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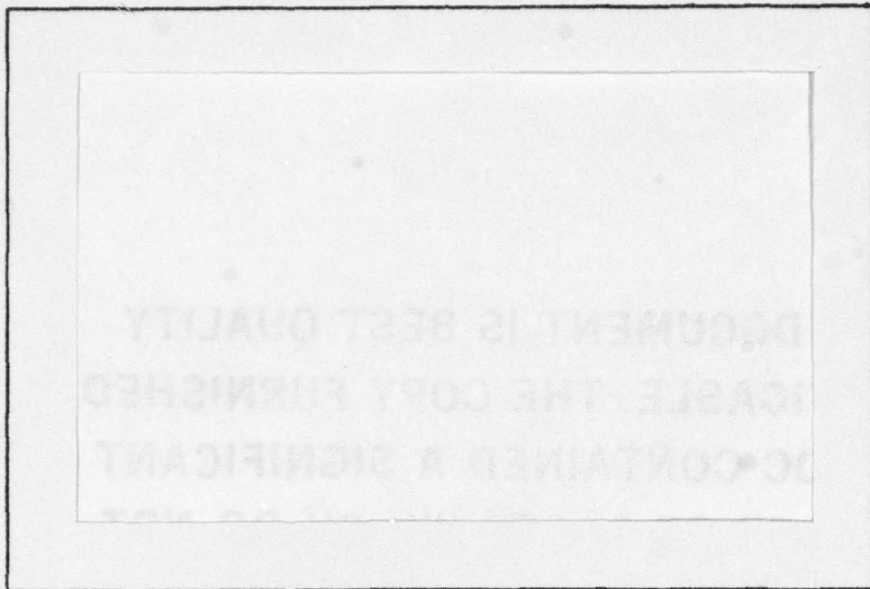
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Individual Differences in Memory Span

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Abstract

One series of experiments examined the correlation between memory span and the speed of symbol manipulation in short-term memory, and another experiment analyzed the effects of extended practice on memory span. In the first study, most of the estimates of processing speed did not correlate with memory span, and it was concluded that short-term memory capacity is not determined by the speed of symbol manipulation in short-term memory. In the second study, memory span greatly increased with extended practice, but this increase was due to the acquisition of a mnemonic system. Short-term memory capacity was unaffected by practice.

Individual differences in memory span are interesting from both a psychometric and an information-processing point of view. From a psychometric perspective, memory span is an important item on IQ tests because of the high correlations between memory span and IQ scores. It has been suggested that memory span is a good index of mental retardation and brain damage, but in the normal adult population, it probably is not a very good predictor of high-school or college grades (Matarazzo, 1972). Some people have even gone so far as to suggest that a pure measure of memory span--span ability--is the best culture-free determiner of intelligence (Bachelder & Denny, 1977a,b).

From an information-processing point of view, memory span is the most often used measure of short-term memory capacity, which in turn is one of the most important human limitations in thinking and problem solving (Newell & Simon, 1972). Recent information-processing studies by Cohen and Sandberg (1977) and Lyon (1977) have ruled out any obvious mnemonic coding strategies as causes of individual differences in short-term memory capacity.

It has been suggested by several people in the information-processing literature that memory span is related to the speed of mental processes in short-term memory. For example, Hunt, Frost and Lunneborg (1973), in their attempt to link psychometric and information-processing theories of intelligence, suggested that verbal intelligence is related to the speed of short-term memory processes. Baddeley, Thompson and Buchanan (1975) suggested that the speed of the rehearsal loop determines the memory span, in large part, because verbal items--those based on a phonemic code--tend to decay away within about 2 sec, and the function of rehearsal is to keep them from decaying. From their analysis of reading rates and memory spans, Baddeley et al concluded that people's memory spans are roughly equivalent to the number of words they can read in 2 sec. In a similar analysis, Cavanagh (1972) has suggested that there is a direct relationship between memory span and short-term memory search rates. From his analysis of memory span and scanning rates, Cavanagh concluded that it takes about 1/4 sec to search short-term memory. The implication is that people's memory search rates are determined by how many items are searched in 1/4 sec.

In this paper we will summarize work in our laboratory on two questions. First, are individual differences in memory span due to differences in the speed of symbol manipulation in short-term memory? And second, is it possible to increase one's short-term memory capacity with extended practice?

Speed of Symbol Manipulation

To summarize in advance our analysis of the first question, we have found very little evidence to support the idea that memory span is determined by the speed of symbol manipulation in short-term memory, at least in the college student population. We have run a series of experiments designed to establish the correlation between short-term memory processing rates and memory span, and one of the most interesting things we found was that the correlation between memory span and rehearsal rate is an artifact. In two studies, no relation was found between people's memory spans and their rehearsal rates for lists of digits well below memory span (3, 4, and 5 digits), but for lists that approach the memory span (6 digits), the correlation is about .50. This correlation is an artifact because people with low memory spans experience difficulties in remembering as memory load increases, and as a result, their rehearsal rate is slowed. There is no relationship between rehearsal rate and memory span for lists of digits below memory span.

In a larger study of 31 college students, we obtained, in addition to memory spans, reliable estimates of several information processing rates. These estimates included search for the presence of an item in short-term memory (Sternberg, 1966), search for the location of an item in short-term memory (Sternberg, 1967), and metered memory search (Weber & Castleman, 1969) in both short-term and long-term memory. The long-term metered memory search task in this study was alphabet search. In this task, the subject is presented both with a probe and a meter, and he must find the item located n places from the probe, where n is the meter. For example, a letter (H) and a number (3) are presented and the task is to name, as quickly as possible, the letter that appears 3 places later in the alphabet (K). This same procedure was used for short-term metered memory search except that the material to be searched is a random list of digits in short-term memory. In addition to these memory

search tasks, we measured the corresponding visual search speeds because we wanted an estimate of processing rates uncontaminated by memory load. Finally, we estimated several components of the rehearsal process, including the time to start rehearsal and the time to execute rehearsal. Start time is the time between onset of a GO signal and rehearsal of the first item, and execution time is the average inter-item time during rehearsal. The correlations between these various processing rates and memory span are shown in Table 1, along with the reliabilities. (Digit span reliability was .96.)

 Insert Table 1 about here

None of the visual search speeds correlated with memory span, nor did memory search for presence. The correlation between memory span and rehearsal execution time increased with memory load as before, but even with large memory loads the correlation was only -.41. Finally, the correlation between memory search for location and memory span is due to the same artifact that underlies the correlation between memory span and rehearsal.

There were only three non-artifactual correlations with memory span: metered short-term memory search, metered alphabet search, and rehearsal start time. At this point we can only speculate about the source of these correlations. In the metered short-term memory search task, it is possible that concurrent indexing (counting items until the meter is reached) imposes an additional load on short-term memory. This concurrent memory load could cause people with low memory spans to slow down. The correlations in the other two tasks--alphabet search and rehearsal start time--may indicate that people with low memory spans are also slower at activating information in memory. That is, people with low memory spans seem to be slower at accessing information in long-term memory, in secondary memory, or in whatever inactive storage systems are used when information is not in short-term memory, but once information is activated, they seem to process it at the same rate as people with high memory spans.

The data in these studies provide very little support for the idea that memory span is determined by the speed of symbol manipulation in short-term memory. If anything, our data suggest that memory span may indirectly affect processing rates. That is, people with low

memory spans may experience delays in processing as the memory load increases because they are forced to take extra time to update their short-term memory.

If the speed of symbol manipulation in short-term memory is not the major cause of individual differences in memory span, then what is? A good case can be made that memory span depends upon long-term memory knowledge structures and processes built up with practice (Chi, 1976). In the next section we explore the issue of whether short-term memory capacity can be increased with practice. An illustrative case study shows that digit span can be increased seemingly indefinitely if long-term memory coding structures are built up with practice.

Extended Practice

There are reports in the literature of increases in memory span with substantial amounts of practice (Gates & Taylor, 1925; Martin & Fernberger, 1924). Since memory span is such an essential ingredient both in psychometric theories of intelligence and information processing theories of thinking, it is of some interest to understand the nature of these practice effects. In our laboratory, we practiced one individual for about an hour a day, 3-5 days a week, for a year on the memory span task. In that time, his memory span increased steadily from seven digits to over fifty digits. How did he do it, and did he increase his short-term memory capacity?

Our analysis (Chase & Ericsson, 1978) indicates that this subject developed an elaborate mnemonic system, based primarily on running times for various races (e.g., 339 = three minutes and thirty-nine seconds, near world-record mile time). Our analysis further indicated that there was no increase in short-term memory capacity. The evidence is the following. First, when the subject groups digits together to form mnemonic codes, his groups are almost always 3- and 4-digit groups, and he has never generated a group larger than five digits. Second, the subject always maintains the last few digits (4-6 digits) as an uncoded rehearsal group, and he never allows the rehearsal group to exceed six digits. In fact, a 6-digit rehearsal group invariably is segmented as two groups of three digits. Third, the subject also hierarchically groups his groups together into supergroups. After some

initial difficulty in remembering 5-group supergroups, the subject generally uses 3-group supergroups and he never allows a supergroup to exceed 4 groups. Finally, when the subject was switched from digits to letters of the alphabet, there was no transfer, and his memory span dropped back to about six consonants.

The outcome of this study makes it clear that one must distinguish between memory span and short-term memory capacity. Memory span is limited both by the capacity of short-term memory and by coding processes, and the more elaborate the coding processes, the greater will be the discrepancy between memory span and short-term memory capacity. It is certainly possible to increase memory span by learning to code information so that it can be retrieved from long-term memory, but it does not seem possible to increase the capacity of short-term memory. It remains an important question to determine the extent to which the correlation between memory span and IQ is due to short-term memory capacity per se, and the extent to which coding processes are important.

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Footnote

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Table 1

Processing Speed Reliabilities (odd-even)
and Correlations with Digit Span

	Reliability Coefficient	Correlation With Digit Span
Visual Search for Presence	.90	.23
Visual Search for Location	.74	-.0-
Visual Metered Search	.84	-.17
Memory Search for Presence	.95	-.17
Memory Search for Location	.82	-.63**
Memory Metered Search	.87	-.62**
Alphabet Metered Search	.95	-.46**
Rehearsal Start Time	.99	-.59**
Rehearsal Execution Time	.99	-.38*

$p < .05^*$
 $p < .01^{**}$

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