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Rice University

Information Processing Correlates of Memory Span:  
An Individual Differences Approach

by

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A Thesis Submitted  
in Partial Fulfillment of the  
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Doctor of Philosophy

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Abstract

Three processes, item identification speed, susceptibility to proactive interference, and memory for order, identified for their potential as sources of memory span differences, were the subjects of the present investigation. A fourth variable, item memory, was included as the experimental complement of order memory (Healy, 1974). Performance on each of these four variables and memory span was obtained for 90 college-aged subjects. Moderate to high reliability was evidenced for each of the tasks. Memory span correlated significantly with each source of differences examined. Additionally, using a multiple regression analysis, each variable was shown to contribute significant, independent variance in the joint prediction of memory span. Subjects' scores on the four predictor variables were used in a cluster analysis which identified four subsets of individuals. An ANOVA determined that the four groups differed in their mean
memory span scores. The differences among these groups were examined using a multiple discriminant analysis. The groups were found to differ along three dimensions. Evidence from these analyses indicates that an individual's memory span is the result of complex processes involving, at least, components of item identification speed, susceptibility to proactive interference, order, and item memory. Finally, individuals' performance levels across these tasks were not uniform, indicating possible differential contributions of these processes.
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Introduction

Memory span, the result of a serial order recall task, was originally conceived as measuring short-term memory capacity (Binet & Simon, 1905). The determination of memory span was the focus of some of the earliest research in psychology. Such memory span tasks are included in both the Wechsler Adult Intelligence Scale (WAIS) and the Stanford-Binet (S-B) intelligence test. Perhaps due to its use diagnostically, memory span has about it an aura of fundamental importance in cognition. However, unlike many of the other memory measures found in cognitive psychology, memory span appears to have little theoretical or explanatory power. While memory span can be reliably assessed and is predictive of some global measures of intelligence, scant attention has been given to its theoretical importance.

The puzzle of memory span may not be easily solved. Cognitive psychologists have shown that even simple acts such as free recall may be composed of a number of complex subprocesses, each influencing the recall of a given item. There is no reason to believe that the memory span task is any less complex than other acts of cognition. Indeed, the
opposite might well be so.

The Construct of Memory Span

The construct, memory span, was initially investigated by Ebbinghaus (1885) in the context of "span of apprehension." Though the basic concept of memory span has remained unchanged through the years, there has been little consensus as to its operationalization and scoring. Guilford and Dallenbach (1925) list 36 variations, and a wide range of methods for determining memory span are still in current use (c.f. Underwood, et al., 1978; Watkins, 1977). The most common of these converge to the notion that memory span is the median list length that can be recalled in order.

Since the general procedure used to obtain one's memory span score is similar to many measures of memory, one might speculate that memory span is just a simple variant of other measures of memory. Evidence suggesting that memory span is distinctive is presented in a study of 25 different episodic memory tasks (Underwood, Boruch, & Malmi, 1978). Performance on all 25 tasks was measured for 200 subjects. A factor analysis of these tasks yielded five stable factors. Tests of paired-associate learning, recognition, recall memory, and verbal discrimination each formed a unique factor. Three memory span tasks formed the
fifth factor on which no other task loaded more than .24. Further, the memory span tasks loaded no more than .11 on any of the other four factors. This display of rather simple structure suggests that the construct of memory span cannot be explained solely as serial-recall (which loaded on the paired-associates factor), free-recall, or some combination of the two. Memory span appears to be tapping a separate dimension of memory.

Individuals, of course, differ in their abilities on a variety of tasks which may be related to memory span. Some of these abilities, like rehearsal, grouping, chunking, or retrieval may be under the control of an individual. Others, such as capacity, memory search rate, output buffer size, item identification speed, memory for order, and susceptibility to proactive interference are thought to be beyond the subject's control. Specifying which variables are more central to the memory span process requires the concurrent evaluation of such variables. No such systematic research has been conducted using all the above tasks. Probably such a massive research effort would be impractical to attempt. It might well be profitable, however, to examine a subset of these tasks in a systematic manner.
Nonpredictive Variables

Preliminary independent analysis of rehearsal, grouping, chunking, and retrieval strategies reveals no strong positive evidence which would lead to their inclusion in such a subset. In fact, there is negative evidence suggesting that explanatory hypotheses relating to memory span differences should not be based on these variables at all. For example, Lyon (1977, Experiment 1) presents negative evidence in a study which proposed that individual differences in ability to rehearse are a significant source of the differences in memory span.

Grouping has also been explored as a potentially important process in memory span performance (Oberly, 1928; Estes, 1974). Krulee, Gapp, Landi, and Manelski (1964) report results showing increased span when subjects are presented digits spatially grouped as compared to an ungrouped condition. Grouping has been thought to have its effect through the enhancement of rehearsal opportunities or increasing the likelihood of chunking (c.f., Dempster, 1981). No empirical support exists for either rehearsal (Lyon, 1977; Ryan, 1969a, b) or chunking (Hunt & Love, 1972; Lyon, 1977) as underlying explanations of grouping effects.

Chunking itself is another process some have
considered basic to memory span. Chunking is defined as the process by which a set of two or more individual items is recoded into a new, functional stimulus (c.f., Miller, 1956). It is this aspect of recoding that distinguishes chunking from grouping.

Lyon (1977, Experiment II) tested the hypothesis that instructions to chunk should differentially benefit a low-span group as compared to a high-span group. The data provide no support for the chunking hypothesis. Hunt and Love's (1972) attempt to train subjects to chunk has also produced negative evidence for the chunking idea. After extensive training, subjects' spans increased slightly only when the presentation rate was drastically lowered (e.g., 1 word per 6 seconds). One can reasonably conclude that chunking is not a significant source of individual differences in memory span.

The possible role of retrieval strategies as a source of individual differences was investigated by Samuel (1978). He felt that developmental differences in memory span could be accounted for by proposing that, as children mature, they are increasingly able to match their output organization to the organization of the presented stimuli. In accordance with this organizational hypothesis, Samuel proposed that younger children should differentially
benefit when list input order matched an imposed recall order, compared to a mismatch condition. Both younger and older children benefitted from matching, but the hypothesized interaction was not obtained, $F(6, 136) < 1.0$. Samuel concludes, "The data thus provide no support for an organizational theory of memory span growth, at input or at output" (1978, p. 314).

In addition to rehearsal, grouping, chunking, and retrieval, evidence for any relationship between memory span and capacity, memory-search rate, or output buffer size is not supportive. Studies by Case, Kurland, and Goldberg (1982) and Dempster (1978) have focused on the possibility that some capacity increase with age is the source of observed memory span differences. Their findings, however, suggest that capacity does not increase developmentally.

Brown and Kirsner (1980) investigated the possible relationship between memory search rate and memory span. Non-significant results were obtained when using digits, letters, words, and nonsense syllables as stimuli. Similar results are reported by Chiang and Atkinson (1976). Thus, capacity and memory search rate do not appear to be likely sources of memory span differences.

Another proposed source of memory span differences is
the output buffer. Viewed as a temporary storage system for holding a motor-response program (Baddeley & Hitch, 1974; Baddeley, Thomson, & Buchanan, 1975; Klapp, 1976), differences in buffer capacity could account for observed differences in memory span. Baddeley, et al. (1975) found that word length influences the number of words subjects will free recall. Klapp (1976) presents results indicating that subjects' latencies are longer for four-syllable digits (i.e., 27) than for three-syllable digits (i.e., 24). The observation that neither study rules out alternative explanations for the results in terms of processes such as item identification speed (Dempster, 1981) lessens one's confidence that the output buffer is a source of memory span differences. Moreover, in neither study was the output buffer directly linked to memory span.

Not all evidence on the subject of individual differences in memory span is negative. Based on previous research, three processes, item identification speed, susceptibility to proactive interference, and memory for order, show promise in accounting for memory span differences.

**Item Identification Speed**

Individual differences in item identification speed are thought to relate to differences in the efficiency of
accessing semantic memory codes. The more efficient such a process, the more time available in which to store an item. Increases in storage might well result in a larger memory span score. The major theoretical assumption involved is that "efficiency" is directly related to "speed of identification." Individual differences have been found in word-naming latency for adults (Baddeley, et al., 1975) and in digit-naming latency within age groups in children (Spring & Capps, 1974).

There is converging evidence that item identification speed and memory span are related. However, very little has been done to directly explore the relationship between them. One suggestive finding is that there is an identical ranking between memory span and item identification speed across various kinds of items. In a study involving 17 types of stimulus material and memory span, Brener (1940) found that digits produced the longest memory spans, followed by words, and geometrical designs. This same order was found in a naming latency study by Mackworth (1963) involving adults, and by Case (cited in Dempster, 1981) using preschoolers.

Another source of converging evidence comes from studies which correlated reading rates with measures of immediate recall. In one such study (Spring & Capps,
1974), children's latencies on a digit-naming task were correlated with their performance on a probed-recall task using digits. This study involved two groups of children, roughly matched on background variables, but differing in reading ability. Subjects were given probed-recall and digit-naming tasks. The poor reading group, averaging 2.3 years below their age norms in reading ability, had a mean digit-naming speed of 1.6 digits per second, while the normal group averaged 2.5 digits per second (estimated from Figure 1, Spring & Capps, 1974). Twenty-four, eight-digit lists were presented in the probed-recall task. Disregarding the last two serial positions, the correlation between digit-naming speed and performance on the probed-recall task was $r = .53$ (df = 44; $p < .001$). Such results support an item identification speed hypothesis, as do similar results from Mackworth (1963). In Mackworth's study, a correlation of .61 was obtained between the results of a serial recall task and a digit-naming task. In a more recent study, Baddeley et al. (1975) found the percentage of words recalled by adults from a five-word list correlated $r = .685$ with the speed of reading a 50-word list.

While the results of such studies (i.e., Baddeley et al., 1975; Mackworth, 1963; Spring & Capps, 1974) are
certainly suggestive and favorable for the identification speed hypothesis, research with memory span itself is meager. Case, Kurland, and Goldberg (1982) assessed both word-naming latency and memory span for words in children aged three to six years. A large and significant negative correlation (r = -.74) was found between the span scores and naming latency. Since the children in this age group are likely to show large developmental differences, the correlation is not, itself, readily interpretable. However, when variance due to age was partialled out, the correlation, though only moderately large (r = -.35), was still significant. Thus, the identification-speed hypothesis has some direct support.

Several investigations have shown that item identification speed is correlated with recall. Additionally, item identification speed has been shown to correlate with memory span in children. Thus, there is reason to consider item identification speed as a possible source of differences in memory span.

**Susceptibility to Proactive Interference**

In the methodology of determining memory span, several lists of the same type of material are usually presented. Thus, the memory span paradigm is similar to the Brown-Peterson paradigm (Peterson & Peterson, 1959). In the
latter paradigm, it has been shown (Wickens, 1972; Wickens, Born, & Allen, 1973) that proactive interference occurs. Given the robustness of these proactive interference findings and the procedural similarity between memory span and Brown-Peterson tasks, one might suppose that the build up of proactive interference also occurs during the memory span task. Thus, individual differences in susceptibility to proactive interference may mediate differences in memory span performance.

As yet, no investigations have directly explored this potential relationship. However, some related research has been done. Differences in the intensity of proactive interference have been shown by good and poor readers performing an immediate recall task (Leslie, 1975). In this study, third- and fourth-grade children, matched on IQ but differing in reading ability, took part in a task designed to measure proactive interference. The two groups performed equally well on the first trial and the res;ease from proactive interference trial. Differences between the two groups appeared in the middle trials with trial five producing the largest difference. The two groups were found to differ significantly \( F(1, 60) = 7.27, p < .01 \) on the combined mean of trials five and six. Thus, proactive inhibition does take place in a task which is similar to a
span task. One difference between good and poor readers is a differential susceptibility to proactive interference. This finding hints at individual differences in this susceptibility, though reliable individual differences have yet to be shown.

Order Information

Intuitively, serial recall involves use of "order" information in some phase of the memorial process. Since memory span tasks involve serial recall, it is reasonable to hypothesize that, if there are individual differences in ability to make use of order information, these differences may mediate differences in memory span.

Martin (1978) presents evidence supportive of this line of thought. She found a significant correlation \( r = .63 \) between digit span and serial order recall. While this result favors the relationship between memory for order and memory span, performance on the serial order recall task may reflect two processes: item and order recall. Whether these two processes are independent or interdependent (and hence not independently measurable) has been the subject of some debate (i.e., Murdock & Vom Saal, 1967; Bjork & Healy, 1973). Healy (1974) has developed a method by which item and order recall can be separately measured. Using her methodology, a strong test of the
order information hypothesis is possible.

Until recently, cognitive psychologists have not been especially interested in investigating individual differences. Focusing on the phenomenon of individual differences in memory span allows some interesting issues to be raised. One such issue is whether subjects' underlying processes actually differ, and if so, whether the differences are similar across various processes. In the present case, the processes under investigation are those which relate to memory span performance.

Three processes, item identification speed, susceptibility to proactive interference, and order memory, appear to have some potential for explaining differences in memory span. The general hypothesis in the following study is that performance differences on tasks measuring these three processes will be predictive of memory span differences. Specifically, the present research is organized around three goals: (1) Investigating differences in ability to perform the previously mentioned tasks and establishing the reliability of such differences; (2) Assessing each task's individual, and joint, predictiveness of memory span differences; and, (3) Examining the heterogeneity of subjects' abilities on the various tasks. Attainment of these goals should provide
answers to the questions raised above as well as more clearly delineating underlying information processing characteristics of memory span.
Method

Stimuli

The type of stimuli used in memory span tasks does not appear to change the nature of the memory span task itself (Brener, 1940). However, the decision to use single-syllable nouns as the stimuli for each task was not totally arbitrary. While the memory span task may be carried out with various types of stimuli, the three information processing tasks virtually necessitate the use of words. In order to equate for word length as nearly as possible, and to maintain the same type of words throughout several tasks with many trials, single-syllable nouns were chosen. In all, approximately 1,000 such nouns were identified from various sources. While a familiarity or frequency index was available for most words identified, norms for every noun did not exist. When such a non-indexed noun was encountered, two graduate students judged its familiarity. In cases of further ambiguity, the noun was eliminated from the word pool.

Nouns for each task were selected randomly, without replacement, from the total word pool with the following stipulations: (1) All nouns for the proactive interference
task fell into one of four categories. These words were selected and withdrawn from the noun pool at the outset; (2) One condition in the order task required nouns belonging to specific categories. These were also deleted from the general pool. Nouns withdrawn to satisfy the categorical requirements totalled 115. Thus, 736 single-syllable nouns were used in all tasks, each word appearing only one time.

**Subjects**

A preliminary power analysis indicated that 90 subjects would be an adequate sample for testing the hypotheses under question. Subjects were sampled from three institutions: Rice University, the University of Houston, and the University of Texas Medical School at Houston. English was the native language for all subjects. Subjects were not all students, but each was of college age, approximately 18-27 years. Sixty-one subjects came from the Rice community, 16 from the University of Houston, and 13 from the University of Texas Medical School. All received class credit or were paid $4.00 for their participation in the experiment.

**General Procedure**

For each subject, the entire set of experiments was run in a single experimental session. Sessions lasted
approximately 60 minutes. No subject refused to participate or withdrew from the experiment before it was completed. Each subject was directed to read and sign a release form concerning the nature and requirements of the experiment. The experimenter began by describing the general structure of the session and then answered any general questions asked by the subject. In order not to confuse the subject, precise descriptions for each task were given just prior to such tasks. Subjects' abilities were measured on all five tasks. The memory span task was always presented first and the fifth task was always that of item identification speed. The proactive interference task and the two conditions of the memory for order task constituted the three middle tasks. These three tasks were arranged in three different permutations. Subjects were randomly assigned to one of the three orders with the constraint that there be an equal number tested with each permutation.

All aspects of stimulus and interpolated task presentation were carried out with the TRS-80 Model III microcomputer. Responses, except for the item identification task, were oral. The experimenter was present at all times and recorded the oral responses on special forms for each task. A pilot study indicated that
experimenter-recording errors were nominally zero and therefore no other method of recording answers was used as a backup.

After the completion of the study, each subject was given an oral and written debriefing. The experimenter answered any further questions about the experiment at this time.

**Memory Span Task**

**Procedure.** Subjects initiated list presentation by pressing the space bar on the computer keyboard. After one sec the first word appeared in the middle of the screen for .75 sec. The word was then followed by a blank screen inter-stimulus-interval of .25 sec. This process of .75 sec presentation and .25 sec of blank screen was continued until the predetermined number of words in the list was presented. Following presentation of the last word, the screen remained blank. This was the subject's cue to begin oral recall of the just-presented list. Recall was scored by the experimenter, who checked off correct words and their order on a tally sheet.

Lists of length four to 10 were presented. Six lists of each length were prepared for possible presentation. The following procedure was used to determine list presentation: Each subject was tested three consecutive
times with lists of length four. If recall was perfect on all of the first three lists, the subject was not tested on the three remaining four-word lists but received full credit for them. If a subject perfectly recalled only one or two of the first three lists, the subject was tested on the remaining three four-word lists. All testing was stopped and the memory span task considered completed when the subject perfectly recalled none of the first three lists. If any list of length four was perfectly recalled, the above procedure was repeated using lists of length five, and so on, increasing the list length by one any time at least one of the six possible lists at each length was perfectly recalled.

At some point, either through failure to perfectly recall any one of the first three lists of a given length, or upon reaching the list length of 10, the memory span session ended. After a one- or two-minute break, a second memory span session was begun. Procedurally, the second was identical to the first session; the only difference being that the second used different stimuli. For some subjects there was one additional difference: any time a subject failed to perfectly recall at least three of six four-word lists in session one, that subject was started with lists of length three in the second session.
**Scoring.** A list was considered to be perfectly recalled only if all the presented words were recalled and in their presented serial order. Each perfectly-recalled list counted one point. Thus, six points were possible for each list length per session. The memory span score was determined by finding the number of perfectly-recalled lists at each list length and then using these values to calculate the median list length recalled. For example, suppose a subject perfectly recalled five four-word lists, four five-word lists, and one six-word list. Using the longest list length at which the subject scores three or more and the shortest list length at which the subject scores less than three as endpoints and interpolating, the median recallable list length would be 5.33. Each subject's memory span score was calculated in this manner for each session. A third memory span score was found by collapsing across both sessions and treating the data as if they were based on a single session of 12 lists per length.

**Proactive Interference Task**

**Procedure.** The proactive interference task involved recall from four, five-word lists in each of four categories of words. The list presentation was category-based; all four lists in a category were presented before changing categories. The order of presentation of
categories was identical for all subjects. Stimuli were one-syllable nouns which fell into the following categories: body parts, articles of clothing, food, and animals. Subjects initiated list presentation by pressing a keyboard space bar. Stimuli were presented at a rate of .75 sec per word with a .25 sec inter-word interval - identical to the memory span presentation rate. Following the fifth word there was a .25 sec inter-stimulus interval, after which a string of four, two-digit, random numbers was displayed on the screen for four secs. Subjects had been previously instructed to read aloud the presented number string. Immediately following the reading of these numbers, subjects began oral recall of the just-presented word list. No restriction was placed on the order of recall. The experimenter recorded the subjects' recall on a prepared tally sheet. Subjects were not told of the categorical nature of the stimulus material, nor of the total number of lists, merely that this was a modified, free-recall task, with the number of words in each list fixed at five.

**Scoring.** Each of the four categories was considered a replication of a single category proactive interference task. Within each category, four lists were presented. Based on previous research (Wickens, et al., 1973), one
might expect all subjects to show near-perfect recall on the first list and, to the extent that an individual is susceptible to proactive interference, he or she would be increasingly less accurate on the second through the fourth lists. One possible method of estimating a subject's susceptibility to proactive interference would be to find the difference between the subject's first list and fourth list performance. As one of the goals of this research was to estimate the reliability of susceptibility to proactive interference and since difference scores are known to produce unreliable indices (Lord, 1963), an alternative scoring method was sought. Subjects' fourth-trial scores were statistically corrected for first-trial performance by ANCOVA methods. The resulting residual fourth-trial scores were used to indicate the amount of resistance to proactive interference evidenced by a subject.

**Item Identification Speed Task**

**Procedure.** The concept of item identification was operationalized as item recognition latency and was determined in a two-part process designed to control for motor-response time. This two-part process consisted of a lexical decision task and a choice reaction time task. A three-stage model was assumed to describe the lexical decision task. The first, or decision, stage was viewed as
essentially equivalent to item identification. The second and third stages consisted of selecting the appropriate response key and executing the motor response. The choice reaction time task was used to approximate these last two stages of the model.

In the lexical decision task, subjects were instructed to respond as quickly as possible indicating whether a just-presented stimulus was a noun or a nonsense word. Stimuli consisted of 25 single-syllable nouns and 25 nonsense words. The nonsense words, taken from a study by Rubenstein, Lewis, & Rubenstein (1971), were those shown to have longer latencies, indicating high similarity to words. Subjects were instructed to press the "Z" key with the left index finger for a nonsense-word response and the "/" key with the right index finger for a noun response. These keys are found on the left and right ends of the bottom row of the TRS-80 keyboard. At the beginning of each trial, subjects' index fingers rested immediately below these keys. The presentation order for the 50 stimuli was randomized. Each trial began with the word "ready," signifying that a stimulus would appear on the screen in one sec. The stimulus then appeared and remained until subjects responded. Subjects decided if the item was a word or a nonword, and pressed the appropriate key. The screen
then cleared, and the next trial began two secs later. The dependent measure was the latency from stimulus presentation to the press. Subjects were instructed to make speed/accuracy trade-offs in favor of accuracy.

In order to distinguish decision time from motor-response time, a choice reaction time measure was determined for each subject. Choice response time was measured on 50 trials, 25 correct responses associated with each of the two keys used in the earlier part of the experiment. Presentation order was randomized. Each trial began with the word "ready" preceding the stimulus by one sec. Following the ready signal, an asterisk appeared either to the left or the right of center screen, designating which key was to be chosen. The asterisk remained on the screen until either key was depressed. The screen then blanked out, signalling the end of the trial. The next trial began two secs later. As in the lexical decision task, the dependent measure was the latency from the onset of the asterisk to the depression of a key.

**Scoring.** The item identification speed measure involved the assumption of a simple additive model for the lexical decision task, as described above. Therefore, choice reaction time was seen as including the same components as lexical decision latency, excluding the
decision component. A median lexical decision latency was calculated for each subject based on correct-response latencies to the "word" stimuli. Each subject's median choice reaction time was computed from the correct-response latencies associated with the word stimulus key. The item identification speed measure was calculated as the residual score when subjects' median choice reaction times were covaried out of subjects' median lexical decision times.

**Memory for Order Task**

As described in the introduction, Healy (1974) carried out research on memory for order. She found two measures: recall for items without the influence of order and recall for order without the influence of item memory. In this study, Healy's method is replicated and extended to longer list lengths (c.f., Drewnowski, 1980).

**Item span procedure.** The item recall task required that subjects recall words from lists of lengths three to seven. Following Healy, each word in the list corresponded to a separate category, and each category occupied a unique serial position. For example, the category "bodies of water" was always associated with the second serial position. Thus, when a word like "lake" or "sea" was presented, it always appeared as the second word in the list.
Three words were associated with each category. One word was randomly selected for presentation on each trial with the constraint that, in the series of five trials per list length, a word could not appear more than twice. For example, if the categories "trees," "bodies of water," and "house parts" were used to construct lists of length three, a subject might be presented the list: "oak, sea, roof" or the list "elm, sea, door." Subjects received five trials at each list length before being presented with trials of the next longer list length. The inter-list interval was self-determined by each subject.

Each trial was initiated by the subject pressing the space bar on the keyboard. A word appeared on the video screen for .75 sec with a .25-sec blank screen between each word. Following presentation of the final word in a list, three, two-digit, random numbers appeared on the screen for four secs. Subjects were instructed to say these numbers aloud as they appeared on the screen, and then immediately begin oral, ordered recall of the just-presented words. Correctly ordered category labels were visible throughout recall to provide knowledge of serial position. Thus, the burden of remembering an item's serial position was removed. By supplying these ordered category labels, transposition errors were eliminated. Observed errors in
recall could thus be attributed to item recall failure.

**Scoring.** An overall item span measure was calculated for each subject in a manner similar to the methodology of the memory span measure. Every trial was scored either correct (receiving 1 point) or incorrect (receiving 0 points). No partial credit was given. For each list length, scores ranging from zero to five could be obtained. The final item span measure was median list length recalled.

**Order span procedure.** The procedure used in the memory-for-order task was similar to that of the item-span task. Subjects attempted to recall lists of lengths three to eight. Subjects were given five trials at each list length. All five trials at a particular length were presented before increasing the length. Presentation rate and distractor task were identical to those used in the item-span task. The requirement for ordered recall was also identical to that of the previous task. The distinction between the two tasks lay in the stimuli and the recall cues. Each of the five lists of a given length contained the same words. However, at each presentation of such a list, the serial order of the words was different. For example, if the words used in the three-item list were "kite," "roof," and "barn," subjects saw these three words
presented on each of the five trials, but in a different order each time. The recall cues for this task were the items themselves. They were printed on a card and available to the subject during recall (their printed order was different from any of the list presentation orders). In the above example, a card with the words roof, barn, and kite was given to the subject for use at the time of recall. Thus, "item" loss was prevented and errors were due to loss of order information. Note that ordered recall was required.

**Scoring.** The scoring procedure was identical to that for the item-span task.
Results and Discussion

The results of the experiments will be used in three ways. The first involves the estimation of reliability coefficients for each of the tasks. The second generates a multiple regression analysis relating all the tasks to memory span. A final analysis explores possible differences in the constellation of processing skills people exhibit and the relationship of these skills to memory span performance.

Descriptive Statistics and Reliability Estimates

Reliability estimates and other descriptive data for the various tasks will be presented on a task by task basis. A preliminary analysis confirmed that no effect of presentation order was evidenced by any task (all F ratios ≤ 1.14, df = 2, 87). Hence, the results discussed below are based on data from all 90 subjects.

Memory span. The mean memory span and other descriptive data for 90 subjects are shown in Table 1. Note that the overall memory span measure is not the simple mean of the two separate sessions. Rather, the value was calculated by combining the results for each list length from the two sessions and then calculating the median list

29
### Table 1

**Descriptive Statistics and Reliability Estimates for Five Information Processing Tasks**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean</th>
<th>Sd</th>
<th>Range</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory Span</td>
<td>4.92</td>
<td>0.709</td>
<td>3.56</td>
<td>8.00</td>
</tr>
<tr>
<td>Resistance to Proactive Interference</td>
<td>0.00</td>
<td>2.797</td>
<td>-5.73</td>
<td>7.14</td>
</tr>
<tr>
<td>Item Identification Speed</td>
<td>0.00</td>
<td>0.095</td>
<td>-0.32</td>
<td>0.24</td>
</tr>
<tr>
<td>Item Span</td>
<td>4.95</td>
<td>1.263</td>
<td>2.63</td>
<td>7.00</td>
</tr>
<tr>
<td>Order Span</td>
<td>4.89</td>
<td>1.098</td>
<td>2.63</td>
<td>7.25</td>
</tr>
</tbody>
</table>

*Based on multiple regression analysis. See text for details.*
length based on 12 trials instead of six. The mean word memory span observed in this study compares favorably with means found by several other investigators, which range from 4.60 to 5.77 (Brener, 1940; Brown & Kirsner, 1980; Cranell & Parrish, 1957).

Since two independent memory span measures were taken, sessions I and II, one may consider each session as a parallel form of the test. Using an ANOVA model in which the variance within a subject and the pooled, within-subject variance each estimate error of measurement (see Winer, 1971, p. 283), the unbiased estimate of reliability for the memory span measure was found to be .869. Reliability in the present study falls in the upper range of those reported. Jensen (1980) reports reliability coefficients for memory span in the range .40 to .93.

**Proactive interference.** The design of this study yielded a four by four matrix of scores, as there were four trials within each of four word categories. Adding across categories, the mean numbers of words recalled per trial (on trials one through four) were 16.77, 15.36, 13.60, and 12.97 out of 20. These means show the characteristic decline associated with the build-up of proactive interference. The linear trend across the means was highly significant $F(1, 267) = 65.163, p < .001$, accounting for
about 97% of the variance due to trials.

One can consider each of the four word-categories as providing a replication of a one-list, proactive interference task. In this context, the residual score associated with each category provides an estimate of a subject's resistance to proactive interference measure. Accordingly, the reliability of the proactive interference measure was estimated by the same model used for the memory span measure. The calculations yielded an unbiased reliability estimate of .493. This estimate is not particularly large, a finding which may be due to the small number of replications per subject. Obviously, reliability would probably be increased by increasing the number of replications. For example, just doubling the number of word categories used would have had the effect of raising the reliability from .493 to .660, other things remaining equal. While not demonstrating the magnitude of reliability associated with memory span, the reliability of the proactive interference measure is adequately high for the purposes of this study.

**Item identification speed.** Recall that the item identification speed measure is based on a subject's median lexical decision and median choice reaction time latencies. Each of these median reaction times is based on the number
of "correct" responses exhibited by the subject. For the lexical decision task, subjects averaged a 94.3% hit rate while the mean percentage of correct trials in the choice reaction time task was 99.6. Thus, subjects' median latencies and their resulting item identification speed measures are based on very acceptable hit rates. Table 1 presents the descriptive statistics for item identification speed.

The reliability of the item identification speed measure was estimated as the reliability of the difference between two scores, lexical decision and choice reaction time. Using the ANOVA model described above, the reliabilities for the lexical decision and choice reaction time tasks were .915 and .957. Knowing these reliabilities and the correlation between the tasks (which was .7015), one can derive the reliability of their difference, .786: the reliability of item identification speed. While not as high as that for lexical decision or choice reaction time measures, the reliability of item identification speed is high, given that it was necessary to estimate it from a difference score rather than from an independent measure of item identification speed.

**Item and order span.** Though basically replicated by Drewnowski (1980), Healy's (1974) method for deriving
measures of item and order span has not been used in any study of individual differences. Since there has been some debate in the literature as to the independence of these two concepts (c.f., Murdock & Vom Saal, 1967), performance differences on these two measures were given close scrutiny. Examining the descriptive data in Table 1, one might be led to the conclusion that both tests are measuring the same aspect of memory. Two lines of evidence suggest that this is not the case. The first is the correlation between the two measures: only .425. While this correlation is significantly greater than zero (p < .01), under the assumption that the two tasks are actually measuring the same process (or processes), one might expect a much stronger relationship. Of course, if their reliabilities were small, one might expect a small correlation.

Stronger evidence suggesting that these two measures are indeed tapping two separate concepts comes from an examination of the effects of increasing list length and an analysis of serial position curves. In Table 2 we find the mean proportions of words recalled for each list length, collapsed across serial positions and conditions. Subjects recalled more words in the item condition than in that for order, \( F(1, 89) = 73.91, p < .001 \), and recalled more words
<table>
<thead>
<tr>
<th>Condition</th>
<th>List Length</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>3</td>
<td>.918</td>
<td>.847</td>
<td>.807</td>
<td>.738</td>
</tr>
<tr>
<td>Order</td>
<td>4</td>
<td>.887</td>
<td>.783</td>
<td>.690</td>
<td>.522</td>
</tr>
</tbody>
</table>
at shorter versus longer list lengths, $F(4, 356) = 81.71, p < .001$. The significant main effect of condition by itself could be taken as indicating that the item task was simply easier than the order task. However, with the finding of a significant task by list length interaction, $F(4, 356) = 13.38, p < .01$, one must conclude that the two tasks are different in some way.

This difference is highlighted when one compares the serial position curves for the two tasks. As can be seen in Figure 1, there is a dramatic qualitative difference between the two sets of curves. The curves for the item task show only a modest decline as a function of serial position and are distinguished by a marked recency effect. Those curves associated with the order task show very little recency effect, with the exception of lengths five and six. To confirm these observations, each pair of equal-length curves was subjected to a two-way, serial position by recall condition ANOVA. Except for lists of length three, the serial position by recall condition interactions were found to be significantly greater than zero (all ps < .005), indicating that the curves differed in their shapes. Thus, combining the correlational evidence, the finding that recall under the two tasks differs as a function of list length, and the serial
Figure 1. Comparison of Serial Position Curves for the Item and Order Memory Tasks
position curves differ, we may conclude that, indeed, the two tasks are measuring different aspects of memory.

Due to constraints of time for each experimental session, only one estimate of each subject's item and order spans was collected. Thus, standard estimates of their reliability cannot be made. However, there is a way to provide a lower bound estimate. Under classical reliability assumptions (Guilford, 1954) measurement error correlates zero with both true scores and error scores in different tests. Therefore, only true score portions of the observed scores are reflected in correlations among different measures. Since the reliability of any test must be at least as great as the squared correlation between that test and any other measure or composite measure, one can find a lower bound estimate through multiple regression analysis. This approach was taken to estimate the minimal reliability coefficients for the item and order tasks.

Using scores from the memory span, proactive interference, and item identification speed tasks, as well as the item and order tasks, the multiple R-squared was calculated for item- and order-span from the remaining four tasks. The results of these analyses yielded reliability estimates of .351 and .399 for the item- and order-span tasks, respectively. These values are by far the lowest
estimates found for the measures used in this study. One can only point out that these are the minimal values the reliabilities can be. Hopefully, the actual values are higher.

**Multiple Regression Analysis of Memory Span**

One of the primary goals of this study was to determine the extent to which individual differences in memory span may be accounted for by individual differences in several underlying tasks. In addition, the design chosen allows for the identification of each such task's relative contribution to the joint prediction of memory span differences. In order to achieve this, subjects' scores on the various tasks were correlated with their memory span scores and with each other. Table 3 presents the simple correlations between memory span and the four information processing measures. All simple correlations are significantly different from zero, \( p < .02 \). Proactive interference, item span, and order span were approximately equally correlated with memory span. This indicates that subjects who show less proactive interference and more item and order recall tend to exhibit longer memory spans. Item identification speed correlated with memory span somewhat less than the other measures. Thus, it has been demonstrated that people differ in their abilities in these
<table>
<thead>
<tr>
<th>Measure</th>
<th>Correlation with Memory Span</th>
<th>Standard Weight</th>
<th>Raw Weight</th>
<th>t(df=85)</th>
<th>Prob(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance to Proactive Interference</td>
<td>.408</td>
<td>.184</td>
<td>0.047</td>
<td>2.059</td>
<td>&lt; .05</td>
</tr>
<tr>
<td>Item Identification Speed</td>
<td>.259</td>
<td>.165</td>
<td>1.208</td>
<td>2.007</td>
<td>&lt; .05</td>
</tr>
<tr>
<td>Item Span</td>
<td>.503</td>
<td>.271</td>
<td>0.152</td>
<td>2.977</td>
<td>&lt; .005</td>
</tr>
<tr>
<td>Order Span</td>
<td>.566</td>
<td>.352</td>
<td>0.227</td>
<td>3.771</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

*Constant added to regression equation = 3.054
tasks (as was shown in Table 1), and such differences are indeed significantly related to observed differences in memory span.

A multiple regression analysis was undertaken to determine the relative contribution to memory span of each processing task when all four tasks are jointly considered. The results of this analysis are presented in Table 3. Perhaps the most important finding is that each task contributes significantly in accounting for variance in the memory span task. This is true for each task, independent of the other tasks. While each task is related to memory span, each is unique in its own contribution. In terms of magnitude of contribution, order span is greatest, followed by resistance to proactive interference, item span, and item identification speed. In all, these tasks accounted for 45.30% of the observed variance in memory span, the multiple correlation being .67, F (4, 85) = 17.60, \( p < .0001 \). Table 3 presents the raw weights and constant for the memory span multiple regression equation. The standard error of the estimate, the root mean squared variation of the predicted and observed scores, was .536.

The results of this analysis suggest that memory span is more complex than presumed previously. The magnitude of independent contributions shown by the various processing
tasks reflects this complexity and indicates that additional processes are probably related to memory span. On the average, higher scores on the processing tasks were associated with higher memory span scores. However, there is much variability in each of these measures. This variance may indicate that the distribution of performance abilities differs from task to task. This possibility is examined in the final set of results.

**Clustering Subjects by Information-Processing Differences**

As suggested, it is possible that there may be differences in the level of processing skills exhibited for each subject. If there are unique, identifiable patterns of processing skills, they may provide new information concerning memory span ability. Thus, entirely different skill combinations may be related to memory span differences across subjects. Some individuals may show weakness in all skills, and it would be expected that they would do poorly in the memory span task. The converse is equally true. The interesting question, however, is not how well individuals perform on memory span if they are either poor or outstanding at every task, but how well they perform given a specific profile of processing task performance.

To answer this question one must first identify
homogeneous groupings or clusters of individuals. To do this, a Linear Typal Analysis (Overall & Klett, 1972) was used to define subject groupings. Conceptually, Linear Typal Analysis is similar to a Q-type factor analysis, with one exception. In Linear Typal Analysis, the origin of the person space is shifted to create an optimal profile elevation for distinguishing subsets of groups. As a consequence of this elevation adjustment, factor axes can be positioned so that profiles for each homogeneous cluster tend to project highly on only a single factor. The factor on which the profile has its highest projection is determined and the profile is then assigned to the cluster associated with that factor. As a final step, a mean profile is calculated to represent each cluster.

Subjects were clustered on the basis of similarity of their four information processing task scores. The analysis yielded four groups whose average task scores are given in Table 4. Note the manner in which the means differ from group to group. For example, group two shows the fastest item identification speed and the greatest resistance to proactive interference. Group three's order span is greater than the other groups', while group four evidences the largest mean item span. Also shown in Table 4 is the mean memory span score for each group. Since memory
### Table 4

**Mean Scores for Groups Determined by Linear Typal Analysis**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Resistance to Proactive Interference</td>
<td>-1.55</td>
</tr>
<tr>
<td>Item Identification Speed</td>
<td>-0.11</td>
</tr>
<tr>
<td>Item Span</td>
<td>3.96</td>
</tr>
<tr>
<td>Order Span</td>
<td>3.99</td>
</tr>
<tr>
<td>Memory Span</td>
<td>4.34</td>
</tr>
<tr>
<td>N per group</td>
<td>20</td>
</tr>
</tbody>
</table>
span was not used to define group membership, the hypothesis that there are no differences among the groups' average memory spans can be tested. When tested, the results indicate the groups do differ on the memory span measure, $F(3, 86) = 6.81, p < .001$. Thus, four subsets of subjects have been identified based on subjects' information processing task profile similarities. These subsets differ significantly in their mean memory span performance.

In order to facilitate the description of group differences along the four measures, the data were subjected to a Multiple Discriminant Analysis. The resulting discriminant function coefficients, discriminant function means, and between-group distances are given in Table 5. Each discriminant function represents a dimension along which the groups differ significantly, $p < .01$, as is evidenced by the Chi-square statistic with which it is associated. The first function's weights primarily contrast groups on their item span and item identification speed versus order span scores. This contrast is the source of the greatest variance among the four groups and is significantly correlated with individuals' memory span scores ($r = .386, p < .01$). The second dimension reflects group differences by contrasting the combination of order
### Table 5

**Several Multiple Discriminant Analysis Statistics**  
for Groups Defined by Linear Typal Analysis

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Measure*</th>
<th>DF</th>
<th>Chi-Square</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>1</td>
<td>1.065</td>
<td>-0.597</td>
<td>0.236</td>
</tr>
<tr>
<td>2</td>
<td>-0.577</td>
<td>0.957</td>
<td>0.189</td>
</tr>
<tr>
<td>3</td>
<td>-0.443</td>
<td>-0.642</td>
<td>1.160</td>
</tr>
</tbody>
</table>

*I = Item span  
II = Order span  
III = Proactive interference  
IV = Item identification speed

### Discriminant Function Means

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Linear Typal Analysis Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>1</td>
<td>0.63</td>
</tr>
<tr>
<td>2</td>
<td>0.70</td>
</tr>
<tr>
<td>3</td>
<td>-5.82</td>
</tr>
</tbody>
</table>
span and item identification speed with item span. This contrast is also significantly correlated with individuals' memory span scores ($r = .394$, $p < .01$). The third discriminant function, while significantly accounting for differences between groups, does not appear to relate directly to memory span, its correlation with memory span being .096.

Restricting this discussion to the two discriminant functions correlated with memory span (functions one and two), and examining their individual weights, the two functions differ only on the weighting of item- and order-span task performance. This becomes more apparent when looking at the discriminant function means for the first two contrasts. Note the correspondence between group means on the first discriminant function and the group means on the item-span task in Table 4. Thus, the first dimension along which the groups differ may be named the item-span dimension. In a similar manner, means associated with the second discriminant function fall in the same rank-order as those group means for order-span found in Table 4. The second dimension may thus be named the order-span dimension. As stated previously, subjects' scores along both dimensions are significantly correlated with memory span performance.
Combining information from the Linear Typal Analysis and the subsequent Multiple Discriminant Analysis reveals that subjects differ in their profiles of information-processing task performance. Subjects were found to cluster into one of four homogeneous groups. These groups reliably differed on their average memory span performance. Further investigation of the nature of the group differences indicated they varied along two dimensions relevant to memory span. Both dimensions were composites of primarily item span, order span, and item identification speed. They differed in the relative importance of item span in the first and order span in the second dimension. However, scores along both dimensions were significantly correlated with memory span. Thus, although subjects show differing patterns of information-processing performance, more than one pattern results in above-average memory span performance.
General Discussion and Conclusions

Memory span, far from its original and popular conceptualization as simple capacity, appears to be quite complex. It involves, at a minimum, measurable components of forgetting (proactive interference), a perceptual phenomenon (item identification speed), and two memory attributes (item and order memory). The results of this study establish and extend the relationship between memory span and certain information processing tasks into the young adult population and provide simple, reliable methods for their measurement. Each task contributed significantly to the prediction of individual differences in memory span.

While the item identification speed task has been previously linked with memory span (i.e., Case, et al., 1982), its operationalization by Case was somewhat different than here. Its simple correlation with memory span in this study was .26 as compared to the value reported by Case (r = .35). In both instances, the correlations are found to be significantly different from zero, indicating that, taken as a group, individuals who take longer to identify a word have shorter memory spans. Thus, item identification speed has been interpreted as
reflecting "operational efficiency" (Case, et al., 1982, p. 389) in individual cognitive processing.

Susceptibility to proactive interference, which had previously been demonstrated empirically in terms of mean group differences (Leslie, 1975), was found to reliably relate to individual differences within this sample of adult subjects. Further, the magnitude of proactive interference exhibited was significantly correlated with memory span. Those with little interference tended to have higher memory span scores. These data suggest that proactive interference, which might be considered a "nuisance" variable in the evaluation of one's memory span, may differentially handicap subjects. Until a properly controlled study is run, perhaps by sufficiently spacing memory span lists, a more exact determination of this variable's effect on memory span cannot be made.

The last two measures, memory for order (order span) and its experimental complement, item span, are both reliable correlates of memory span. This study supports the idea that the two measures appear to reflect different processes. However, serial position effects observed in the present study do not closely resemble those obtained by Drewnowski (1980). This failure to replicate may not be surprising, given that Drewnowski's subjects attempted to
recall letter strings, while the stimulus items in this study were words. Memory span is, of course, an order-dependent task. The results for order were as expected. Subjects showing less order memory also evidenced shorter memory spans. The same was found to be true for item span recall. Such results may not be surprising, but they do provide experimental support for the relationship. As a whole, the results of this study indicate that several information processing correlates are closely related to memory span. Moving a step further in the analysis, the results from the multiple regression analysis demonstrate the independent relationship of the various tasks to memory span.

Though this study yielded significant correlations between several, logically-independent tasks and memory span, one is faced with the possibility that a unitary phenomenon underlies all of these tasks. Such a phenomenon could possibly be the source of observed correlations with memory span. The fact that each task independently contributed significantly to the prediction of memory span reduces this possibility. Each task appears to capture a unique aspect of memory span. This finding strengthens the idea that memory span is a complex phenomenon.

Examining the data at a more complex level, one can
explore the manner in which these processes are distributed in the current subject population. The clustering results suggest subjects are well described on more than a single continuum. Such a unitary continuum underlying the data would have been found had all subjects' abilities in one area correlated highly with their abilities in all other areas. Indeed, the typical analysis generated four distinct groups whose mean scores on the predictor tasks took the form of four complex patterns. The groups had significantly different mean memory span scores. Such a finding indicates that certain information processing abilities, or combinations of such abilities, may be more important in determining one's memory span performance than others. However, the designation of certain combinations of skills as more critical than others can only be speculative at this time. The stability of groups identified in the current analysis would need to be ascertained before generalizations to other individuals could properly be made. However, the methodology does appear to be fruitful for mapping the interrelationships of a group of information processing tasks to a higher-order task.

Such an approach is reminiscent of those advocated by several authors (Hunt, Frost, & Lunneborg, 1973; Carroll,
1976; Chiang & Atkinson, 1976; Resnick, 1976), but differs in an important manner. Such investigators used extremely low-level tasks, such as the slope of a visual- or memory-search task, as predictors. As criteria, much more global measures, such as Scholastic Aptitude Test scores, were used. There may, of course, be myriad moderating variables between such disparate measures. The point is, one can simply correlate measures without presuming a theoretical link. The numbers may be impressive, yet devoid of meaning. In the present study, which is perhaps more modest in design, findings were based on predictors previously shown to have an empirical or logical relationship to the criterion. This contrast of approaches may appear to be subtle, but the differences are crucial. If the links among the tasks are not theory-bound, such correlational methods of analysis will yield as little true advancement in knowledge as factor analysis has yielded for the concept of intelligence.

The individual-differences approach to cognitive psychology can lead to a fruitful application of that which is currently known about cognition to various research problems. A specific instance of this approach in a quite different content area involves the assessment of changes in cognitive functioning, concurrent with the
administration of various psychotropic drugs (c.f., Davis, Hollister, Overall, Johnson, & Train, 1976). In this area, both psychopharmacology and cognitive psychology benefit from a close interaction. Researchers in psychopharmacology gain from having sensitive and diverse measures of cognitive change. Researchers in cognitive psychology gain valuable insight into the interaction of various cognitive processes as they are related to various drug treatments which have known biological consequences. Other populations which have been the object of research in cognition are the very young (e.g., Case, et al., 1982) and the aging (e.g., Fozard, 1980). Investigators have even taken cross-sections of the life span for purposes of measuring cognitive change (e.g., Horn, 1980). For many reasons, most research in these areas has not taken an individual differences approach to the assessment of cognition. Research tactics are beginning to change, however, as the individual differences approach provides us a method for refining our knowledge of cognitive processes. It is certainly too early to consider the present results in terms of a unique cognitive structure for describing individual differences in memory span, or even as specifying the nature of homogeneous subsets of people. However, this general approach to individual differences in
cognitive functioning is promising. It is true that different analyses will yield different results, depending on the nature of the tasks chosen and the subject population from which one samples. However, applications of this methodology might fruitfully augment cognitive psychology's more standard methods of inquiry.

Memory span does not owe its widespread use to laboratory research. It is a measure of cognition which is assessed daily in diverse settings such as schools, psychiatric wards, and head trauma clinics. Its usual interpretation has been one of memory capacity; however, previous investigation (i.e., Underwood, et al., 1979) indicates it is different from other memory measures. The results presented here suggest it is a complex phenomenon, involving several underlying processes. This does not make memory span less useful, but points to the intricacies of the human cognitive system.
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Appendix

Intercorrelation Matrix of Four Information Processing Variables and Memory Span Based on 90 Subjects

<table>
<thead>
<tr>
<th>Variables*</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td></td>
<td>.4247</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>.3413</td>
<td></td>
<td>.3785</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>.1191</td>
<td>.1797</td>
<td></td>
<td>-.0068</td>
</tr>
<tr>
<td>V</td>
<td>.5025</td>
<td>.5663</td>
<td>.4081</td>
<td>.2589</td>
</tr>
</tbody>
</table>

*I = Item span  
II = Order span  
III = Resistance to proactive interference  
IV = Item identification speed  
V = Memory span