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DISSERTATION

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School of The Ohio State University

By

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The Ohio State University
1970

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MEMORY FOR DIGIT SERIES

By

James Donald Fritzen, Ph. D.

The Ohio State University, 1969

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The central concern of the present paper was with an explanation of how repetition benefits accrue across trials for complex response sequences, the digit-series task in particular. Previous literature has indicated that when its repeat back strings of digits and when every third string is identical, recall of those strings improves. It was assumed that each recall of a digit string contributes partially to the learning of the whole string. A description of how that contribution takes place was of primary interest.

Two hypotheses, previously mentioned in the literature, were examined. According to the bin hypothesis, memory consists of a single location and every string is shunted to that location, automatically combining with previous traces. Thus, information automatically accrues about a repeated string. According to the reallocation hypothesis memory consists of many locations and whenever a string is presented, a memory search is conducted using the first few digits in a string to locate past occurrences of the string. If a location is found containing a past occurrence, the information from the just-presented string is stored in that location
and the combined information is used to recall the string.

The first experiment of the dissertation was a replication of a study evaluating those two alternatives (Bower and Winzenz, 1969, Exps. VI and VII). In that experiment each string was divided into groups and each group contained two or three digits. The groups were presented visually in rapid succession. Either the first, the third, or the fifth group was held constant across trials. It was found that improvement occurred only when the first group was held constant.

One explanation of that result is that of reallocation. An alternative explanation is that in an immediate-recall task there is a tendency to store only the first few items of a digit-string in long-term store (LTS).

It was hypothesized that with a delayed-recall task all of the items should tend to be stored in LTS and that under those conditions any constant group, first, third, or fifth, would improve. That result was obtained in Exp. I.

The finding that any constant-chunk improves can be explained in terms of either single or multiple locations in memory. Experiments II and III were designed to evaluate single vs. multiple-location descriptions. In those experiments the groups in a repeated string first occurred in either one previous string or as parts of two different previous strings. A single-location hypothesis would predict that all groups in a string should improve in both conditions. A multi-location hypothesis would predict that in the condition where the groups came from two different strings only the groups from one string should improve. The results indicated that in both conditions
all repeated groups tended to improve, supporting the single-location view.

The question of how repetition effects accrue within a single location was not resolved but it was tentatively assumed that they combined automatically. Given that assumption, different predictions can be made about the boundary conditions of repetition effects. Those conditions were examined in Exp. IV.

In Exp. IV groups were repeated entirely from trial-to-trial in one condition and partially repeated from trial-to-trial in another condition. When recall was immediate, repetition effects accrued only when the groups were repeated exactly. When recall was delayed repetition effects occurred even when only some of the digits in the groups remained constant. It was suggested that information in memory may be stored at both the group-level and the digit-level but that in immediate recall Ss tend not to make use of digit-level information.
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INTRODUCTION

The problem of explaining why performance improves with repetition has a long history in verbal learning. A large share of the research done on that problem has involved either the all-or-none vs. incremental issue (e.g., Restle, 1965) or the effect of massed vs. distributed presentations (e.g., Waugh, 1969). Those studies have typically used fairly simple, well-integrated response units e.g. a letter, a digit, a word. Little is known, however, about the mechanisms involved in repetition for a variety of tasks dealing with complex response sequences, for example multi-trial free recall (Tulving, 1968), serial learning (Young, 1968), and paired-associate learning with complex responses (Johnson, 1968).

It has become apparent that Ss organize or chunk complex response sequences (Johnson, 1968). Chunking is S-defined and refers to the subjective grouping or segmentation of the input that Ss might impose. The input sequence may be physically or temporally segmented into groups by the experimenter in order to influence the chunking scheme Ss might use and whether or not that manipulation was successful can be determined by various dependent variables e.g. transitional-error probabilities (Johnson, 1966) or pauses (McLean and Gregg, 1967). In what follows, when input groups are referred to as chunks it is assumed that S adopts the experimental segmentation as his own.
It also has become apparent that the organization of the response is a critical component independent of the elements. Johnson and Miggold (in press) had Ss learn two consonant sequences in response to two digits. The sequences were physically grouped e.g. MK XVG %L. After 20 trials S learned two additional sequences for 20 trials. One group of Ss had the same consonants and same grouping during the second task, another had the same consonants but a different grouping, and a third had different consonants and a different grouping. It was hypothesized that if the organization of a response is a critical part of the response then the condition that had the same letters but a different grouping should treat the second list as an entirely different sequence in spite of the fact that the underlying sequence of consonants was exactly the same.

The results indicated that second-list learning of the same consonant-different grouping condition was not significantly different than that for the different consonant-different grouping condition. The same consonant-same grouping condition was significantly superior to the other two conditions. Thus a change in grouping of the first-list sequences appeared to result in entirely new sequences as far as the Ss were concerned.

Tulving and Osler (1967) have shown that changing structure in a second task can result in interference over and beyond that found in learning an unrelated task. First-list learning involved several trials on an 18 word free-recall list. One group of Ss then had 9 of those words as their second list while a control group had an unrelated 9 word list. The experimental group evidenced negative
transfer when compared to the control group. It was hypothesized that during the second-list learning the first-list organization of the experimental Ss interfered with the formation of a new organization for the second list. The Johnson and Migdoll (in press) and the Tulving and Osier (1967) studies would indicate that an explanation of how complex response sequences are learned must deal with the organization of those sequences as if it is part of the response.

The main concern of the present paper is the explanation of the accumulation of repetition effects for a complex response sequence. The basic repetition effect was demonstrated in some early work by Hebb (1961) and Melton (1963). Hebb (1961) was concerned with a description of memory in terms of two storage systems: a transient, short-term, or "activity" component and a more permanent, long-term, or "structural" component. An item presented once is assumed to leave behind only a transient activity trace, whereas if it is presented over and over in immediate succession it is assumed to lay down a structural trace.

To test that prediction Hebb presented Ss with 24 strings of digits. Each string consisted of the digits one through nine in random order and was read to S at a rate of one digit per second and the Ss were tested for immediate recall. Every third string was an identical series (repeated strings) while the remaining strings varied randomly (noise strings). The results clearly indicated an enhancement in recall of the repeated strings as a function of repetition, while recall of the noise strings did not improve. Hebb reasoned that a structural or long-term trace could result from even a single presentation of a string.
Melton (1963) replicated the Hebb experiment and hypothesized that the mechanism which resulted in improved recall as a function of repetition was a reduction in the number of chunks in the repeated strings. In essence, he supposed Ss subjectively group the digits in the strings as a function of repetition, which would result in fewer "things" or chunks to be retained. Since it is assumed that the fewer the chunks, the smaller the intra-string interference, recall would be expected to improve.

More recently, Bower and Winzenz (1969) demonstrated the importance of chunking in the Hebb (1961) experimental paradigm. They attempted to control subjective grouping by presenting strings of digits aurally, according to the common names of digit groups i.e. 17586 might be read as "seventeen...five hundred eighty-six." In Exp. I Ss were presented with 12 nine-digit strings to repeat back. The same string appeared on every third trial. In the same-structure condition the aural grouping was the same on the repetition trials while in the changed-structure condition the aural grouping changed from trial to trial. The results indicated that benefits of repetition accrued only when temporal grouping remained the same on the critical trials. Those results would indicate that consistent chunking is essential for improved recall in the Hebb (1961) experiment. The role of structure in repetition, then, must be considered in any explanation of repetition effects in the digit-series task.

Nelson (1970) addressed himself to the issue of all-or-none learning in the digit series task. In line with Restle's analysis of that issue, Nelson was concerned with all-or-none vs. incremental learning
at the component level, i.e., the digit level rather than at the level of the entire digit string. Nelson was interested in the issue of exactly what was indicated by errors in recalling a repeated nine-digit string. Half of the Ss had the same string repeated on every critical (i.e., every third) trial, the other half had their errors on that string replaced by new digits on the next critical trial. An all-or-none position would predict that since an error indicates no learning at all, it should make no difference whether the incorrectly recalled digits are repeated or changed. According to an incremental position, errors may occur when there is some trace strength for the correct response which is below threshold. To the extent that there is sub-threshold trace strength the group that has its errors replaced by new digits on each successive critical trial should do worse than the group that is presented the same digits on each critical trial. No difference was found between the two conditions, in accord with the all-or-none view.

Despite the Nelson data, the present paper will use the terminology of an incremental position. That terminology can easily be translated into all-or-none terms without altering any of the basic issues to be discussed. The terminology in the present paper is basically the same as that of Bower and Winzenz (1969) where most of the issues to be examined were initially formulated.

Since the level of analysis of the all-or-none issue is at a component level (e.g., digits) both the all-or-none and incremental views describe learning of the entire string as a cumulative result of several repetitions, each repetition having a partial effect on the learning of the entire string. That description raises the question of how
the effects accumulate across repetitions. The mechanisms involved in that accumulation are a central point of this paper and there are a variety of ways it could occur.

Given the effects of repeated strings accumulate across trials, there must be some mechanism allowing Ss to make contact with past traces representing the string. One possible description is that each string presented to S is stored in a single location and that within that location traces combine automatically. The traces of the repeated string would have predominant representation at that location and recall would improve.

Another possibility is that memory consists of an array of locations and that at the time a string is presented the S initiates a search through memory locations for a possible match. If a match is found the string is shunted to that location and combined with the previous trace. If no match is found the string is shunted to a new location. As more and more information accrues in the location of the repeated string, recall should improve.

A third possibility is that every trace is stored at a different location, even those of repeated strings, and that the traces in each location are intermittently available. As the number of locations containing information about the repeated strings increase, the greater the availability of information about that sequence (Tulving, 1969). This latter alternative was formulated within the context of the free-recall task and leaves unspecified how Ss make use of the increased availability in the framework of the digit-series task.

In addition to the trace contact issue two storage issues will be
considered which have direct bearing on the conditions under which repetition effects are found. The first has to do with the role of short-term store (STS) in the recall of digit series, where STS is conceptualized as a time-dependent decaying store in which repetition benefits do not occur. If any chunks of a digit string are recalled exclusively from STS, no repetition effects would be predicted for the chunks. The second storage issue deals with the nature of information stored, whether it is exclusively at the digit level, or the chunk level.

The Bin and Reallocation Hypotheses

Bower and Winzenz (1969) considered two alternative explanations of how repetition effects accumulate - the bin hypothesis and the reallocation hypothesis. The bin hypothesis rests on the assumption that memory consists of a set of bins at a single location or address where "the successive bins may be conceived as implicit positional 'stimuli' to which coded response units become associated" (Bower and Winzenz, 1969, p. 12). Every experimental input is shunted to the same address with the first chunk of each string being assigned to the first bin, the second chunk to the second bin, and so on. As a function of repetition the traces of the chunks within each of the bins increase in strength and recall improves. If the chunking scheme varied from trial to trial, as it did in the changed-structure condition of Exp. I of Bower and Winzenz (1969), recall would not be expected to improve in that the chunks assigned to any one bin are constantly changing across trials.

The reallocation hypothesis is based on the assumption that memory consists of many locations. Whenever a string is presented, it is as-
sumed to carry out a memory search, the purpose of which is to locate a possible match in memory for the just-presented string. On the basis of data obtained in their series of experiments Bower and Winzenz (1969) assume the search is based on the first chunk or two. If the first few chunks of the string being presented match the first few chunks of some stored string, the just-presented string is assigned (shunted) to that location and recall is based on that combined trace. If the first few chunks are not repeated, the string is shunted to a new location. Thus, when the first chunk constantly changes, as in the changed-structure condition of their Exp. I, Ss cannot locate traces of past repetitions and recall would not be expected to improve.

Bower and Winzenz (1969) introduced what they refer to as a constant-chunk paradigm in their Exp. VI as an experimental test of the bin and reallocation hypotheses. In the constant-chunk paradigm the repeated strings were aurally segmented as in their Exp. I (five chunks per digit string) and only one chunk (i.e. first, third, or fifth) was repeated across trials. The remaining chunks varied in size and content from trial to trial. The outcome of interest was whether or not the recall of a single constant chunk improved regardless of its locus in the digit string. The bin hypothesis would predict that any constant chunk would improve. All of the strings are hypothesized to go to the same location in memory and each chunk within a string goes to a separate bin. A constant chunk in the first position builds up strength in the first bin, a constant chunk in the third position builds up strength in the third bin, etc. The reallocation hypothesis would predict improvement only if the first chunk is constant. If the
first chunk is not constant, then a constant third or fifth chunk would not improve because each string would be assigned a different location.

In Exps. VI and VII, Bower and Winzenz (1969) found that only when the first chunk was repeated did recall of the string improve across trials. That result was taken as ruling out the bin hypothesis and supporting the reallocation hypothesis.

Bower and Winzenz (1969) in their Exps. VI and VII ruled out the bin hypothesis but not necessarily the notion of bins. It is possible that there are a set of bins in each of the locations implied by the reallocation hypothesis and that when traces combine it is in a chunk-by-chunk fashion. An alternative possibility is that each location contains a set of slots, one for each digit, and that traces combine in a digit-by-digit overlay fashion. Bower and Winzenz (1969) present data in favor of the latter possibility and that issue will be discussed later.

The Selective-Storage Hypothesis

Both the bin hypothesis and the reallocation hypothesis implicitly assume that all chunks in a digit string are stored. It is possible however, that memory can be described in terms of a short-term store (STS) and a long-term store (LTS) and that in an immediate memory task the first few chunks tend to be stored primarily in LTS while there is a tendency for the last few chunks to be recalled from a decaying STS. In short, it is hypothesized that Ss might tend to differentially or selectively store the chunks within a digit string in an immediate memory task. That hypothesis will be referred to as the selective-storage hypothesis.

Indirect evidence that there is a tendency not to store some chunks in LTS in an immediate memory task is given by Bartz (1969). Bartz
presented Ss with three nine-digit sequences. Each sequence consisted of the numbers one through nine in randomized order and they were not grouped. Every third sequence (i.e. sequences 3, 6, 9, etc.) was identical. In addition, recall was either immediately after presentation or there was a delay. His results indicated that the effect of repetition on the last items in the sequence was greater for the delay condition than when recall was immediate. One possible explanation is that in immediate recall there is a tendency for items in terminal positions of the string to be recalled from STS and not transferred to LTS. In delayed recall, where dependency upon STS is eliminated, it may be that Ss change their strategy and tend to store the last few chunks in LTS to a greater degree.

If the selective-storage hypothesis accurately describes recall in an immediate memory task, the lack of improvement for constant third or fifth chunks in the constant-chunk paradigm might then be explained in terms of the lack of an LTS trace of sufficient strength representing those chunks from trial to trial. That explanation would qualify the conclusions of Bower and Winzenz (1969) in that they took the finding of significant improvement only when the first chunk was constant as support for the reallocation hypothesis.

Delayed recall might result in a strategy change so that the terminal chunks tend to be stored in LTS to a greater degree. Thus, use of delayed recall in conjunction with the constant-chunk paradigm might better enable one to choose between the bin and reallocation hypotheses.

Some Assumptions of Selective-Storage. The selective-storage hypothesis entails three assumptions. First, it is assumed that Ss main-
tain the terminal items of a digit string in STS during the recall of the initial items. It might be argued that recall of the initial items should interfere with the contents of STS. Tulving and Arbuckle (1963, 1966) have demonstrated interference due to recall, but their experimental task differed considerably from that used here. The extent to which such interference occurs in the digit series task is an open question and it will be assumed to be minimal.

Second, it is emphasized that storage of terminal chunks in STS is only a tendency and some strength in LTS may build up. For example, Bartz (1969) demonstrated that all portions of a digit string improve in immediate recall as a function of repetition. It is assumed that the tendency could change as a function of certain conditions. For example, if all five chunks in a string were held constant the fifth chunk might build up LTS strength more rapidly than it would if the fifth chunk alone was held constant. Perhaps Ss would change their storage strategy once they begin to see that all chunks are being repeated.

Third, it is assumed that information can be held in STS and result in little transfer to LTS. An issue arises then as to the exact nature of transfer of information from STS to LTS. That issue is of independent theoretical interest and will be discussed in more detail.

A classic statement of the STS-LTS dichotomy is found in Waugh and Norman (1965). STS was described as a limited capacity buffer which every input enters upon presentation. LTS was described as an unlimited capacity storage system where each item enters with a certain probability. The longer an item is held in STS (i.e. rehearsed) the greater the probability it would transfer to LTS. It is probably not unreason-
able to infer that transfer in the Waugh and Norman model can be described as an automatic copying of information from STS to LTS with no new information added in the process. Given that description, the selective-storage hypothesis would imply that the information-copying process can be partially blocked.

It is possible, however, that LTS transfer is not a mere copy of STS information but that the process of transfer is the result of added information to a transient STS trace, e.g. integrative processes (Johnson, 1968) or the addition of mnemonic information (Tulving and Osler, 1968). If information is not encoded beyond some initial low level (perhaps auditory) it rapidly decays from memory (e.g. Treisman and Geffen, 1967). Bjork (1970) has invoked such coding processes to explain his findings on intentional forgetting.

Bjork (1970) in his first experiment presented Ss with 64 paired-associate lists varying in size from one to eight pairs. After each list Ss were tested for the recall of one of the pairs. One-fourth of the lists were on either a yellow or a green background. In the remaining lists the background changed from yellow to green or green to yellow. Ss were instructed that whenever a color-change occurred they could forget the items up to that point in that they would not be tested on those items. The data indicated that in the color-change condition the items of the first color did not have the usual proactive effects nor did those items tend to intrude as erroneous responses.

Bjork hypothesized that during the presentation of a list when a color change occurred, Ss ceased to process the items up to that point any further. Instead they devoted "all rehearsal, mnemonic, and integrat-
ing activities" to the set of items following the cue. As a result, the initial items were less available in memory and did not interfere.

The recall of digit series may involve similar processes when recall is immediate although the explanation is somewhat different. The selective-storage hypothesis asserts that the first few and last few chunks tend to be handled differently. Ss may devote all rehearsal, mnemonic, and integrating activities to the first few chunks and mainly preserve the last few chunks at some low, perhaps auditory, level. Thus STS is described as preserving information at a low level so that only a few items - the first few chunks - need be integrated.

Single vs. Multiple Locations in Memory

If the Bower and Winzenz (1969) results are not replicated when recall is delayed (i.e. if all constant chunks are found to improve), their reallocation hypothesis would be ruled out. However, it would still be possible to explain that outcome in terms of either a single or multiple locations in memory. The bin hypothesis would predict those results in that all traces are assumed to be stored in the same location. However, an alternative explanation of that outcome would be possible in terms of memory consisting of many locations if the assumption is made that a memory search is carried out on the basis of all chunks in a string. That hypothesis will be termed the modified reallocation hypothesis and implies that any constant chunk can determine the location to which a string is shunted. In that both single- and multiple-location descriptions make the same prediction, an alternative test of the issue is needed in the event that all constant
chunks would improve with delayed recall.

If the four chunks in a digit string are repetitions, and if there is only a single location in memory, it should make no difference whether those chunks previously occurred in a single string or in two different strings. The S would have access to the single location at recall and automatically would have access to all four past occurrences in both cases. Recall should improve for all four chunks.

However, if each string is stored in a different location in memory, S has access to only one past string. Thus, in the case where the four chunks occurred in two different strings, S can gain access to the previous trace of only two chunks and only those chunks will improve in recall. The different predictions made by the single vs. multiple descriptions in the above situation seem to afford an experimental basis for deciding between them.

It should be noted that if the Bower and Winzenz (1969) result is replicated with delayed recall the reallocation hypothesis would be supported. In that case, the above experimental test should substantiate a description in terms of multiple locations in memory i.e. when the chunks initially occur in two different strings Ss should gain access to the string where the first chunk is the same and the first chunk should derive the major repetition benefit.

Trace Combination

Multiple-location hypotheses make the assumption that repetition effects accumulate as a result of a search through memory locations. The bin hypothesis implies that the effects accumulate automatically in that all strings are chunted to a single location. Whatever the case
may be, when a trace is shunted to a location where there is already some prior trace, the two can be described as combining in some fashion.

Bower and Winzenz (1969) concluded that trace combination of digit strings took place in a digit-by-digit overlay fashion without regard to segmentation. In Exp. VII the first and third chunks were held constant while the second chunk varied in size (and content) from one to three digits. If each memory location was subdivided into bins it would be expected that the first chunk would be assigned to the first bin, the second to the second bin, and so on. Thus, since the first and third chunks were constant, improved recall would be expected for both. No such improvement was found. It was hypothesized that trace combination takes place in a digit-by-digit overlay fashion and that since the serial positions occupied by the constant third chunk varied from trial to trial, no repetition benefits were found.

Support for that hypothesis was found in Exp. VIII where the first and third chunks were held constant and the second chunk was of constant size (two digits). Under those conditions recall of both the first and third chunks improved. Thus, trace combination can be best described as taking place in a digit-by-digit overlay fashion. According to that explanation a sufficient description of information stored in memory need only involve information at the digit level and there is no need to hypothesize stored information at the chunk level.

Johnson (in press) summarizes several studies concerned with the information stored at the chunk level. His data indicate that memory codes representing chunks are unitary and that the code for the chunks SBQ and SBJ are as different from each other as either is from the
If it is possible to generalize across differences in procedure and materials, the Johnson studies have several implications for the Bower and Winzenz studies. One implication has to do with the representation of digit groups in memory by unitary memory codes. If such representation is the case, then repetition benefits in the Bower and Winzenz task should accrue only when entire chunks are repeated and there should be no benefit when only part of the chunks are repeated from trial to trial.

The issue of unitary storage in memory codes is an important one for the digit series task. The Bower and Winzenz studies emphasize the importance of organization when a scan is carried out in memory with the first chunk. However, little is said in the way of accounting for patterns of transitional errors. To account for those patterns it would seem that the major explanatory burden must be placed on storage or retrieval or both. If improvement in the recall of digit groups takes place only when the entire group is exactly repeated it would seem that a description of storage of digit groups in terms of unitary memory codes would be in order. Such a description would be consistent with the patterns of transitional errors typically found in the digit series task. Specifically, if the digit groups are represented in memory by unitary codes the information about all the digits in a group would be retrieved in an all-or-none fashion. Such retrieval would result in low transitional-error probabilities within digit groups and relatively high transitional-error probabilities between groups.
Thus far, emphasis has been placed upon storage and little has been said about retrieval. For example, the selective-storage hypothesis assumes that there is a tendency for the first few chunks to be stored in LTS and the last chunks in the STS buffer. The retrieval assumptions are trivial in the sense that it is assumed that everything that is stored is retrieved.

Appropriate retrieval assumptions, however, make it possible to predict patterns of results similar to those predicted by the selective-storage hypothesis even when selective storage is not assumed. For example, it is possible that in immediate recall the first few chunks are retrieved from LTS while the last chunks are retrieved from the STS buffer even though the last few chunks have strength in LTS. In delayed recall, where retrieval from the buffer is not possible, all chunks would be retrieved from LTS. Thus, storage strategies are the same in both immediate and delayed recall, while retrieval strategies differ. Although interpretations of results will primarily emphasize storage implications, it is acknowledged here that explanations in terms of retrieval may be just as feasible.

Experimentation

The central concern of the experiments to follow is with an explanation of how repetition effects accumulate across trials. Two alternative descriptions are considered in Exp. I, the bin and the reallocation hypotheses. Exp. I consists of a replication of the Bower and Winzenz (1969) constant-chunk experiments where either the first, the third, or the fifth chunk is held constant. If only the
first chunk improves, as was the case in the Bower and Winzenz studies, 
the reallocation explanation is favored. In addition a delayed 
condition was added in that selective-storage may have been responsible 
for the Bower and Winzenz findings. If that is the case, all constant 
chunks might improve in delayed recall.

Single vs. multiple location descriptions in general are 
examined in Exps. II and III. In those experiments repeated strings 
are composed of either chunks from a single previous string or 
chunks taken from two separate strings. A multiple location description 
would predict that in the latter case Es can make use of only some 
of the stored information about the chunks to be repeated. Exps. II 
and III are designed to distinguish between single vs. multiple 
locations in the event that all constant chunks improve in Exp. I with 
delayed recall. Given that outcome, both types of descriptions 
would be possible for Exp. I.

The final issue to be considered is the level at which information 
is stored i.e. chunk vs. digit level. In Exp. IV chunks are either 
repeated identically or repeated partially across trials. If the 
information is stored exclusively at the chunk level it is hypothesized 
that chunks must be repeated exactly for recall to improve.
Chapter II

EXPERIMENT I

Experiment I is essentially a replication of the Bower and Winsenz (1969) constant-chunk experiment. Specifically, in every other digit string (e.g. on even-numbered trials) a single chunk is held constant in either the first, third, or fifth chunk position. Bower and Winsenz found that only the first chunk improved across trials and they interpreted the result in terms of the reallocation hypothesis. That hypothesis assumes that memory consists of an array of locations and that the first chunk or two in a digit string is used to scan the locations for a match in memory. The string is stored at the location of a match and recall is based on that location.

There are two possible reasons, other than reallocation, why Bower and Winsenz (1969) may have obtained their results. First, Bower and Winsenz frequently used groups of only one digit and it is possible that Ss may have combined small groups into a single subjective group. Thus, a constant third or fifth group might have been held only nominally constant from trial to trial. If such a chunking strategy was responsible for the Bower and Winsenz results then it would be predicted that all constant chunks would improve if that strategy could be avoided. In order to discourage that strategy the present experiment involved paced presentation of the digit groups.
and the smallest chunk size was two digits.

Second, it is possible that the third and fifth chunks in the Bower and Winzenz experiments did not improve because of a tendency for Ss to recall the last few chunks in a string from LTS and not store them in LTS. If selective storage was responsible for the Bower and Winzenz results it would be predicted that only the first constant chunk would improve in immediate recall.

The Bartz (1969) data indicate that Ss may store terminal chunks in LTS to a greater degree when recall is delayed. Thus, a delayed condition was added in the present experiment where either the first, third, or fifth chunk was held constant. Insofar as Ss change their strategy when recall is delayed, all constant chunks might improve.

It should be emphasized that if either of the above changes result in the improvement of all constant chunks it is not possible to decide upon either a multiple- or single-storage location explanation. The modified reallocation-hypothesis includes the assumption of many locations in memory and a scanning process to detect a match on the basis of all chunks. The bin hypothesis includes the assumption of a single location in which traces of all presented strings combine group by group. Both predict the improvement of any constant chunk.

Method

Design

Every S recalled 20 13-digit strings. The strings were presented by means of a Carousel projector and each string was divided
into five groups that were presented successively. Each group was presented on a separate slide and contained either two or three digits. The Ss read each group out loud with its label, e.g., 321 was read as "three twenty-one".

Half of the 20 strings were noise strings (N-strings) and half were repeat strings (R-strings). The N-strings contained no repeated chunks and they occurred on every other trial. For half of the Ss they appeared on the even-numbered trials and for the other half they appeared on the odd-numbered trials. The R-strings occurred on the remaining trials and thus general practice effects were equivalent for R- and N-strings, on the average. The R-strings differed from the N-strings only in that a single chunk was held constant from trial to trial, i.e., the same chunk was repeated in the same position of each of the strings.

The fact that general practice effects were equivalent for the two types of strings enables one to partial out general practice effects in looking at the recall of the R-strings across trials. A difference score for each of the ten R-strings can be found by subtracting out recall of each of the associated N-strings. That index gives a purer estimate of repetition effects.

The two independent variables in the experiment were locus of the constant chunk (first, third, or fifth) and the interval between presentation and recall (0 seconds or 15 seconds). The filler task for the 15-second retention interval involved shadowing random strings of consonants presented at a .75 second rate. That was the filler task used by Hartz (1969).
Materials

The ten noise strings were constructed from a table of random numbers using the digits 1-9 such that each digit could appear zero, once, or twice within a string, with the restriction that no digit could immediately repeat itself within the string. The repeat strings were constructed in the same fashion except that the ten strings had a three-digit group in common, either the first group, the middle group, or the last group. Five different lists were constructed as a precaution for list effects. The same constant groups were used equally often in each of the conditions.

The noise strings contained three three-digit groups and two two-digit groups. There are ten different ways a string can be divided into five such groups, and each noise string was assigned a different segmentation within each list. For the repeat strings there are only six ways that the four non-constant chunks can be segmented: 3/2/3/2, 2/2/3/3, 3/3/2/2, 2/3/2/3, 2/3/3/2, and 3/2/2/3, with the repeated chunk inserted in its appropriate position. Since each S had ten repeat strings the first four divisions were used twice for each S and the last two were used once.

Procedure

Prior to the experiment Ss were instructed as to the nature of the task. Each S then recalled 20 strings of 13 digits. The strings were presented in five groups on five successive slides at a 1.5 second rate (.8 seconds on and .7 seconds off). The Ss read out the numbers on each slide by their label, e.g. 321 was read as "three twenty-one". For Ss in the immediate-recall condition, the
E said "recall" immediately after the last slide was shown. For Ss in the delay condition, recall occurred immediately after the 15 second filler task. Ss wrote their responses on separate pages in an answer booklet. Each page in the booklet had 13 evenly-spaced dashes - one dash for each digit. Twenty seconds were allowed for recall. As in the Bower and Winzenz (1968) studies Ss in the immediate-recall condition were instructed to write down their answers from beginning to end, but were not penalized for doing otherwise.

Prior to the 20 experimental trials, 3 practice trials were given. Practice trials differed from the critical trials only in that consonants were used instead of digits, the number of slides was three (three consonants on each slide), and there were nine spaces on each page in the response booklet.

Subjects

One-hundred-twenty introductory psychology students served as Ss. They were successively assigned to one of the six groups as they came to the experiment.

Results

One-third of the Ss had the first chunk constant on repeat strings (R-strings), one-third had the third chunk constant, and one-third the fifth. Each S had 10 N-strings and 10 R-strings. In referring to the conditions, Condition R1 refers to the repeat strings where the first chunk was constant, Condition R3 refers to the repeat string where the third chunk was constant, and Condition R5 refers to the repeat strings with a constant fifth chunk. Conditions N1, N3, and N5 refer to the corresponding noise strings of the three
Immediate Recall

The immediate-recall data were analyzed first. Transitional-error probabilities (TEPs) were scored for both the repeat and the noise strings. A TEP at transition n refers to the conditional probability that the digit following that transition is incorrect, given the preceding digit is correct. The pattern of TEPs defines the basic all-or-none response units i.e. basic response units are the set of digits located between TEP spikes. The finding that the TEPs at digit-group boundaries (between-group TEPs) are significantly greater than the TEPs within the digit group boundaries (within-group TEPs), would indicate that the experimental grouping of digits was successful in inducing Ss to adopt those groups as their basic response units. Table 1 gives the mean within-group and between-group TEPs for each of the six conditions. For each condition the between-group TEP is significantly greater than the within-group TEP. The smallest difference was that for Condition N3 and that difference was significant at the .001 level, t(19) = 4.22. Thus, it would appear that Ss were adopting the experimental grouping as their own subjective grouping.

Mean-number correct digits per string (maximum score = 13) across the ten trials for each of the six conditions is given in Table 2. A 2 X 3 mixed-design analysis of variance with locus as the between factor and type-of-string (N vs. R) as the within factor indicated that the main effect of locus had no effect, F(2, 57) = 1.30, p > .05, but there was a higher level of recall for the R-strings.
than the N-strings, $F(1, 57) = 25.53, p < .001$, and the interaction was significant, $F(2, 57) = 10.41, p < .001$. The interaction would indicate that the difference between type-of-string was greater for the group whose constant chunk was first than for the other two groups. That interpretation was confirmed by a Newman-Keuls test (alpha = .05) of pairwise comparisons. The difference between Conditions R1 and N1 was significant whereas the differences between Conditions R3 and N3, and between R5 and N5 were not significant. These data are consistent with those reported by Bower and Winzenz.

Subsequent analyses within each condition were carried out to investigate trial-to-trial improvement of the constant chunks. Across the first four trials (the number of repetitions used by Bower and Winzenz) the effect of trials on mean recall of digits in the constant chunk did not reach significance for the Conditions R1, $F(3, 57) = 2.38, p > .05$, R3, $p < 1$, or R5, $F(3, 57) = 2.28, p > .05$. Across all ten trials (see Fig. 1) the main effect of trials on mean digits recalled in the constant chunk was significant for Condition R1, $F(9, 171) = 3.12, p < .001$ and for Condition R5, $F(9, 171) = 2.55, p < .001$. For Condition R3 the trials effect was not significant, $p < 1$. Therefore, across the range of trials used by Bower and Winzenz (1969) there was no evidence of improvement in recall of the constant chunk, but across all ten trials there was improvement for both a constant first and a constant fifth chunk.

The mean number of digits recalled in the noise strings as a function of trials is given in Fig. 2. The effect of trials was not significant for either Condition N1, $F(9, 171) = 1.53, p > .05$,
or N3, $F(9, 171) = 1.65, p > .05$. However, for Condition N5, the effect did reach significance, $F(9, 171) = 1.96, p < .05$. That improvement for N5 might explain the increase found in R5.

Given such trial-to-trial improvement in the N-strings for condition N5, or even a tendency for such improvement, the appropriate index of repetition effects in the R-strings must take into account both absolute improvement in the R-strings across trials and the improvement in the N-strings across trials. A difference score was calculated for constant-chunk recall, which consisted of taking the number of digits recalled in the constant chunk and subtracting from it the number of digits recalled in the same serial positions in the corresponding N-string. The value of the difference score can vary between minus 3 and plus 3. When the difference score was used to index the repetition effect (see Fig. 3), the effect of trials was significant for Condition R1, $F(9, 171) = 1.97, p < .05$, but not for Conditions R3 and R5, $F$s < 1.

For immediate recall, then, constant chunks in the first and fifth positions showed significant improvement as a function of trials in terms of absolute recall. The use of difference scores to partial out general practice effects, however, replicates the Bower and Winzenz (1969) finding that a constant chunk accrues repetition benefits only if it is the first chunk in the string.

**Delayed Recall**

Mean within-group and mean between-group TEPs for each of the six conditions are given in Table 3. For each condition the mean between-group TEP is significantly greater than the mean within-
group TEP. The smallest difference is for Condition N1 and that difference was significant at the .005 level, \( t(19) = 3.15 \).

The mean-number correct digits per string across the 10 trials for the 6 conditions are given in Table 4. Recall of the R-strings was greater than the N-strings, \( F(1, 57) = 35.26, p < .001 \). The main effect of locus was not significant, \( F(2, 57) = 2.43, p > .05 \), and, in contrast to the immediate-recall data, the interaction was not significant, \( F(2, 57) = 2.31, p > .05 \). For delayed recall, the effect of the repetition of the constant chunk was significant and it did not make a difference as to which chunk was repeated.

The effect of the first four trials on the mean number of digits recalled in the constant chunk was not significant for Conditions R1, R3, and R5: \( F(3, 57) = 1.39, p > .05 \), \( F(3, 57) = 1.15, p > .05 \), and \( F(3, 57) = 2.47, p > .05 \). Across all ten trials (see Fig. 4) the effect was not significant for Condition R3, \( F(9, 171) = 1.70, p > .05 \). However, the effect was significant for both Conditions R1, and R5: \( F(9, 171) = 8.82, p < .001 \), and \( F(9, 171) = 10.65, p < .001 \), respectively. That is the same pattern of results found for the immediate-recall data.

The trials effect was significant for the mean number of digits recalled in the noise strings in Condition N1, \( F(9, 171) = 1.98, p < .05 \), although the erratic pattern of recall could hardly be described as an increase as a function of trials. For Conditions M3 and N5 the effect was not significant, \( F < 1 \) (see Fig. 5).

The repetition effect, as indexed by the difference score (see Fig. 6), was significant for Condition R1, \( F(9, 171) = 4.26, p < .01 \), but was not significant for either Condition R3, \( F(9, 171) = 1.85, p > .05 \).
Thus, for delayed recall, the absolute improvement score indicated significant improvement for a constant chunk in the first and fifth positions. However, as was found with immediate recall, the difference score indicated only a constant chunk in the first position improved when practice effects were partialled out.

Although the repetition effect is not significant for Conditions R3 and R5, an observation indicates a clear numerical improvement of the difference scores across trials for delayed recall. The response protocols indicate a considerable amount of fluctuation in the difference scores across trials. It was felt that more reliable estimates of recall would be provided by averaging the difference scores on successive pairs of trials, i.e. by blocking the ten trials for each S into five blocks of two trials each and averaging the difference scores within each block. More reliable estimates of recall should reduce trial-to-trial fluctuation and as a result reduce the error term in an analysis of variance. If such a reduction in the error term did result, it might be expected that the trend of increasing recall performance as a function of trials might be significant when the blocked scoring procedure is used.

When the blocked difference-scores were used, the repetition effect was significant for Condition R1, $F(4, 76) = 4.08$, $p < .01$. In addition, the effect was significant for Condition R3, $F(4, 76) = 2.91$, $p < .05$ and for Condition R5, $F(4, 76) = 2.92$, $p < .05$. In contrast to this, when blocked difference-scores were used for the immediate
conditions only Condition R1 yielded a significant effect for repetition, 
\( F(4, 76) = 3.01, p < .05 \), while for Conditions R3 and R5 the effect was not significant, \( F < 1 \). Thus, when trials were blocked the difference scores were significant for all constant-chunks in delayed recall while only the first constant-chunk improved in immediate recall.

The blocked difference-scores offer support for the hypothesis of selective-storage of chunks in an immediate-memory task, and a change in that strategy when recall is delayed. That explanation would imply that in an immediate-recall task (as in Bower and Winzenz, 1969), improvement of only a first constant-chunk cannot be taken as conclusive support for the reallocation hypothesis.

Melton (1963) hypothesized that as chunking progressed across trials there should be a reduction in intra-string interference. If that was the case, it would be expected that recall of the non-repeated digits in the R-strings should increase as a function of trials. For the immediate recall groups, the effect of trials on the recall of non-repeated items is significant for Condition R1, 
\( F(9, 171) = 2.35, p < .05 \). For Condition R3, the effect is not significant, \( F(9, 171) = 1.83, p > .05 \), nor is it significant for Condition R5, \( F < 1 \). For the delayed-recall groups, the effect is not significant for Conditions R1, R3, or R5, \( F < 1 \). However, when difference scores are used (recall of non-constant items in the R-strings minus recall of items in the same positions in N-strings), none of the conditions indicate significance of the trials effect: only for Condition R3, immediate recall, \( F(9, 171) = 1.26, p > .05 \), is the \( F \) value greater than one.
Discussion

In this discussion the outcome of the constant-chunk paradigm will be regarded as differing depending upon whether recall is immediate or delayed. That conclusion, however, should be tempered by the statement that such a difference was found only when blocked difference scores were used. That index indicated that in immediate recall improvement is found only for a constant chunk in the first position while in delayed recall the constant chunk improves irrespective of locus.

The procedure in the present study differed from that of Bower and Winzenz (1969) to better insure a one-to-one correspondence between the chunks defined by the experimenter and the chunks used by the Ss. Insofar as those changes were effective it would appear that the Bower and Winzenz results were not due to lack of correspondence between E and S defined units. Both studies indicate improvement of a constant chunk only if it is in the first position when recall is immediate.

The finding that difference scores indicated improvement in recall only for the constant first chunk in immediate recall is inconsistent with the bin hypothesis of a single memory location. It would seem that each string is stored in a different location and that a memory search for identity is carried out using the first chunk in the string.

For the delay condition, however, the blocked difference scores indicated that recall of the constant chunks improved across trials irrespective of their locus. That result is consistent with either a single- or multiple-location explanation. The bin hypothesis
predicts improved recall of any constant chunk since only one memory location is hypothesized and the constant chunk is consequently always shunted to the same bin. The modified reallocation-hypothesis assumes that there are an array of locations but that the search for a match involves all chunks in a string. Such a search process would lead to the improved recall of the constant chunk independent of its locus.

The two alternative explanations of the data in the delay condition are inconsistent with the explanation of the results for immediate recall, i.e., of many locations in memory and a memory search using the first chunk. One possibility is that different search processes are involved in immediate and delayed recall. Another possibility is that selective storage is operating in immediate recall and only the first chunk or two is stored in memory. If that were the case, then no improvement in recall of the constant chunks in the third and fifth positions would be expected on the basis of either the bin hypothesis or the reallocation hypothesis. Both of those hypotheses make predictions of improved recall contingent upon the storage of all chunks in the string. If all chunks are not stored when recall is immediate, as the selective-storage hypothesis would suggest, then lack of improved recall cannot be taken as support for the reallocation hypothesis.

To reiterate, for delayed recall, the results of Exp. I were consistent with a) a single location in memory, or b) multi-locations in memory and memory search carried out on the basis of all chunks. For immediate recall, the results are consistent with multi-locations
in memory and a scan carried out with the first chunk, or b) selective storage and either a single location or multi-locations.

If the blocked difference scores in Exp. I are regarded as suspect it may be argued that a constant chunk improves only in the first position for both types of recall. That interpretation would be consistent with an explanation in terms of reallocation for both immediate and delayed recall.
Chapter III

EXPERIMENT II

As noted in the discussion of Exp. I, there are a variety of explanations that account for the outcome of the constant-chunk paradigm. Those explanations involve descriptions of memory in terms of both single and multiple locations. Exp. II attempts to assess the issue of single vs. multiple locations using a different procedure.

If the data in Exp. II favor a single-location explanation, then the data of Exp. I can be taken as support for a selective-storage strategy in an immediate-memory task and a change in that strategy when recall is delayed.

If the data in Exp. II favor a multiple-location explanation, the data in Exp. I can be explained by assuming different search processes in immediate and delayed recall. When recall occurs immediately after presentation Ss might scan memory locations with only the first chunk or two and when recall is delayed Ss might use all chunks to scan the locations.

Exp. II involved two types of presentation sequences in which the four chunks in the third (critical) string are repeats of chunks appearing in the first two strings. For the repeat condition the
third string is a complete repeat of either the first or second string.

<table>
<thead>
<tr>
<th>REPEAT SEQUENCE</th>
<th>COMPOSITE SEQUENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRING 1) 823 285 196 795</td>
<td></td>
</tr>
<tr>
<td>2) 163 574 872 145</td>
<td></td>
</tr>
<tr>
<td>3) 163 574 872 145</td>
<td></td>
</tr>
<tr>
<td>1) 823 285 872 145</td>
<td></td>
</tr>
<tr>
<td>2) 163 574 196 795</td>
<td></td>
</tr>
<tr>
<td>3) 163 574 872 145</td>
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</tr>
</tbody>
</table>

A single location hypothesis would predict equal recall of the third critical string in the two conditions. For the repeat condition, the bin hypothesis would assume that on the first two presentations the strings are stored in the same location and the presentation of the critical string is also stored in that location. Thus, after the three strings have been presented, bins 1, 2, 3, and 4 each contain a chunk that has been repeated twice, once in the first or second string and once in the third string. Similarly, for the composite condition, all three strings are stored in the same location and again each bin contains a chunk that has been repeated twice, once in the first or second string and once in the third string. Thus, recall of the third critical string should not be different for the repeat and the composite conditions.

A multi-location hypothesis would predict lower recall of the critical string in the composite condition than in the repeat condition. A multi-location hypothesis would assume that the first two presentations are stored in different locations. In the repeat
condition the third string would combine with the previous occurrence of that string i.e. each chunk in the third string could combine with a previous instance of that chunk in memory. Recall is then based upon the combined trace. In the composite condition, however, since the critical string can only combine in memory with one previous string, only two of the four chunks in the critical string can combine with previous instances of those chunks in memory. The assumption is made here, as was the case with Bower and Winsen (1969), that recall can be based on only one location. Thus, the multi-location position would predict lower recall for the critical string in the composite condition than in the repeat condition. In short, a significant difference between the two conditions would favor the multi-location hypothesis while a non-significant difference would be consistent with the single-location hypothesis.

Method

Procedure and Design

Each trial in Exp. II involved the presentation and recall of three 12-digit strings. Each S had 12 trials, with 6 being in the composite condition and 6 being in the repeat condition. Five different random orders of the trials were used. To equate for difficulty of the critical strings two different lists were used. The critical strings in list A for the repeat condition were the same as the critical strings in list B for the composite condition, and vice versa. There were two independent groups involved in the experiment. One group recalled the strings immediately after presentation and the other group recalled the strings after a delay of
15 seconds. The delay procedure was the same as in Exp. I. The design was a 2 x 2 mixed-design with type-of-recall (i.e. immediate vs. delayed) as the between Ss variable and type-of-trial (i.e. repeat vs. composite) as the within Ss variable.

The procedures were essentially the same as in Exp. I except that Ss were informed that the strings were grouped into three's. After recall of the final string in each trial there was a 15 second interval after which E informed S that the "next group" would be presented. Nothing was said about a relationship among the three strings within a trial.

Materials

Half the trials in the repeat condition involved repetition of the first string and half involved the repetition of the second string. For the six composite trials there are exactly six different ways that two chunks from the first string and two chunks from the second string can be taken to form the four chunks in the critical string. Each of the six combinations was used once.

The digit strings were generated from a table of random numbers in the same manner as in Exp. I. The digits 1-9 could appear zero, once, or twice in the sequence, and the same number could not be repeated twice in succession.

Subjects

Forty introductory psychology students served as Ss. They were assigned in alternating order to one of the two groups as they came to the experiment.
Results

Within the repeat and composite conditions, for both immediate and delayed recall, the recall of the critical string was compared to the recall of the first and second strings. If repetition of chunks had an effect the recall of the critical string should be superior to the recall of the initial strings. It was found that with one exception the recall of the critical strings was superior. That exception was for the immediate repeat condition where recall of the second string (mean = 5.68) did not differ from the recall of the critical string (mean = 6.06), $t(19) = 1.40$, $p > .05$, although the difference was in the right direction. Generally, there did appear to be a clear influence of the repetition on performance.

When the repeat and composite conditions were compared for critical-string recall it was found that they did not differ for either immediate or delayed recall. For immediate recall (see Table 5), the mean number of digits recalled were 6.15 and 6.06 for the composite and repeat conditions respectively, $t(19) = .30$, $p > .05$. For delayed recall (see Table 6) the means for the composite condition and repeat condition were 4.03 and 4.18 respectively, $t(19) = .45$, $p > .05$.

When critical-string recall is compared between the repeat and composite conditions, the level of recall of the initial strings in those conditions must be taken into account. For the delayed procedure the recall of the first string in the composite condition (mean = 3.42) was significantly greater than recall of the first string in the repeat condition (mean = 2.81), $t(19) = 2.21$, $p < .05$. 
That result might indicate superior learning of the chunks in the first string in the composite condition which were to later appear in the critical string. The situation is analogous to differential degrees of original learning in a transfer situation.

An alternative index, an improvement score, was devised to handle the problem of differential recall between the two conditions for the first two strings. The improvement score for each critical string was found by taking the number of digits recalled in the four chunks in the critical string and subtracting from it the number of digits recalled for those same chunks as they appeared in the first two strings. When that index was used, the difference in mean improvement between the two conditions approached significance for delayed recall, \( t(19) = 1.65 \), (1.73 needed for the .05 level). The means were .65 and 1.08 items respectively, for the composite and repeat conditions.

For immediate recall, the improvement scores of the two conditions did not differ, \( t(19) = .26, p > .05 \). The means were .71 and .79 for the composite and repeat conditions respectively.

Thus, for immediate recall the repeat and composite conditions did not differ in terms of either absolute or improvement scores. For delayed recall those two conditions did not differ in terms of absolute scores but the difference approached significance for improvement scores.

It was proposed in the introduction that in immediate recall Ss might selectively shunt only some of the chunks into LTS and thus allow repetition benefits to accrue mainly for the first chunk or two. If selective shunting was taking place in immediate recall
it would be predicted that improvement in both the composite and repeat conditions should be confined to the first chunk or two. That prediction was born out by the data (see Fig. 7). For the composite condition, mean improvement scores for the four chunks were: first chunk, .29, t(19) = 2.16, p < .05; second chunk, .28, t(19) = 2.07, p < .05; third chunk, .08, t(19) = .70, p > .05; and fourth chunk, .03, t(19) = .21, p > .05. For the repeat condition: first chunk, .48, t(19) = 5.18, p < .01; second chunk, .29, t(19) = 2.54, p < .05; third chunk, .00; and fourth chunk, .03, t(19) = .21, p > .05. The improvement score for the first chunk in the repeat condition appears appreciably larger than that for the first chunk in the composite condition, .48 and .29 respectively. That difference, however, was not significant, t(19) = 1.17, p > .05.

For delayed recall, it was hypothesized that the selective-storage strategy would not be used. Thus, in the delayed condition, it would be predicted that significant improvement in recall should be found across all four chunks. In the repeat condition (see Fig. 8), the mean improvement scores for the first four chunks were: first chunk, .28, t(19) = 2.83, p < .01; second chunk, .17, t(19) = 1.45; p > .05; third chunk, .34, t(19) = 2.53, p < .05; fourth chunk, .30, t(19) = 4.00, p < .01. For the composite condition the means were: second chunk, .25, t(19) = 2.08, p < .05; third chunk, .35, t(19) = 4.36; p < .01, fourth chunk, .28, t(19) = 3.00, p < .01. The improvement score for the first chunk was significantly negative, -.23, t(19) = 2.18, p < .05. These results do seem generally in accord with the selective-storage hypothesis.
For immediate recall, the improvement scores did not differ between the composite and repeat conditions. That result is consistent with the bin notion of a single location in memory for the immediate-recall task. The finding that in both of the conditions the locus of improvement was confined to the first two chunks is consistent with the selective-storage hypothesis. In short, although there is a tendency for only some of the chunks to be stored in LTS, it appears as though they are shunted to a single location in memory.

For delayed recall, the results were ambiguous. The superiority of the improvement scores for the repeat condition were of borderline significance (approximately .06 level, one-tail test). With respect to selective-storage, it appears as though Ss tend to change their storage strategy in the delayed-recall task. In the repeat condition, the locus of improvement was fairly well spread out across the four positions: it was significant for the first, third, and fourth chunks, and in the right direction for the second chunk. In the composite condition it was significant for the second, third, and fourth chunks.

One puzzling finding in Exp. II was that for delayed recall in the composite condition, the improvement scores indicated a significant decrement in recall of the first chunk. One possibility is that the result is due to chance. Another is that when a search is conducted for identity in the locations in memory, there is a tendency to contact traces with those locations in which terminal (i.e. third and fourth) chunks are identical to those in the critical strings.
Such a search strategy might result in a deficit in recall for the first chunk of the critical string. If the effect is a reliable one, it would be difficult to explain such a decrement if only a single location in memory is assumed.

It should be noted that in Exp. II it is assumed that significant improvement scores for the critical strings are the result of specific repetition effects rather than some general improvement e.g. learning to learn which dissipated between blocks. Theoretically, the best way to assess specific effects would have been to include a control condition which would have involved the recall of three strings for which no chunks were repeated. Such a condition would control for general practice effects and could have been used as a baseline to assess specific effects in the repeat and composite conditions. However, such a condition was not included in Exp. II.

Recall of the third string was superior to the recall of the first two strings for all conditions except for the repeat condition with immediate recall (seven out of eight comparisons) where the recall of the second and third strings did not significantly differ. If the typical superior recall of the third strings was due to a general learning-to-learn effect, then it would be expected that the recall of the second strings should be superior to the first strings. However, in all four comparisons, the recall of the first two strings did not differ reliably. It is acknowledged that those comparisons are merely suggestive and do not rule out entirely a general learning-to-learn effect. For that reason, an additional
experiment was run which included a control condition.
Chapter IV

EXPERIMENT III

Experiment III was essentially the same as Exp. II except for the inclusion of a control condition. There are several advantages in the replication. First, support for a single-location explanation under conditions of immediate recall was based on acceptance of the null hypothesis. Replicating that result might lend more confidence to that interpretation. Second, in delayed recall the interpretation was ambiguous in that the difference in improvement between the repeat and composite conditions was of borderline significance. Third, a significant decrement in recall of the first chunk in the critical string with delayed recall was found. Exp. III would provide information as to the reliability of that effect.

Design

Each S had 18 trials instead of 12 as in Exp. II, with 6 being in the composite condition, 6 in the repeat condition, and 6 in the control condition. Seven different random orders of the trials were used. Each control trial involved the presentation of three digit strings, none of which had any chunks in common. To equate for difficulty of the critical strings, three different lists were used. Across the lists, the critical strings were the same for the three conditions. As in Exp. II, there were two independent groups; one immediate and one delayed.
Subjects

Forty-two introductory psychology students served as Ss. They were assigned in alternating order to one of the two groups as they came to the experiment.

Results

Immediate Recall

The level of recall of the initial strings (see Table 7) was equivalent for the three conditions. For the first string the mean number of digits recalled for the control, composite, and repeat conditions respectively were 6.35, 6.47, and 6.10, p < .01. For the second string the means were 6.10, 6.16, and 6.32 respectively, p < .1.

The repetition effects, although typically significant, were small in magnitude. The mean number of digits recalled in the third string was 5.95 for the control condition and 6.85 for the composite condition, t(20) = 2.66, p < .01. Also, the improvement score for the composite condition (mean = .42) was significant, t(20) = 1.81, p < .05.

For the repeat condition, mean recall of the third string (mean = 6.60) was significantly greater than the control condition, t(20) = 1.78, p < .05. The improvement score for the repeat condition (mean = .24), however, was not significant, t(20) = .88, p > .05. The composite and repeat conditions did not significantly differ either in terms of the third strings, t(20) = .89, p > .05, or in terms of the improvement score, t(20) = .45, p > .05. Thus, the immediate recall data of Experiment III confirm those of Experiment II and are con-
sistent with a description of memory in terms of a single location.

Figure 9 shows the improvement scores for each chunk separately in the composite and repeat conditions. The only significant improvement score (mean = .19) was for the first chunk in the repeat condition, $t(20) = 2.15, p < .05$. That finding is consistent with the notion of selective-storage in an immediate recall task.

Delayed Recall

The level of recall was not equivalent among the three conditions for either the first or second strings (see Table 8). For the first string, the mean number of digits recalled in the control, composite, and repeat conditions were 3.17, 3.88, and 3.35 respectively, $F(2, 40) = 4.64, p < .05$. For the second string the means were 3.25, 4.01, and 3.31 respectively, $F(2, 40) = 6.65, p < .05$. In both cases the recall in the composite condition was superior to that of the other two conditions. That result would lead to overestimation of the repetition effect for the composite condition when recall of the third string is used to index that effect. The bias, however, is eliminated when improvement scores are used.

The repetition effect was significant for both the composite and repeat conditions. The mean number of digits recalled from the third string was $3.34$ in the control condition and $5.29$ in the repeat condition, $t(20) = 6.54, p < .001$. For the composite condition the mean was $4.75$ which was also superior to the control, $t(20) = 6.06, p < .01$. The recall in the composite condition was significantly lower than that in the repeat condition, $t(20) = 2.10, p < .05$.  

The improvement scores for both the repeat (mean = 1.91) and composite condition (mean = .84) were significant, \( t(20) = 6.14, p < .001 \) and \( t(20) = 3.16, p < .005 \), respectively. As with the absolute score, the improvement score for the repeat condition was significantly greater than for the composite condition, \( t(20) = 3.28, p < .005 \). That finding is in agreement with the data of Exp. II, although the comparison was of only borderline significance in that experiment.

When the improvement score was examined for each chunk separately (see Fig. 10) the only effect not reliable was for the fourth chunk in the composite condition (mean = .23), \( t(20) = 1.55, p > .05 \). That finding would suggest that the finding of a significant decrement for the first chunk in the composite condition of Exp. II was due to chance.

The finding that the recall of the critical string in the composite condition is below that of the repeat condition in delayed recall can be taken as tentative support for a multi-location hypothesis. That is, in the composite condition, since the critical string can combine with only one previous string, only two of the four repeated chunks can be involved in repetition benefits. It is possible to test that hypothesis. If separate improvement scores are found for the two chunks from the first string and the two chunks from the second string, the larger score should indicate the pair of chunks that received repetition benefits and the smaller score should indicate the pair for which there was no effect. These scores should differ significantly. A similar scoring
procedure can be used for the repeat condition, in which improve-
ment scores are comparably assigned to pairs of chunks in the
critical string. The difference between large and small scores
should be significantly smaller in the repeat condition than the
difference in the composite condition in that repetition effects
should contribute to both large and small scores in the repeat
condition.

For the delayed recall data of Exp. II the mean-improvement for
the composite condition indexed by the smaller score was -.66 while
that of the larger score was 1.32. For the repeat condition the
means were -.31 and 1.37 respectively. A two-way analysis of
variance indicated that the difference between large and small
scores was not differential for the two conditions, $F(1, 19) = 3.35, p \geq .05$. The same analysis on the data in Exp. III yielded an $F$
value less than one. In Exp. III for the composite condition the
means were -.63 and 1.48 and for the repeat condition they were
.00 and 1.91. It would seem, then, that Ss make use of the past
occurrences of all four chunks in both the repeat and composite
conditions. That result is predicted by a description of memory in
terms of a single location in memory.

Discussion

As in Exp. II, the immediate recall data of Exp. III indicated
no difference in the recall of the critical strings in the repeat
and composite conditions: in fact, the ordering of the means was in
the reverse direction in Exp. III. There is a problem in Exp. III
with respect to the small magnitude of the repetition effects and
there is always the possibility that differential performance could be found if recall were at a higher level.

For delayed recall both Exps. II and III indicate that repetition benefits did occur for all four of the repeated chunks in both conditions. That would imply that Ss had access to the traces of all four chunks and favors a description of delayed recall in terms of a single location in memory.

A single-location explanation, however, does not explain the overall superiority in recall of the terminal strings in the repeat condition. One possibility is that along with the information stored about the digits of each string, retrieval rules also are stored which facilitate the retrieval of the digit information. For example, the digits in the string 458 685 749 613 might be stored along with the retrieval rule that the last two digits in the first two chunks are the same but reversed. Or, in the sequence 739 749 645 856, the retrieval rule might be that the second chunk is ten more than the first. When an entire string is repeated as in the repeat condition, the same retrieval rule can be used again. In the composite condition, however, insofar as such retrieval rules apply to interchunk information, the old retrieval rules for the repeated chunks may not apply and a new rule might have to be found for the composite terminal string. That description would predict somewhat lower recall in the composite condition than in the repeat condition and would reconcile that finding with a single-storage explanation.

In summary then, the results of Exps. II and III are consistent with a description of memory in terms of a single location. When recall
is immediate Ss tend to selectively store the initial chunks in LTS. When recall is delayed Ss tend to change that strategy. The superiority of the repeat condition in delayed recall is attributed to some factor other than number of locations in memory.

Support for a single location in memory is not necessarily support for the bin hypothesis. The bin hypothesis includes two additional assumptions a) that traces combine automatically, and b) that they do so in a chunk-by-chunk fashion. In the following experiment it is assumed that trace combination takes place automatically so that alternative predictions about the nature of combination can be examined.
Chapter V

EXPERIMENT IV

The TEP data of the previous experiments indicate that digit groups tend to be recalled in an all-or-none manner. That result could be taken to indicate that digit-groups have a unitary representation in memory, similar to the representation in memory for letter groups proposed by Johnson (in press). If unitary representation is indeed the case, then it might be expected that the representation of the digit group 734, for example, is as different from that of the group 754 as it is from a totally different group e.g. 286. That description of information in memory will be referred to as the code-dissimilarity hypothesis. The code-dissimilarity hypothesis asserts that memory codes for different digit groups are totally different, regardless of the degree of partial formal overlap with respect to individual digits. Insofar as the repetition effects depend upon the group encoding itself rather than identity of individual members, it is hypothesized that all items in a chunk must be the same for a repetition benefit to occur. The code-dissimilarity hypothesis predicts no repetition benefits unless all items in a group are the same.

An alternative prediction is made from the digit-by-digit overlay hypothesis of Bower and Winzenz (1969). In Cond. C of Exp. VII Bower and Winzenz had both the first and third chunks remain constant
in the R-strings while the second chunk varied in size from one to three. Only recall of the first chunk improved. In Exp. VIII the first and third chunks were held constant and the second chunk was always of size two. Here, both the first and third chunks improved. From these two studies Bower and Winzenz concluded that traces combine in strict digit-by-digit overlay fashion.

According to the overlay hypothesis, if a chunk occupies positions 1, 5, and 6, repetition of digits in positions 1 and 6 should result in improved recall of those digits even if digit 5 is not repeated. According to that hypothesis, the important condition for a repeated digit is that it consistently maintain the same serial position and whether or not other digits in the digit group are repeated makes no difference. Exp. IV was designed to assess that prediction.

**Method**

**Procedure and Design**

Each S recalled 14 strings of 15 digits - 7 N-strings and 7 R-strings. Each string was divided into five groups of three digits each. The procedure and construction of strings were essentially the same as described in Exp. I. There were two main variables of interest, and two levels of each variable for a total of four independent groups. The first variable was immediate vs. delayed recall. The second was locus of repeated digits. All Ss had six repeated digits in the R-strings. For Ss in the constant chunk condition (Condition CC), one-half the Ss had the first and third chunks constant, and the other half had the first and second chunks
constant. For Ss in the constant digit condition (Condition CD), half the Ss had the first chunk constant plus the digits in positions 4, 6, and 8 and for the other half the first chunk was constant plus the digits in positions 5, 7, and 9. Five different lists were constructed as a precaution against list effects and within each list the set of six digits held constant in Conditions CC and CD was the same.

According to the overlay hypothesis both Conditions CC and CD should show significant and equal improvement across trials for the repeated set of six digits. However, the code-dissimilarity hypothesis would predict no improvement for the repeated digits in the second and third chunks for Condition CD.

A control condition (Condition C) was added in which the first three chunks in the R-strings were constant. As with Conditions CC and CD, one group had immediate recall and the other delayed, for a total of six independent groups in Exp. II. The control condition was designed to assess the possible effect that the presence of a third constant (dummy) chunk would have upon the recall of the other two constant chunks as in Condition CC. The R-strings of Conditions C and CC were the same except that a constant dummy chunk in Condition C was substituted for the non-repeated second or third chunk in Condition CC. One expectation was that the greater the number of constant chunks, the more likely it would be for Ss to detect repetition, and thus recall of the two other constant chunks in Condition C would be enhanced (relative to Condition CC) by the dummy chunk.
Subjects

One-hundred-twenty introductory psychology students served as Ss. They were successively assigned to one of the six groups as they came to the experiment.

Results

The mean-within and mean-between group TEPs for Conditions C, CC, and CD, both immediate and delayed are given in Table 9. The mean within-group TEPs are significantly smaller than the mean between-group TEPs for all conditions except the N-strings of Condition C immediate, $t(19) = 1.04$, $p > .05$. It is difficult to explain why a significant difference was not obtained since the N-strings used in Condition C immediate were the same as those used in Conditions CD and CC immediate for which significant differences were found.

For immediate recall, the mean number of digits recalled for the R-strings (maximum = 15) was 6.80 for Condition CC and 5.74 for Condition CD. That difference was significant, $t(19) = 1.81$, $p < .05$ (one tail). For delayed recall the means were 4.66 for Condition CC and 4.79 for Condition CD, $t(19) = .01$, $p > .05$. The mean number of repeated digits recalled (maximum = 6) indicated a similar pattern. For immediate recall the means were 3.72 and 3.07 for Conditions CC and CD respectively, $t(19) = 3.99$, $p < .01$. For delayed recall the means were virtually identical: 2.85 for Condition CC and 2.86 for Condition CD. Thus performance in Condition CC tends to be greater than that of Condition CD when recall is immediate, but there is no difference when recall is delayed.
Unlike the results in Exp. I, the recall of the N-strings in Exp. IV did not significantly increase as a function of trials (see Fig. 11). Despite that finding it was decided that difference scores should again be used to eliminate nonsignificant trends of improvement (or decrement). In particular, the recall of N-strings shows a consistent drop from the first to the second trial in each of the conditions, which might serve to obscure repetition effects in the N-strings.

**Repeated Items**

In order to compare the recall of the constant digits in the second and third chunks in Conditions CC and CD it should be established that the improvement of the first chunks in those conditions are comparable. For immediate recall (see Fig. 12), a two-way analysis of variance indicated that the effect of trials was significant, \( F(6, 228) = 5.43, p < .001 \), and that it was not differential for the two conditions, \( F < 1 \). Similarly, for delayed recall (see Fig. 13), the improvement across trials occurred, \( F(6, 228) = 9.04, p < .001 \), and it was not differential, \( F < 1 \).

For the immediate condition, recall of the digits in the second and third chunks (see Fig. 14) did not significantly increase for Condition CD, \( F(6, 114) = 1.30, p > .05 \). For Condition CC however, recall of the repeated second or third chunk did increase significantly, \( F(6, 114) = 7.30, p < .01 \). A two-way analysis of variance indicated that the improvement was differential, i.e. the Trials X Conditions interaction was significant, \( F(6, 228) = 2.20, p < .05 \).
A similar pattern is obtained when difference scores are used (see Fig. 15). The recall in Condition CD did not improve across trials, $F < 1$, and, in addition, the smallest mean did not differ from the largest mean, $t(19) = 1.33, p > .05$. Recall did improve, however, for Condition CC, $F(6, 114) = 5.22, p < .01$. The difference in improvement across trials between the two conditions was significant, $F(6, 220) = 4.72, p < .01$.

For delayed recall, recall of the constant digits in the second and third chunks did not improve for either Condition CD or CC (see Fig. 16), $F(6, 114) = 1.22, p > .05$, and $F(6, 114) = 1.61, p > .05$, respectively. However, when difference scores (see Fig. 17) were used both Conditions CD, $F(6, 114) = 2.97, p < .05$, and Condition CC, $F(6, 114) = 4.99, p < .01$, showed significant improvement. That improvement was not differential, $F < 1$.

It would seem that with immediate recall, only Condition CC shows improvement across trials for the constant digits in the second and third chunks. With delayed recall, however, both Conditions CC and CD appear to improve an equivalent amount.

**Nonrepeated Items**

Trial-by-trial recall of the nine nonrepeated digits in Conditions CD immediate, CC immediate, CD delayed, and CC delayed is given in Fig. 18. The effect of trials was not significant for Condition CD immediate, $F < 1$, nor for Condition CC immediate, $F(6, 114) = 1.82, p > .05$. The trials effect was significant for Condition CD delayed, $F(6, 114) = 2.94, p < .01$, but the function was erratic and certainly not a trial-to-trial improvement (for the linear component, $F = 0.00$). The effect
was not significant for Condition CC delayed, $F < 1$.

The same data is given in Fig. 19 in terms of difference scores. Again, the effect of trials was not significant for Condition CC either immediate or delayed, $F < 1$. Similarly, for Condition CD the effect was not significant for either immediate or delayed recall, $F(6, 114) = 1.12, p > .05$, and $F(6, 114) = 1.27, p > .05$ respectively.

The finding that performance on nonrepeated items did not increase as a function of trials is contrary to what one would expect on the basis of the Melton (1963) hypothesis of interchunk interference. According to that hypothesis, as Ss progress in chunking the repeated items across trials there should be a reduction in interchunk interference. On that basis one would expect the nonrepeated items to improve across trials. No such improvement was found.

**Control Conditions**

Ss in the control (C) condition had the same R-strings as Ss in the constant-chunk condition except that the nonrepeated digits that constituted the second or third chunk in Condition CC were replaced by a constant (dummy) chunk that was repeated in each R-string. Thus, the first chunk was constant in both conditions. The second (third) chunk was also constant, while the third (second) consisted of either a constant dummy chunk for Condition C or a non-repeated chunk in Condition CC. The fourth and fifth chunks in both conditions were non-repeating.

Conditions C and CC were compared in terms of total recall,
first chunk recall, dummy vs. nonrepeating chunk recall, and nonrepeating fourth and fifth chunk recall. For both the immediate and delayed conditions the only significant effect was that of higher recall for the repeated dummy chunk of Condition C than for the nonrepeating chunk of Condition CC.

For immediate recall, the mean number of digits recalled for the R-strings (maximum = 15) was 6.80 for Condition CC and 6.87 for Condition C, \( t(19) = 0.10, p > 0.05 \). Mean digit-recall of the constant first chunk was 2.04 for Condition CC and 1.81 for Condition C, \( t(19) = 0.79, p > 0.05 \). Mean digit recall of the constant second or third chunk was 1.68 for Condition CC and 1.40 for Condition C, \( t(19) = 1.11, p > 0.05 \). Thus, there was a non-significant tendency for lower recall of the constant items in Condition C. That tendency was offset, however, by higher recall of digits from the dummy chunk (mean = 1.24) in Condition C, than that of the nonrepeated second or third chunk in Condition CC (mean = 0.75), \( t(19) = 2.05, p < 0.05 \). Mean recall of digits in the last two chunks (maximum = 6) was 2.33 for Condition CC and 2.43 for Condition C, \( t(19) = 0.23, p > 0.05 \).

For delayed recall, the mean number of digits recalled for the R-strings was 4.86 for Condition CC and 6.09 for Condition C, \( t(19) = 1.62, p < 0.05 \). Mean recall of digits from the first chunk was 1.73 for Condition CC and 1.82 for Condition C, \( t(19) = 0.31, p > 0.05 \). Mean recall of digits from the constant second or third chunk was 1.12 for Condition CC and 1.25 for Condition C, \( t(19) = 0.50, p > 0.05 \). Mean recall of digits from the dummy chunk was 1.56 for Condition C while the mean recall of digits in the non-repeated second or third
chunk was .72 for Condition CC. As with immediate recall, that difference was significant, \( t(19) = 1.95, p < .05 \). The mean number of digits recalled in the last two chunks was 1.29 for Condition CC and 1.46 for Condition C, \( t(19) = .63, p > .05 \).

The results indicate that the presence of a third constant chunk does not facilitate the recall of the other two constant chunks. On the contrary, in the immediate condition there was a nonsignificant tendency for the presence of a third constant chunk to result in a decrement in the recall of the other two.

**Discussion**

For immediate recall, the recall of the repeated letters in the second and third chunks was greater for Condition CC than in Condition CD, which is contrary to what one would expect on the basis of the simple overlay hypothesis. The finding that the recall of the repeated digits in the second and third chunks did not improve across trials for Condition CD would indicate that all digits in a chunk must be repeated before repetition benefits can accrue.

One possible explanation of the lack of improvement in the CD condition is that proposed by the code-dissimilarity hypothesis. That is, when traces combine in a location in memory, the combination does not take place according to a digit-by-digit overlay within chunks but by a chunk-by-chunk overlay where only chunks that are exactly repeated combine so as to increase recall. The information stored in memory locations is not in a simple form of digit identity and digit position, but rather it is hypothesized to be in some more abstract form, i.e. a code characteristic of the group of
digits itself. If one digit is different, the entire abstract characterization would be different and no repetition benefits would accrue.

For delayed recall, when absolute recall of the repeated digits in the second and third chunks was examined across trials, no improvement was found for either Condition CC or CD. When difference scores were used, improvement was found for both conditions but it was not differential for the two conditions. That result is consistent with an explanation of combination of traces according to a digit-by-digit overlay within chunks.

It is hard to explain why improvement in recall in the CD condition is different for immediate and delayed recall. The TEP data indicate that in both immediate and delayed recall, the Ss use the digit groups as their basic units of recall. One possible explanation is that information is always stored in LTS at both the digit and chunk level. Under conditions of delayed recall, Ss can make use of either type of information with equal facility. In immediate recall, however, Ss may be relying on STS to recall some of the chunks. If that is the case they would be under a certain degree of time pressure to retrieve LTS information as fast as possible before the STS trace decays. Under the assumption that time is saved by dealing with information only at the chunk level, Ss in immediate recall may not make use of digit-level information.
Chapter VI

GENERAL DISCUSSION

One of the most salient aspects of the present set of experiments is the different pattern of results obtained depending upon whether recall is immediate or delayed. Operationally, the basic difference in the two types of tasks is the insertion of filler activity. Theoretically, such filler activity does not allow Ss in the delayed condition to base their recall on a short-term trace. The position will be adopted here that the differences obtained between immediate and delayed recall in the present studies are due to dependency of Ss on STS when recall is immediate.

It would appear that delayed recall can best be described in terms of a single location in memory. That description is consistent with the finding in Exps. II and III that when a digit string is a composite of two previously presented strings, Ss appear to capitalize on the past occurrence of chunks from both strings. In addition, the single location description predicted the pattern of results obtained in Exp. I for delayed recall. In that experiment a single constant chunk improved as a function of trials regardless of its position within the string. When recall is delayed it was found that a chunk need be repeated only in part for repetition benefits to occur (Exp. IV) and that might indicate that the information stored
at the single location can be described at the digit level.

A single location in memory also seems to hold for immediate recall. In Exps. II and III recall of critical strings was equivalent for both the repeat and composite strings. It also was found that in those experiments the improvement in recall in both conditions was restricted to the first chunk or two. That outcome is consistent with a selective storage notion. Selective-storage also reconciles a single location explanation with the outcome of the constant-chunk paradigm when recall is immediate. Specifically, constant third or fifth chunks do not improve in the constant-chunk paradigm in that Ss tend not to store them in LTS. The information stored in the single location when recall is immediate might be described at the chunk level in that Exp. IV indicated a chunk must be repeated entirely for repetition benefits to occur.

It is possible that the information stored in memory is not stored at one level when recall is immediate and another level when recall is delayed. It may be that the information is always stored at both the digit and chunk level but that in immediate recall (where Ss are under time pressure when relying on LTS) Ss find it more efficient to make use of information only at the chunk level.

There is an important issue left unresolved by the interpretation given to the above data. Bower and Winzenz (1969) found that a constant first and third chunk both improved when the nonrepeating second chunk was of a constant size (Exp. VIII) but that only the first
chunk improved when the second chunk varied in size (Exp. VII). Those results were taken as support for a digit-by-digit overlay description of trace combination. Those data pose a problem for the selective-storage hypothesis in that the third chunk had sufficient LTS strength in one case and not in the other.

Selective-storage is assumed to be a strategy which can change as a function of certain conditions. The improvement found for the third chunk in Exp. VIII but not in Exp. VII may have been due to some condition present in one experiment but not the other which altered the selective-storage strategy.

Both Exps. VII and VIII were repeated measures experiments. In Exp. VII each S experienced four instances of three experimental conditions a) a constant first chunk, b) a constant fifth chunk, and c) a constant first and third chunk with a second chunk varying in size. In Exp. VIII each S had eight instances of a single condition, i.e. a constant first and third chunk with a second chunk of constant size.

It is possible that the optimal strategy in Exp. VII, given those conditions, was to concentrate LTS storage mainly for the first two chunks. In Exp. VIII the optimal strategy may have involved the first three chunks. One factor which may have contributed to different strategies is that the segmentation of the digit strings was less constrained in Exp. VII and thus more variable. In Condition a,
only the first chunk of the repeated strings was constrained in size, in Condition b, only the last, and in Condition c, only the first and third. In Exp. VIII, the first three chunks of every repeated string the Ss recalled were of constant size. Thus, the assumption that variability of segmentation can alter the selective-storage strategy may account for the different findings in the two studies.
APPENDIX A

TABLES
<table>
<thead>
<tr>
<th>Type of string</th>
<th>Repeat</th>
<th>Noise</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Between 3A</td>
<td>.83</td>
<td>.48</td>
</tr>
<tr>
<td>Within 3A</td>
<td>.17</td>
<td>.21</td>
</tr>
</tbody>
</table>
TABLE 2
MEAN CORRECT DIGITS PER STRING FOR THE IMMEDIATE-RECALL CONDITIONS OF EXP. I

<table>
<thead>
<tr>
<th></th>
<th>Focus 1</th>
<th>Focus 2</th>
<th>Focus 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeat string</td>
<td>5.93</td>
<td>5.46</td>
<td>4.89</td>
</tr>
<tr>
<td>Morse string</td>
<td>1.39</td>
<td>5.25</td>
<td>4.61</td>
</tr>
</tbody>
</table>
TABLE 3
TRANSITIONAL ERROR PROBABILITIES FOR THE DELAYED
RECALL CONDITIONS OF EXP. I

<table>
<thead>
<tr>
<th>Type of string</th>
<th>Repeat</th>
<th>Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 8 5</td>
<td>1 8 5</td>
</tr>
<tr>
<td>locus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between 32</td>
<td>.45 .55 .57</td>
<td>.60 .70 .58</td>
</tr>
<tr>
<td>Within 32</td>
<td>.26 .44 .25</td>
<td>.43 .40 .38</td>
</tr>
</tbody>
</table>
**TABLE 4**

**MEAN CORRECT DIGITS PER STRING FOR THE DELAYED-RECALL CONDITIONS OF EXP. I**

<table>
<thead>
<tr>
<th></th>
<th>Focus 1</th>
<th>Focus 3</th>
<th>Focus 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Repeat</strong> string</td>
<td>4.20</td>
<td>2.97</td>
<td>3.67</td>
</tr>
<tr>
<td><strong>Noise</strong> string</td>
<td>2.91</td>
<td>2.44</td>
<td>2.98</td>
</tr>
</tbody>
</table>
TABLE 5
MEAN CORRECT DIGITS PER STRING FOR THE IMMEDIATE-RECALL CONDITIONS OF EXP. II

<table>
<thead>
<tr>
<th></th>
<th>String 1st</th>
<th>String 2nd</th>
<th>String 3rd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeat Cond.</td>
<td>5.45</td>
<td>5.68</td>
<td>6.06</td>
</tr>
<tr>
<td>Composite Cond.</td>
<td>5.53</td>
<td>5.21</td>
<td>6.15</td>
</tr>
</tbody>
</table>
TABLE 6
MEAN CORRECT DIGITS PER STRING FOR THE DELAYED-RECALL CONDITIONS OF EXP. II

<table>
<thead>
<tr>
<th></th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Repeat Cond</strong></td>
<td>2.61</td>
<td>3.11</td>
<td>4.15</td>
</tr>
<tr>
<td><strong>Composite Cond</strong></td>
<td>3.42</td>
<td>3.40</td>
<td>4.08</td>
</tr>
</tbody>
</table>
TABLE 7

MEAN CORRECT DIGITS PER STRING FOR THE IMMEDIATE-RECALL CONDITIONS OF EXP. III

<table>
<thead>
<tr>
<th>String</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.95</td>
<td>6.10</td>
<td>5.25</td>
</tr>
<tr>
<td>Composite</td>
<td>6.47</td>
<td>6.16</td>
<td>6.88</td>
</tr>
<tr>
<td>Repeat</td>
<td>6.10</td>
<td>6.32</td>
<td>6.60</td>
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</table>
TABLE 8

MEAN CORRECT DIGITS PER STRING FOR THE DELAYED RECALL CONDITIONS OF EXP. III

<table>
<thead>
<tr>
<th></th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.17</td>
<td>3.25</td>
<td>3.84</td>
</tr>
<tr>
<td>Composite</td>
<td>3.85</td>
<td>4.01</td>
<td>4.76</td>
</tr>
<tr>
<td>Repeat</td>
<td>5.25</td>
<td>3.31</td>
<td>5.29</td>
</tr>
</tbody>
</table>
TABLE 9

TRANSITIONAL ERROR PROBABILITIES FOR EXP. IV

**R-strings**

<table>
<thead>
<tr>
<th></th>
<th>Immediate</th>
<th></th>
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<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CC</td>
<td>CD</td>
<td>C</td>
<td>CC</td>
<td>CD</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Between</td>
<td>.51</td>
<td>.69</td>
<td>.44</td>
<td>.59</td>
<td>.67</td>
<td>.54</td>
<td></td>
</tr>
<tr>
<td>Within</td>
<td>.18</td>
<td>.28</td>
<td>.20</td>
<td>.30</td>
<td>.35</td>
<td>.38</td>
<td></td>
</tr>
</tbody>
</table>

**N-strings**

<table>
<thead>
<tr>
<th></th>
<th>Immediate</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CC</td>
<td>CD</td>
<td>C</td>
<td>CC</td>
<td>CD</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Between</td>
<td>.45</td>
<td>.60</td>
<td>.41</td>
<td>.64</td>
<td>.70</td>
<td>.68</td>
<td></td>
</tr>
<tr>
<td>Within</td>
<td>.27</td>
<td>.36</td>
<td>.26</td>
<td>.48</td>
<td>.35</td>
<td>.41</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B

FIGURES
Figure 1. Mean number of digits recalled for the constant chunks (immediate recall) in Exp. I as a function of trials. R1, R3, and R5 refer to the first, third, and fifth constant chunks respectively.
Figure 2. Mean number of digits recalled for the noise strings (immediate recall) in Exp. I as a function of trials. Maximum possible is 13.
Figure 3. Recall (difference scores) of the constant chunks in Exp. I as a function of trials. R1, R3, and R5 refer to the three constant-chunk positions for immediate recall.
Figure 4. Mean number of digits recalled for the constant chunks (delayed recall) in Exp. I as a function of trials. R1, R3, and R5 refer to the first, third, and fifth constant chunks respectively.
Figure 5. Mean number of digits recalled for the noise strings (delayed recall) in Exp. I as a function of trials.
Figure 6. Recall (difference scores) of the constant chunks in Exp. 1 as a function of trials. R1, R3, and R5 refer to the three constant-chunk positions for immediate recall.
Figure 7. Pattern of improvement scores across chunk positions for immediate recall in exp. II.
Figure 8. Pattern of improvement scores across chunk positions for delayed recall in Exp. II.
Figure 9. Pattern of improvement scores across chunks for immediate recall in Exp. III.
Figure 10. Pattern of improvement scores across chunk positions for delayed recall in Exp. III.
Figure 11. Mean number of digits recalled for the noise strings in Exp. IV as a function of trials.
Figure 12. Recall of digits repeated in the first chunk, immediate recall, for the constant chunk (CC) and the constant digit (CD) conditions of Exp. IV.
Figure 13. Recall of digits repeated in the first chunk, delayed recall, for the constant chunk (CC) and the constant digit (CD) conditions of Exp. IV.
Figure 14. Recall of digits repeated in second and third chunks, immediate recall, for the constant chunk (CC) and the constant digit (CD) conditions of Exp. IV.
Figure 15. Recall (difference score) of repeated digits in the second and third chunks, immediate recall of Exp. IV.
Figure 16. Recall of digits repeated in the second or third chunk, delayed recall, for the constant chunk (CC) and the constant digit (CD) conditions of Exp. IV.
Figure 17. Recall (difference score) of digits repeated in the second and third chunks, delayed recall of Exp. IV.
Figure 18. Recall of non-repeated items in the repeated strings as a function of trials in Exp. IV.
Figure 19. Recall of the non-repeated items (difference scores) in the repeated strings as a function of trials in Exp. IV.
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