

## *Individual Differences in Memory*

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Outside of our laboratories we will all admit to—indeed, sometimes even marvel at—the striking differences in memory that exist among people. Within the “normal” range, we are impressed when a friend remembers all of the lyrics to a song or knows the answers to a wide variety of trivia questions. With respect to more exceptional individuals, we find it difficult to imagine what it would be like to be learning disabled and unable to recall a phone number, or to be a mnemonist who can remember hundreds of names after a brief round of introductions. If not always this dramatic, individual differences in memory are still always important.

We cannot possibly have a good theory of the processes involved in remembering, either in a short-term or a long-term sense, unless we have procedures for assessing the status and change of such processes within individuals. As long as we throw possible within-individual and between-individual differences together in a measurement, we have no way to think clearly about the effects of variables in experiments . . . the sooner our experiments on human memory and human learning consider the differences between individuals in our experimental analyses of component processes in memory and learning, the sooner we will have theories and experiments that have some substantial probability of reflecting the fundamental characteristics of those processes.

*(Melton, 1967, pp. 249–250)*

Time and again, psychologists have called for a greater integration of individual differences into the development of our research and theorizing

*Memory*

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about psychological processes (Cronbach, 1957; Sargent, 1942). Although this request may have been made less often in the field of memory, it nevertheless has been made forcefully on occasion (Melton, 1967; Underwood, 1975). Techniques have even been proposed to decipher individual differences within experiments (Battig, 1979; Kareev, 1982), so that experimental psychologists will not have to calculate the dreaded correlation coefficient. Yet, rarely do cognitive psychologists examine or even consider individual differences, unless those differences are so obvious that they can no longer be treated as "error variance."

In fact, over the last one hundred years or so, a considerable body of work has accumulated relevant to the question of individual differences in memory, particularly over the past twenty-five years. Our goal in this chapter is to survey that work, especially the most recent research, attempting to draw out the basic principles and to demonstrate the relevance of these variations over people to theoretical development in the study of memory. To do so, we have chosen the most obvious organization, the one seen most frequently in introductory and cognitive texts. We first discuss individual differences in working memory and then turn to individual differences that are more related to long-term memory, concluding with a discussion of expertise that ties together many of the ideas in the two larger sections.

This organization is not meant to imply any structural distinction between working memory and long-term memory, though some individual differences work clearly supports such a distinction (Geiselman, Woodward, & Beatty, 1982). Rather, in addition to providing a convenient way to divide the labor between co-authors, it reflects the fact that there are two main ways to study individual differences. First, one can attempt to relate some intellectual ability measure (a test) to some cognitive process measure (a task), hopefully with the goal of evaluating a theory. This has been called the "cognitive correlates" approach (Pellegrino & Glaser, 1979). Second, one can delve into a cognitive task, attempting to identify different ways that different subjects perform that task, hopefully to shed light on the basic processes beneath. This has been labeled the "cognitive components" approach. In writing this chapter, we noticed an interesting feature of the work on individual differences in memory: The research on working memory largely uses the correlates approach, whereas the research on long-term memory primarily relies on the components approach. Thus, this distinction provided an additional rationale for our chosen organization. We begin, then, with working memory.

## I. WORKING MEMORY

Although the architecture of memory was conceptualized differently at the time, interest in individual differences in working memory goes back over

one hundred years. Because it is impossible to be fully comprehensive and to do justice to the entire corpus in any one review, we have restricted ourselves to three realms of research that reflect the field's theoretical development in the area of working memory: memory span, information processing tasks, and working memory capacity.

### A. Memory Span

Ebbinghaus (1885/1913) discovered that he could reliably learn to repeat in order lists of up to seven nonsense syllables after only a single study period, whereas lists of greater lengths required repeated exposures. From Ebbinghaus's pioneering serial learning experiments emerged a task initially called mental span, then later referred to as memory span. Surprisingly, despite continuing research interest, our understanding of performance on this modest task is still far from complete. In a standard forward memory span experiment, subjects are presented with a list of verbal items (typically from three to nine digits or letters) and then are immediately asked to recall the items in their presented order. Quite quickly, a more difficult modified version of the task was produced: Backward memory span required subjects to recall the items in reverse order of presentation. Though some researchers have varied the display of the stimuli, the form of the required response, or the method of scoring, the task has remained essentially the same over the past century.

Almost immediately, researchers began pursuing the question of whether memory span was connected to other individual differences in cognitive performance, usually more global measures of aptitude and achievement. Investigations, such as that of Jacobs (1887), found the forward memory spans of both boys and girls in the top of their classes to be greater than those of their cohorts at the bottom. Others found the memory spans of "idiots" (mentally retarded) to be inferior to those of normals (Galton, 1887). Pondering such findings, Oliver Wendell Holmes (1871) was one of the first to speculate on the implications, referring to memory span as a simple mental "dynamometer" that could have applications in education. Burnham (1888-1889), in one of the early reviews of research on memory, proposed that memory span "should be used as a test for cerebral fatigue" (p. 609) and called for investigation into the links between memory performance and general intellectual powers.

This early work did not go unnoticed by those occupied with constructing the first intelligence (IQ) tests. The memory span task was understood to be indexing a simple yet central ability. Thus, Binet and Henri (1895) held that it assessed an important individual difference fundamental to other higher order abilities. Since Binet developed his first instrument for identifying children who would not benefit from standard instruction, memory span has remained a constituent of most individual tests of intelligence and

mental status exams. And even as recently as 1977, Bachelder and Denny suggested constructing a general model of intelligence with memory span as the cornerstone. Its historical popularity has no doubt been based on the fact that it is uncomplicated to administer, simple to score, and easy to understand—or so it has been assumed.

Blankenship's (1938) review of the memory span literature highlighted several findings pertinent to individual differences. Critical for any task regarded to be a measure of individual difference is its stability. Blankenship's review of reported reliabilities revealed that the coefficients for six visual digit-span studies ranged from .68 to .93 and the coefficients for six auditory digit-span studies ranged from .28 to .80, leading him to conclude that "the test is one that shows surprisingly high reliability" (p. 7). When he examined memory span's relation to IQ, however, what he discovered was quite startling. The four correlations he found between forward digit-span and measures of intelligence (.03, .21, .16, and .18) clearly were less impressive than what would have been expected in light of the earlier studies and the weight Binet and others had put on the task. In contrast, the single study of reverse memory span that he reviewed produced a correlation of .75 with intelligence. In terms of sex differences, Blankenship located nine studies reporting the superiority of females on various memory span tasks, six studies reporting no differences between males and females, and five studies reporting some superiority of males on the task. Understandingly, he concluded that no judgment concerning sex differences in memory span could be made.

More recently, Miller and Vernon (1992) reported forward digit-span split-half reliability coefficients of .75 (auditory) and .66 (visual) and forward letter-span reliability coefficients of .26 (auditory) and .73 (visual). They assumed that the low reliability for the auditory forward letter-span task was connected to the fact that several of the letters used in the test were phonetically similar, thus producing interference. Roznowski (1993) found moderate test-retest reliability coefficients for both forward (.44) and backward (.50) digit spans.

Further research regarding reliability has also supported the belief that individual differences in memory span are consistent across stimulus materials and sensory modalities. Brener (1940) found that subjects whose memory spans were the longest for visually presented material tended to be those who had the longest spans for orally presented material as well. He also found that those subjects who performed well on memory span tasks with digits also performed well on tasks with letters, patches of color, words, and common geometrical shapes. Jensen (1971) affirmed the reliability of memory span across sensory modalities. He reported a strong relation between performances on visually and orally presented material (digits), and asserted that the two conditions were perfectly related when the correlations

were corrected for attenuation. A factor-analytic study conducted by MacKenzie (1972) provided confirmation for the across-material reliability. Others have reported significant correlations between memory span tasks using digits and words (Cantor, Engle, & Hamilton, 1991) and between tasks using letters and words (Palmer, MacLeod, Hunt, & Davidson, 1985). But the idea that there is a single important process or mechanism that dominates performance on all types of memory span tasks has been challenged somewhat in a recent study by Miller and Vernon (1992). Although they found a matrix of positive correlations among the forward digit- and letter-span tasks presented both orally and visually, the strength of the coefficients was notably less impressive than those found in the referenced studies presented earlier. The within-modality but across-material correlations were .40 and .42; the within-material but across-modality correlations were .30 and .11; and the across-modality and across-material correlations were .19 and .17.

The latest version of the WAIS-R, presently the most popular IQ test, corroborated the relations between tests of memory span, other tests of cognitive abilities, and overall IQ. Of central importance, research on the WAIS-R again demonstrated that memory span (Digit Span) was a reliable measure of individual differences. The test-retest reliability coefficients across adult age groups ranged from .70 (ages 16–17) to .89 (ages 25–34), with an average of .83 (Wechsler, 1981, p. 30). Additionally, Digit Span was moderately correlated with the other subtests ( $r = .43$ ) and with overall Full Scale scores (.58). One reason for the higher correlations between digit span and intelligence (Full Scale score) in comparison to the studies reviewed by Blankenship may be the fact that the Digit Span score on the WAIS-R is based on the subject's performance on both forward and backward digit-span tasks.

There is also evidence, however, challenging the long-held belief that memory span is of fundamental importance, or that it is at least predictive of psychometric measures of aptitude and achievement. For example, Rohwer (1967) failed to find a significant difference in digit span between two groups of children whose mean IQ differed by 18 points. Correlations between a modified version of forward digit span and Scholastic Aptitude Test (SAT) scores were found by Chiang and Atkinson (1976) to be near zero. In his commentary on the WAIS, Matarazzo (1972) concluded that memory span, as administered on the WAIS-R, although a useful diagnostic instrument for certain forms of organic disorder and mental impairment, is a poor measure of intelligence (p. 204). In his opinion, what justified the retention of digit span on the WAIS was its power to differentiate at lower levels of intelligence. Recently, Miller and Vernon (1992) correlated aural and visual forward memory span (digit and letters) tests with the ten subsets of the Multidimensional Aptitude Battery (MAB). The 40 coefficients

ranged from  $-.02$  to  $.27$  with a mean of  $.12$ . Still other researchers have reported mixed results. Palmer et al. (1985) found memory span (words) to be moderately correlated with both the Nelson–Denny (reading comprehension) test ( $.44$ ) and IQ ( $.24$ ), whereas the correlations between memory span (letters) and the two tests were considerably smaller,  $.17$  (Nelson–Denny) and  $.09$  (IQ).

Other researchers continue to report substantial correlations between memory span tasks and tests of aptitude or achievement. For example, Jensen and Figueroa (1975) found both forward and especially backward digit span to be correlated with IQ. Dempster and Cooney (1982) reported two experiments where memory span correlated with assorted measures of aptitude and achievement. Digit span correlated positively with SAT scores ( $r = .65$ ) and with College Entrance Examination Boards tests ( $r = .68$ ). In neither experiment, however, did digit span correlate significantly with the Nelson–Denny Reading Rate Test. Yet the Nelson–Denny Vocabulary Test was significantly correlated with memory span in both experiments ( $.66$ ). Finally, to further muddle the picture, whereas the correlation between memory span and the Nelson–Denny Reading Comprehension Test was nonsignificant in the first experiment ( $.30$ ), it was significant in the second ( $.50$ ).

Recent research does little to clear things up. Cantor et al. (1991) found memory span for words ( $.35$ ), but not memory span for digits ( $.04$ ), to be significantly correlated with the Scholastic Aptitude Tests (Verbal). In a test–retest study, Roznowski (1993) reported small to moderate (but significant) correlations between forward and backward digit-span tasks and scores on the American College Testing Program examination.

Regardless of its relation, or lack thereof, with aptitude and achievement, several explanations for individual differences in memory span itself have been offered. Historically, the most prevalent explanations have focused on the encoding of the stimulus list, contending that memory span reflects an individual's ability to group or *chunk* the individual items in the list (Blanchenship, 1938; Estes, 1974; Hunt & Lansman, 1975). Although there are numerous data demonstrating that these and other strategic variables affect memory span performance, there is evidence that calls into question their role as sources of individual differences. A study by Lyon (1977) has been influential in this regard. In the first experiment, subjects were tested at two different rates of item presentation:  $1/s$  (standard rate) and  $3/s$ . At a rate of  $3/s$ , subjects have sufficient time to recognize the digit and generate its linguistic code, but, unlike in the  $1/s$  condition, there is not enough time to rehearse preceding items. If individual differences in memory span are the result of rehearsal or chunking strategies, then performance on the task with the faster rate of presentation should be a poor predictor of performance on the task at the standard rate. Lyon (1977, p. 406) found, however, that the

correlation between performances on the two tasks was  $.82$  ( $.95$  when corrected for attenuation), indicating that individual differences are probably based on other factors.

In the second experiment, in addition to being tested again in the standard condition, Lyon presented subjects with the items temporally grouped by threes and told them to chunk the items into three-digit numbers (e.g., four hundred twenty-seven). If grouping and chunking are responsible for the individual differences, then a task where these variables were held constant should be unrelated to performance in the standard condition. The  $.85$  correlation between these two conditions again suggested that other factors are responsible for individual differences. Additionally, a study by Dempster and Zinkgraf (1982), where degree of chunking was indexed by the serial position of errors, supported Lyon's conclusion by finding no significant correlations between chunking and memory span.

Reflecting theoretical developments that accompanied the cognitive revolution, other explanations for the individual differences in memory span have stressed the subject's ability to identify items (Huttenlocher & Burke, 1976) or proficiency at encoding the order of items (Martin, 1978). Hoping to narrow the field of suspects, Dempster (1981) carried out an extensive review of the relevant literature. Like others, he also concluded that—although strategic variables such as rehearsal, grouping, and chunking influence performance and are related to age—it has not been convincingly demonstrated that any of these strategic factors are responsible for within-age individual differences in memory span. In his opinion, item ordering and, in particular, item identification were good candidates as possible sources of individual differences in memory span. In support of the item-identification hypothesis, Dempster pointed to research revealing a relation between how quickly subjects could name items of particular type (digits or letters) and the average memory span. For example, digits are named faster than words and yield greater average memory spans than do words; words are named faster than pictures and yield greater average memory spans than do pictures (Mackworth, 1963). No one, however, appears to have reported a within-material correlation between naming speed and memory span.

In summary, with respect to individual differences, memory span has received immense attention, far more than any other memory task. We can safely say that there is a reliably identified common factor relating memory span tasks across both sensory modalities and stimulus material. Furthermore, there are established individual differences in this factor that are at least moderately stable. Yet, the nature of this factor remains undetermined. The historically popular explanations for these individual differences are at best questionable, and the more recent hypotheses (item ordering and item identification) require further testing before any conclusions can be drawn

concerning their veracity. Finally, because of the continuing contradictory character of the empirical findings, we must conclude that memory span's relation to aptitude and achievement remains equivocal.

Before leaving this section, brief mention should be made of a related task, *span of apprehension*. Although the evidence is sparse, the account appears to be analogous to that for memory span. In a span-of-apprehension task, subjects again must immediately recall items in order; however, all items in the list are presented simultaneously for a brief period, usually 100 ms. With respect to reliability, Palmer et al. (1985) reported that span of apprehension for letters correlated with span of apprehension for words (.59). Regarding span of apprehension's relation to aptitude and achievement, they found that scores on the Nelson-Denny (reading comprehension) test correlated .05 and .31 with span of apprehension for letters and words, respectively. Scores on the Raven Progressive Matrices correlated .15 and .17 with the two span-of-apprehension tasks. Finally, with respect to the Palmer et al. study, of note is the fact that memory span and span of apprehension were unrelated. This result suggests that whatever process or mechanism is responsible for the individual differences in memory span apparently is not responsible for the individual differences in span of apprehension, differences that themselves remain to be explained.

## B. Information Processing Approaches

With the cognitive revolution of the 1960s and 1970s came the development of a host of information processing paradigms for researching memory. Psychologists concerned with individual differences in aptitude and achievement began employing many of these paradigms in their investigations in what came to be called the "cognitive correlates" approach (Pellegrino & Glaser, 1979). Typically, researchers would correlate performance on these information processing tasks with scores on standardized psychometric tests, in the hope of revealing the basic cognitive processes responsible for the individual differences on the more complex tasks found on tests of aptitude and achievement. Note that some of these information processing tasks are concerned with measuring the movement of information in and out of long-term memory and therefore are discussed in the second half of this chapter.

Some of the first and most ambitious cognitive correlates studies were carried out by Hunt and colleagues (Hunt, Frost, & Lunneborg, 1973; Hunt, Lunneborg, & Lewis, 1975). One of the short-term memory (STM) information processing measures that was thought to be promising was Sternberg's (1966) STM scanning task. Here, a subject is presented with a list of items (the memory set), usually digits or letters. The subject is then asked to determine, as quickly as possible, whether a probe item was in the memory set. The number of items in the memory set is varied from trial to

trial, typically ranging from one to seven digits or letters. Error rates usually are very low, so response latency is used as the dependent measure. Latencies have been discovered to be a linear function of the size of the memory set. The slop across memory set sizes (scanning time) has been construed as the time required by a subject to access a single item in STM, which could prove to be implicated in general intelligence or aptitude in specific domains, such as reading comprehension.

Unfortunately, the results have been less than compelling. Although Hunt et al. (1973) did report that the mean scanning time of 8 high-verbal subjects was shorter than the mean scanning time of 8 low-verbal subjects, they failed to find a relation between scanning time and quantitative ability. Chiang and Atkinson (1976) found scanning time to correlate with neither the verbal nor the mathematical portions of the SAT. The findings from more recent studies are somewhat less equivocal. Miller and Vernon (1992) found scanning time to have small but consistently negative correlations ( $r = -.12$ ) with the 10 subtests of the MAB. Similarly, Roznowski (1993) has reported weak negative correlations between scanning time and ACT (composite) scores of  $-.15$  on one occasion and  $-.07$  with the same subjects on a subsequent occasion. In summary, if scanning time is related to performance on aptitude tests, it likely accounts for only an extremely small proportion of the variance.

Although scanning time may not be a good predictor of individual differences in aptitude and achievement, it has been suggested that there are moderately reliable individual differences in scanning time itself. Chiang and Atkinson (1976), after testing subjects on three consecutive days, found test-retest correlations of .28 (Day 1/Day 2) and .78 (Day 2/Day 3). They concluded that there were reliable individual differences in scanning time, but that a large number of trials were required for stability to be established. In support of Chiang and Atkinson's conclusion, Roznowski and Smith (1993) found moderate to strong correlations among scanning times for different stimulus materials (digits, letters, words, and symbols) over a week. Further, subjects' median latencies were significantly correlated across the two occasions for the four different stimulus materials: numbers (.74), letters (.68), words (.63), and symbols (.51). The important question, however, concerns the stability of the scanning times across occasions. The across-occasion correlations were .05 (numbers), .33 (letters), .21 (words), and .30 (symbols). These test-retest correlations suggest that individual differences in scanning time probably reflect state factors rather than trait differences.

Another, albeit less studied, information processing task has been the visual search task (search). Here, a single item—a digit, letter, or word—is first presented to serve as the target for which the subject must search. This target is then followed by the simultaneous presentation of one to seven

items, the set of items through which the subject must search. Subjects indicate, as quickly as possible, whether the search set includes the target. As in the scanning task, the dependent measure is response latency (search time).

Chiang and Atkinson (1976) reported test-retest correlations of .29 (Day 1/Day 2) and .70 (Day 2/Day 3). Again, they concluded that there were reliable individual differences in search time, but that a large number of trials were required to establish stability. The correlations between the slope across search set sizes and SAT scores were mixed: .34 (Verbal) and  $-.05$  (Math). Palmer et al. (1985) found search speed for letters and words to be correlated .07 and .20, respectively, with the Nelson-Denny reading comprehension test. The relation was somewhat stronger with IQ (.28 and .19). Palmer et al. did find, however, that search speed for letters and words was highly correlated (.70).

Another measure investigated in Hunt et al.'s (1973) seminal study was the Brown-Peterson task. In this task, subjects are presented with a consonant trigram (e.g., BXN) and then must count backward for a brief period as a rehearsal-preventing activity. The duration of this number-counting retention interval varies over trials from 1 to 30 s. Hunt et al. (1973) found that subjects with high qualitative abilities demonstrated consistently better performance at all retention intervals, and interpreted this result as suggesting that high-quantitative subjects were more resistant to interference. Earlier, Borkowski (1965) had discovered a greater decline in STM over increasing retention intervals for low-IQ than for high-IQ subjects. His conclusion was that susceptibility to proactive interference is related to IQ. Subsequent studies comparing the performances of retarded and normal subjects have suggested that susceptibility to proactive interference is linked to both reading abilities and IQ (Farnham-Diggory & Gregg, 1975). The obvious question is whether this link applies to individual differences within the "normal" range. In a study of university students, Dempster and Cooney (1982) found that although susceptibility to proactive interference was not predictive of mathematical ability, it was implicated in individual differences in verbal ability, particularly with respect to high-level reading skills (meaning) but not necessarily with low-level skills (knowledge of grammar and rate of decoding).

In summary, research on working memory using the cognitive correlates approach has not yet made the hoped-for impact. The prospect of revealing the basic working memory processes responsible for the individual differences in aptitude and achievement remains just that: a prospect. In fact, researchers operating within a cognitive correlates approach appear to have shifted their attention to working memory capacity, the topic to which we now shift our focus.

### C. Working Memory Capacity

Most contemporary approaches to memory distinguish between an STM storage buffer, as exemplified by simple immediate recall tasks such as memory span, and a "mental scratch pad" where processing is carried out (Baddeley, 1986). Working memory (WM) can be seen as this scratch pad, a sort of librarian of the memory system. In a typical WM experiment (Daneman & Carpenter, 1980), subjects read a series of unrelated sentences aloud with the goal of remembering the last word in each sentence (targets). Subjects then recall these targets, with the number correctly recalled deemed to reflect that subject's WM capacity. Over the past decade, a growing number of researchers concerned with individual differences have concentrated their efforts around this paradigm.

Individual differences in WM capacity have been discovered to correlate with various measures of aptitude and achievement. For example, WM capacity has been found to predict performance on problem-solving and abstract-reasoning tasks (Anderson, 1983; Baddeley & Hitch, 1974; Kyllonen & Christal, 1990), to correlate with tests of general intelligence (Daneman & Tardiff, 1987; Larson & Alderton, 1992), and to be implicated in the acquisition of procedural skills (Woltz, 1988). Most frequently, however, WM capacity has been examined with regard to its relation to reading comprehension (Daneman & Carpenter, 1980; Swanson, 1992).

Daneman and Carpenter (1980, 1983) were among the first to articulate a theory explaining the basis of individual differences in WM capacity. They, like Baddeley, considered WM to be the arena where information is processed and the partial or completed products are temporarily stored. Additionally, WM is seen as a "bottleneck," having a limited amount of attentional resources for accomplishing these tasks. Using the WM task just described, Daneman and Carpenter (1980) measured the residual WM capacity the subject had for storage after the processing demands were met. In this and a subsequent study (Daneman & Carpenter, 1983), the number of final target words recalled was found to be positively correlated with scores on the Verbal SAT (.49). Daneman and Carpenter argued that individual differences in processing efficiency were responsible for the correlation between WM capacity and reading comprehension.

A similar position has been advanced by Salthouse (1992). He has contended that individual differences in WM capacity are the result of individual differences in the rates at which subjects activate stored information. In a later study, Carpenter and Just (1989) reported that subjects with large WM capacities spent less time reading the sentences than did subjects with smaller WM capacities. Further, large-capacity subjects spent more time staring at the target words than did subjects with smaller capacities. These findings

were viewed as confirmation for the hypothesis that individual differences in processing efficiency were the crucial factor. As pointed out by Engle, Cantor, and Carullo (1992), however, because subjects with larger WM capacities also had higher IQs than did subjects with smaller capacities, it might be that larger capacity subjects more effectively allocated their limited resources; that is, could it be that strategy—not processing speed or efficiency—is responsible for individual differences in WM capacity?

Turner and Engle (1989) demonstrated that the correlation between WM capacity and reading comprehension is not restricted to tasks requiring subjects to read sentences. In addition to the standard sentence-reading condition, they had subjects confirm the products of simple mathematical operations, each followed by a target word. Individual differences in WM capacity resulting from this latter condition correlated equally as well with reading comprehension scores as did individual differences in capacity resulting from the standard procedure. Turner and Engle (1989), along with others (Cantor et al., 1991), interpreted these and similar results as suggesting that individual differences in WM capacity are the product of general capacity differences, rather than the consequence of individual differences in processing efficiency. A vexing additional finding in the Turner and Engle (1989) study was that only WM capacities resulting from moderately difficult processing tasks were significantly correlated with comprehension. This potentially complicating finding is yet to be elucidated.

There has been some suggestion that performance on WM capacity tasks and memory span tasks reflect a single underlying process or mechanism (Engle, Nations, & Cantor, 1990; LaPointe & Engle, 1990). Cantor et al. (1991) reported that memory span (words) and WM capacity (words) were both moderately correlated with SAT (Verbal) scores: .35 and .42, respectively. Contradicting the suggestion of a common process or mechanism, however, was the finding that the two tasks loaded on different factors.

Although there is yet to be a test of the stability of performance on WM capacity tasks, the consistent correlations indicate to us that the task produces reliable individual differences. Unfortunately, as was the case regarding memory span, the source of the individual differences in WM capacity is as yet undetermined. This is also true with respect to the cause for the correlations between WM capacity and reading comprehension and between WM capacity and IQ. We are certain, though, that the WM capacity paradigm will continue to receive attention from psychologists concerned with individual differences.

#### D. Summary

As we have seen, psychologists have taken great interest in individual differences in working memory. The paradigms used by these investigators have

paralleled the theoretical evolution in the field. Moreover, explorations of individual differences in working memory have contributed to that evolution. Furthermore, in our view, converging evidence from both memory span and working memory capacity experiments indicates that the nature of the established individual differences can be captured in a single word: capacity. Presently, priority is being given to locating the source or sources of these capacity differences.

## II. LONG-TERM MEMORY

Intuitively, individual differences might seem to be more plausible in working memory than in long-term memory. Seen as the “mental scratch pad” where the rapid manipulation of information is carried out, as well as an early “bottleneck” in the memory system, any variations in working memory ability would have profound implications that would echo throughout the memory system. If working memory is the librarian and long-term memory is the library, then the obvious place to look for differences in efficiency would be in the active entity, the librarian. And we have seen that there are individual differences in working memory, though perhaps not as sweeping nor as dramatic as one might have anticipated. But to continue the analogy, libraries also differ in their contents, organization, and operation. We will now consider whether corresponding variations can be isolated uniquely in long-term memory.

We have organized this half of the chapter along quite familiar lines: encoding, storage, and retrieval. We begin by focusing on how the different amounts and kinds of knowledge that people possess influence their ability to acquire new knowledge. We then move to how that knowledge is organized in long-term memory. From there, we examine the recent work differentiating implicit from explicit remembering. Finally, we turn to how people differ in their ability to retrieve knowledge from long-term memory.

### A. Knowledge and Learning

Without question, people differ in the ways they go about acquiring information (Gagné, 1967; Ackerman, Sternberg, & Glaser, 1989). Educational psychologists have invested vast amounts of research effort in studying the different ways people learn (Cronbach & Snow, 1977). There are differences in ability and in approach, as well as in capacity and in knowledge (Resnick & Neches, 1984). Indeed, learning *style* is important: Some learners emphasize overall comprehension and are conclusion oriented, leading them to engage in deep processing; others concentrate on specific details and are description oriented, causing them to do more surface processing (Schmeck, 1983). The implications of such strategies are profound, but we

cannot capture that huge literature here. Instead, having provided a few leads to the applied literature, we now highlight studies done within a cognitive, theoretical framework.

### 1. General Knowledge and Fact Learning

A plausible hypothesis about learning might be expressed as "the more you know, the more you can learn and remember." Is this true? There is, in fact, evidence that it is. Over four experiments, Kyllonen, Tirre, and Christal (1991; see also Kyllonen & Tirre, 1988) consistently found that the extent of factual knowledge an individual already possessed (indexed by a standard vocabulary test) predicted both that individual's rate of learning and ultimate retention test score in paired associate learning. Indeed, the greater the study time available in paired associate learning, the more impact knowledge differences had. In contrast, measures like simple and choice response time, as well as access time to physical and name codes in long-term memory (see also Posner, Boies, Eichelman, & Taylor, 1969), contributed little to this prediction. Kyllonen et al. (1991) also showed that subjects who search long-term memory faster perform much better than slower subjects when study time is limited, but that this advantage vanishes as study time increases.

Could this advantage for individuals with more knowledge be due not to the knowledge difference itself but to some correlated variable, such as the likelihood of using mnemonic techniques? When Kyllonen et al. gave all subjects a "minicourse" in mnemonics to try to level the playing field, both high-knowledge and low-knowledge subjects showed improved learning, but the difference between them remained at least as large. They concluded from their series of studies that high-knowledge individuals learn better "because knowledge is the essential material used in generating elaborations and forming links" (p. 75).

Kyllonen et al. (1991) also hastened to add that familiarity with mnemonic techniques did influence learning, a fact nicely illustrated in a study by Wang (1983; see also Mandler & Huttenlocher, 1956). Wang showed that subjects who learned paired associates faster were those who could quickly produce more "elaborations" (mnemonic-based associations) during acquisition. In addition, fast learners were more consistent in using a given elaboration during study; this consistency led to a greater likelihood of a match between study and test conditions, thereby providing a further boost from transfer-appropriate processing (Morris, Bransford, & Franks, 1977). Indeed, the slow learners were even at a disadvantage if they used the same techniques as fast learners because they did not use them as effectively. When Wang provided the elaborations generated by slow versus fast learners to another group of subjects, the subjects in this new group learned

faster using the elaborations produced by the fast learners. It is also relevant here that individuals low in intellectual ability are more sensitive to the quality of the instruction they receive than are those high in intellectual ability (Cronbach & Snow, 1977).

On the issue of mnemonics, Karis, Fabiani, and Donchin (1984) conducted a particularly interesting study. They explored the von Restorff effect, the well-known phenomenon that a word that stands out from its surroundings (in their case by the different size of its font) is especially well learned. Subjects who reported little in the way of mnemonics use, and therefore presumably learned mostly by rote, showed overall poor recall but a very strong von Restorff effect. Intriguingly, the magnitudes of their P300 components in simultaneously recorded event-related brain potentials correlated well with individual word recall. In marked contrast, subjects who made extensive use of organizational mnemonics recalled more of the words and did not produce a von Restorff effect. In their case, P300 did not correlate with later recall. Karis et al. interpreted this pattern of individual differences as evidence that the initial encoding was dominant in later recall for those who failed to use mnemonics but that, for those who did employ mnemonics, the elaborated encoding overruled the initial encoding during recall.

### 2. General Knowledge and Skill Learning

We have highlighted the learning of facts, or declarative information, but there is also the issue of skill (or procedural) learning. If Humphreys (1979, p. 115) is on the right track, and general intelligence consists of "acquiring, storing in memory, retrieving, combining, comparing, and using in new contexts information and conceptual skills," then both facts and skills are relevant. Ackerman (1986, 1987, 1988, 1990) has been carrying out an extensive and comprehensive series of studies on individual differences and skill learning.

One of the frequently encountered ideas in the skill learning literature is that skills are highly specific. Ackerman (1990) tackled this issue head on by obtaining ability profiles of subjects and then having them repeatedly practice several clerical tasks as well as simple and choice RT tasks. The goal was to relate performance on these tasks—and changes in performance with practice—to performance on the learning of a criterion task, in the form of an air traffic controller "simulation." He observed that performance on the information processing measures showed consistent patterns of correlation with the criterion air traffic task, and apparently shared even more in common as practice progressed. These findings contradict the idea that all skills are necessarily specific and again highlight the role of individual differences in learning.



### 3. Specific Knowledge

So far, we have examined how breadth of knowledge influences learning, but only at a general level. We now turn to how the extent of knowledge of a particular topic influences further learning related to that topic—the question of domain-specific learning (see Resnick & Neches, 1984, for overview). Voss and colleagues tackled this question in the domain of baseball. In the first study, Chiesi, Spilich, and Voss (1979) demonstrated that people high in baseball knowledge were better able than people low in baseball knowledge to recognize newly acquired information about baseball and to notice important changes between study and test. Furthermore, high-knowledge individuals needed less information to support recognition, they could better predict upcoming information, and they could better recall the order of events, presumably because they related them more successfully.

Spilich, Vesonder, Chiesi, and Voss (1979) provided an explanatory context. They had subjects listen to and then summarize the text of a fictional baseball game. High-knowledge subjects produced larger chunks of information, augmented the actually presented information with more plausible inferences, and more accurately ordered the information. Voss, Vesonder, and Spilich (1980) extended this analysis to the case where subjects generated their own text and recalled it two weeks later. High-knowledge individuals produced more detailed texts and more closely attended to the sequence of events and critical changes as events progressed. These differences in the generation of the text reappeared in recall. When given texts produced by other subjects and later asked to recall them, high-knowledge subjects remembered much more than low-knowledge subjects if the text had originated with a high-knowledge subject, but there was little difference if the text had been generated by a low-knowledge subject.

Taken together, this work can be interpreted as evidence that the high-knowledge individuals more consistently tied events to the goal structure and kept the important information in working memory, strategies that are important during both acquisition and remembering. Other research dovetails nicely with this interpretation. As one illustration, Lee-Sammons and Whitney (1991), using the WM capacity paradigm discussed earlier, showed that high-span individuals were more able than low-span individuals to recall information from a text when the subjects were forced to change perspectives between reading and recalling the text. They argued that low-span subjects were more constrained by the perspective they had taken during initial reading, relying on that perspective to help compensate for their reduced working memory capacity. Perhaps the high-span individuals also had higher knowledge; certainly the working memory findings are quite consistent between the two lines of research and mesh with other work in that domain (see, e.g., Daneman & Tardiff, 1987).

We could go on. For example, Curtis and Glaser (1981) found that individuals with larger vocabularies and more knowledge about word meanings tended to obtain higher scores on tests of verbal aptitude when those tests included verbal analogies. Clearly, knowledge—both general and specific—makes learning and remembering easier, and therefore individuals with higher knowledge have a significant edge. A possible reason can be gleaned from the “paradox of the expert”: If forgetting is due to interference among related concepts in memory, how is it that an expert in a particular domain can overcome this problem? Smith, Adams, and Schorr (1978) suggested that we all overcome this problem by integrating our knowledge such that related ideas are linked and therefore support, rather than compete with, each other.

### B. Organization of Long-Term Memory

Underwood, Boruch, and Malmi (1978) conducted what is still probably the largest investigation of individual differences in episodic memory. Using 200 subjects and 28 tasks, they identified five episodic memory factors based on a factor analysis. These factors seemed very much to be sets of similar tasks—free recall on one, paired associates and serial tasks on another, memory span on a third, verbal discrimination on a fourth, and frequency and recognition on a fifth—rather than suggesting deeper process overlap. Underwood et al. concluded that the rate of forming associations during learning was the critical determinant of individual differences in episodic memory performance. In passing, we note two interesting aspects of the Underwood et al. study: First, given our prior discussion of chunking in working memory and our upcoming coverage of clustering in long-term memory, it is comforting that organization did not relate to any of the other episodic memory measures; second, the absence of a deeper relation underlying the tests does conflict with some of the more recent evidence, such as the Kyllonen and Tirre (1988) finding of a .53 correlation between a general knowledge factor and an associative learning factor.

Geiselman et al. (1982) took a similar tack, studying individual differences in episodic memory using both behavioral (several measures of recall) and physiological (heart rate, galvanic skin response, and eye movements) indices. Like Underwood et al. (1978), they argued that the critical determinant of success in remembering occurred during learning, and they identified rehearsal, coupled with the “intensity” or effort that subjects put into acquisition, as crucial. Enhanced recall from long-term memory was held to be due to effective use of semantic rehearsal strategies and extra effort, whereas effort made little contribution to immediate recall from working memory. Overall, they interpreted their individual-differences evidence as supporting a dissociation between working memory and long-term memory.

## 1. Episodic Memory

If Landauer's (1986) estimate that we store  $10^9$  facts in memory is anywhere near correct, then organization is essential. No doubt, this need for organization is true both in episodic memory, which contains our autobiographical knowledge, and in semantic memory, where our general knowledge is held (Tulving, 1972). Tulving (1962) showed that, even for a list of nominally unrelated words, subjects organize those words and tend to recall them in consistent patterns, though the patterns differ over individuals. Such subjective organization is very reminiscent of the idea of chunking in memory span: both can be indexed by the degree to which people consistently cluster words. Do people differ in how they cluster or in the benefits they accrue from clustering in episodic memory?

The results obtained by S. C. Brown, Conover, Flores, and Goodman (1991) offer some insight into this question. They grouped their subjects according to the degree of clustering they showed in their free recall of categorized words, and then examined several aspects of the performance of the high and low clusterers. Overall, subjects recalled the most instances of each category when given category names and allowed to exhaust recall within each category; they showed worst performance when given category cues at random and allowed to recall only one instance each time a cue appeared; and their free recall fell between these two extremes. The really noteworthy aspect of these results, however, was that this pattern held for both high and low clusterers and that high clusterers showed a constant advantage regardless of how they were cued. This advantage was not due to differential study or to inherent list organization: High clusterers continued to outperform low clusterers (1) whether categories were blocked or random during study, and (2) even for lists made up of unrelated words (where, surprisingly, high clusterers did not show more subjective organization). Brown et al. concluded that clustering was essentially a symptom of general ability differences among subjects, consistent with the evidence reviewed in the section on knowledge and learning. From our perspective, although clustering clearly affects performance on episodic memory tasks, it does not appear to be the source of individual differences, much as was the case with memory span.

## 2. Semantic Memory

How we arrange information in semantic memory should also be crucial, governing how quickly and reliably we can access it. This topic seems ripe for studies of individual differences, yet there has been surprisingly little work on the topic. Loftus and Loftus (1974) made a provocative beginning by showing that advanced psychology graduate students possess a superior

organization of psychology by subarea. Coltheart and Evans (1981) delved more into the mainstream work on semantic memory. Following Rips, Shoben, and Smith (1973), they investigated how subjects represented instances of a single category, birds. Each subject generated 20 birds (e.g., robin, swan) and 20 dimensions of "birdness" (e.g., predatory, water dwelling), and then rated each bird he or she had provided on each of his or her dimensions. There was wide variation both in the birds and in the dimensions, but an individual subject's ratings predicted both (1) subsequent response latency to judge the degree to which each bird fit each dimension, and (2) subsequent amount of priming in a categorization task when a target bird was preceded by a nearby or a distant bird. To our knowledge, there has been no effort to follow up or to extend the Coltheart and Evans (1981) study.

The other approach to individual differences in semantic memory is the correlational approach, most recently used by Roznowski (1993). She showed that the best predictor ( $r = .32$ ) of scores on the ACT was a subject's time to verify sentences of the type used in the classic Collins and Quillian (1969) studies of semantic memory (e.g., "a sparrow has wings"). Second best ( $r = .26$ ) was the Clark and Chase (1972) sentence-picture verification task, arguably also a semantic memory task. All of the other response time measures—simple and choice reaction time, Sternberg memory scanning, and mental rotation—failed to predict test performance. Such findings are in accord with the notion that knowledge, here viewed in terms of rapid access to semantic memory, is a critical component in individual differences in long-term memory.

A number of correlational studies have tried to ascertain the degree to which semantic and episodic memory share processes or structure. The general conclusion seems to be that there is relatively little overlap, providing some reassurance for theories of independent memory systems (Tulving, 1983). In their large factor-analytic study, Underwood et al. (1978) found little correlation between their three measures of semantic memory—word frequency, vocabulary, and spelling—and their numerous measures of episodic memory. Similarly, Cohen (1984) showed that free recall of words and subject-performed tasks correlated quite highly ( $r = .61$ , episodic), that production of category-cued and letter-cued words correlated highly ( $r = .70$ , semantic), but that the members of these two sets were only modestly correlated, in the range of  $r = .36$ . Cohen suggested two specific factors and a more general one.

## C. Implicit versus Explicit Remembering

In the past decade or so, a new distinction has emerged to command the lion's share of attention in episodic memory research. This is the contrast between

explicit remembering, done with awareness, and implicit remembering, done without awareness (see Graf & Schacter, 1985; see also Kelley & Lindsay, Chapter 2, this volume for a review of differences between explicit and implicit memories). Much of the now quite substantial literature has sought to demonstrate dissociations between the two ways of remembering, an enterprise that has been quite successful (Roediger & McDermott, 1993). Only very recently has any attention been paid to whether there are individual differences in implicit remembering and, if so, to how those differences might relate to differences in explicit remembering.

Reber, Walkenfeld, and Hernstadt (1991) examined implicit versus explicit learning using one task from each domain. The implicit measure was Reber's artificial grammar task (subjects implicitly learn the rules by which letters are combined into strings and then demonstrate their learning by choosing grammatically correct strings); the explicit measure was a series-completion problem-solving task (subjects explicitly work out the pattern in a series of letters and then choose the appropriate completion). The principle findings were as predicted: There was substantially smaller individual differences in the implicit task as compared to the explicit task, and IQ correlated better with the implicit measure ( $r = .69$ ) than with the explicit measure ( $r = .25$ ). Furthermore, performance on the explicit and implicit tasks was only weakly correlated ( $r = .32$ ). These observations are all in keeping with the idea that implicit and explicit memory are dissociable.

Perruchet and Baveux (1989) adopted Underwood's (1975) logic of using individual-differences data to test theories. They examined correlations between performance on two explicit tests—recall and recognition—and four implicit tests—clarification (a word embedded in a gradually disappearing mask), fragment completion, perceptual identification, and anagram solution—to assess the degree of dependence between the two types of remembering. Recall and recognition were quite highly correlated with each other ( $r = .50$ ), whereas the correlations among the four implicit tests were considerably smaller (all  $r$ s = .30 or lower). Moreover, clarification and fragment completion were at least as well correlated with the explicit measures as they were with each other or with the other two implicit measures. Overall, it was clear that the evidence was not as supportive of independence between implicit and explicit remembering as might have been hoped. (See also Kelley and Lindsay, Chapter 2, this volume, for a discussion of correlations within and between measures of explicit and implicit memory.) Further work of this sort, where individual-differences patterns are used to help evaluate more global theories, is needed.

Woltz and Shute (1993) investigated individual differences in the hallmark measure of implicit remembering, repetition priming (the facilitation in processing the second occurrence of a piece of information). Working with impressive sample sizes (342 and 250 in Experiments 1 and 2, respec-

tively), they explored a semantic comparison task in which subjects had to judge whether word pairs were related or unrelated over a series of trials in which pairs could reappear. The advantage due to reprocessing a pair was moderately correlated over 30–90 min in Experiment 1 ( $r = .46$ ), indicating that subjects who benefited more from repetition at one point in time also did so at other points within that range. However, this relation virtually disappeared in Experiment 2 when performance at 30 s was correlated with that at 8 days ( $r = .14$ ). Perhaps the decline in relation between Experiments 1 and 2 occurred because the very short and very long lags in Experiment 2 essentially amounted to correlating working memory with long-term memory, whereas the more intermediate lags in Experiment 1 all corresponded to long-term memory.

Additionally, Woltz and Shute (1993) looked at the degree to which repetition priming could predict fact learning. Are the subjects who show larger benefits from repetition also those who learn facts better? In Experiment 1, they found a moderate relation between repetition priming and paired-associate learning ( $r = .33$ ), considerably better than the relation between repetition priming and either a two-choice reaction-time task ( $r = .15$ ) or a letter arithmetic working memory task ( $r = .24$ ), in which the subject must treat letters as standing for digits (e.g.,  $A = 1$ ,  $B = 2$ , etc.). This ability of repetition priming to predict explicit learning held up ( $r = .35$ ) in Experiment 2 when the learning task switched to learning computer programming concepts. Basically, Woltz and Shute found that the implicit measure predicted the explicit measure within individuals, leading them to conclude that “declarative learning may involve more passive, implicit memory processes” (p. 356). It is worth noting that this kind of result, contrary to the supportive evidence in the previous section, presents a challenge for those who wish to claim that implicit and explicit remembering are broadly dissociated.

Woltz (1988, 1990) had previously shown that repetition priming also predicts procedural learning, and that the pattern of relation between these two types of implicit learning was independent of the relation between repetition priming and tasks measuring working memory capacity or semantic knowledge. Taken together, Woltz's studies demonstrate that what is learned from a single exposure to a piece of information can predict how learning will proceed in quite disparate settings.

#### D. Retrieval from Long-Term Memory

One of the best known research programs in individual differences has been that of Hunt and colleagues (see Hunt, 1978, for an overview). In their early studies (Hunt et al., 1973, 1975), the focus was on the manipulation of information in working memory, which we have already discussed. Gradu-

ally, though, the emphasis shifted to the retrieval of information from long-term memory (Hunt, 1978; Hunt, Davidson, & Lansman, 1981), where results proved to be less equivocal. The major finding that emerged from this work hinged on Posner's letter identification task (Posner et al., 1969), in which subjects had to determine as rapidly as possible whether two letters had the same name. On trials when they did, the letters could be physically identical (AA) or name identical (Aa). Whereas subjects' response times are always longer to Aa pairs than to AA pairs, Hunt's studies repeatedly showed that subjects higher in verbal ability showed a smaller difference between name and physical identity response times. This result was taken as evidence of a rapid and probably automatic process of decoding information from long-term memory that differed among individuals.

From the work using individual letters, investigators went on to study the processing of words. Goldberg, Schwartz, and Stewart (1978) used physically identical (*deer-deer*), phonologically identical (*deer-dear*), and semantically related (*deer-elk*) words, and found that the difference between subjects who were high versus low in verbal ability increased as the required comparison became more abstract and semantic. Hunt et al. (1981; see also Hogaboam & Pellegrino, 1978) looked at two semantic tasks—time to verify whether a single instance belonged to a category and time to verify whether two instances belonged to the same category—plus a word version of the Posner et al. (1969) task, all as a function of verbal ability. They consistently observed small but reliable correlations in the range of .25 to .30, leading them to conclude that “the process of accessing overlearned material is one of the important individual-differences variables that underlies skilled verbal performance” (p. 608). Although the differences between skilled and less skilled subjects were small in all of these studies, multiplying them many times over in situations such as reading (Palmer et al., 1985) would certainly make their impact an important one. When the most basic processes differ, the echoes throughout the system are likely to be loud and long.

### E. Summary

In discussing individual differences in long-term memory, we have sketched three principal differences. First, people vary in how much they know, which has serious ramifications for learning, whether the learning is declarative or procedural. Those who know more learn better, whether the knowledge and learning are in a specific domain or more global. Second, individuals vary reliably and systematically in how the knowledge they possess is organized in memory. Third, there are consistent differences in retrieval speed for well-known information in long-term memory, and these are related to measures of intellectual ability, most notably verbal ability. Where

our single-word summary of research on individual differences in working memory was capacity, the single word for long-term memory is clearly knowledge.

### III. EXPERTISE IN REMEMBERING

We turn finally to an examination of expert and exceptional memories. Extraordinary memory ability is popularly thought to be something with which an individual must be born, but research suggests that this is not true. As Ericsson (1992, pp. 166–167) put it, “experts' superior memory is limited to meaningful information from their domains of expertise and can be viewed as the result of acquired skills and knowledge specific to each domain.”

Probably the best known work on expertise in memory is that of Chase and Simon (1973), pursuing the pioneering research on expert chess layers begun by de Groot (1965). The most striking difference between beginners and experts was that experts faced with a 5-s exposure to the playing board of a chess game in progress could recall the locations of all of the 24 or so pieces, whereas novices could reproduce only about 4 locations accurately. This advantage, however, appeared only when the pieces were in actual game positions: With randomly located pieces, recall by the experts fell to that of the novices. Similar results have been obtained in a variety of games and sports (Ericsson, 1992). The strong suggestion is that chess experts can create larger chunks of information based on their superior knowledge of the game.

How does one develop an expert memory in a domain? Certainly one must acquire a lot of knowledge about the topic, but that knowledge must also be efficiently organized and readily retrievable. In studying physics experts versus novices solving physics problems, Chi, Feltovich, and Glaser (1981) showed that the experts identify the problems as members of conceptual groups, whereas the novices categorize by surface similarities. It appears that experts bring to bear their knowledge and rapidly integrate it, something novices do not do even when they possess the relevant knowledge. This rapid retrieval is the real hallmark of expertise.

#### A. Mnemonists

The individuals we have just been discussing have excellent memories for a particular specialty area, but are otherwise quite normal in their memory skills. There is, however, another group of individuals whose exceptional feats of memory are even more startling. These individuals are mnemonists, and they have always fascinated memory researchers and laypeople alike (E. Brown & Deffenbacher, 1975). Whereas the experts just discussed excel

because of rapid retrieval of knowledge in a particular specialty area, mnemonists appear to excel because of the techniques they have learned by dint of extensive practice (Higbee, 1988; see also Bellezza, Chapter 10, this volume, for a discussion of mnemonic methods).

The best known mnemonist was Shereshevski, Luria's (1968) famous subject S. Luria studied S for 30 years, documenting his amazing feats of recollection and identifying three primary techniques that S used, often in combination. First, S produced vivid and detailed images. He then coupled this imagery ability with two mnemonic strategies: the method of loci (locating images in familiar places) and narrative chaining (weaving images into a story). The combined use of these techniques permitted him to acquire vast amounts of information quickly and to remember that information in virtually flawless detail for a very long time.

Other famous mnemonists have been reported as case studies; Bower (1973) and Thompson (1992) summarize these. We consider just one other here to show the breadth of tactics used by mnemonists. Hunt and Love (1972) studied VP, an expert chess player with a phenomenal memory for facts. Unlike S, VP used verbal associations to accomplish his feats, and clearly had practiced these extensively. Perhaps the most amazing fact about VP was a coincidence: He and S were from the same town in the then Soviet Union!

Finally, there are individuals who use mnemonics to memorize amazing amounts of information of one type. The best known of these are two individuals who memorize numbers. Rajan (described in Thompson, 1992) has learned vast lengths of numbers, including pi to over 30,000 decimal places. He does this by methodically organizing digits into chunks and placing them in an imagined matrix. In addition to helping him be a rapid learner, his use of this scheme permits him to rapidly recover portions of the matrix. Ericsson and Chase (1982) studied a subject who began with a normal digit span and then gradually increased his span with practice until he could rapidly encode numeric strings over 80 digits long. A runner, his tactic was to relate the numbers to running times and then to group them hierarchically.

These individuals illustrate the three main elements of superior memory (Ericsson & Chase, 1982). First, as it is encoded, the information must be elaborated with existing knowledge to give it meaning. This elaboration facilitates the second step, which involves consciously attaching cues to the to-be-remembered information during study so that these cues will be available later to aid retrieval. And third, both the mnemonic skill itself and the information being acquired must be practiced heavily or overlearned. There are, no doubt, a variety of ways to implement these steps, as the various mnemonists illustrate, but these steps do appear to be the fundamental building blocks of exceptional memory.

## B. Imagery

A domain where individual differences are often discussed is that of visual imagery. There is a large body of evidence that people vary in the vividness, speed, frequency, and extent of their ability to image (Ernest, 1977) (indeed, some apparently do not image at all), but the degree to which this variation predicts memory performance is less clear. Thus, Katz (1983, p. 39) argued that "clear-cut and consistent relationships do not tend to emerge when variations in imagery level are used to predict task performance," although Paivio (1983) cited several situations that conflict with this conclusion. Perhaps the best summary statement about individual differences in imagery is one offered by Katz (1983, p. 53): "one might characterize high imagers as those who are more sensitive to the tasks that can be solved by imagistic means." If you have good imagery, you look for places to use it.

Reading about S's fantastic imagery ability brings to mind the question of eidetic imagery. Haber and Haber (1964) examined imagery ability in 150 children shown pictures to remember. Half of them showed some imagery, but about 8% showed a very unusual pattern of eye movements and reports of color that suggested an exceptional ability. Later, Leask, Haber, and Haber (1969) developed the "fusion" test of eidetic imagery where two meaningless pictures are mentally superimposed to produce an interpretable picture. Individuals who could do so were considered to be eidetic, and it was shown that such individuals were very likely to be under 6 years old (see also Haber, 1979). Thus, eidetic ability is unlikely to have much to do with the popular notion of "photographic memory" attributed to but rarely observed in adults (Crowder, 1992).

## IV. CONCLUSION

At the outset, we argued that research on individual differences in memory is valuable in terms of broadening our understanding of memory processes and in terms of providing an additional testing ground for our theories. We have tried to illustrate both of these merits by showing that individual differences exist in working memory and especially long-term memory, and that sensitivity to these differences informs our overall understanding of memory.<sup>1</sup> The extent of the individual differences in long-term memory

<sup>1</sup> In examining the literature to prepare this chapter, we made every effort to locate reliable, consistent sex differences in memory. We found none. Almost invariably, analyses of sex differences appear to be afterthoughts in the memory literature, at best subsidiary goals in studies conducted for other reasons. Thus, we agree with the conclusion Maccoby and Jacklin (1974, p. 59) reached after their review of the literature: "it clearly cannot be said that either sex has a superior memory capacity, or a superior set of skills in the storage and retrieval of information, when a variety of contents is considered. Nor does existing evidence point to a difference in choice of mnemonic strategies."

may point to the importance of "top-down" strategic elements in the use of memory. Of course, like any good research, answering one question immediately opens up others. If individuals who have more and better organized knowledge in long-term memory benefit from this difference, we must begin to ask how this difference arose in the first place. Doing so will help us not only in furthering our understanding of how people differ in their memory abilities, but also in deciphering the basic structure and processes of memory.

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