit Name Condition

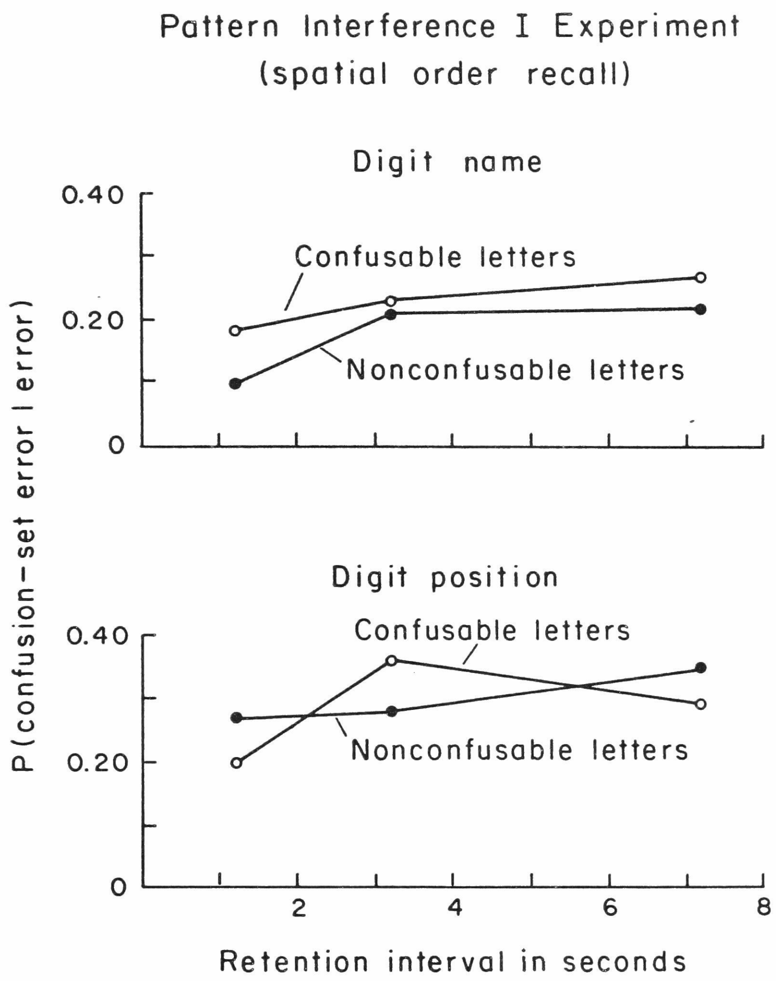

Figure 39. Conditional proportions of confusion-set errors given that an error was made at each of the three retention intervals for letters from the paired context strings (confusable letters) and letters from the all-different context strings (nonconfusable letters) in the Digit Name and Digit Position Conditions of the Pattern Interference I Experiment. Solid circles stand for nonconfusable letters; unfilled circles stand for confusable letters.

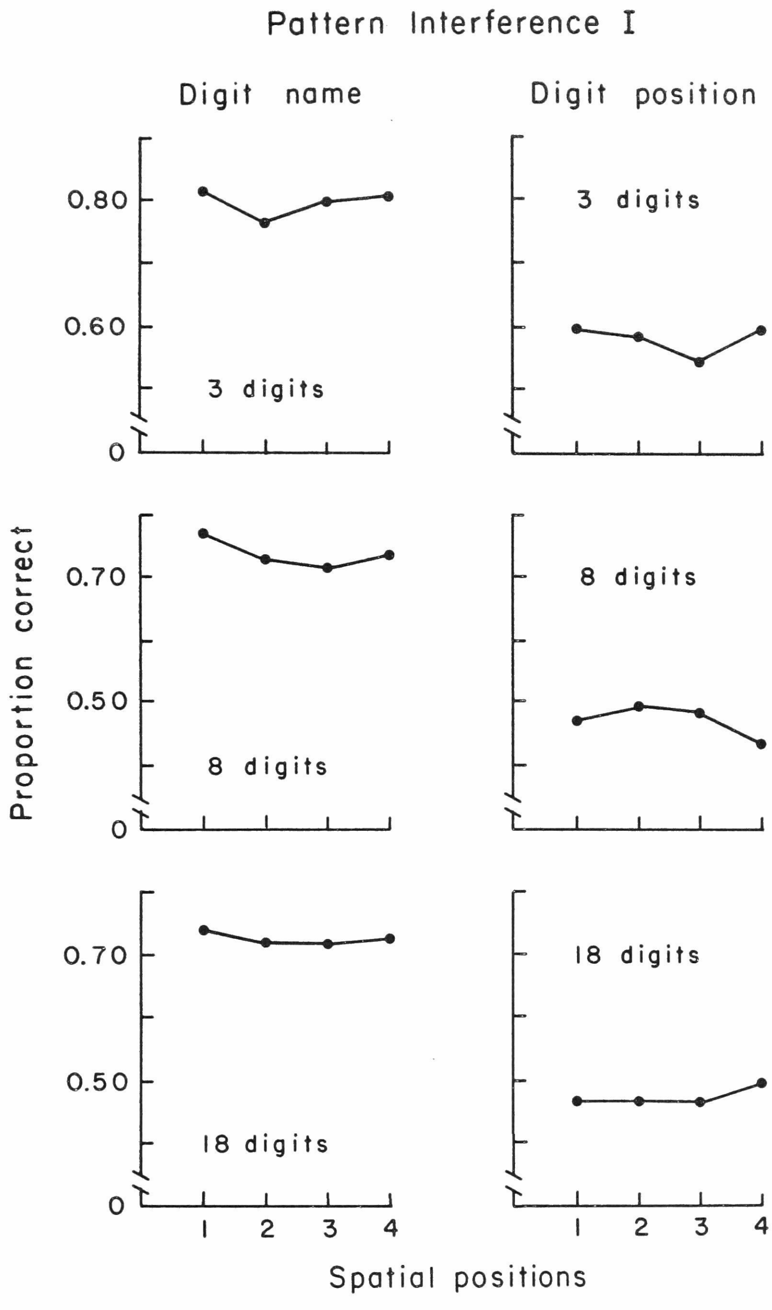

Figure 40. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the Digit Name and Digit Position Conditions of the Pattern Interference I Experiment. The serial positions represented are the spatial positions.

and at the shortest retention interval in the Digit Position Condition. An ANOVA yielded an estimate of .02 for the standard error of the points on Figure 40. The ANOVA did find the factor of serial position to be marginally significant ($F = 4.30$, $.05 < p < .10$, $df = 3,66$) but found no significant interaction of the factors condition and serial position ($F = 1.23$, $p > .05$, $df = 3,66$).

Although previous Spatial Order Recall Conditions revealed rather flat serial position curves when the spatial positions were considered, the temporal positions did seem to influence the proportion of correct responses. The serial position curves for the Digit Name and Digit Position Conditions are shown in Figure 41 plotted as a function of temporal position in each case. As in the earlier Spatial Order Recall Conditions, in general the curves are bow-shaped and asymmetrical with a loss of recency. However, at the middle retention interval of the Digit Name Condition and the shortest and longest retention intervals of the Digit Position Condition, the bow-shape, but not the asymmetry, is lost because of an increased decrement in proportion correct at the last serial position. An ANOVA computed on these data yielded .02 as the standard error of the points in Figure 41. The ANOVA revealed that the serial position factor was significant ($F = 18.48$, $p < .01$, $df = 3,66$) but not the interaction of the serial position factor and the Digit Name vs. Digit Position factor ($F = 1.21$, $p > .05$, $df = 3,66$).

Distance Functions The distance functions at each of the three retention intervals are presented in Figures 42 and 43 for the Digit Name and Digit Position Conditions, respectively. In each case, the serial positions considered are the spatial positions. Here, as with the serial position curves with the spatial positions and as in the earlier Spatial Order Recall Conditions, the functions are irregular and quite flat. The curves reflect a tendency toward an equal probability of putting an item from a given serial position into any one of the other serial positions.

On the other hand, as in the earlier Spatial Order Recall Conditions, a somewhat more regular picture is observed when the temporal serial

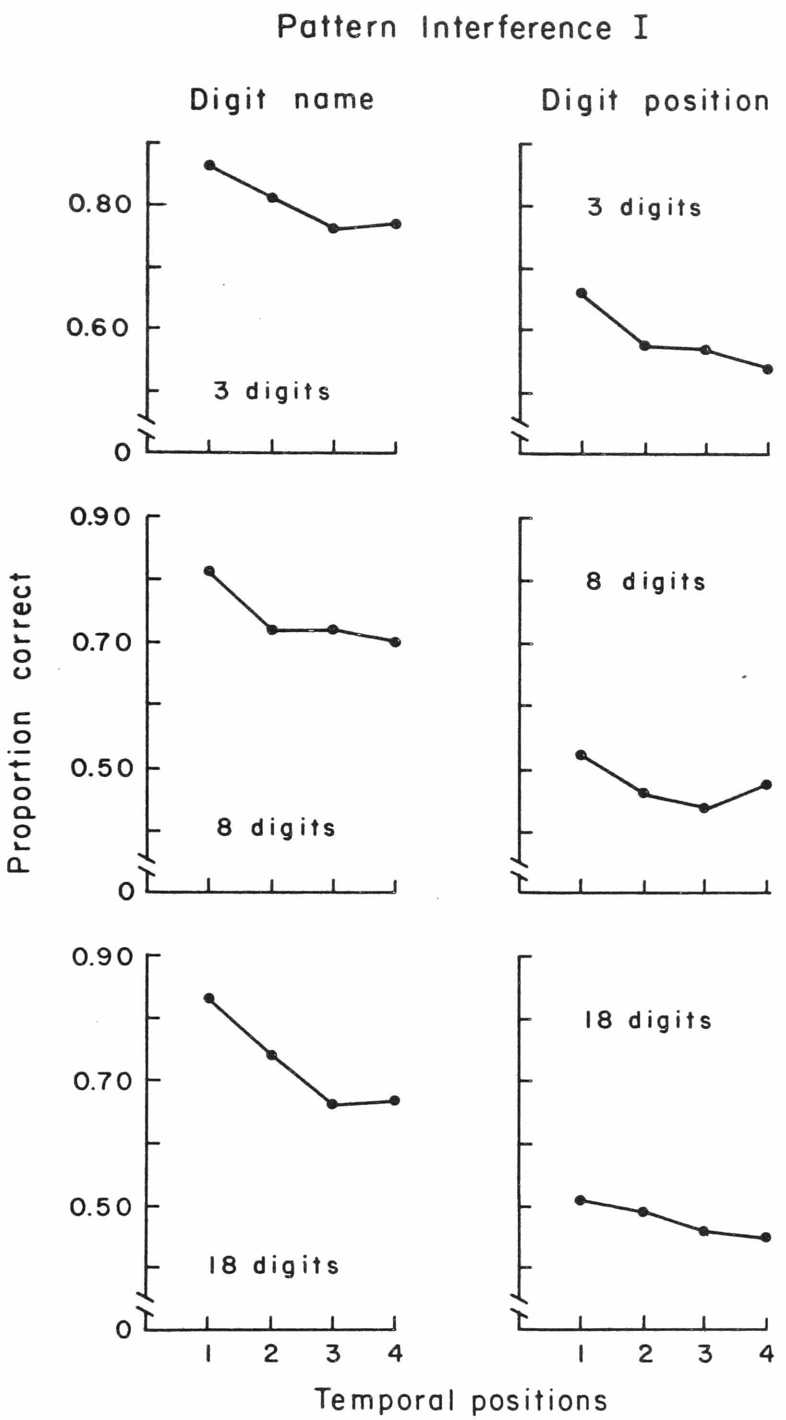

Figure 41. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the Digit Name and Digit Position Conditions of the Pattern Interference I Experiment. The serial positions represented are the temporal positions.

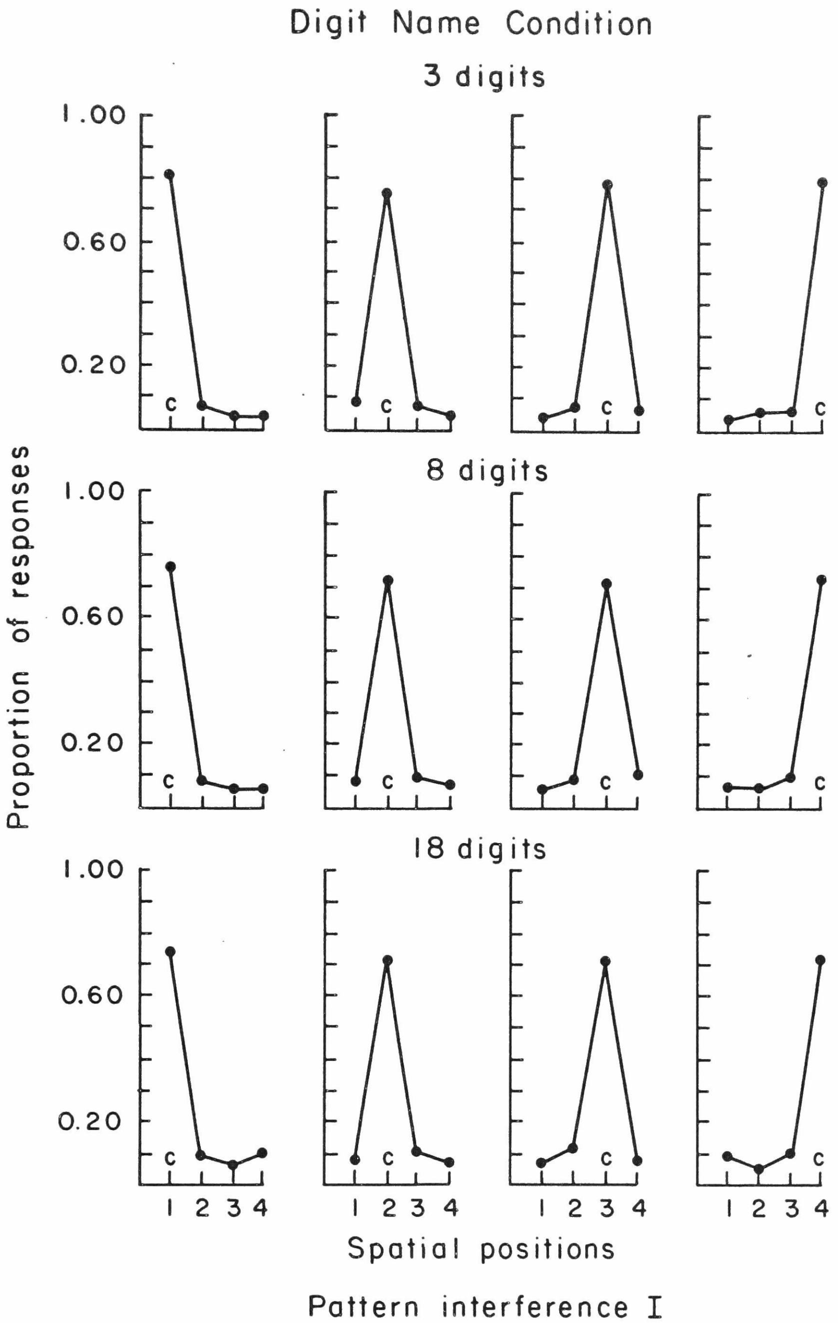

Figure 42. Distance functions for the Digit Name Condition of the Pattern Interference I Experiment. The serial positions represented are the spatial positions. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

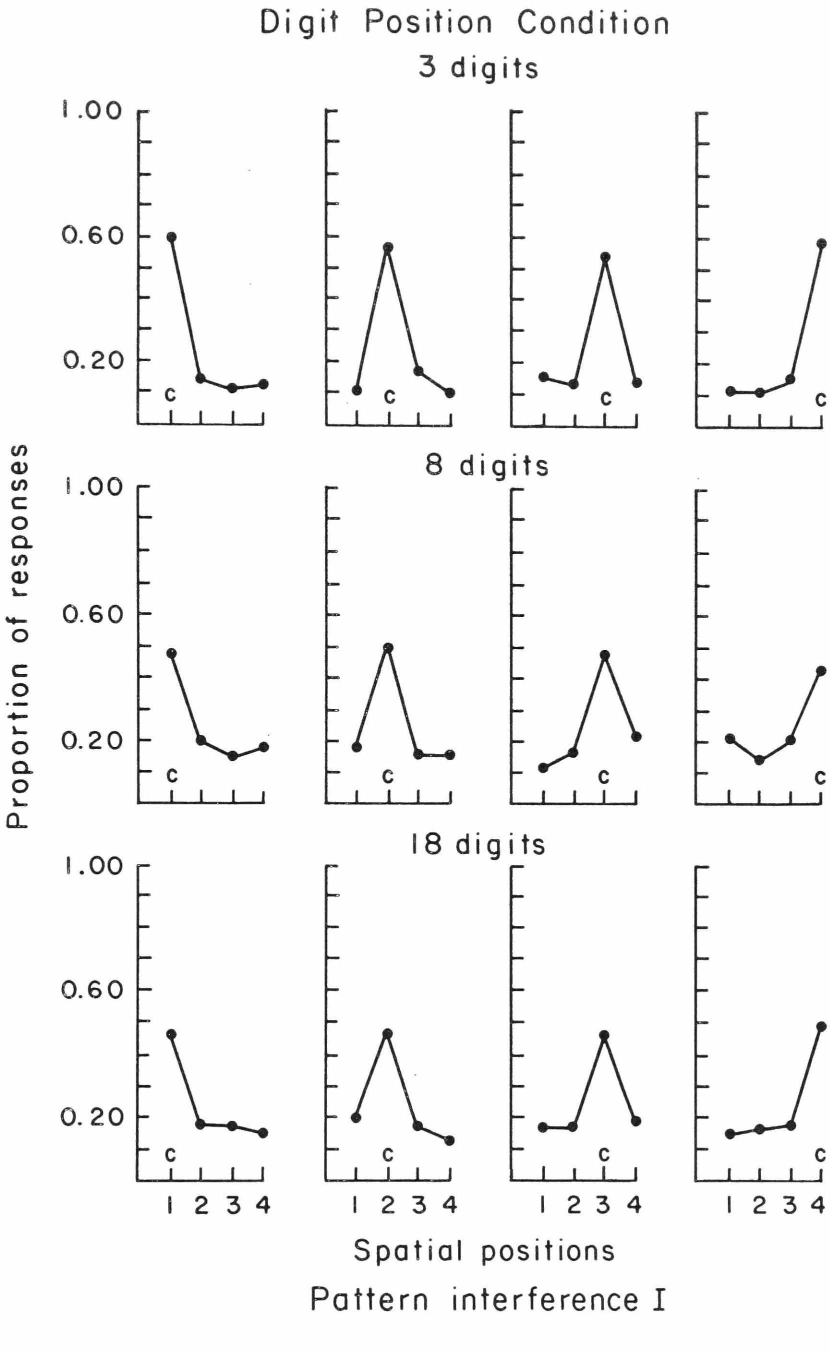

Figure 43. Distance functions for the Digit Position Condition of the Pattern Interference I Experiment. The serial positions represented are the spatial positions. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

positions are considered (see Figures 44 and 45 for the Digit Name and Digit Position Conditions, respectively). In fact, the picture here is strictly similar to that observed in each of the earlier Spatial Order Recall Conditions.

Pattern Analysis Distance functions with the spatial positions are shown for each of the 24 patterns in Tables XXI and XXII for the Digit Name and Digit Position Conditions, respectively. The picture in each case is similar to that observed in the earlier Spatial Order Recall Conditions. Not only do the patterns differ in their overall probability correct, but also, for the most part the patterns show the same characteristic distance functions as observed in the earlier Spatial Order Recall Conditions.

Correlation coefficients were computed using the proportion of correct responses made on each of the 24 patterns in order to compare the various Spatial Order Recall Conditions in terms of their pattern analyses. Correlation coefficients were .57 between the Digit Name and Digit Position Conditions, .62 between the Digit Name Condition and the Spatial Order Recall Condition of the Constant Temporal Spatial Experiment, .66 between the Digit Name Condition and the Spatial Order Recall Condition of the 1234 Experiment, .59 between the Digit Position Condition and the Spatial Order Recall Condition of the Constant Temporal Spatial Experiment, and .63 between the Digit Position Condition and the Spatial Order Recall Condition of the 1234 Experiment. These correlation coefficients are all significant at the .01 level. This consistency in the effect of pattern on probability correct seems to indicate that the subjects are specifically paying attention to these temporal spatial patterns.

Pattern Interference II

The hypothesis put forth earlier that the intervening task must involve similar processes as the recall task in order to be effective is supported by the marked difference in performance between the Digit Name and Digit Position Conditions of the preceding experiment. The task demands in the two conditions were similar except that in the Digit

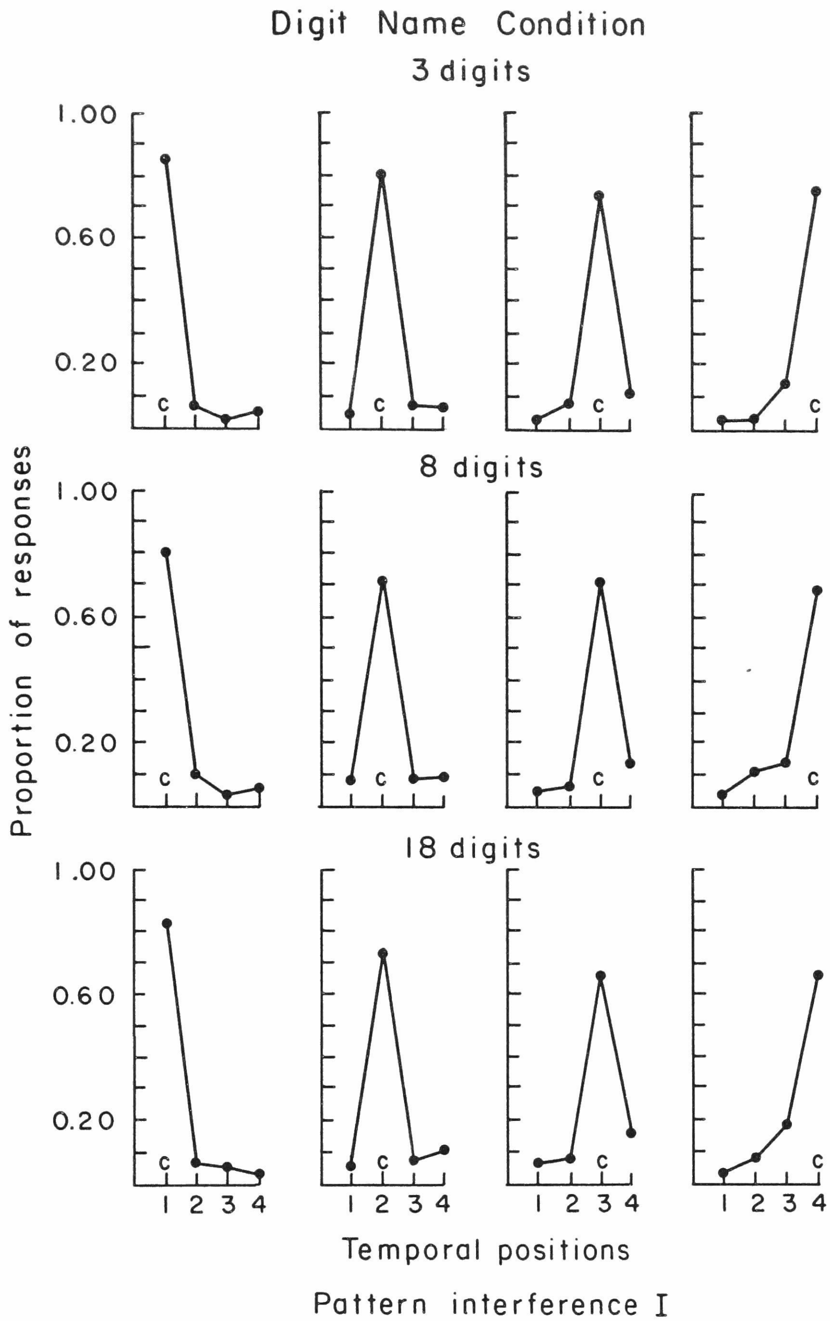

Figure 44. Distance functions for the Digit Name Condition of the Pattern Interference I Experiment. The serial positions represented are the temporal positions. The point plotted for position i of any panel represents the proportion of instances in which the letter that was shown in the temporal position marked C was replaced in the subject's protocol by the letter that was shown in temporal position i on the given trial.

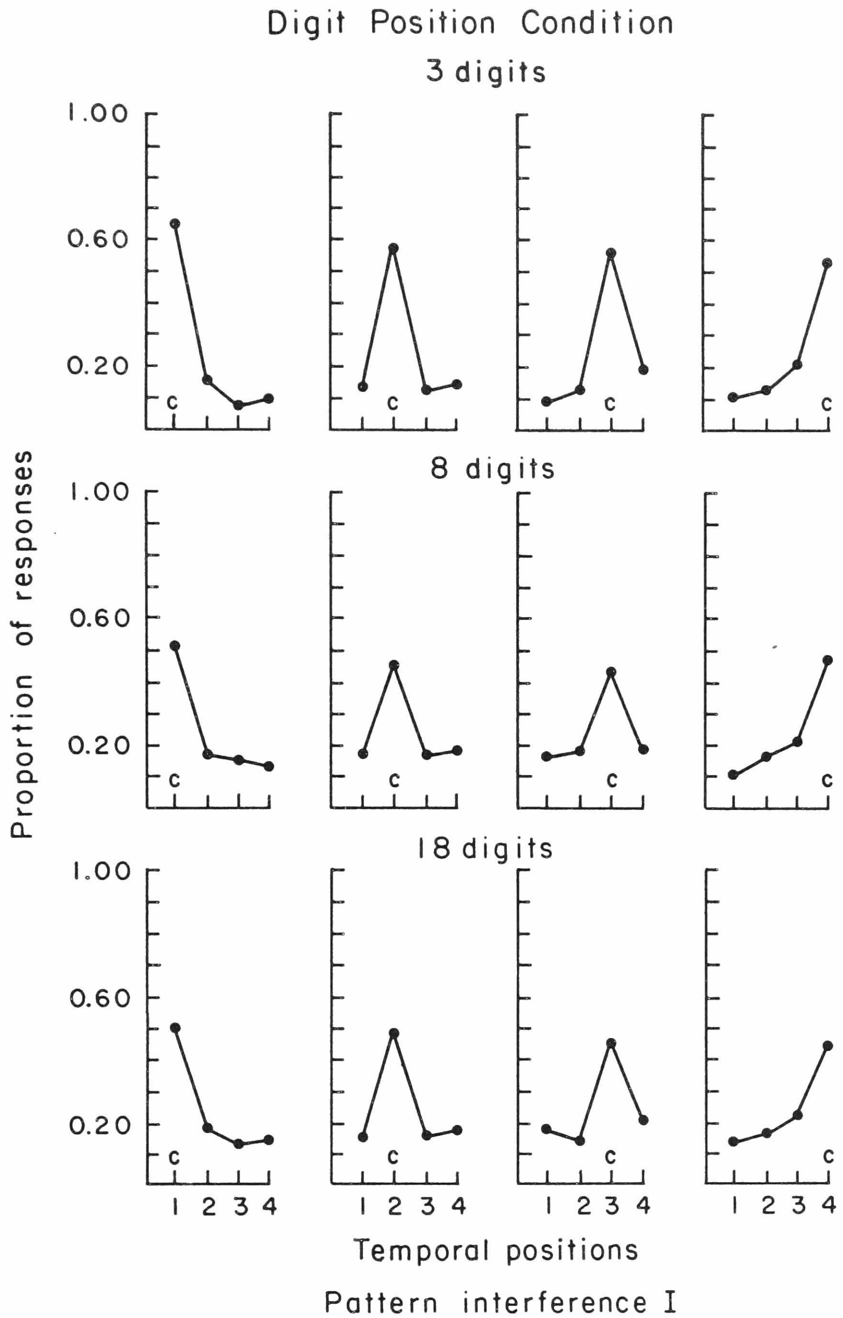

Figure 45. Distance functions for the Digit Position Condition of the Pattern Interference I Experiment. The serial positions represented are the temporal positions. The point plotted for position i of any panel represents the proportion of instances in which the letter that was shown in the temporal position marked C was replaced in the subject's protocol by the letter that was shown in temporal position i on the given trial.

Table XXI

Spatial Distance Functions for Digit Name Condition of Pattern Interference I Experiment

Pattern	Distance Function (Response Position, Stimulus Position)															
No.	1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
1	36	0	0	0	0	35	1	0	0	1	35	0	0	0	0	36
2	27	8	1	0	8	27	1	0	0	0	26	10	1	1	8	26
3	29	7	0	0	1	24	8	3	2	5	26	3	4	0	2	30
4	24	0	2	10	4	28	2	2	1	8	27	0	7	0	5	24
5	27	3	1	5	5	22	6	3	0	7	27	2	4	4	2	26
6	30	3	0	3	0	22	12	2	6	8	21	1	0	3	3	30
7	35	0	0	1	1	34	0	1	0	0	34	2	0	2	1	33
8	25	1	5	5	2	29	3	2	4	5	21	6	5	1	7	23
9	35	0	1	0	0	28	2	6	1	4	30	1	0	4	3	29
10	17	15	1	3	14	21	0	1	0	0	33	3	5	0	2	29
11	24	2	5	5	3	29	2	2	4	5	25	2	5	0	4	27
12	31	3	2	0	4	29	3	0	1	3	23	9	0	1	8	27
13	32	3	0	1	3	32	1	0	0	1	31	4	1	0	4	31
14	27	1	2	6	2	33	1	0	4	2	27	3	3	0	6	27
15	25	2	7	2	3	21	9	3	3	10	19	4	5	3	1	27
16	26	2	0	8	5	27	3	1	1	2	33	0	4	5	0	27
17	31	3	2	0	2	32	2	0	3	1	30	2	0	0	2	34
18	31	3	1	1	3	27	5	1	1	4	26	5	1	2	4	29
19	27	3	2	4	1	26	2	7	3	0	32	1	5	7	0	24
20	21	6	7	2	6	24	5	1	5	4	21	6	4	2	3	27
21	30	1	1	4	5	15	1	15	0	9	22	5	1	11	12	12
22	23	0	10	3	1	32	2	1	7	4	23	2	5	0	1	30
23	26	7	2	1	2	18	7	9	2	5	26	3	6	6	1	23
24	29	4	3	0	2	25	6	3	4	2	23	7	1	5	4	26

Table XXII

Spatial Distance Functions for Digit Position Condition of Pattern Interference I Experiment

Pattern	Distance Function (Response Position, Stimulus Position)															
No.	1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
1	32	2	1	1	1	32	2	1	1	1	31	3	2	1	2	31
2	31	1	4	0	3	33	0	0	1	0	29	6	1	2	3	30
3	16	2	6	12	1	22	8	5	6	9	16	5	14	3	5	14
4	22	4	1	9	5	23	4	4	3	8	21	4	6	1	10	19
5	15	7	7	7	11	14	9	2	2	10	15	9	8	5	5	18
6	19	6	3	8	8	17	10	1	4	6	20	6	5	7	3	21
7	20	8	3	5	8	20	5	3	3	5	24	4	5	3	4	24
8	12	10	6	8	6	16	9	5	7	8	11	10	11	2	10	13
9	26	5	1	4	0	23	9	4	7	5	20	4	3	4	5	24
10	20	11	3	2	7	19	6	4	3	4	23	6	6	2	4	24
11	10	6	12	8	4	24	5	3	12	5	13	6	10	1	6	19
12	21	6	4	5	8	19	4	5	4	7	20	5	3	4	8	21
13	18	7	2	9	6	19	7	4	6	6	21	3	6	4	6	20
14	18	5	5	8	4	22	4	6	4	7	19	6	10	2	8	16
15	14	7	11	4	14	9	9	4	2	10	9	15	6	10	7	13
16	17	10	0	9	8	15	6	7	6	4	20	6	5	7	10	14
17	20	9	6	1	9	19	2	6	6	3	17	10	1	5	11	19
18	18	8	5	5	9	20	5	2	5	4	13	14	4	4	13	15
19	14	7	4	11	4	11	10	11	7	4	20	5	11	14	2	9
20	15	6	9	6	7	15	8	6	11	5	14	6	3	10	5	18
21	23	5	2	6	7	14	2	13	5	7	18	6	1	10	14	11
22	22	1	11	2	4	19	6	7	7	13	16	0	3	3	3	27
23	9	12	9	6	7	12	10	7	10	3	14	9	10	9	3	14
24	15	8	10	3	6	13	9	8	9	5	9	13	6	10	8	12

Position Condition the subjects were forced to process the spatial characteristics of the intervening digits, whereas in the Digit Name Condition the subjects could ignore these spatial characteristics.

It could be argued, though, that the Digit Position Condition was more difficult than the Digit Name Condition since it produced a conflict between what the subject said and what he saw. For example, as in Figure 37, the subject may see the digit 2 but have to respond with the digit 1. It may be then that difficulty per se, rather than similarity to the recall task, was the essential cause of the difference between the Digit Name and Digit Position Conditions.

The present experiment was designed to test this hypothesis. Like the previous experiment it consisted of two spatial order recall conditions, with a difference in the intervening tasks. The first condition was designed to be less difficult than the Digit Position Condition but to impose the same spatial processing demands. Here the subjects' task was identical to that in the Digit Position Condition; however, instead of digits only zeros appeared in the Bina-view cells. The second condition was designed to be at least as difficult as the Digit Position Condition without the spatial processing demands. Here the items shown to the subjects were identical to those shown to subjects in the previous experiments, but the subjects' task was different. The subjects were to name aloud the successor of each digit that appeared. If difficulty were the essential determiner of intervening task effectiveness, then the Successor Name Condition should cause more forgetting; yet if similarity of processing demands were the important factor then the Zero Position Condition should prove to be more effective.

Method

Subjects Twenty-four male and female young adults served as subjects in the present experiment. There were two conditions in this experiment with twelve subjects in each condition. No subject had previously participated in a short-term memory experiment at Rockefeller. Subjects were recruited in the same manner as in the previous experiments

and were paid at the rate of $2.50 per hour.

Apparatus The same apparatus was employed in the present experiment as had been employed in the previous experiments.

Materials Four experimental and one practice paper tape employed were identical to those employed in Pattern Interference I. These tapes were all used for one of the conditions of the present experiment, Successor Name Condition. In addition, four new experimental and one new practice tape were constructed for the other condition of the present experiment, Zero Position Condition. These new tapes were identical to the tapes from Pattern Interference I with one exception involving the intervening digits. Wherever a digit appeared on the Pattern Interference I tapes, it was replaced by a zero on the new tapes. Thus, like the digits in Pattern Interference I, each zero was displayed in only one of the four cells of the screen, while the other three cells were left blank. The cell location where each zero appeared varied from item to item; the location was quasi-random and was determined with the aid of a table of random numbers. The one constraint imposed was that no two successive zeros appeared in the same cell location.

Procedure Each subject was tested individually in an hour-long session. The 24 subjects were assigned to the eight experimental tapes according to their time of arrival for testing. Each of the eight tapes was shown to three subjects. Each session was begun with the experimenter's reading the instructions to the subject and then conducting the six practice trials from the appropriate practice tape.

The testing sessions of the present experiment were conducted in the same manner as in the previous experiments.

The instructions read to subjects in the Successor Name Condition of the present experiment were identical to those read to subjects in the Digit Name Condition of Pattern Interference I except that the subjects were not instructed to read each digit aloud; rather they were instructed to say aloud the successor of each digit that appeared. For instance, they were told that if they saw the digit "three," they should say "four,"

and if they saw "six," they should say "seven." The instructions read to subjects in the Zero Position Condition of the present experiment were identical to those in the Digit Position Condition of Pattern Interference I except that subjects were not told that digits would be shown; instead they were told that zeros would be shown after the consonants. As in the Digit Position Condition, they were told to say aloud the cell number where each intervening item appeared. Thus, if a zero appeared in the cell closest to the left, the subject was to say "one" as it appeared; if a zero appeared in the cell second from the left, he was to say "two" as it appeared; if a zero appeared in the cell third from the left, he was to say "three" as it appeared; and if a zero appeared in the cell closest to the right, he was to say "four" as it appeared. (See Appendix C for the exact instructions read to the subjects and Figure 37 for sample intervening tasks in the two conditions.)

Results and Discussion

Time Course of Forgetting The time course of forgetting is shown in Figure 38 for the two conditions of the present experiment as well as for the Digit Name and Digit Position Conditions of the preceding experiment. The retention curves for the Digit Name, Digit Position, Zero Position, and Successor Name Conditions are strikingly similar and relatively flat in each case. At each of the three retention intervals the Successor Name Condition falls midway between the Digit Name and Digit Position Conditions of the earlier experiments. On the other hand, comparison of the Zero Position and Digit Position Conditions reveals no significant difference even at the middle retention interval where the difference seems largest ($t = 0.51$, $p > .05$; $t = 1.57$, $p > .05$; $t = 0.08$, $p > .05$ at 3, 8, and 18 digits respectively with $df = 22$ and a two-tailed test in each case). An ANOVA yielded an estimate of .04 for the standard error of the points on Figure 38 representing the data from the present experiment. In accordance with the observations described above, the ANOVA found the factor of conditions (Zero Position vs. Successor Name) significant ($F = 4.68$, $p < .05$, $df = 1,22$) as well as the factor of retention interval ($F = 8.77$, $p < .01$, $df = 2,44$); however the inter-

action of these two factors was not significant ($F = 1.71$, $p > .05$, $df = 2,44$).

The argument that difficulty _per se_ was the essential cause of the difference between the Digit Name and Digit Position Conditions was not supported since the Zero Position Condition, less difficult than the Digit Position Condition because the conflict between what the subject said and what he saw was removed, was nevertheless just as effective in reducing recall, presumably because it was just as effective in forcing the subject to process the spatial characteristics of the items. Difficulty, however, was not ruled out entirely as a partial determiner of intervening task effectiveness since the Successor Name Condition, which involved a difficult task but no spatial processing demands, did prove to be more disruptive than the Digit Name Condition.

Confusion Errors The conditional proportions of confusion-set errors given that an error was made on a letter from one of the two acoustic confusion sets in the present experiment are shown on Figure 46. These conditional proportions are compared for confusable and nonconfusable letters in the Zero Position and Successor Name Conditions. An ANOVA yielded an estimate of .04 for the standard error of the means. No difference is seen between confusion-set errors on confusable and nonconfusable letters in either condition. The ANOVA did not find the factor of context to be significant ($F = 0.27$, $p > .05$, $df = 1,20$). Thus, here, as in the earlier spatial order recall conditions, there is no evidence for acoustic coding.

Serial Position Curves Serial position curves are shown in Figure 47 for the Zero Position and Successor Name Conditions at each of the three retention intervals. The serial positions used for the analyses of these spatial order recall tasks are the spatial positions. As in the earlier Spatial Order Recall Conditions, the curves are only slightly bowed. An ANOVA performed on these data yielded .02 as the standard error of the points on Figure 47. As in the previous experiment, the ANOVA did find the factor of serial position to be significant ($F = 11.48$, $p < .01$, $df = 3,66$) but not the interaction of serial position and condition

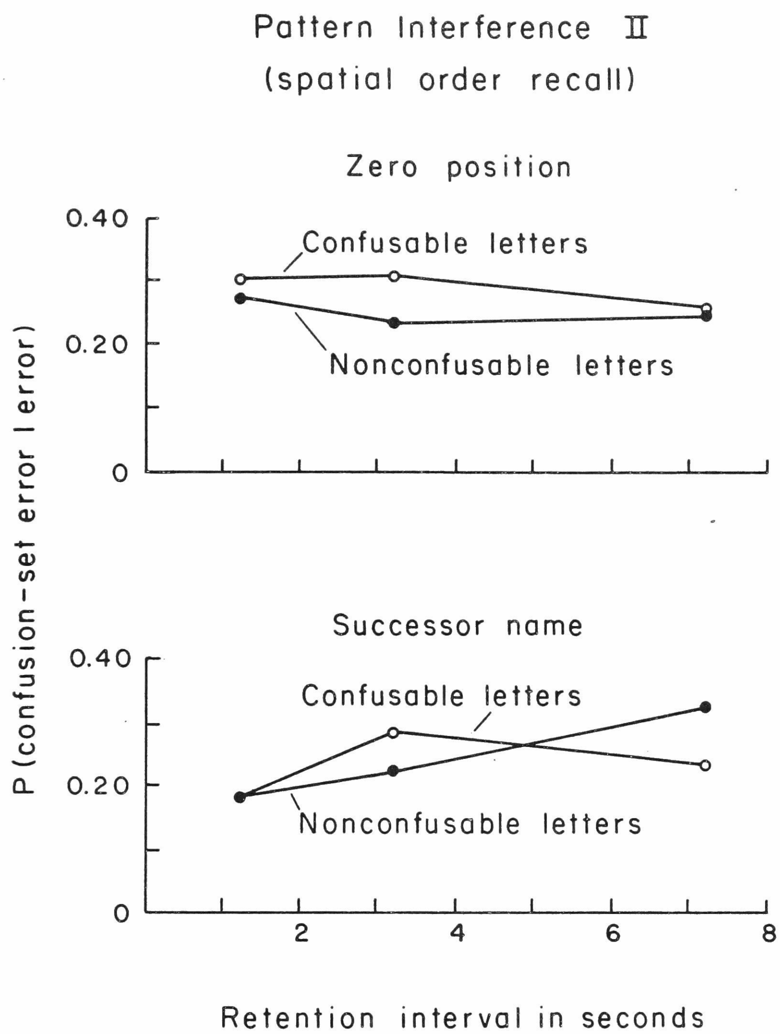

Figure 46. Conditional proportions of confusion-set errors given that an error was made at each of the three retention intervals for letters from the paired context strings (confusable letters) and letters from the all-different context strings (nonconfusable letters) in the Zero Position and Successor Name Conditions of the Pattern Interference II Experiment. Solid circles stand for nonconfusable letters; unfilled circles stand for confusable letters.

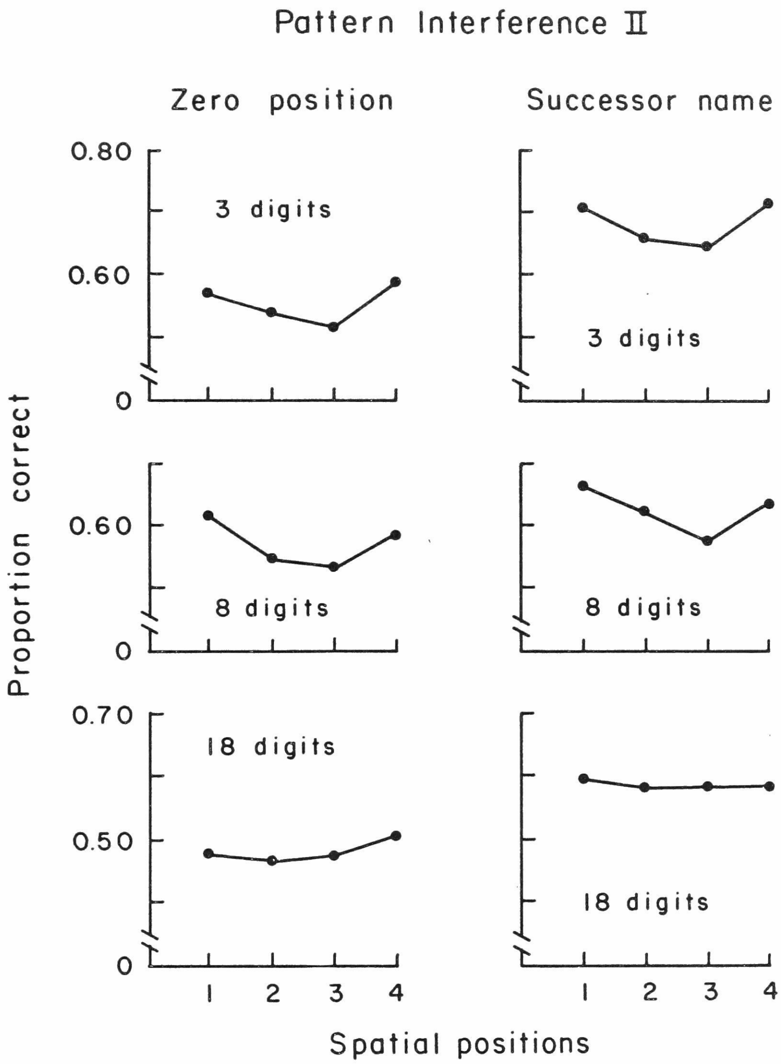

Figure 47. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the Zero Position and Successor Name Conditions of the Pattern Interference II Experiment. The serial positions represented are the spatial positions.

($F = 0.54$, $p > .05$, df = 3,66).

Although spatial position does influence proportion correct to some extent, temporal position seems to be even more influential. The serial position curves are presented in Figure 48 for the Zero Position and Successor Name Conditions plotted as a function of temporal position. As in the earlier Spatial Order Recall Conditions, the curves are bow-shaped and asymmetrical with a loss of recency. An ANOVA computed on these data yielded .02 as the standard error of the points on Figure 48. The ANOVA revealed that the serial position factor was significant ($F = 19.87$, $p < .01$, df = 3,66) but not the interaction of the serial position factor and the Zero Position vs. Successor Name factor ($F = 0.01$, $p > .05$, df = 3,66).

Distance Functions The distance functions at each of the three retention intervals are presented in Figures 49 and 50 for the Zero Position and Successor Name Conditions, respectively. In each case the serial positions considered are the spatial positions. Little regularity is seen here as was the case for the other Spatial Order Recall Conditions. On the other hand, also as in the previous Spatial Order Recall Conditions, a more regular picture is found when the temporal positions are considered. The distance functions for the Zero Position and Successor Name Conditions are presented in Figures 51 and 52 plotted as a function of temporal position. The pattern of results here is quite similar to that seen in the previous spatial order recall conditions.

Pattern Analysis Distance functions with the spatial positions are shown for each of the 24 patterns in Tables XXIII and XXIV for the Zero Position and Successor Name Conditions respectively. The picture in each case is similar to that observed in the earlier Spatial Order Recall tasks. Not only do the patterns differ in their overall probability correct, but also, for the most part, the patterns show the same characteristic distance functions observed in the earlier spatial order recall tasks.

Correlation coefficients were computed using the proportion correct at each of the 24 patterns in order to compare the various spatial order

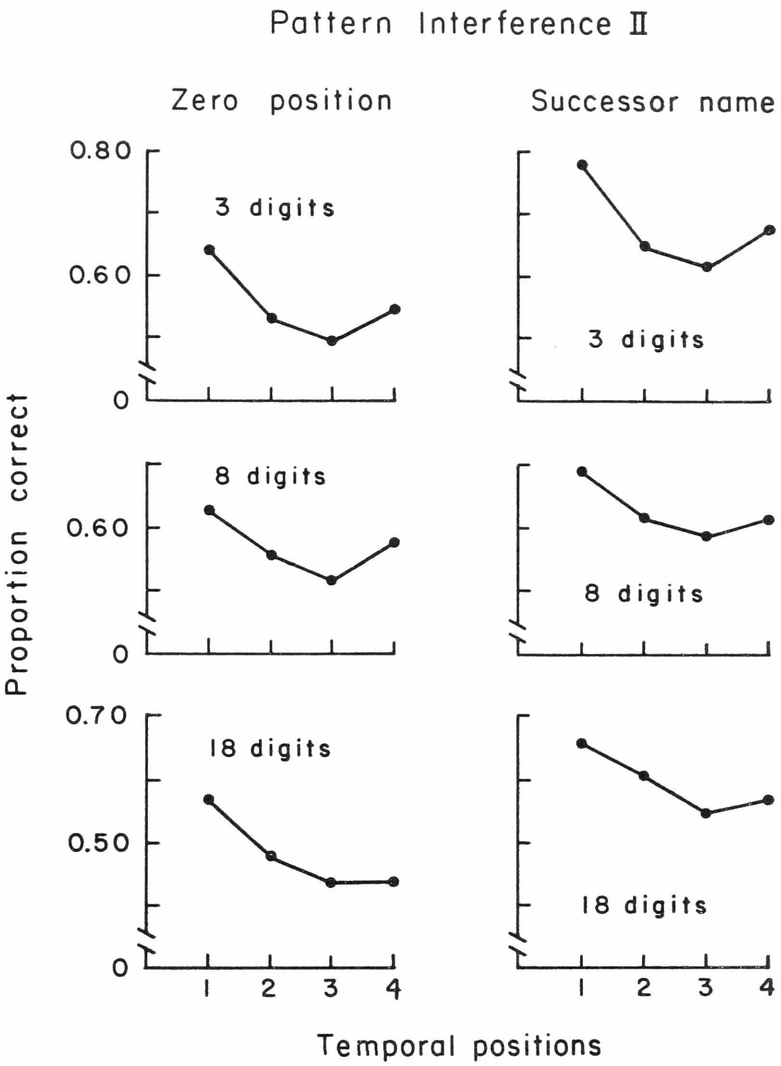

Figure 48. Serial position functions in terms of proportions of correct responses at each of the three retention intervals in the Zero Position and Successor Name Conditions of the Pattern Interference II Experiment. The serial positions represented are the temporal positions.

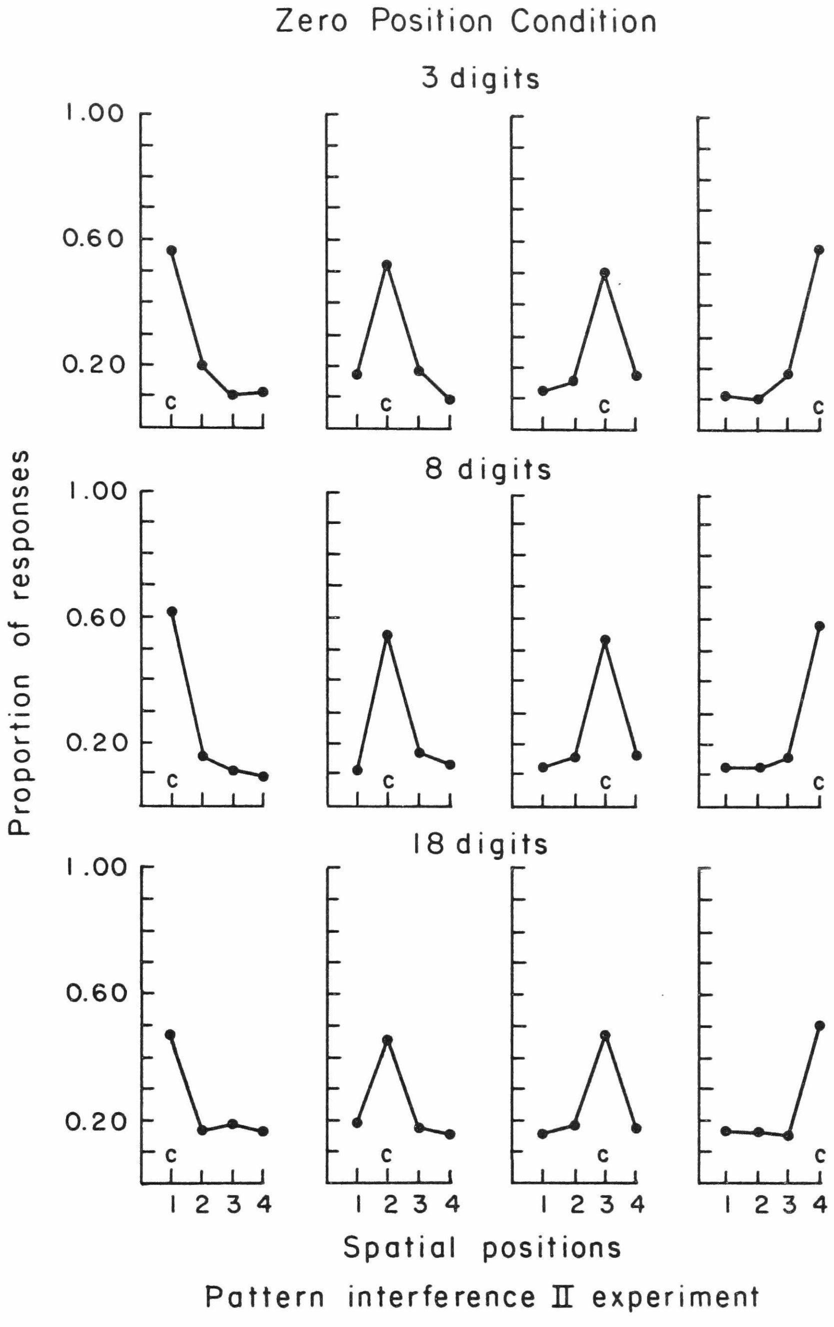

Figure 49. Distance functions for the Zero Position Condition of the Pattern Interference II Experiment. The serial positions represented are the spatial positions. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

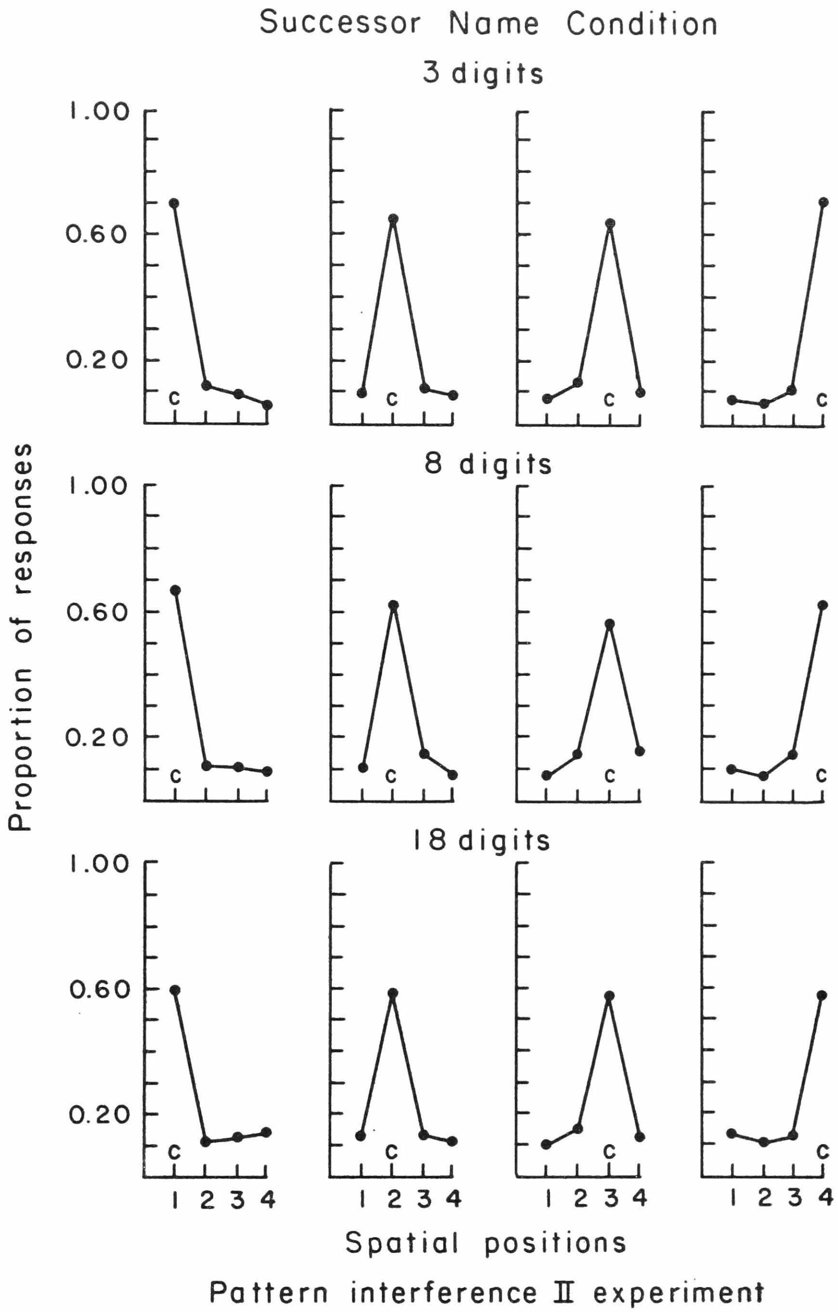

Figure 50. Distance functions for the Successor Name Condition of the Pattern Interference II Experiment. The serial positions represented are the spatial positions. The point plotted for position i of any panel represents the proportion of instances in which the response occurring in the position marked C on the subject's answer card was the letter appearing at position i of the string on the given trial.

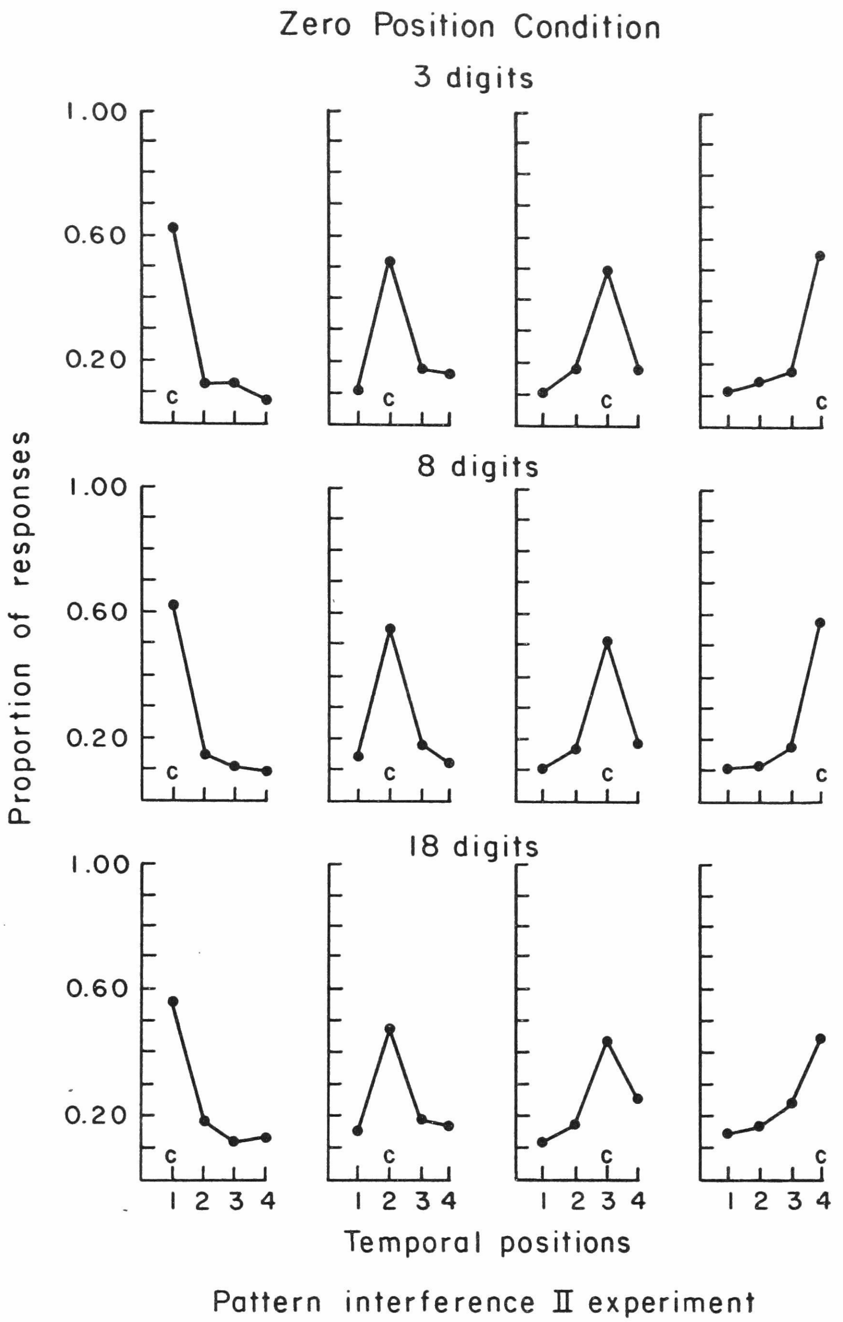

Figure 51. Distance functions for the Zero Position Condition of the Pattern Interference II Experiment. The serial positions represented are the temporal positions. The point plotted for position i of any panel represents the proportion of instances in which the letter that was shown in the temporal position marked C was replaced in the subject's protocol by the letter that was shown in temporal position i on the given trial.

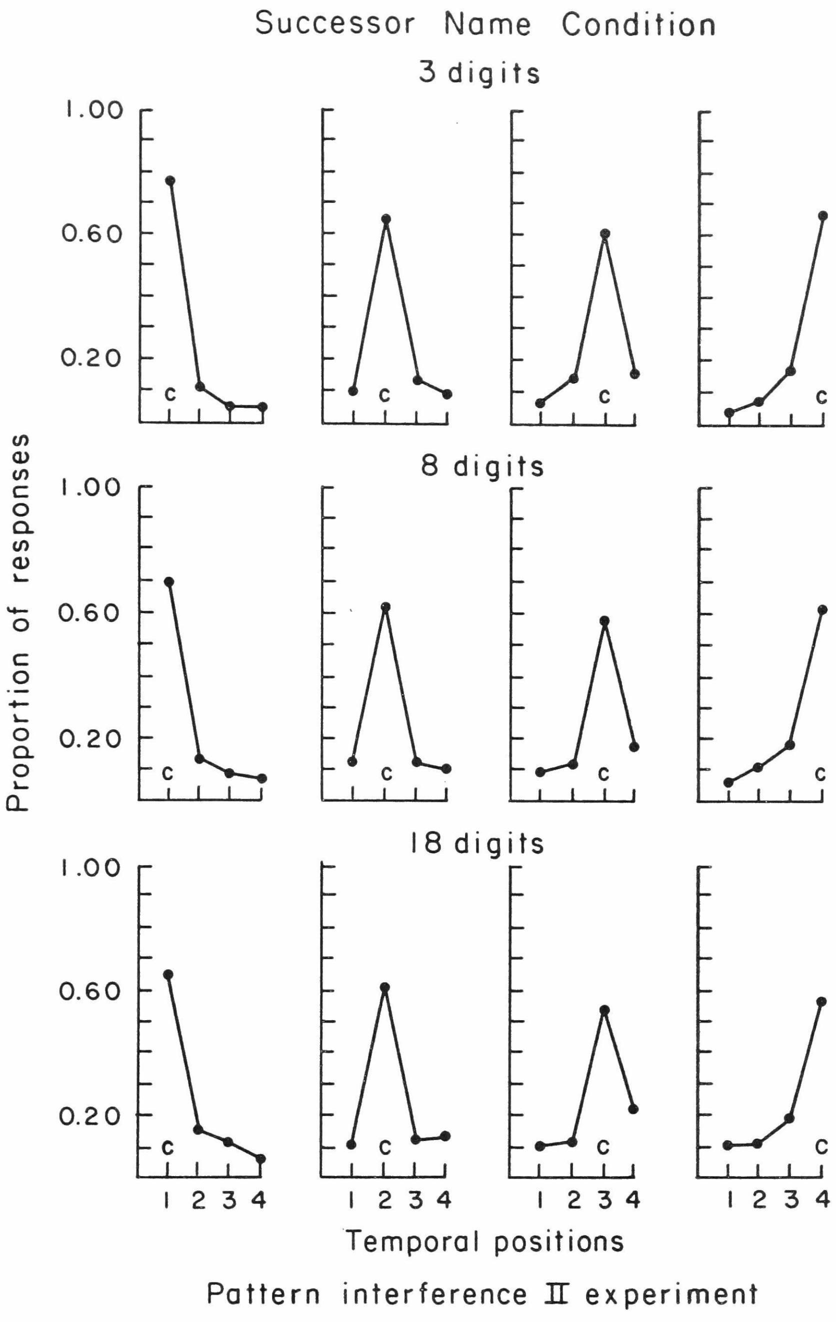

Figure 52. Distance functions for the Successor Name Condition of the Pattern Interference II Experiment. The serial positions represented are the temporal positions. The point plotted for position i of any panel represents the proportion of instances in which the letter that was shown in the temporal position marked C was replaced in the subject's protocol by the letter that was shown in temporal position i on the given trial.

Table XXIII

Spatial Distance Functions for Zero Position Condition of Pattern Interference II Experiment

Pattern No.	Distance Function (Response Position, Stimulus Position) 1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
1	32	1	1	2	1	31	4	0	1	4	30	1	2	0	1	33
2	28	4	4	0	4	26	3	3	2	3	27	4	2	3	2	29
3	18	8	5	5	4	19	6	7	6	4	19	7	8	5	6	17
4	28	3	0	5	1	29	4	2	4	3	25	4	3	1	7	25
5	18	7	2	9	8	9	16	3	4	16	14	2	6	4	4	22
6	17	10	5	4	9	15	8	4	4	9	15	8	6	2	8	20
7	28	6	0	2	1	27	5	3	2	1	28	5	5	2	3	26
8	15	2	9	10	7	21	3	5	3	13	13	7	11	0	11	14
9	21	6	3	6	5	19	7	5	8	7	17	4	2	4	9	21
10	19	10	2	5	8	10	10	8	3	7	21	5	6	9	3	18
11	17	5	9	5	2	28	5	1	9	2	18	7	8	1	4	23
12	23	8	5	0	7	21	5	3	4	3	14	15	2	4	12	18
13	25	4	4	3	5	19	8	4	4	6	20	6	2	7	4	23
14	18	3	8	7	4	26	2	4	7	6	17	6	7	1	9	19
15	18	8	9	1	11	8	12	5	6	12	8	10	1	8	7	20
16	12	9	3	12	10	13	9	4	1	9	20	6	13	5	4	14
17	22	7	5	2	11	17	1	7	3	5	23	5	0	7	7	22
18	20	4	4	8	6	25	2	3	6	5	20	5	4	2	10	20
19	16	10	3	7	4	12	9	11	7	3	23	3	9	11	1	15
20	17	6	13	0	5	17	8	6	10	6	11	9	4	7	4	21
21	17	5	6	8	11	10	4	11	7	7	18	4	1	14	8	13
22	22	2	8	4	6	21	3	6	5	9	16	6	3	4	9	20
23	17	9	6	4	4	15	11	6	6	4	18	8	9	8	1	18
24	11	16	7	2	8	12	12	4	10	3	9	14	7	6	8	15

Table XXIV

Spatial Distance Functions for Successor Name Condition of Pattern Interference II Experiment

Pattern No.	Distance Function (Response Position, Stimulus Position) 1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
1	36	0	0	0	0	36	0	0	0	0	36	0	0	0	0	36
2	35	1	0	0	1	34	1	0	0	0	34	2	0	1	1	34
3	24	3	4	5	3	25	6	2	2	6	22	6	7	2	4	23
4	29	3	0	4	1	30	3	2	0	3	30	3	6	0	3	27
5	25	2	1	8	1	17	17	1	2	15	17	2	8	2	1	25
6	24	3	4	5	4	15	14	3	5	10	13	8	3	8	5	20
7	27	5	1	3	4	26	3	3	2	2	27	5	3	3	5	25
8	16	3	5	12	2	22	7	5	8	7	11	10	10	4	13	9
9	34	0	2	0	1	30	2	3	1	4	30	1	0	2	2	32
10	14	22	0	0	18	8	5	5	3	3	24	6	1	3	7	25
11	9	6	15	6	7	24	3	2	13	6	9	8	7	0	9	20
12	24	6	6	0	8	26	1	1	2	3	19	12	2	1	10	23
13	29	0	2	5	1	30	4	1	1	2	29	4	5	4	1	26
14	28	1	2	5	5	30	1	0	0	4	28	4	3	1	5	27
15	22	4	9	1	5	19	11	1	5	12	11	8	4	1	5	26
16	20	7	0	9	7	18	3	8	1	5	28	2	8	6	5	17
17	29	3	4	0	2	31	1	2	5	0	28	3	0	2	3	31
18	20	2	7	7	6	23	3	4	4	10	16	6	6	1	10	19
19	22	6	3	5	4	13	6	13	3	4	24	5	7	13	3	13
20	25	4	7	0	3	27	4	2	6	3	20	7	2	2	5	27
21	25	3	2	6	7	12	5	12	3	11	21	1	1	10	8	17
22	19	1	10	6	5	16	3	12	6	14	13	3	6	5	10	15
23	15	12	6	3	7	17	10	2	9	2	19	6	5	5	1	25
24	20	7	7	2	7	14	10	5	4	6	16	10	5	9	3	19

recall tasks in terms of their pattern analyses. Correlation coefficients were .72 between the Zero Position and the Successor Name Conditions of the present experiment, .67, .82, .65, and .65 between the Zero Position and the Digit Name, Digit Position, Spatial Order Recall Condition of the Constant Temporal Spatial Experiment, and Spatial Order Recall Condition of the 1234 Experiment, respectively. Furthermore, correlation coefficients were found of .61, .74, .76, and .77 between the Successor Name and the Digit Name, Digit Position, Spatial Order Recall Condition of the Constant Temporal Spatial Experiment, and Spatial Order Recall Condition of the 1234 Experiment, respectively. In each case the coefficients are significant at the .01 level. Again, there is considerable consistency across conditions in the effect of temporal spatial patterns on probability correct which supports the notion that in spatial order recall the basic memory unit is the temporal spatial pattern.

V. A MODEL FOR SPATIAL ORDER RECALL

The data from the Temporal Order Recall Condition of the Constant Temporal Spatial Experiment are very similar to those from the Order Only Experiment. The time courses of forgetting in the two conditions are remarkably close; the serial position and distance functions are similar in the two cases; and in both cases the confusion error analyses give evidence for use of acoustic information at the short retention intervals. Therefore, it is reasonable to assume that the two models proposed to handle the data from the Item + Order Experiment could also account for the data of the Temporal Order Recall Condition of the Constant Temporal Spatial Experiment since these models were able to fit the similar data from the Order Only Experiment.

On the other hand, clearly the two models could not account for the data from the various Spatial Order Recall Conditions. For these conditions there was no evidence of acoustic coding even at the shortest retention interval. The time course of forgetting in these cases was considerably flatter than in the temporal order cases even in the Digit Position and Zero Position Conditions which involved intervening tasks that effectively disrupted recall. Furthermore, in the spatial order recall conditions the serial position curves for temporal positions were asymmetrical, with a much greater primacy effect than in the temporal order recall situations. In addition, the distance functions for spatial order recall with the temporal positions showed a much larger frequency of interchanges of items from temporal positions 3 and 4 than had been shown in the temporal order cases. Moreover, evidence was found supporting the notion that subjects in the spatial order recall conditions were attending to the temporal spatial pattern of consonant presentations. This notion is clearly incompatible with the assumption included in the two models that information about each consonant is independently represented in memory.

Description of the Spatial Order Model

A new model was therefore developed to account for the data from the spatial order recall situations. This model is very similar in form

to the earlier models. The main difference between the present model and the earlier models is that, whereas the temporal order models include the assumptions that each of the four consonants has a separate and independent representation in memory and that acoustic information is coded about the consonants, quite a different assumption is included in the spatial order model. Here it is assumed that the basic memory unit is the temporal spatial pattern of consonant presentations. In the spatial order model it is assumed not that the pattern as a whole is represented but rather three items of information referring to aspects of the pattern. Together these three items are sufficient to specify exactly any one of the 24 patterns.

The first item of information assumed to be coded about each pattern is the spatial location of the first consonant in the temporal sequence. One source of evidence that subjects make use of this type of information is the large primacy portion of the serial position curve when the temporal positions are considered. The second type of information is the "pattern class name": there are "alternating" (A) patterns (e.g., #17), "inside/outside" (I) patterns (e.g., #13), "paired" (P) patterns (e.g., #7), and "straight across" (S) patterns (e.g., #1). Evidence for making use of such classes is found in the specific errors made on a given pattern. Often the response for a given pattern was another pattern with the same pattern class name. The last item of information is the spatial order of the last two consonants. More specifically, the subject seems to code whether the last two consonants appeared in the usual left-to-right spatial sequence or in the reverse order. The evidence for such coding comes from the distance functions by pattern analyses. These analyses reveal a substantial frequency of cases in which the subject correctly identified the pattern except for an interchange of the last two items, especially when these last two items were presented from right-to-left spatially.

The spatial order model differs from the temporal order models in one other respect. The temporal models include only one memory store, and information that enters that memory store is lost with a certain

probability as each digit intervenes. The steep time courses of forgetting in temporal order recall are consonant with this conception. However, the time courses of forgetting in the spatial order case are much flatter; the curves seem to reach an asymptote so that increasing the number of intervening digits does not produce a corresponding decrease in recall. On the basis of this observation it seemed reasonable to postulate two memory stores for the spatial order case. One memory store (STS), like that postulated in the earlier models, is temporary since information is lost from that store with a given probability at each successive instant in time or digit presentation. The other memory store (LTS) is more permanent. In fact, for simplicity, since the time intervals considered in this situation are so short, it is assumed that information entering this second memory store is never lost. It is further assumed that all information enters STS, but that not all information enters LTS. Information in STS enters LTS with a given probability at each successive instant in time, or each successive digit presentation. This dual storage conception is similar to those of Atkinson and Shiffrin (1968) and Waugh and Norman (1965).

Otherwise, the spatial order model is quite similar to the temporal order models. Just as in the temporal order models, in the spatial order model the subject's memory is described in terms of a small number of states which are defined in terms of the particular type of information held in memory. There are 8 STS states (1S-8S) in the present model which are defined in terms of the particular type of information held in STS, and there are 8 corresponding LTS states (1L-8L) which are defined in terms of the particular type of information held in LTS. The content of STS or LTS for each of these memory states is as follows:

States 1S and 1L: All information about pattern

States 2S and 2L: Location of first item and pattern class name

States 3S and 3L: Location of first item and order of last two items

States 4S and 4L: Location of first item

States 5S and 5L: Pattern class name and order of last two items

States 6S and 6L: Pattern class name

States 7S and 7L: Order of last two items

States 8S and 8L: No information about pattern.

It is assumed that immediately following the presentation of a pattern its representation in the subject's memory starts off in state S1 and then, during successive instants in time or successive digit presentations, there may be a transition to one of the other seven STS states or a transfer to one of the eight LTS states. (Note that this assumption, which is similar to that made in the temporal order models, is neutral with respect to the controversy of whether forgetting is due to a mere decay with time or to interference during the retention interval.) The probabilities for such information transfers are not known in advance but, as in the temporal order models, are rather left as free parameters in the model, their values being assumed to depend on characteristics of the individual and the material.

There are four free parameters in the spatial order model, three parameters representing the probabilities of information losses from STS and one parameter representing the probability of information transfer from STS to LTS. The four parameters are as follows:

A is the probability of loss of information from STS about the location of the first item.

B is the probability of loss of information from STS about the pattern class name.

C is the probability of loss of information from STS about the order of the last two items.

U is the probability of transferring all information in STS to LTS.

As each digit occurs during the retention interval, each of these information transfers takes place with the given probability. It is assumed that at each digit presentation first the three parameters denoting loss of information from STS apply, and then the parameter denoting transfer of information from STS to LTS applies.

The probabilities for transitions between the various STS states are the cell entries of transition matrix D shown on Figure 53. The rows of

$$D = \begin{bmatrix} A'B'C' & A'B'C & A'BC' & A'BC & AB'C' & AB'C & ABC' & ABC \\ 0 & A'B' & 0 & A'B & 0 & AB' & 0 & AB \\ 0 & 0 & A'C' & A'C & 0 & 0 & AC' & AC \\ 0 & 0 & 0 & A' & 0 & 0 & 0 & A \\ 0 & 0 & 0 & 0 & B'C' & B'C & BC' & BC \\ 0 & 0 & 0 & 0 & 0 & B' & 0 & B \\ 0 & 0 & 0 & 0 & 0 & 0 & C' & C \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$A' = 1-A \qquad B' = 1-B \qquad C' = 1-C$

Figure 53. Transition matrix for Spatial Order Recall Model representing information losses from short-term store. The rows and columns of this matrix correspond to memory states S1 to S8.

this matrix represent the STS state of the subject's memory for a pattern before a given digit has been presented, and the columns represent the STS state of a subject's memory after the digit presentation. This transition matrix applies once at the presentation of each intervening digit. In addition, in each case immediately after the matrix D has been applied, another transition matrix E applies which determines whether the information in STS will be transferred to the more permanent LTS. Matrix E is shown in Figure 54. Note that both the rows and the columns of this matrix are numbered from S1 to S8 and then from L1 to L8. Furthermore, since information about each pattern is assumed to start off in state S1, the initial vector is also numbered from S1 to S8 and then from L1 to L8. There is a 1 in the first row of this vector, the row representing state S1, and there are 0's in the other 15 rows.

Multiplication of the initial vector by appropriate powers of the two transition matrices yields the following expressions for the probabilities of being in the various states after n digits:

$$P_n(S1) = (1-A)^n(1-B)^n(1-C)^n(1-U)^n$$
$$P_n(S2) = (1-A)^n(1-B)^n[1-(1-C)^n](1-U)^n$$
$$P_n(S3) = (1-A)^n[1-(1-B)^n](1-C)^n(1-U)^n$$
$$P_n(S4) = (1-A)^n[1-(1-B)^n][1-(1-C)^n](1-U)^n$$
$$P_n(S5) = [1-(1-A)^n](1-B)^n(1-C)^n(1-U)^n$$
$$P_n(S6) = [1-(1-A)^n](1-B)^n[1-(1-C)^n](1-U)^n$$
$$P_n(S7) = [1-(1-A)^n][1-(1-B)^n](1-C)^n(1-U)^n$$
$$P_n(S8) = [1-(1-A)^n][1-(1-B)^n][1-(1-C)^n](1-U)^n$$
$$P_n(L1) = \sum_{i=1}^{n} (1-A)^i(1-B)^i(1-C)^i U(1-U)^{i-1}$$
$$P_n(L2) = \sum_{i=1}^{n} (1-A)^i(1-B)^i[1-(1-C)^i]U(1-U)^{i-1}$$
$$P_n(L3) = \sum_{i=1}^{n} (1-A)^i[1-(1-B)^i](1-C)^i U(1-U)^{i-1}$$
$$P_n(L4) = \sum_{i=1}^{n} (1-A)^i[1-(1-B)^i][1-(1-C)^i]U(1-U)^{i-1}$$

E =

	S1	S2	S3	S4	S5	S6	S7	S8	L1	L2	L3	L4	L5	L6	L7	L8
S1	1-U	0	0	0	0	0	0	0	U	0	0	0	0	0	0	0
S2	0	1-U	0	0	0	0	0	0	0	U	0	0	0	0	0	0
S3	0	0	1-U	0	0	0	0	0	0	0	U	0	0	0	0	0
S4	0	0	0	1-U	0	0	0	0	0	0	0	U	0	0	0	0
S5	0	0	0	0	1-U	0	0	0	0	0	0	0	U	0	0	0
S6	0	0	0	0	0	1-U	0	0	0	0	0	0	0	U	0	0
S7	0	0	0	0	0	0	1-U	0	0	0	0	0	0	0	U	0
S8	0	0	0	0	0	0	0	1-U	0	0	0	0	0	0	0	U
L1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
L2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
L3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
L4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
L5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
L6	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
L7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
L8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Figure 54. Transition matrix for Spatial Order Recall Model representing information transfers from short-term store to long-term store. The rows and columns of this matrix correspond to memory states S1 to S8 and L1 to L8.

$$P_n(L5) = \sum_{i=1}^{n} [1-(1-A)^i](1-B)^i(1-C)^iU(1-U)^{i-1}$$

$$P_n(L6) = \sum_{i=1}^{n} [1-(1-A)^i](1-B)^i[1-(1-C)^i]U(1-U)^{i-1}$$

$$P_n(L7) = \sum_{i=1}^{n} [1-(1-A)^i][1-(1-B)^i](1-C)^iU(1-U)^{i-1}$$

$$P_n(L8) = \sum_{i=1}^{n} [1-(1-A)^i][1-(1-B)^i][1-(1-C)^i]U(1-U)^{i-1}$$

How a subject responds depends both on his state of knowledge and on the specific pattern he is shown. The following labels, which stand for the three types of pattern information, can be used to specify each pattern exactly:

Location of first item -- 1,2,3,4

Pattern Class Name -- S,I,P,A

Reversal in usual left-to-right presentation of last two items -- R.

When each pattern is identified with these labels it is easy to determine the various patterns that may characterize the subject's response protocol given that he saw a particular stimulus pattern and that he is in a particular memory state. This information is presented on Table XXV. Table XXV reveals one peculiarity of the model. It is assumed that a subject in States S2 or L2, that is one who knows the pattern class name and location of the first item but not the reversal information, will not realize that he does not have complete information and will therefore respond with a pattern in which the last two items are not reversed but are rather in the usual left-to-right order.

In order to compute the probability that a subject will generate a particular type of response protocol given his state of knowledge and given that he saw a particular stimulus pattern, it is assumed that all the patterns shown on Table XXV that are determined to be possible responses have equal probabilities of being employed. Using this assumption and the fact that every subject saw each of the 24 stimulus patterns an equal number of times, it was possible to construct Tables XXVI and XXVII where the conditional probabilities that the subject's responses

Table XXVa

Response Pattern Numbers Corresponding to Each Stimulus Pattern and State in Spatial Order Model

Stimulus Pattern No.	Label	State S1 & L1	S2 & L2	S3 & L3
1	1S	1	1	1 13 17
2	4SR	2	2	2 15 20
3	4I	3	3	3 12 24
4	2IR	4	14	4 8 22
5	3I	5	5	5 7 23
6	1IR	6	13	6 9 21
7	3P	7	7	5 7 23
8	2PR	8	11	4 8 22
9	1PR	9	9	6 9 21
10	3PR	10	7	10 16 19
11	2P	11	11	11 14 18
12	4P	12	12	3 12 24
13	1I	13	13	1 13 17
14	2I	14	14	11 14 18
15	4IR	15	3	2 15 20
16	3IR	16	5	10 16 19
17	1A	17	17	1 13 17
18	2A	18	18	11 14 18
19	3AR	19	23	10 16 19
20	4AR	20	24	2 15 20
21	1AR	21	17	6 9 21
22	2AR	22	18	4 8 22
23	3A	23	23	5 7 23
24	4A	24	24	3 12 24

Table XXVb

Response Pattern Numbers Corresponding to Each Stimulus Pattern and State in Spatial Order Model

Stimulus Pattern No.	State: S4 & L4	State: S5 & L5	State: S6 & L6
1	1 13 17 6 9 21	1	1 2
2	2 15 20 3 12 24	2	1 2
3	2 15 20 3 12 24	3 5 13 14	3 5 13 14 4 6 15 16
4	4 8 22 11 14 18	4 6 15 16	3 5 13 14 4 6 15 16
5	5 7 23 10 16 19	3 5 13 14	3 5 13 14 4 6 15 16
6	1 13 17 6 9 21	4 6 15 16	3 5 13 14 4 6 15 16
7	5 7 23 10 16 19	7 11 12	7 11 12 8 9 10
8	4 8 22 11 14 18	8 9 10	7 11 12 8 9 10
9	1 13 17 6 9 21	8 9 10	7 11 12 8 9 10
10	5 7 23 10 16 19	8 9 10	7 11 12 8 9 10
11	4 8 22 11 14 18	7 11 12	7 11 12 8 9 10
12	2 15 20 3 12 24	7 11 12	7 11 12 8 9 10
13	1 13 17 6 9 21	3 5 13 14	3 5 13 14 4 6 15 16
14	4 8 22 11 14 18	3 5 13 14	3 5 13 14 4 6 15 16
15	2 15 20 3 12 24	4 6 15 16	3 5 13 14 4 6 15 16
16	5 7 23 10 16 19	4 6 15 16	3 5 13 14 4 6 15 16
17	1 13 17 6 9 21	17 18 23 24	17 18 23 24 19 20 21 22
18	4 8 22 11 14 18	17 18 23 24	17 18 23 24 19 20 21 22
19	5 7 23 10 16 19	19 20 21 22	17 18 23 24 19 20 21 22
20	2 15 20 3 12 24	19 20 21 22	17 18 23 24 19 20 21 22
21	1 13 17 6 9 21	19 20 21 22	17 18 23 24 19 20 21 22
22	4 8 22 11 14 18	19 20 21 22	17 18 23 24 19 20 21 22
23	5 7 23 10 16 19	17 18 23 24	17 18 23 24 19 20 21 22
24	2 15 20 3 12 24	17 18 23 24	17 18 23 24 19 20 21 22

Table XXVc

Response Pattern Numbers Corresponding to Each Stimulus Pattern and State in Spatial Order Model

Stimulus Pattern No.	State: S7 & L7	State: S8 & L8
1	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
2	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
3	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
4	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
5	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
6	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
7	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
8	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
9	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
10	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
11	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
12	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
13	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
14	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
15	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
16	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
17	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
18	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
19	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
20	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
21	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
22	2 4 6 8 9 10 15 16 19 20 21 22	All Patterns
23	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns
24	1 3 5 7 11 12 13 14 17 18 23 24	All Patterns

Table XXVI

Theoretical Distance Functions With Respect to Temporal Position for the Spatial Order Model

	Position**															
State*	1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
2	1	0	0	0	0	1	0	0	0	0	$\frac{7}{12}$	$\frac{5}{12}$	0	0	$\frac{5}{12}$	$\frac{7}{12}$
3	1	0	0	0	0	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	0	$\frac{1}{3}$	$\frac{5}{9}$	$\frac{1}{9}$	0	$\frac{1}{3}$	$\frac{1}{9}$	$\frac{5}{9}$
4	1	0	0	0	0	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	0	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	0	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
5	$\frac{1}{3}$	$\frac{2}{9}$	$\frac{7}{36}$	$\frac{1}{4}$	$\frac{2}{9}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{7}{36}$	$\frac{7}{36}$	$\frac{1}{4}$	$\frac{5}{9}$	0	$\frac{1}{4}$	$\frac{7}{36}$	0	$\frac{5}{9}$
6	$\frac{5}{18}$	$\frac{2}{9}$	$\frac{2}{9}$	$\frac{5}{18}$	$\frac{2}{9}$	$\frac{5}{18}$	$\frac{5}{18}$	$\frac{2}{9}$	$\frac{2}{9}$	$\frac{5}{18}$	$\frac{5}{18}$	$\frac{2}{9}$	$\frac{5}{18}$	$\frac{2}{9}$	$\frac{2}{9}$	$\frac{5}{18}$
7	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{7}{18}$	$\frac{1}{9}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{9}$	$\frac{7}{18}$
8	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$

* Each row represents both the long-term and the short-term state.

** The position code i,j refers to instances in which the correct letter for the spatial position being scored was presented in temporal position i and the subject's response was the letter presented in temporal position j.

Table XXVII

Theoretical Conditional Probabilities of Correct Response
Given State and Pattern for Spatial Order Model

Pattern No.	State* 1	2	3	4	5	6	7	8
1	1	1	7/12	1/2	1	1/2	7/24	1/4
2	1	1	7/12	1/2	1	1/2	7/24	1/4
3	1	1	7/12	1/2	3/8	1/4	7/24	1/4
4	1	1/2	2/3	1/2	3/8	1/4	3/8	1/4
5	1	1	2/3	1/2	3/8	1/4	3/8	1/4
6	1	1/2	7/12	1/2	3/8	1/4	7/24	1/4
7	1	1	7/12	1/2	1/2	1/3	7/24	1/4
8	1	1/2	7/12	1/2	1/2	1/3	7/24	1/4
9	1	1	7/12	1/2	1/2	1/4	7/24	1/4
10	1	1/2	7/12	1/2	1/3	1/4	7/24	1/4
11	1	1	7/12	1/2	1/3	1/4	7/24	1/4
12	1	1	7/12	1/2	1/2	1/4	7/24	1/4
13	1	1	7/12	1/2	3/8	1/4	7/24	1/4
14	1	1	2/3	1/2	3/8	1/4	3/8	1/4
15	1	1/2	7/12	1/2	3/8	1/4	7/24	1/4
16	1	1/2	2/3	1/2	3/8	1/4	3/8	1/4
17	1	1	2/3	1/2	3/8	1/4	1/3	1/4
18	1	1	7/12	1/2	3/8	1/4	1/3	1/4
19	1	1/2	7/12	1/2	3/8	1/4	1/3	1/4
20	1	1/2	2/3	1/2	3/8	1/4	1/3	1/4
21	1	1/2	2/3	1/2	3/8	1/4	1/3	1/4
22	1	1/2	7/12	1/2	3/8	1/4	1/3	1/4
23	1	1	7/12	1/2	3/8	1/4	1/3	1/4
24	1	1	2/3	1/2	3/8	1/4	1/3	1/4

* Each column represents both the long-term and the short-term state.

will fall into the various categories given his state of knowledge are shown. The response categories considered in Table XXVI are those that define the distance functions with the temporal positions, and the response categories considered in Table XXVII are correct responses on each of the 24 stimulus patterns. Note in examining Table XXVII that the responses are scored separately for each letter so that, for example, if a subject has no information about which pattern he saw and guesses randomly from among the 24 patterns, on the average 1/4 of the consonants will be put in their correct spatial position.

Fit of the Model

A minimum chi-square routine, similar to that employed for the temporal order models, was employed to find the values of the four parameters of the present model that give the best fit to the observed data. Separate parameter estimations were made for the data from three of the spatial order recall conditions -- the Digit Name, the Digit Position, and the Successor Name Conditions. The data considered in each case were the distance functions with the temporal positions. For the Digit Name Condition, the minimum chi-square fit was found when $U = .26$, $A = .09$, $B = .05$, $C = .18$, $X^2 = 52$, $df = 23$. For the Digit Position Condition, $U = .15$, $A = .23$, $B = .08$, $C = .31$, $X^2 = 41$, $df = 23$. For the Successor Name Condition, $U = .26$, $A = .18$, $B = .06$, $C = .28$, $X^2 = 78$, $df = 23$.

When the parameter values yielding the minimum chi-square fits to the three conditions were compared, no regularity was observed. However, some regularity was expected because the time courses of forgetting in the three conditions were parallel; they only differed in their asymptotes. In fact, because of this observation about the time courses, one would predict that the three parameters A, B, and C representing loss of information from STS would have the same values in the three conditions. All that should differ from condition to condition is the value of the one parameter U, representing the transfer of information from STS to LTS.

In order to test this prediction, the values of the three parameters

A, B, and C that were found to give the minimum chi-square fit to the data of the Digit Position Condition were used to determine the fit of the model to the Digit Name and Successor Name Conditions. Only the value of the parameter U was left to vary in order to fit the data from these two conditions. With these constraints, the minimum chi-square fit for the Digit Name Condition was found when U = .78, A = .23, B = .08, C = .31, X^2 = 80, df = 26, and the minimum chi-square fit for the Successor Name Condition was found when U = .37, A = .23, B = .08, C = .31, X^2 = 85, df = 26. Clearly the value of the minimum chi-square is not greatly changed when the constraints are imposed. Significant chi-square values are found in each case, but the fit of the models to the data of the three conditions using these constrained parameter values appears very close to the eye. Tables XXVIII, XXIX, and XXX allow one to compare the predictions and the observed data from the Digit Name, Digit Position, and Successor Name Conditions, respectively, using these constrained parameter values. Correlation coefficients were computed to compare these predictions of the model to the observed data. These correlation coefficients revealed that in each case at least 98 percent of the variance in the data can be accounted for by the model (Digit Name Condition, r = .995; Digit Position Condition, r = .990; Successor Name Condition, r = .991).

In addition, with these same parameter values another aspect of the data from these conditions was predicted -- the proportion of correct responses at each of the 24 temporal spatial patterns. Correlation coefficients were again computed to compare these parameter free predictions of the model to the data observed in the three conditions. In each case the correlation coefficient was positive and statistically significant at the .01 level. For the Digit Position Condition, r = .62; for the Digit Name Condition, r = .58; and for the Successor Name Condition, r = .65.

Conclusions

What then does the relatively accurate description of the response patterns by the model suggest? First of all it lends support to the

Table XXVIII

Observed Temporal Distance Functions for Digit Name Condition Compared with Predictions from Spatial Order Model

No. of Digits		Position* 1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
3	Obs.	.86	.07	.02	.05	.06	.81	.07	.07	.03	.09	.76	.12	.04	.04	.15	.77
	Prd.	.81	.06	.06	.07	.06	.76	.09	.08	.06	.09	.71	.14	.07	.08	.14	.71
8	Obs.	.81	.10	.04	.06	.09	.72	.09	.10	.06	.07	.72	.15	.04	.12	.14	.70
	Prd.	.81	.06	.06	.07	.06	.76	.09	.08	.06	.09	.71	.14	.07	.08	.14	.71
18	Obs.	.83	.07	.06	.04	.06	.74	.08	.11	.07	.09	.66	.18	.04	.09	.20	.67
	Prd.	.81	.06	.06	.07	.06	.76	.09	.08	.06	.09	.71	.14	.07	.08	.14	.71

* The position code i,j refers to instances in which the correct letter for the spatial position being scored was presented in temporal position i and the subject's response was the letter presented in temporal position j.

Table XXIX

Observed Temporal Distance Functions for Digit Position Condition Compared with Predictions from Spatial Order Model

No. of Digits		Position*															
		1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
3	Obs.	.66	.16	.08	.10	.14	.58	.13	.15	.09	.13	.57	.20	.11	.13	.22	.54
	Prd.	.66	.11	.10	.12	.11	.60	.16	.14	.10	.16	.54	.19	.12	.14	.19	.54
8	Obs.	.52	.17	.16	.14	.18	.46	.17	.19	.17	.19	.44	.19	.12	.18	.22	.48
	Prd.	.53	.15	.15	.17	.15	.48	.19	.17	.15	.19	.44	.21	.17	.17	.21	.44
18	Obs.	.51	.19	.15	.16	.16	.49	.17	.18	.18	.15	.46	.21	.15	.17	.23	.45
	Prd.	.52	.16	.15	.17	.16	.47	.20	.18	.15	.20	.44	.21	.17	.18	.21	.44

* The position code i,j refers to instances in which the correct letter for the spatial position being scored was presented in temporal position i and the subject's response was the letter presented in temporal position j.

Table XXX

Observed Temporal Distance Functions for Successor Name Condition Compared with Predictions from Spatial Order Model

No. of Digits		1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4
		Position*															
3	Obs.	.78	.12	.05	.05	.11	.65	.14	.10	.07	.15	.62	.17	.04	.08	.19	.68
	Prd.	.72	.09	.09	.10	.09	.66	.13	.11	.09	.13	.61	.17	.10	.11	.17	.61
8	Obs.	.69	.14	.09	.08	.14	.62	.13	.11	.10	.12	.59	.18	.07	.11	.19	.62
	Prd.	.68	.10	.10	.12	.10	.63	.14	.12	.10	.14	.58	.18	.12	.12	.18	.58
18	Obs.	.66	.16	.12	.07	.12	.61	.13	.14	.11	.12	.55	.22	.11	.11	.20	.57
	Prd.	.68	.10	.10	.12	.10	.63	.14	.12	.10	.14	.58	.18	.12	.12	.18	.58

* The position code i,j refers to instances in which the correct letter for the spatial position being scored was presented in temporal position i and the subject's response was the letter presented in temporal position j.

notion that in the spatial order recall situation the subject codes information about the temporal spatial pattern of consonant presentations rather than about each consonant separately, as he does in the temporal order case. Furthermore, it gives support to the more specific hypotheses postulating three specific items of information that are coded about each temporal spatial pattern. Moreover, it lends support to the notion that the three spatial order recall situations differ only in the extent to which information is transferred from a temporary memory store to a more permanent store.

This last notion has some interesting implications. The three spatial order recall conditions differed only in their intervening tasks. The changes in proportion correct that resulted from these intervening tasks are attributable to changes in the amount of rehearsal, according to decay theory, and to changes in the amount of interference, according to interference theory. Therefore, although the present experimental situation may not be able to discriminate between a decay theory and an interference theory, it is able to restrict the form of an acceptable decay or interference theory. An interference theory is compatible with the results from the present experiment only if it implies that interference does not affect the rate of information loss from STS but does affect the amount of information transfer from STS to LTS. Similarly, a decay theory is compatible with the results from the present experiment only if it implies that a decrease in rehearsal does not lead to an increase in the rate of forgetting from STS but does lead to a decrease in the rate of transfer of information from STS to LTS.

VI. CONCLUSIONS

Two questions were of central interest to the present study: How is information stored in short-term memory, and how is information lost from short-term memory? More specific considerations arose as a result of trying to answer these questions. Attempting to answer the first question led to considering the notion of acoustic coding as well as the notions of independent representations of item and order information and independent representations of each item in a sequence. Attempting to answer the second question led to evaluating interference and decay theories. Progress toward answers to these two questions came by way of a theoretical and experimental comparison of short-term memory for temporal and spatial order information.

Acoustic Coding

As in previous studies, the present series of experiments found evidence for acoustic coding from the predominance of acoustic confusion errors in recall. In addition, by comparing recall at various retention intervals, the present study was able to get a clear picture of the way in which these acoustic confusion errors change in frequency with time. As a result of this analysis it was concluded that acoustic information is employed at first but that this information decays rapidly and is no longer available after a few seconds of intervening activity. Support for acoustic coding also came by way of two mathematical models which incorporated the hypothesis that acoustic information was encoded about each item. These models provided good fits to the data of several temporal order experiments. The two models were proposed in part to answer the question of whether acoustic confusion errors occur as a result of information mis-storage or as a result of loss during the retention interval. One model incorporated the former notion, and one the latter. However, since both models gave almost equally good fits to the data of the various temporal order experiments, no conclusion could be reached on this issue.

In contrast to the results of the temporal order experiments, the

present study yielded no evidence for acoustic coding in those cases where the subjects were to recall the spatial order of the items. Therefore the present experiment gave support to the notion of a flexible coding process as had earlier studies (Atwood, 1971; den Heyer & Barrett, 1971; Kroll, Parks, Parkinson, Bieber, & Johnson, 1970; Margrain, 1967; Meudell, 1972; Scarborough, 1972a). What is novel about the present study is that different forms of coding were implicated in the different situations even though the materials presented in each case were the same and were presented in the same modalities. The critical difference in procedure was a change in the manner in which the items were to be recalled. When items were to be recalled in their temporal order, acoustic coding was employed, but when items were to be recalled in their spatial order, coding did not involve acoustic properties.

Independence of Item and Order Information

The high frequency of transposition errors in the Item + Order and Item Only Experiments suggests independent loss of item and order information. In addition, support for item and order independence came from the two Item + Order models. Both models include independent parameters for loss of order information, and both models were able to fit the data from the Item + Order Experiment.

Item and order information were separated experimentally in the present study. In one experiment, the Order Only Experiment, the subject knew the identity of the items; he only had to remember their temporal order. In another experiment, the Item Only Experiment, the subject knew the order of the items that would be shown; he only had to learn their exact identity. These experiments, as well as previous studies in the literature (*e.g.*, Fuchs, 1969) and the Item + Order study, revealed that item and order errors show different serial position functions. In the Order Only Experiment, the serial position functions were bow-shaped. However, in the All-Different Context Condition of the Item Only Experiment, the condition where no order errors were possible, the serial position functions were flat.

The high frequency of acoustic confusion errors in the Order Only situation suggests that subjects coded both item and order information even though only order information was required. If subjects were coding only order information, these acoustic confusion errors would not be expected. Furthermore, the two models which accounted for the data from the Item + Order Experiment also accounted for the data from the Order Only Experiment. These models implied that the subject encoded item information as well as order information. An alternative model which implied that the subject coded only order information in the Order Only situation did not account for certain aspects of the data.

<u>Independent Representations for Each Item</u>

The two models proposed to account for the data of the Item + Order Experiment incorporated the hypothesis that information about each consonant was independently represented in memory. The close fit of these models to the data of the Item + Order and Order Only Experiments gave support to this hypothesis. Additional support for the notion of independent representations of the items came from the Item Only Experiment. The comparison of the two paired context conditions of that experiment revealed little difference in the proportion of correct responses in the two conditions even though one of the conditions placed restrictions on the number of item permutations that were allowed. These restrictions would have been expected to aid recall if subjects had coded the sequence as a unit.

In contrast to the results from the temporal order recall situation, the results from the spatial order recall situation yielded no evidence that items were independently represented in memory. To the contrary, in the latter situation subjects paid attention to the temporal spatial pattern of consonant presentations rather than to each consonant separately. Both the proportion of correct responses and the particular errors made depended on the temporal spatial pattern shown on the given trial.

Further, a model including the temporal spatial pattern of consonant presentations as the basic memory unit described the data of the various

spatial order recall tasks. Therefore, an answer to the question whether a sequence of items is coded as a unit or whether each item is independently coded depends on the specific experimental situation. Different coding strategies have been found to occur even in situations where the items and the manners of presenting the items are the same. The critical difference in procedure in these cases proves to be the manner in which the items are to be recalled.

A Comparison of Temporal and Spatial Order Recall

One of the goals of the present study was to separate and compare temporal and spatial order information. Earlier experimenters (e.g., Murdock, 1969) varied the temporal and spatial order of a set of items independently. However, analysis of the design and procedures of such experiments leads to the conclusion that an adequately controlled comparison of temporal and spatial order requires that the temporal order of the consonants be constant whenever the spatial order is to be recalled and, similarly, that the spatial order of the consonants be constant whenever the temporal order is to be recalled. These constraints were introduced in the present study. The constant order constraint proved to be a significant factor since its addition drastically modified the conclusions that had been reached about spatial order recall on the basis of the results from the Temporal Spatial Experiment.

The experiments employing the constant order constraint revealed significant differences in recall of temporal and spatial order information. In fact, as reviewed above, different coding processes were implicated in temporal and spatial order recall. There was evidence for acoustic coding in temporal order recall, whereas there was no evidence for acoustic coding in spatial order recall. The distinction between acoustic and nonacoustic coding was confounded with the distinction between temporal and spatial order recall. In the 1234 Experiment acoustic coding was eliminated by requiring the subjects to pronounce irrelevant items. In the 1234 Experiment the data in the Temporal Order Recall Condition were quite similar to those in the Spatial Order Recall Condition. The time courses of forgetting in the two conditions were parallel,

and the proportions of correct responses made at the different temporal spatial patterns were correlated in the two conditions.

As the 1234 Experiment demonstrated, subjects in the temporal order recall condition could use the same coding strategies as those used in the spatial order recall condition. In both conditions, the subject could respond accurately if he recalled which one of the 24 temporal spatial patterns was shown on the given trial. Nevertheless, when free to use acoustic coding, subjects in the temporal order recall situation employed an acoustic coding strategy even though this strategy was not as effective as the pattern strategy at the longer retention intervals. This observation is consonant with the notion that temporal order information is dealt with largely by the auditory modality (Goodfellow, 1934; O'Connor & Hermelin, 1972) and that spatial order information is dealt with largely by the visual modality (Attneave & Benson, 1969; O'Connor & Hermelin, 1972).

Interference vs. Decay

The intervening task, reading digits aloud, produced considerable forgetting in the Temporal Order Recall Condition, but not in the Spatial Order Recall Condition of the Constant Temporal Spatial Experiment. This finding can be accounted for by a decay theory only if different types of rehearsal are postulated. The argument can be made that reading digits aloud prevented the type of rehearsal necessary to maintain temporal order recall but not the type of rehearsal necessary to maintain spatial order recall.

On the other hand, an interference theory can account for these results with the assumption that reading digits aloud is more similar to the temporal order recall task than to the spatial order recall task. In fact similarity of recall and intervening task processes was found to be an essential determinant of intervening task effectiveness. This conclusion was reached on the basis of the results of the Pattern Interference Experiments where the Digit Position and Zero Position intervening tasks, those tasks most similar to the recall task, were most successful at reducing recall. However, similarity in this context is more broadly

defined than in previous interference theories (*e.g.*, Keppel, 1968; Waugh & Norman, 1965). Item similarity is held to be the essential cause of interference in the previous theories, but process similarity is held to be the important variable in the present study. The intervening items were the same in the Digit Name, Digit Position, and Successor Name Conditions of the Pattern Interference Experiments; only the subjects' responses varied from condition to condition. Nevertheless, the extent of interference produced in the three conditions differed considerably.

Neither an interference theory nor a decay theory can be ruled out on the basis of the present study. However, the present study imposes severe restrictions on the form of an acceptable interference or decay theory. The present study, like previous studies, has shown that a decay theory must include different types of rehearsal and that an interference theory must include process similarity as well as item similarity as a source of interference. Another restriction on both types of theories came from the spatial order recall model. This model was able to fit the data from the Digit Name, Digit Position, and Successor Name Conditions by changing the value of only one parameter, the parameter representing transfer of information from STS to LTS. Therefore an interference theory must imply that interference does not affect the rate of information loss from STS but only affects the amount of information transfer from STS to LTS, and a decay theory must imply that a decrease in rehearsal does not lead to an increase in the rate of forgetting from STS but does lead to a decrease in the rate of transfer from STS to LTS.

Plans for Future Research

A number of follow-up experiments are suggested by the results of the present study. In the temporal order recall situation each item in a sequence is independently represented in memory, and item and order information are lost independently. On the other hand, in the spatial order recall situation, the items of a sequence are coded as a unit or pattern. The question then arises whether item and order information are

lost independently in the spatial order recall situation. A tachistoscopic recognition study led Cumming and Coltheart (1969) to conclude that, on the contrary, item and spatial order information are interdependent. However, no evaluation of item and spatial order independence can be made on the basis of the present series of experiments since in the present study item information was eliminated from every spatial order recall situation. Therefore, an experiment adding item information to the spatial order recall situation was planned and, in fact, has already been conducted. The details of this experiment will be described in a later paper. Unlike the Cumming and Coltheart experiment, the results of the present experiment provided support for the notion of independent loss of item and spatial order information. This support came from different serial position functions and different time courses for item and order errors. In addition, the correlation between the proportions of item and order errors made on the 24 temporal spatial patterns was not significant.

Another proposed follow-up to the present study is an experiment in which intervening tasks are varied in the temporal order recall situation as they were in the spatial order recall situation. On the basis of Wickelgren's (1965c, 1966) results, intervening tasks that include items that are acoustically similar to the items to be recalled are expected to be most effective in reducing temporal order recall. On the other hand, one would not expect the Digit Position and Zero Position intervening tasks to be as effective in the temporal order recall situation as they were in the case of spatial order recall.

Final Remarks

Although this study has provided models that fit the data from the various temporal and spatial order recall situations, the task of understanding short-term memory is far from accomplished. The models in their present form are very specific to the given experimental situations, and these situations themselves are quite limited. Yet however limited are the models and the experiments of this study, their implications are much broader. They have provided an opportunity to test some very

general hypotheses about short-term memory. In fact, through them evidence was found which bears on some of the long-standing controversies in the field. The popular notion that short-term memory is limited to a verbal-acoustic coding system was shown to be inadequate. Rather, evidence was found for a more flexible coding system which selects different types of information to be coded and stored in memory depending on the specific recall task. These variations with the task are so substantial that in some cases the subject codes the separate items independently, whereas in other cases he codes the same items as a pattern. The present results could not settle the popular controversy whether forgetting is due to decay or interference. However, the present results suffice to restrict the form of an acceptable decay or interference theory. It is concluded that an acceptable decay theory must include different types of rehearsal, and an acceptable interference theory must include process similarity as well as item similarity as a source of interference.

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APPENDIX A

SETS OF CONSONANTS USED AS STIMULI

Experiment	Confusable Sets	Control Sets
Estes (1970)	BCPTV	None
	FSX	
	MN	
Item + Order, Item Only	BPV	KMR
	FSX	HLQ
Order Only	BP*	KM*
	FS*	HL*
	BPVD**	
	CTGZ**	
Temporal Spatial, Constant Temporal Spatial, 1234, Pattern Interference I, Pattern Interference II	BP	KM
	FS	HL

* Paired and All-Different Contexts

** All-same Context

APPENDIX B

COMPUTER SIMULATION OF THE TWO MODELS

In order to determine whether the calculations of the conditional probabilities shown on Table II were accurate, a Fortran program was written for the PDP 8/I computer to simulate the behavior in each model by the use of a Monte Carlo analysis. This technique makes use of a random number generator which enables one to choose one of several outcomes with various probabilities. For instance, say that the subject was constrained to act in one and only one of three ways -- X, Y, and Z. Assume further that the subject will choose X with probability .3, Y with probability .5, and Z with probability .2. The computer then generates a random number q between 0 and 1.0. If $0 \leq q \leq .3$, the hypothetical subject will choose X; if $.3 < q \leq .8$, the subject will choose Y, and if $.8 < q \leq 1.00$, the subject will choose Z.

Each run of the simulation program was in effect a double replication of six subjects in the Bjork and Healy (1970) study; the first half of a run simulated the experiment according to the assumptions of Model 1, and the second half simulated the experiment according to Model 2. In each experimental replication the six subjects were run in two sessions each for 72 trials at each session. On each trial the subject viewed four consonant stimuli and made four responses, one response for each of the four stimuli. Similarly, each computer replication of the experiment included 6 x 2 x 72 x 4 stimuli, each of which was the basis for one response. In the experiment 1/4 of all the stimuli were in the paired context and acoustic confusion sets; 1/4 of all the stimuli were in the all-different context and acoustic confusion sets; 1/4 of all the stimuli were in the paired context and control confusion sets, and 1/4 of all the stimuli were in the all-different context and control confusion sets. For each of these four sets of stimuli, 1/3 were to be remembered after 3 intervening digits, 1/3 after 8 intervening digits, and 1/3 after 18 intervening digits. The stimuli in the computer replication were similarly divided into twelve categories. Yet whereas the experimental subjects were presented representatives from these twelve categories in a pseudo-

random order, the computer subjects were presented with all of the stimuli from one category together. The assumption of independence of successive responses justifies this simplification.

In order to determine the probability of the subject's being in a certain state after being presented with a given stimulus, the simulation program uses the values of the parameters found earlier to give the best fit to the data for each model. Then for every stimulus in each of the twelve categories, the program chooses one of the subject's five states of knowledge by making use of the random number generator. Next, also employing the random number generator, the program determines the subject's response to the stimulus. The program never makes use of the information in Table II on the specific conditional probabilities of a response type given the state of knowledge. All that the program employs is the more general definition of the subject's response given his state of knowledge as exemplified on page 26. After the program decides the response to each stimulus, it classifies the response into one of the five categories -- correct; confusion-transposition error; confusion-nontransposition error; nonconfusion-transposition error; or nonconfusion-nontransposition error -- by comparing it with the stimulus letters shown on that trial. At the end of each run, the computer presents a table of results of a simulated replication with Model 1 and a table of results of a simulated replication with Model 2. At the end of two runs of the program the two experimental replications involving twelve subjects in all are simulated. Table XXXI allows one to compare the complete experimental results with the results from the first two simulated replications with Model 1 and with those from the first two simulated replications with Model 2. Since the simulated results are close to those calculated by the model, support is given to the analysis in Table II. Furthermore, the close resemblance of the simulated data to the experimental data gives additional support to the models since it shows that a limited sample of hypothetical subjects acting according to the models can produce data similar to that generated by the limited sample of subjects run in the experiment.

Table XXXI

Proportions of Response Types Observed in Item + Order Experiment Compared With Proportions Generated by Computer Simulation of Models 1 and 2

		Letter Category					
		Confusable			Control		
Context	No. of Digits	Obs.	Mod.1	Mod.2	Obs.	Mod.1	Mod.2
Correct Responses							
	3	.80	.83	.81	.93	.88	.87
Paired	8	.59	.60	.61	.66	.66	.66
	18	.35	.36	.37	.38	.34	.37
	3	.89	.82	.77	.90	.86	.85
All-Different	8	.66	.60	.60	.70	.64	.66
	18	.36	.35	.34	.41	.36	.40
Confusion Transposition Errors							
	3	.10	.05	.04	.02	.02	.03
Paired	8	.10	.08	.07	.07	.07	.07
	18	.12	.11	.12	.10	.11	.12
	3	---	---	---	---	---	---
All-Different	8	---	---	---	---	---	---
	18	---	---	---	---	---	---
Confusion Nontransposition Errors							
	3	.02	.02	.03	.00	.01	.01
Paired	8	.05	.03	.05	.02	.02	.02
	18	.06	.05	.04	.03	.04	.04
	3	.03	.06	.08	.01	.01	.02
All-Different	8	.11	.07	.08	.05	.04	.05
	18	.10	.11	.12	.07	.10	.06
Nonconfusion Transposition Errors							
	3	.05	.07	.05	.03	.06	.05
Paired	8	.16	.14	.14	.14	.14	.13
	18	.20	.22	.20	.16	.21	.19
	3	.08	.10	.08	.07	.11	.10
All-Different	8	.17	.20	.20	.17	.23	.20
	18	.34	.30	.30	.30	.31	.31
Nonconfusion Nontransposition Errors							
	3	.02	.03	.06	.01	.03	.05
Paired	8	.09	.15	.12	.10	.11	.12
	18	.28	.27	.26	.33	.30	.28
	3	.01	.02	.06	.02	.02	.03
All-Different	8	.07	.12	.12	.09	.09	.09
	18	.21	.25	.25	.22	.24	.24

APPENDIX C

INSTRUCTIONS TO SUBJECTS

Item + Order Experiment

On each trial of this experiment you will be seeing a series of four letters followed by a series of numbers which will appear on the small screen in front of you.

You are to read aloud the letters and numbers as they appear. This is a fairly hard task as the letters and numbers will be appearing quite rapidly. However, if you pay attention you will be able to read them accurately. Remember it is very important that you read aloud every letter and number.

At the end of each string of letters and numbers the screen will become blank and you are to write down the four letters you just saw at the beginning of the string in the same order as they appeared.

You will write the letters you remember on this card (show). Put each of the four letters in the box corresponding to the order in which it appeared on the screen. Underneath each box you will see the numbers 3, 2, and 1. For each of the four letters you write, you are to circle one of these numbers. If for example, you are certain the letter you write in the first box was the first letter you read on that trial, then you will circle the #3 for the highest confidence. If instead you know you are only guessing, you would circle the #1. If you are more certain of your response than just guessing, but you are not sure that it is correct, you should circle the #2.

So, at the end of each trial, as soon as the screen goes blank, you will write down the four letters in the order they appeared. Then for each letter you will circle one of the three numbers beneath it depending on how confident you are that it is the correct letter for that position. Do you have any questions so far?

At the end of the recall time, you will hear a double click. This is a warning that you should immediately finish responding and hand your

card to the Experimenter. Then get ready for the next trial.

Order Only Experiment

On each trial of this experiment you will be seeing a series of four letters followed by a series of numbers which will appear on the small screen in front of you. In this experiment the same four letters will be shown on each trial. The letters shown will be __ __ __ __. They will appear in a different order on each trial.

You are to read aloud the letters and numbers as they appear. This is a fairly hard task as the letters and numbers will be appearing quite rapidly. However, if you pay attention you will be able to read them accurately. Remember it is very important that you read aloud every letter and number.

At the end of each string of letters and numbers the screen will become blank and you are to write down the four letters you just saw at the beginning of the string in the same order as they appeared.

You will write the letters you remember on this card (show). Put each of the four letters in the box corresponding to the order in which it appeared on the screen. Underneath each box you will see the numbers 3, 2, and 1. For each of the four letters you write, you are to circle one of these numbers. If, for example, you are certain the letter you write in the first box was the first letter you read on that trial, then you will circle the #3 for the highest confidence. If instead you know you are only guessing, you would circle the #1. If you are more certain of your response than just guessing, but you are not sure that it is correct, you should circle the #2.

So, at the end of each trial, as soon as the screen goes blank, you will write down the four letters in the order they appeared. Then for each letter you will circle one of the three numbers beneath it depending on how confident you are that it is the correct letter for that position. Do you have any questions so far?

At the end of the recall time, you will hear a double click. This is a warning that you should immediately finish responding and hand your

card to the Experimenter. Then get ready for the next trial.

Let me remind you again that the same four letters will be shown on each trial of this experiment. The letters shown will be __ __ __ __. They will appear in a different order on each trial.

Item Only Experiment

On each trial of this experiment you will be seeing a series of four letters followed by a series of numbers which will appear on the small screen in front of you. You are to read aloud the letters and numbers as they appear. This is a fairly hard task as the letters and numbers will be appearing quite rapidly. However, if you pay attention, you will be able to read them accurately. Remember it is very important that you read aloud every letter and number.

At the end of each string of letters and numbers, the screen will become blank, and you are to write down the four letters you just saw at the beginning of the string in the same order as they appeared.

You will write the letters you remember on this card (show). Put each of the four letters in the box corresponding to the order in which it appeared on the screen. Underneath each box you will see the numbers 3, 2, and 1. For each of the four letters you write, you are to circle one of these numbers. If, for example, you are certain the letter you write in the first box was the first letter you read on that trial, then you will circle the #3 for the highest confidence. If instead you know you are only guessing, you would circle the #1. If you are more certain of your response than just guessing but you are not sure that it is correct, you should circle the #2.

So, at the end of each trial, as soon as the screen goes blank, you will write down the four letters in the order they appeared. Then for each letter you will circle one of the three numbers beneath it depending on how confident you are that it is the correct letter for that position. Do you have any questions so far?

At the end of the recall time, you will hear a double click. This

is a warning that you should immediately finish responding and hand your card to the Experimenter. Then get ready for the next trial.

Before we start, let me tell you one more thing about the four letters you will see on each trial. The first letter you see will always be either __, __, or __. The second letter you see will always be either __, __, or __. The third letter you see will always be either __, __, or __, and the fourth letter you see will always be either __, __, or __. Here is a card which gives you this same information. You may keep this card in front of you at all times. Refer to it whenever you need help during the recall period.

<u>Temporal Spatial Experiment</u>

On each trial of this experiment you will be seeing a series of four consonants followed by a series of digits which will appear on the small screen in front of you. There will always be just four consonants, but the number of digits will vary. In fact, on some trials no digits will appear. In this experiment the same four consonants will be shown on each trial. The consonants shown will be __ __ __ __. They will appear in a different order on each trial.

You are to read aloud the consonants and digits as they appear. This is a fairly hard task as the consonants and digits will be appearing quite rapidly. However, if you pay attention you will be able to read them accurately. Remember, it is very important that you read aloud every consonant and digit.

At the end of each string of consonants and digits, the screen will become blank and you are to write down the four consonants you just saw at the beginning of the string in the same order as they appeared.

You will write the consonants you remember on this card (show). Put each of the four consonants in the box corresponding to the order in which it appeared on the screen. Underneath each box you will see the numbers 3, 2, and 1. For each of the four consonants you write, you are to circle one of these numbers. If, for example, you are certain the consonant you write in the first box was the first consonant you read on that trial,

then you will circle the #3 for highest confidence. If instead you know you are only guessing, you would circle the #1. If you are more certain of your response than just guessing, but you are not sure that it is correct, you should circle the #2.

So, at the end of each trial, as soon as the screen goes blank, you will write down the four consonants in the order they appeared. Then for each consonant you will circle one of the three numbers beneath it depending on how confident you are that it is the correct consonant for that position. Do you have any questions so far?

At the end of the recall time, you will hear a double click. This is a warning that you should immediately finish responding and hand your card to the Experimenter. Then get ready for the next trial.

There is one more feature of the experiment I must explain to you before we begin. As you can see there are four cells across the screen in front of you. On every trial each digit will appear in all four cells simultaneously so you will see the same digit repeated in every cell. However, on every trial each of the four consonants you are to remember will appear in only one of the four cells. The other three cells will be blank. In addition, each of the four consonants on a trial will appear in a different one of the four cells of the screen. However, the first consonant you see will not necessarily appear in the first cell; the second won't necessarily appear in the second cell, and so on. Therefore, the position order of the four consonants will not coincide with their time order. Let me explain what I mean by that. The time order of the consonants is the order in which they are flashed on the screen and the order in which you will read them aloud. The position order, on the other hand, is the order of the consonants when only their spatial position is considered so that the letter which appeared in the left-most cell is the first letter in the position order, the letter which appeared in the cell next to that one is the second letter in the position order, and so on. Therefore, you can see, as I just stated, the position order will not necessarily correspond to the time order. In which order are you supposed to recall the consonants, in their time order or in their

position order?

Precue Condition

On some trials you are to recall the position order of the consonants and on some trials you are to recall the time order. At the beginning of every trial you will be told in which order to recall the consonants. The trial will start with a blink of the screen and then one of the vowels, I or O, will appear in every cell of the screen just as do the digits. Read aloud the vowel I or O just as you read aloud the consonants and digits. The vowel I will tell you that you are to recall the time order (this is easy to remember because of the I in time); the vowel O will tell you that you are to recall the position order (this is easy to remember because of the O's in position). After the vowel I or O appears, the screen will blink several times and then the consonants and digits will appear immediately, so keep your eyes on the screen. At the end of every trial, right after the last digit, and right before the screen becomes blank, the same vowel either I or O will appear again. It is there to remind you in which order you are to recall the consonants. Remember to read aloud the vowel I or O just as you read aloud the digits that preceded it. Then immediately start responding by writing down the four consonants in their proper order and by indicating your confidence ratings. Do you understand?

Now there will be a series of six practice trials. They are just like the real trials except the letters ABCD will appear on the screen instead of the consonants __ __ __ __. If you have any questions please ask me now or right after the practice trials since I cannot stop the tape after it's begun. However, there will be one break half way through the session when you will be able to relax.

... Let me remind you again that the same four consonants will be shown on each trial of this experiment. The consonants shown will be __ __ __ __. They will appear in a different order on each trial.

Postcue Condition

On some trials you are to recall the position order of the consonants

and on some trials you are to recall the time order. At the end of every trial you will be told in which order to recall the consonants. The trial will start with a blink of the screen and then the vowel U will appear in every cell of the screen just as do the digits. Read aloud the vowel U just as you read aloud the consonants and digits. The vowel U will tell you that the trial is beginning. After the vowel U appears the screen will blink several times and then the consonants and digits will appear immediately so keep your eyes on the screen. At the end of every trial, right after the last digit and right before the screen becomes blank, the vowel I or O will appear. It is there to tell you in which order you are to recall the four consonants. The vowel I will tell you that you are to recall the time order (this is easy to remember because of the I in time); the vowel O will tell you that you are to recall the position order (this is easy to remember because of the O's in the word position). Remember to read aloud the vowel I or O just as you read aloud the digits that preceded it. Then, immediately start responding by writing down the four consonants in their proper order and by indicating your confidence ratings. Do you understand?

Now there will be a series of six practice trials. They are just like the real trials except the letters ABCD will appear on the screen instead of the consonants __ __ __ __. If you have any questions please ask me now or right after the practice trials since I cannot stop the tape after it's begun. However, there will be one break half way through the session when you will be able to relax.

... Let me remind you again that the same four consonants will be shown on each trial of this experiment. The consonants shown will be __ __ __ __. They will appear in a different order on each trial.

Constant Temporal Spatial Experiment

On each trial of this experiment you will be seeing a series of four consonants followed by a series of digits which will appear on the small screen in front of you. There will always be just four consonants, but the number of digits will vary. In this experiment the same four consonants will be shown on each trial. The consonants shown will be __ __ __

___. They will appear in a different order on each trial.

You are to read aloud the consonants and digits as they appear. This is a fairly hard task as the consonants and digits will be appearing quite rapidly. However, if you pay attention you will be able to read them accurately. Remember, it is very important that you read aloud every consonant and digit.

At the end of each string of consonants and digits, the screen will become blank and you are to write down the four consonants you just saw at the beginning of the string in the same order as they appeared.

You will write the consonants you remember on this card (show). Put each of the four consonants in the box corresponding to the order in which it appeared on the screen. Do not leave any boxes blank. Make sure that you put a consonant in each of the four boxes on the card. If you have to guess, then do guess. You'll be able to guess because you know the four consonants that will be shown on each trial. Do you have any questions so far?

At the end of the recall time you will hear a double click. This is a warning that you should immediately finish responding and hand your card to the Experimenter. Then get ready for the next trial.

There is one more feature of the experiment I must explain to you before we begin. As you can see there are four cells across the screen in front of you. On every trial each digit will appear in all four cells simultaneously so you will see the same digit repeated in every cell. However, on every trial each of the four consonants you are to remember will appear in only one of the four cells. The other three cells will be blank. In addition, each of the four consonants on a trial will appear in a different one of the four cells of the screen. However, the first consonant you see will <u>not</u> necessarily appear in the first cell; the second won't necessarily appear in the second cell and so on. Therefore, the <u>position</u> order of the four consonants will not coincide with their <u>time</u> order. Let me explain what I mean by that. The time order of the consonants is the order in which they are flashed on the screen and the order in which

you will read them aloud. The position order, on the other hand, is the order of the consonants when only their spatial position is considered so that the letter which appeared in the left-most cell is the first letter in the position order, the letter which appeared in the cell next to that one is the second letter in the position order, and so on. Therefore, you can see, as I just stated, the position order will not necessarily correspond to the time order. In which order are you supposed to recall the consonants, in their time order or in their position order?

Spatial Order Recall

You are to recall the consonants in their position order. In fact, the time order of the letters will be the same on every trial so that you will always see the letters in the time order __ __ __ __. Therefore, for instance, __ will always be the first letter you see, but it won't necessarily be in the first cell. Remember if it was in the first, second, third, or fourth cell so that you can recall it in its proper position order. Write the letter that appeared in the first cell in the first box on the card, the letter that appeared in the second cell in the second box on the card, and so on. Do you understand?

Now there will be a series of six practice trials. They are just like the real trials except the letters ABCD will appear on the screen instead of the consonants __ __ __ __. They will always appear in the time order ABCD but the position order will vary. You are to recall the letters in their proper position order.

... Let me remind you again that the same four consonants will be shown on each trial of this experiment. The consonants shown will be __ __ __ __. They will appear in the time order __ __ __ __, but they will appear in a different position order on every trial. You are to write down the letters in their proper position order.

Temporal Order Recall

You are to recall the consonants in their time order. In fact, the position order of the letters will be the same on every trial so that you will always see the letters in the position order __ __ __ __. Therefore,

for instance, __ will always be the letter in the first cell but it won't necessarily be the first letter you will see. Remember if it was the first, second, third, or fourth letter you saw so that you can recall it in its proper time order. Write the letter you saw first in the first box on the card, the letter you saw second on the second box on the card, and so on. Do you understand?

Now there will be a series of six practice trials. They are just like the real trials except the letters ABCD will appear on the screen instead of the consonants __ __ __ __. They will always appear in the position order ABCD but the time order will vary. You are to recall the letters in their proper time order.

... Let me remind you again that the same four consonants will be shown on each trial of this experiment. The consonants shown will be __ __ __ __. They will always appear in the position order __ __ __ __, but they will appear in a different time order on every trial. You are to write down the letters in their proper time order.

<u>1234 Experiment</u>

On each trial of this experiment you will be seeing a series of four consonants followed by a series of digits which will appear on the small screen in front of you. There will always be just four consonants, but the number of digits will vary. In this experiment the same four consonants will be shown on each trial. The consonants shown will be __ __ __ __. They will appear in a different order on each trial.

As the first of the four consonants appears, you are to say aloud the number "one". As the second of the four consonants appears, say aloud "two"; as the third consonant appears, say aloud "three", and as the fourth consonant appears, say aloud "four". Then, as each digit appears, read it aloud. This is a fairly hard task as the consonants and digits will be appearing quite rapidly. However, if you pay attention, you will have no trouble. Remember, it is very important that I hear you say "one, two, three, four" as the consonants appear and that I hear you read each digit as it appears. Don't forget that you are not to read the consonants

aloud, only the digits.

At the end of each string of consonants and digits, the screen will become blank and you are to write down the four consonants you just saw at the beginning of the string in the same order as they appeared.

You will write the consonants you remember on this card (show). Put each of the four consonants in the box corresponding to the order in which it appeared on the screen. Do not leave any boxes blank; make sure that you put a consonant in each of the four boxes on the card. If you have to guess, then do guess. You'll be able to guess because you know the four consonants that will be shown on each trial. Do you have any questions so far?

At the end of the recall time you will hear a double click. This is a warning that you should immediately finish responding and hand your card to the Experimenter. Then get ready for the next trial.

There is one more feature of the experiment I must explain to you before we begin. As you can see there are four cells across the screen in front of you. On every trial each digit will appear in all four cells simultaneously so you will see the same digit repeated in every cell. However, on every trial each of the four consonants you are to remember will appear in only one of the four cells. The other three cells will be blank. In addition, each of the four consonants on a trial will appear in a different one of the four cells of the screen. However, the first consonant you see will <u>not</u> necessarily appear in the first cell; the second won't necessarily appear in the second cell, and so on. Therefore, the <u>position</u> order of the four consonants will not coincide with their <u>time</u> order. Let me explain what I mean by that. The time order of the consonants is the order in which they are flashed on the screen. The position order, on the other hand, is the order of the consonants when only their spatial position is considered so that the letter which appeared in the left-most cell is the first letter in the position order, the letter which appeared in the cell next to that one is the second letter in the position order, and so on. Therefore, you can see, as I

just stated, the position order will not necessarily correspond to the time order. In which order are you supposed to recall the consonants, in their time order or in their position order?

Spatial Order Recall

You are to recall the consonants in their position order. In fact, the time order of the letters will be the same on every trial so that you will always see the letters in the time order __ __ __ __. Therefore, for instance, __ will always be the first letter you see, but it won't necessarily be in the first cell. Remember if it was in the first, second, third, or fourth cell so that you can recall it in its proper position order. Write the letter that appeared in the first cell in the first box on the card, the letter that appeared in the second cell in the second box on the card, and so on. Do you understand?

Now there will be a series of six practice trials. They are just like the real trials except the letters ABCD will appear on the screen instead of the consonants __ __ __ __. They will always appear in the time order ABCD but the position order will vary. You are to recall the letters in their proper position order.

... Let me remind you again that the same four consonants will be shown on each trial of this experiment. The consonants shown will be __ __ __ __. They will always appear in the time order __ __ __ __, but they will appear in a different position order on every trial. You are to write down the letters in their proper position order.

Temporal Order Recall

You are to recall the consonants in their time order. In fact, the position order of the letters will be the same on every trial so that you will always see the letters in the position order __ __ __ __. Therefore, for instance, __ will always be the letter in the first cell but it won't necessarily be the first letter you will see. Remember if it was the first, second, third, or fourth letter you saw so that you can recall it in its proper time order. Write the letter you saw first in the first box on the card, the letter you saw second in the second box on the card,

and so on. Do you understand?

Now there will be a series of six practice trials. They are just like the real trials except the letters ABCD will appear on the screen instead of the consonants ___ ___ ___ ___. They will always appear in the position order ABCD, but the time order will vary. You are to recall the letters in their proper time order.

... Let me remind you again that the same four consonants will be shown on each trial of this experiment. The consonants shown will be ___ ___ ___ ___. They will always appear in the position order ___ ___ ___ ___, but they will appear in a different time order on every trial. You are to write down the letters in their proper time order.

Pattern Interference I Experiment

Digit Name Condition

On each trial of this experiment you will be seeing a series of four consonants followed by a series of digits which will appear on the small screen in front of you. There will always be just four consonants but the number of digits will vary. In this experiment the same four consonants will be shown on each trial. The consonants shown will be ___ ___ ___ ___. They will appear in a different order on each trial.

As you can see there are four cells across the screen in front of you. Each consonant and digit will appear in only one of the four cells. The other three cells will be blank. In addition, the cell where a given item appears will vary from item to item.

You are to read aloud the consonants and digits as they appear.

This is a fairly hard task as the consonants and digits will be appearing quite rapidly; however, if you pay attention you will have no trouble.

Remember, it is very important that I hear you read aloud every consonant and digit.

At the end of each string of consonants and digits, the screen will

become blank, and you are to write down the four consonants you just saw at the beginning of the string in the same order as they appeared on the screen.

You will write the consonants you remember on this card (show). Put each of the four consonants in the box corresponding to the order in which it appeared on the screen. Do not leave any boxes blank; make sure that you put a consonant in each of the four boxes on the card. If you have to guess, then do guess. You'll be able to guess because you know the four consonants that will be shown on each trial. Do you have any questions so far?

At the end of the recall time you will hear a double click. This is a warning that you should immediately finish responding and hand your card to the Experimenter. Then get ready for the next trial.

There is one more feature of the experiment I must explain to you before we begin. As I said earlier, each consonant and digit will appear in only one of the four cells of the screen. The other three cells will be blank. In addition, the cell where a given item appears will vary from item to item. Moreover, it will also be true that each of the four consonants on a trial will appear in a different one of the four cells of the screen. However, the first consonant you see will <u>not</u> necessarily appear in the first cell; the second won't necessarily appear in the second cell, and so on. Therefore, the <u>position</u> order of the four consonants will not coincide with their <u>time</u> order. Let me explain what I mean by that. The time order of the consonants is the order in which they are flashed on the screen. The position order, on the other hand, is the order of the consonants when only their spatial position is considered so that the letter which appeared in the left-most cell is the first letter in the position order, the letter which appeared in the cell next to that one is the second letter in the position order, and so on. Therefore, you can see, as I just stated, the position order will not necessarily correspond to the time order. In which order are you supposed to recall the consonants, in their time order or in their position order?

You are to recall the consonants in their position order. In fact,

the time order of the letters will be the same on every trial so that you will always see the letters in the time order __ __ __ __. Therefore, for instance, __ will always be the first letter you see, but it won't necessarily be in the first cell. Remember if it was in the first, second, third, or fourth cell so that you can recall it in its proper position order. Write the letter that appeared in the first cell in the first box on the card, the letter that appeared in the second cell in the second box on the card, and so on. Do you understand?

Now there will be a series of six practice trials. They are just like the real trials except the letters ABCD will appear on the screen instead of the consonants __ __ __ __. They will always appear in the time order ABCD, but the position order will vary. You are to recall the letters in their proper position order.

... Let me remind you again that the same four consonants will be shown on each trial of this experiment. The consonants shown will be __ __ __ __. They will always appear in the time order __ __ __ __, but they will appear in a different position order on every trial. You are to write down the letters in their proper position order.

Digit Position Condition

On each trial of this experiment you will be seeing a series of four consonants followed by a series of digits which will appear on the small screen in front of you. There will always be just four consonants but the number of digits will vary. In this experiment the same four consonants will be shown on each trial. The consonants shown will be __ __ __ __. They will appear in a different order on each trial.

As you can see there are four cells across the screen in front of you. Each consonant and digit will appear in only one of the four cells. The other three cells will be blank. In addition, the cell where a given item appears will vary from item to item.

You are to read aloud the consonants as they appear. However, as the digits appear, don't read them aloud. Instead for each digit say aloud the number of the cell in which it appears, assuming that the cells are numbered from one to four, as you go from left to right. Thus, if a digit,

any digit, appears in the cell closest to the left, say "one" as it appears; if a digit appears in the cell second from the left, say "two" as it appears; if a digit appears in the cell third from the left, say "three" as it appears, and if a digit appears in the cell closest to the right, say "four" as it appears.

This is a fairly hard task as the consonants and digits will be appearing quite rapidly; however, if you pay attention you will have no trouble.

Remember, it is very important that I hear you read each consonant as it appears and that I hear you say the number of the cell where each digit appears. Don't forget that you are not to read the digits aloud, only the consonants.

At the end of each string of consonants and digits, the screen will become blank and you are to write down the four consonants you just saw at the beginning of the string in the same order as they appeared on the screen.

You will write the consonants you remember on this card (show). Put each of the four consonants in the box corresponding to the order in which it appeared on the screen. Do not leave any boxes blank; make sure that you put a consonant in each of the four boxes on the card. If you have to guess, then do guess. You'll be able to guess because you know the four consonants that will be shown on each trial. Do you have any questions so far?

At the end of the recall time you will hear a double click. This is a warning that you should immediately finish responding and hand your card to the Experimenter. Then get ready for the next trial.

There is one more feature of the experiment I must explain to you before we begin. As I said earlier, each consonant and digit will appear in only one of the four cells of the screen. The other three cells will be blank. In addition, the cell where a given item appears will vary from item to item. Moreover, it will also be true that each of the four consonants on a trial will appear in a different one of the four cells of the screen. However, the first consonant you see will not necessarily appear in the first cell; the second won't necessarily appear in the second cell, and so on. Therefore, the position order of the four consonants will not coincide with their time order. Let me explain what I

mean by that. The time order of the consonants is the order in which they are flashed on the screen. The position order, on the other hand, is the order of the consonants when only their spatial position is considered so that the letter which appeared in the left-most cell is the first letter in the position order, the letter which appeared in the cell next to that one is the second letter in the position order, and so on. Therefore, you can see, as I just stated, the position order will not necessarily correspond to the time order. In which order are you supposed to recall the consonants, in their time order or in their position order?

You are to recall the consonants in their position order. In fact, the time order of the letters will be the same on every trial so that you will always see the letters in the time order __ __ __ __. Therefore, for instance, __ will always be the first letter you see, but it won't necessarily be in the first cell. Remember if it was in the first, second, third, or fourth cell so that you can recall it in its proper position order. Write the letter that appeared in the first cell in the first box on the card, the letter that appeared in the second cell in the second box on the card, and so on. Do you understand?

Now there will be a series of six practice trials. They are just like the real trials except the letters ABCD will appear on the screen instead of the consonants __ __ __ __. They will always appear in the time order ABCD but the position order will vary. You are to recall the letters in their proper position order.

... Let me remind you again that the same four consonants will be shown on each trial of this experiment. The consonants shown will be __ __ __ __. They will always appear in the time order __ __ __ __, but they will appear in a different position order on every trial. You are to write down the letters in their proper position order.

Pattern Interference II Experiment

Zero Position Condition

On each trial of this experiment you will be seeing a series of four consonants followed by a series of zeros which will appear on the small

screen in front of you. There will always be just four consonants but the number of zeros will vary. In this experiment the same four consonants will be shown on each trial. The consonants shown will be __ __ __ __. They will appear in a different order on each trial.

As you can see there are four cells across the screen in front of you. Each consonant and zero will appear in only one of the four cells. The other three cells will be blank. In addition, the cell where a given item appears will vary from item to item.

You are to read aloud the consonants as they appear. However, as the zeros appear, don't read them aloud. Instead for each zero say aloud the number of the cell in which it appears, assuming that the cells are numbered from one to four, as you go from left to right. Thus, if a zero appears in the cell closest to the left, say "one" as it appears; if a zero appears in the cell second from the left, say "two" as it appears; if a zero appears in the cell third from the left, say "three" as it appears, and if a zero appears in the cell closest to the right, say "four" as it appears.

This is a fairly hard task as the consonants and zeros will be appearing quite rapidly; however, if you pay attention you will have no trouble.

Remember, it is very important that I hear you read each consonant as it appears and that I hear you say the number of the cell where each zero appears.

At the end of each string of consonants and zeros, the screen will become blank and you are to write down the four consonants you just saw at the beginning of the string in the same order as they appeared on the screen.

You will write the consonants you remember on this card (show). Put each of the four consonants in the box corresponding to the order in which it appeared on the screen. Do not leave any boxes blank; make sure that you put a consonant in each of the four boxes on the card. If you have to guess, then do guess. You'll be able to guess because you know the

four consonants that will be shown on each trial. Do you have any questions so far?

At the end of the recall time you will hear a double click. This is a warning that you should immediately finish responding and hand your card to the Experimenter. Then get ready for the next trial.

There is one more feature of the experiment I must explain to you before we begin. As I said earlier, each consonant and zero will appear in only one of the four cells of the screen. The other three cells will be blank. In addition, the cell where a given item appears will vary from item to item. Moreover, it will also be true that each of the four consonants on a trial will appear in a different one of the four cells of the screen. However, the first consonant you see will not necessarily appear in the first cell; the second won't necessarily appear in the second cell, and so on. Therefore, the position order of the four consonants will not coincide with their time order. Let me explain what I mean by that. The time order of the consonants is the order in which they are flashed on the screen. The position order, on the other hand, is the order of the consonants when only their spatial position is considered so that the letter which appeared in the left-most cell is the first letter in the position order, the letter which appeared in the cell next to that one is the second letter in the position order, and so on. Therefore, you can see, as I just stated, the position order will not necessarily correspond to the time order. In which order are you supposed to recall the consonants, in their time order or in their position order?

You are to recall the consonants in their position order. In fact, the time order of the letters will be the same on every trial so that you will always see the letters in the time order __ __ __ __. Therefore, for instance, __ will always be the first letter you see, but it won't necessarily be in the first cell. Remember if it was in the first, second, third, or fourth cell so that you can recall it in its proper position order. Write the letter that appeared in the first cell in the first box on the card, the letter that appeared in the second cell in the

second box on the card, and so on. Do you understand?

Now there will be a series of six practice trials. They are just like the real trials except the letters ABCD will appear on the screen instead of the consonants __ __ __ __. They will always appear in the time order ABCD but the position order will vary. You are to recall the letters in their proper position order.

... Let me remind you again that the same four consonants will be shown on each trial of this experiment. The consonants shown will be __ __ __ __. They will always appear in the time order __ __ __ __, but they will appear in a different position order on every trial. You are to write down the letters in their proper position order.

Successor Name Condition

On each trial of this experiment you will be seeing a series of four consonants followed by a series of digits which will appear on the small screen in front of you. There will always be just four consonants, but the number of digits will vary. In this experiment the same four consonants will be shown on each trial. The consonants shown will be __ __ __ __. They will appear in a different order on each trial.

As you can see there are four cells across the screen in front of you. Each consonant and digit will appear in only one of the four cells. The other three cells will be blank. In addition, the cell where a given item appears will vary from item to item.

You are to read aloud the consonants as they appear. However, as the digits appear, don't read them aloud. Instead for each digit say aloud its successor; so, for instance, if you see a 4, say 5, and if you see a 6, say 7.

This is a fairly hard task as the consonants and digits will be appearing quite rapidly; however, if you pay attention, you will have no trouble.

Remember, it is very important that I hear you read each consonant as it appears and that I hear you say the successor of each digit that

appears. Don't forget that you are not to read the digits aloud, only the consonants.

At the end of each string of consonants and digits, the screen will become blank, and you are to write down the four consonants you just saw at the beginning of the string in the same order as they appeared on the screen.

You will write the consonants you remember on this card (show). Put each of the four consonants in the box corresponding to the order in which it appeared on the screen. Do not leave any boxes blank; make sure that you put a consonant in each of the four boxes on the card. If you have to guess, then do guess. You'll be able to guess because you know the four consonants that will be shown on each trial. Do you have any questions so far?

At the end of the recall time you will hear a double click. This is a warning that you should immediately finish responding and hand your card to the Experimenter. Then get ready for the next trial.

There is one more feature of the experiment I must explain to you before we begin. As I said earlier, each consonant and digit will appear in only one of the four cells of the screen. The other three cells will be blank. In addition, the cell where a given item appears will vary from item to item. Moreover, it will also be true that each of the four consonants on a trial will appear in a different one of the four cells of the screen. However, the first consonant you see will <u>not</u> necessarily appear in the first cell; the second won't necessarily appear in the second cell, and so on. Therefore, the <u>position</u> order of the four consonants will not coincide with their <u>time</u> order. Let me explain what I mean by that. The time order of the consonants is the order in which they are flashed on the screen. The position order, on the other hand, is the order of the consonants when only their spatial position is considered so that the letter which appeared in the left-most cell is the first letter in the position order, the letter which appeared in the cell next to that one is the second letter in the position order, and so on.

Therefore, you can see, as I just stated, the position order will not necessarily correspond to the time order. In which order are you supposed to recall the consonants, in their time order or in their position order?

You are to recall the consonants in their position order. In fact, the time order of the letters will be the same on every trial so that you will always see the letters in the time order __ __ __ __. Therefore, for instance, __ will always be the first letter you see, but it won't necessarily be in the first cell. Remember if it was in the first, second, third, or fourth cell so that you can recall it in its proper position order. Write the letter that appeared in the first cell in the first box on the card, the letter that appeared in the second cell in the second box on the card, and so on. Do you understand?

Now there will be a series of six practice trials. They are just like the real trials except the letters ABCD will appear on the screen instead of the consonants __ __ __ __. They will always appear in the time order ABCD, but the position order will vary. You are to recall the letters in their proper position order.

... Let me remind you again that the same four consonants will be shown on each trial of this experiment. The consonants shown will be __ __ __ __. They will always appear in the time order __ __ __ __, but they will appear in a different position order on every trial. You are to write down the letters in their proper position order.

End