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A mnemonic for remembering long strings of digits

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We tested a procedure for memorizing long strings of digits. As a preliminary step, two subjects memorized a substitute word for each of the 100 possible digit pairs by using the digit-consonant mnemonic. Next, for each string to be memorized, successive pairs of digits were encoded into their corresponding substitute words. These words were then memorized using the story mnemonic. To reduce forgetting of long, 80-digit strings, a hierarchical story mnemonic was developed. In this procedure, each successive set of 10 words (20 digits) was organized into a story episode that occurred in a predetermined location. The location served as a context cue during recall. An experiment in which a practiced subject memorized 80-digit strings showed that recall with the hierarchical story mnemonic (99.1%) was superior to the unstructured story mnemonic (92.2%). The procedure and results of this experiment are compared with those of Chase and Ericsson (1981) and Kliegl, Smith, Heckhausen, and Baltes (1987).

It is more difficult to remember numbers than words. But mnemonists have devised procedures for encoding numbers as words so they can be remembered. One system, developed in 1634 by a French mathematician named Pietro Herigon, became the basis for many later techniques (Norman, 1976). It involved substituting a letter for each digit and then using the letters to form words. The system most commonly used today was first introduced by Gregor von Feinaigle in 1813. Paivio (1971, chap. 6) and Higbee (1988, chap. 12) discussed the history of these systems. The Feinaigle system was designed to be easily remembered, but its implementation is a complicated process. Each digit from a large number can be replaced by a particular consonant sound. Vowels are then added wherever needed so that the consonant sounds can be formed into words. The added vowels themselves have no numerical value. The resulting words are then memorized. Later, when the number is to be recalled, the words are first recalled and then decoded back into the original string of digits using the digit-consonant system.

The digit-consonant mnemonic system is summarized in Table 1. The consonant sounds substituted for each digit are similar. The digit 0 can be replaced by the sounds z, s, or soft c. The digit 1 can be replaced by the sounds t, th, or d. Other families of sounds represent the other digits. Also listed in Table 1 are some traditional hints for remembering the replacement system. Bower (1978) recommends the sentence "Satan may relish coffee pie" as a way to remember one consonant sound for each of the digits 0 to 9. All vowel sounds and the sounds for the consonants w, h, and y can be added anywhere and have no numerical value. Hence, the word *whale* represents the digit 5 and the word *arrow* represents the digit 4. There are multiple possibilities for substitution. The digit 5 can be represented by the word *law* and the digit 4 by *hair*. What is important is sound, not spelling. The word *thorough* represents the number 14. The word *knife* represents 28. More complete discussions of the system can be found in Bellezza (1982, chap. 5) and Higbee (1988, chap. 12).

It is difficult to find substitute words for large numbers using the digit-consonant mnemonic. The number 89, for example, provides only a few choices, such as *fib*, *fob*, *fop*, *VIP*, and *Phoebe*. Many three-digit numbers have no single-word substitutes. One way around this problem is to memorize a single-word substitute only for the single digits 0 to 9 and for the double digits 00 to 99. These substitute words should be familiar and of high imagery to allow combinations of substitute words to be easily remembered (Paivio, 1971). A long number, such as the telephone number 517-894-6330, can then be broken into the digit pairs 51, 78, 94, 63, and 30 and encoded as *lady*, *coffee*, *bear*, *jam*, and *moose*. Using another mnemonic, the story mnemonic (Bellezza, 1982; Higbee, 1988), a string of words can be memorized by creating a story like the following: The *lady* drank *coffee*, while the *bear* ate *jam* with the *moose*. If this story can be remembered with the italicized words maintained in the correct order, then the telephone number has been memorized. To recall the number, the story is recalled and the substitute words in the story identified. It is surprisingly easy for the learner to identify the substitute words once the story is remembered. The substitute words are then decoded as 51, 78, 94, 63, and 30.

Tests of the effectiveness of the digit-consonant mnemonic have been performed with mixed results. Bruce and Clemons (1982) had students learn 24 conversions between metric and standard measurement units using the mnemonic, but the trained group remembered no better

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Table 1
The Digit-Consonant Mnemonic

Digit	Consonant Sound	Mnemonic Aid
0	z, s, soft c	z is the first sound in zero
1	t, th, d	t and d have one downstroke
2	n	n has two downstrokes
3	m	m has three downstrokes
4	r	4 ends with the sound r
5	l	L is the Roman numeral for 50
6	ch, j, or soft g	a 6 looks like a backward j
7	k, hard c, hard g, or qu	an uppercase K is made up of two 7s
8	f, v, or ph	an 8 looks like a handwritten f
9	p, b	9 and p are mirror images

than a control group. Somewhat better results have been obtained using the digit-consonant mnemonic to remember lists of numbers (Kliegl, Smith, Heckhausen, & Baltes, 1987; Morris & Greer, 1984; Patton & Lantzy, 1987, Experiment 2; Slak, 1970). Furthermore, the results of Patton and Lantzy (1987) and Kliegl et al. (1987) suggest that successful use of the digit-consonant mnemonic is what has been termed a cognitive skill by Chase and Ericsson (1981). This suggests that effective use of the digit-consonant mnemonic requires a good deal of practice. Chase and Ericsson's subject S.F. was presented digit strings at the rate of one digit per second and had to recall the strings in order. At first, the number of digits he could recall correctly was about 7, which is typical of a normal adult. After 250 h of practice, however, S.F. was able to recall up to 80 digits correctly. What factors accounted for this remarkable improvement? S.F. was taught no mnemonic procedure, such as the digit-consonant mnemonic, but developed one on his own. He was an amateur runner and was knowledgeable about the record times of various track events, and he began to code strings of digits as times of track events. For example, the digit series 411 might be encoded as a "slow mile," meaning that 4 min and 11 sec is a slow time for running a mile. He also used ages and dates. The number 85 might be encoded as "old man," and 1980 would be encoded as the year 1980. Hence, S.F. developed an encoding mnemonic on his own for remembering digit strings. In summary, S.F. used an encoding procedure analogous to the digit-consonant mnemonic to encode relatively meaningless digits into more memorable concepts. Similar results have been demonstrated by Kliegl et al. (1987), who taught their subject B.B. to use the digit-consonant mnemonic. After 86 h of practice, B.B. could recall 80-digit strings but needed about 5 sec to encode each digit, rather than the 1 sec used by S.F.

S.F.'s encoding process does not explain how he was able to remember 80 digits. If he encoded the 80 digits as 20 events of 4 digits each, how did he maintain the 20 events in memory? At the time of recall, the last few digits in the series were available in working memory, but the previous coded digits were stored in a hierarchical organization in long-term memory. After grouping the digits into running times, ages, or years, as described above, he organized each set of two or three groups into supergroups. Finally, these supergroups were organized into clusters. At recall, S.F. waited 30 sec to 2 min after digits had been presented before he began to recall. During this time, he rehearsed the digit sequence in reverse, supergroup by supergroup. Within each group, he generally rehearsed in the forward order. He then recalled the digits from the beginning of the series. S.F. always tried to group the digits for each test string into the same hierarchical organization.

Kliegl et al.'s (1987) subject B.B. was trained to use the digit-consonant mnemonic and to substitute a word for each pair of digits presented. He then used the method of loci to remember the substitute words. The method of loci is a mnemonic procedure by which the learner mentally associates each item to be memorized with the mental image of a location (Yates, 1966). B.B. had previously memorized 40 locations from the city of Berlin and associated the word representing each digit pair to its corresponding location. When he had to recall, B.B. imaged each location, remembered the associated substitute word, and decoded it into its 2 digits. After 70 sessions of training, B.B. was able to recall strings of 80 digits, each digit having been presented for 5 sec.

The purpose of the experiment described here was twofold. First, we wished to determine if a practiced subject could learn to recall long strings of digits using the digit-consonant system in conjunction with the story mnemonic (Bellezza, 1982, chap. 6). The story mnemonic is somewhat simpler to use than is the method of loci used by Kliegl et al. (1987). Second, we wished to test a hierarchical retrieval scheme based on the story mnemonic. Chase and Ericsson (1981) suggested that a hierarchical retrieval scheme may be necessary for recalling long strings of digits. The two practiced subjects in this experiment reported difficulty remembering their stories using an unstructured story mnemonic and developed a hierarchical retrieval scheme on their own.

METHOD

Subjects

Two female subjects, D.P. and L.S., spent approximately 100 h each learning and practicing the digit-consonant mnemonic in conjunction with the story mnemonic. Both volunteered to participate as part of an undergraduate research project. D.P. started on the project a year before L.S., they both worked on the project for about half a year, and L.S. practiced about another half a year. The data presented below are from L.S.

Procedure

The procedure involved three stages. The subjects worked in 50-min periods three or four times a week during those times classes were in session. First, they memorized the digit-consonant substitution rules outlined in Table 1. Next, they learned one substitute word for each of the digit pairs from 00 to 99. Lists of such words can be found in Bellezza (1982) and Higbee (1988). These words were practiced so that the correct word could be recalled for each of the 100 digit pairs. Next, 10 randomly selected digit pairs (20 digits) were presented on an Apple II computer screen, 1 pair at a time. The presentation of the digit pairs was paced by the subject. As each pair appeared, it was encoded into its substitute word and incorporated into a story. After the last digit pair was presented, the subject recalled her story, decoded each substitute word into its appropriate 2 digits, and keyed the digits into the computer. The computer recorded presentation time, response time, and the accuracy of the serial recall. When a digit string of a particular length could be correctly recalled 90% of the time, the length was incremented by 10 words (20 digits).

There was considerable overlap between learning the substitute words and using them in stories. Early in training, a list of the substitute words was available during memorization of the digit strings. D.P. or L.S. would occasionally forget so many of the substitute words that she would spend an hour or two simply reviewing the substitute words.

As the lists grew longer, the subjects began to have trouble remembering all the words in the story. Part of the problem was that words were repeated in the story whenever a digit pair was repeated in the series. As a consequence, both subjects tended to review their stories after every 10 pairs of digits. They were able to do this because the presentation of the digit pairs was self-paced. However, this review process did not eliminate the problem of forgetting. Working together, D.P. and L.S. developed the practice of placing each set of 10 words (20 digits) in a different setting or context in the story. For example, for the first 10 words the story would take place on campus, for the next 10 words at the beach, for the next 10 words downtown, and so on. The subjects used the same locations in the same order for each digit series. Hence, they used a procedure that combined the story mnemonic with the method of loci (Kliegl et al., 1987; Yates, 1966), with a segment of their story occurring in each location. This procedure created a hierarchical retrieval structure (Chase & Ericsson, 1981). During the presentation of the list, they reviewed the 10 words in a location after they were presented the last pair of digits to be associated with that location.

At the end of training, both subjects could recall 40 word pairs (80 digits) with high accuracy. At this point, an experiment was performed to determine if the hierarchical story mnemonic developed by the subjects was superior to the unstructured story mnemonic. Only L.S. was available to participate in this part of the experiment. Over a period of several weeks, she was tested on digit strings made up of 80 digits, 14 strings using the unstructured story mnemonic and 13 strings using the hierarchical story mnemonic. Only one test was performed each day, 2 to 4 days per week. L.S. used the unstructured story mnemonic and the hierarchical story mnemonic for alternate tests. Presentation of the digit pairs was self-paced, as it always had been. As customary, L.S. reviewed her story every 10 words (20 digits), regardless of the method used. The data are presented below.

RESULTS

Serial Recall

Table 2 shows recall performance for the 80-digit lists. Data was summed over the various tests, and a 2×4×10×2 analysis of variance (ANOVA) was performed, the factors being type of mnemonic, list quarter, word position, and individual digit. Every factor was a within-subject factor. The error term used to test all effects was the four-way interaction (MS_e = .00056). The effect of type of mnemonic was significant [$F(1,27) = 337.48$, $p < .001$]. Mean recall was .922 for the unstructured story mnemonic and .991 for the hierarchical story mnemonic. List quarter was also significant [$F(3,27) = 75.58$, $p < .001$]. As can be seen in Table 2, recall declined over serial position for both strategies, but more so for the unstructured story mnemonic than for the hierarchical story mnemonic. The mnemonic × list quarter interaction was significant [$F(3,27) = 40.34$, $p < .001$].

Table 2
Recall Performance on Digit Recall Using the Two Story Mnemonics

	Serial Position			
	1-20	21-40	41-60	61-80
Story mnemonic	.997	.934	.888	.871
Hierarchical story mnemonic	1.000	1.000	.981	.984

Presentation Time

A 2×4×10 ANOVA was performed on the study times for the pairs of digits, the factors being type of mnemonic, list quarter, and word position. All factors were within-subject factors. The error term used to test all effects was the three-way interaction (MS_e = 5.70). The mean study time per pair was 15.65 sec for the unstructured story mnemonic versus 13.56 sec for the hierarchical story mnemonic [$F(1,27) = 15.29$, $p < .001$]. Therefore, encoding time in the story mnemonic was 7.83 sec per digit and in the hierarchical story mnemonic 6.78 sec per digit. Study time did not change as a function of list quarter, but it did change according to word position. As stated above, L.S. reviewed her story every 10 words when using either type of mnemonic, so words in the 10th position of the set were studied for a mean of 22.67 sec, which included a review of the previous 9 words, whereas the mean study times for the other 9 positions ranged from 11.18 to 15.41 sec. There was no significant mnemonic × word position interaction.

Recall Time

Because digits were encoded as pairs, they were recalled as pairs. (Preliminary analysis showed that mean recall latency of the first digits was 6.23 sec, whereas mean recall latency of the second digits was .92 sec.) A 2×4×10 ANOVA was performed on the recall latencies for the pairs of digits, the factors being mnemonic type, list quarter, and word position. All factors were within-subject factors. The error term used to test all effects was the three-way interaction (MS_e = 4.90). Recall was slower for the unstructured story mnemonic than for the hierarchical story mnemonic [$F(1,27) = 10.74$, $p < .001$], with each pair taking a mean of 7.04 sec in the unstructured story mnemonic and 5.42 sec in the hierarchical story mnemonic. For both conditions, the words were organized in sets of 10. The first word from each set of 10 took longer to recall than the following 9 words [$F(9,27) = 14.58$, $p < .001$]. In the unstructured story mnemonic, the mean recall time for the first word was 12.27 sec, compared with a range of 5.00 to 8.14 sec for the other 9 pairs. In the hierarchical story mnemonic, the time for the 1st pair was 16.88 sec, compared with a range of 3.13 to 6.66 sec for the other pairs. The difference between the 1st word and the other 9 words was greater in the hierarchical story mnemonic than in the unstructured story mnemonic, as indicated by the significant mnemonic × word position interaction [$F(9,27) = 3.52$, $p < .01$].

DISCUSSION

The results of this experiment demonstrate that the digit-consonant mnemonic coupled with the story mnemonic is an effective method for memorizing strings of digits. Although data are presented only for L.S., both participants recalled 80-digit strings with high accuracy. The data also corroborate what both L.S. and D.P. reported when developing this story mnemonic procedure; that is, that use of the unstructured story mnemonic results in more recall failures than does the hierarchical story mnemonic. In the 14 lists L.S. memorized using the unstructured story mnemonic, the proportion of correct digits was .922. However, when using the hierarchical story mnemonic with 13 lists, the proportion of digits recalled was .991. The use of predetermined locations for story segments, with each segment made up of 10 words, improved recall performance significantly. A story structure without a predetermined organization is a chain-type mnemonic (Bellezza, 1981) and is a primarily self-cuing retrieval structure, with each recalled item acting as a cue for the next item. The cues are intrinsic to the story. If at any point during recall a word is forgotten, then the recall performance may stop. On the other hand, the hierarchical story mnemonic includes components of a peg-type mnemonic (Bellezza, 1981), having some extrinsic cues built into it. The story locations act as recall cues, as do pegs or loci in any peg-type mnemonic. By using a predetermined locus for each segment of the story, the mnemonist has an extrinsic recall cue in addition to those cues intrinsic to the story she created.

A problem specific to making up stories with digit-consonant substitute words that does not occur when using the story mnemonic in other situations is that there are only 100 possible words. In any 40-word story, there are usually multiple occurrences of the same words. This and the repetitions of words between stories result in more interference than would typically occur in a story mnemonic. Hence, with a large pool of words, the superiority of the hierarchical story mnemonic over the unstructured story mnemonic may be less than we found here.

There are other ways to reduce the interference caused by word repetitions besides making the story mnemonic hierarchical. Mnemonists with expertise in the digit-consonant mnemonic can use different substitute words for different occurrences of the same digit pair. For example, the digit pair 72 can be encoded as *coin*, *queen*, *wagon*, *can*, *cane*, *gown*, or *canoe*. However, D.P. and L.S. did not have this expertise.

The superiority of the hierarchical story mnemonic over the unstructured story mnemonic supports the conclusion of Chase and Ericsson (1981) that their subject S.F. needed a hierarchical retrieval system to organize sets of multiple-digit codes into superchunks. These superchunks correspond to the locations used by L.S. However, the locations are content defined to a greater extent than are S.F.'s superchunks. That is, the locations can be described as familiar ones, such as campus or beach scenes, independent of their order and of the digit codes in them. S.F.'s superchunks, however, seem to represent nodes from a formal hierarchical memory structure and seem not to have any content other than the number codes placed there.

Ericsson and Staszewski (1989) suggested that skilled memory is evidenced when (1) subjects exploit well-organized and meaningful prior knowledge to encode information, (2) subjects have a retrieval structure to facilitate the recall of the encoded information, and (3) the speed at which subjects store and retrieve information approaches that at which they can store and retrieve information from short-term memory. It appears that the performance of L.S. reported here certainly meets the first two of these criteria. However, L.S. needed a mean of 6.78 sec to encode each digit when using the digit-consonant mnemonic in conjunction with the hierarchical story mnemonic, compared with the 1 sec per digit imposed on S.F. by Chase and Ericsson (1981) or the speed of 5 sec per digit imposed on B.B. by Kliegl et al. (1987). Though slower than other mnemonists, L.S.'s recall was very accurate. On 13 lists using the hierarchical story mnemonic, her recall accuracy was 99.1%. What encoding speed L.S. would eventually achieve with continued practice cannot be determined.

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