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CARNEGIE-MELLON UNIV PITTSBURGH PA DEPT OF PSYCHOLOGY
A MNEMONIC SYSTEM FOR DIGIT SPAN: ONE YEAR LATER.(U)
NOV 79 W G CHASE, K A ERICSSON

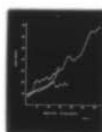
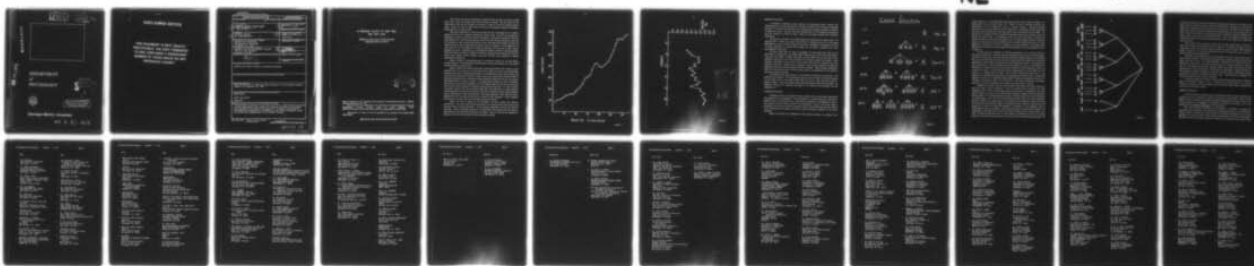
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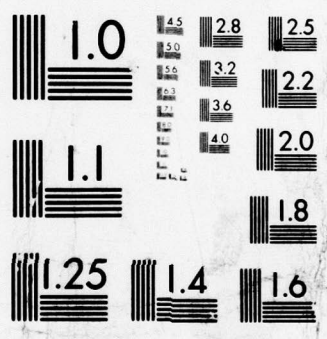
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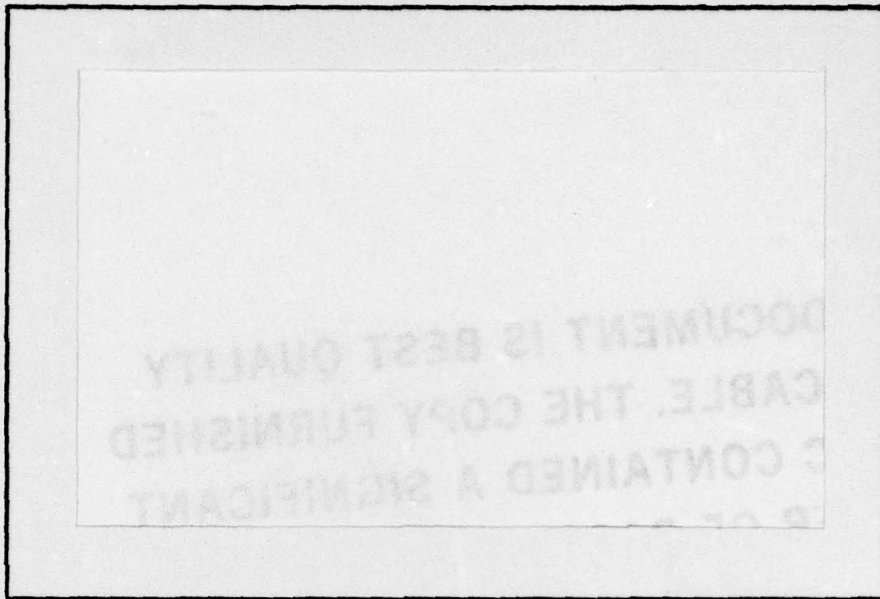


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A Mnemonic System for Digit Span: One Year Later

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Paper presented at the Twentieth Annual Meeting of the Psychonomic Society. Phoenix, Arizona, November 8-10, 1979.

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Last year at this time, we reported on a subject (SF) who was able to increase his digit span from 7 digits to 38 digits after about 6 months of practice. One year later, SF has increased his digit span to 70 digits, an increase by a factor of 10 from his original memory span. Today, we want to report what we think are the important cognitive mechanisms responsible for this memory feat.

The basic procedure we used was to present SF with random digits in the auditory mode at the rate of 1 digit/sec., followed by ordered recall. We used the up-and-down procedure; if recall is correct, the size of the sequence is increased by one digit for the next trial; otherwise it is decreased by one digit. On half the trials, randomly selected, we also ask SF to provide us with a verbal report after his recall. Also, after every session, we ask SF to recall as much of the material from that section as he can remember. In the beginning, we were able to run five sessions per week, but nowadays we run three or fewer hourly sessions per week. Sometimes we run experimental sessions instead of practice sessions. The total amount of practice is slightly over 200 hours spread over 18 months, 160 hours of which were regular practice sessions, and about 40 hours were devoted to various experimental procedures.

Figure 1 shows the average digit span as a function of practice for the 160 regular practice sessions. There has been a steady increase in memory performance over this period of time without any sign of a limit.

Figure 2 shows that there has also been a steady improvement in SF's ability to recall materials after the session is over (at least for the range over which we systematically collected these data, from Session 35 onward). In the beginning SF, like everyone else, could recall virtually nothing after an hour's session. Now he can consistently recall about 80% of the digits presented to him. Moreover, we have additional evidence that he now has virtually everything stored in long-term memory. In one experimental session, we used a recognition test, and we found perfect recognition of 3- and 4-digit groups that SF had seen that day, and he also showed substantial recognition of groups that he had seen 3 or 4 days earlier. In another session, after SF had recalled about 80% of the digits from a regular session, (which generally takes about 5 minutes), we asked SF to remember the other digit sequences that he had failed to recall (about twelve 3- and 4-digit sequences). After about an hour's intense effort, SF was able to recall all but a couple of these sequences. Thus, it appears that now SF is storing virtually all the material in long-term memory.

Today, we want to report on the mechanisms we think underlie SF's memory performance. Two of the most essential mechanisms are revealed in the verbal reports, and we first report on these mechanisms: (a) the mnemonic associations, and (b) the retrieval structure. These mechanisms, however, are not sufficient to fully explain SF's skill, and we next consider what additional mechanisms are needed. Finally, we take up the question of whether or not SF has increased his short-term memory capacity.

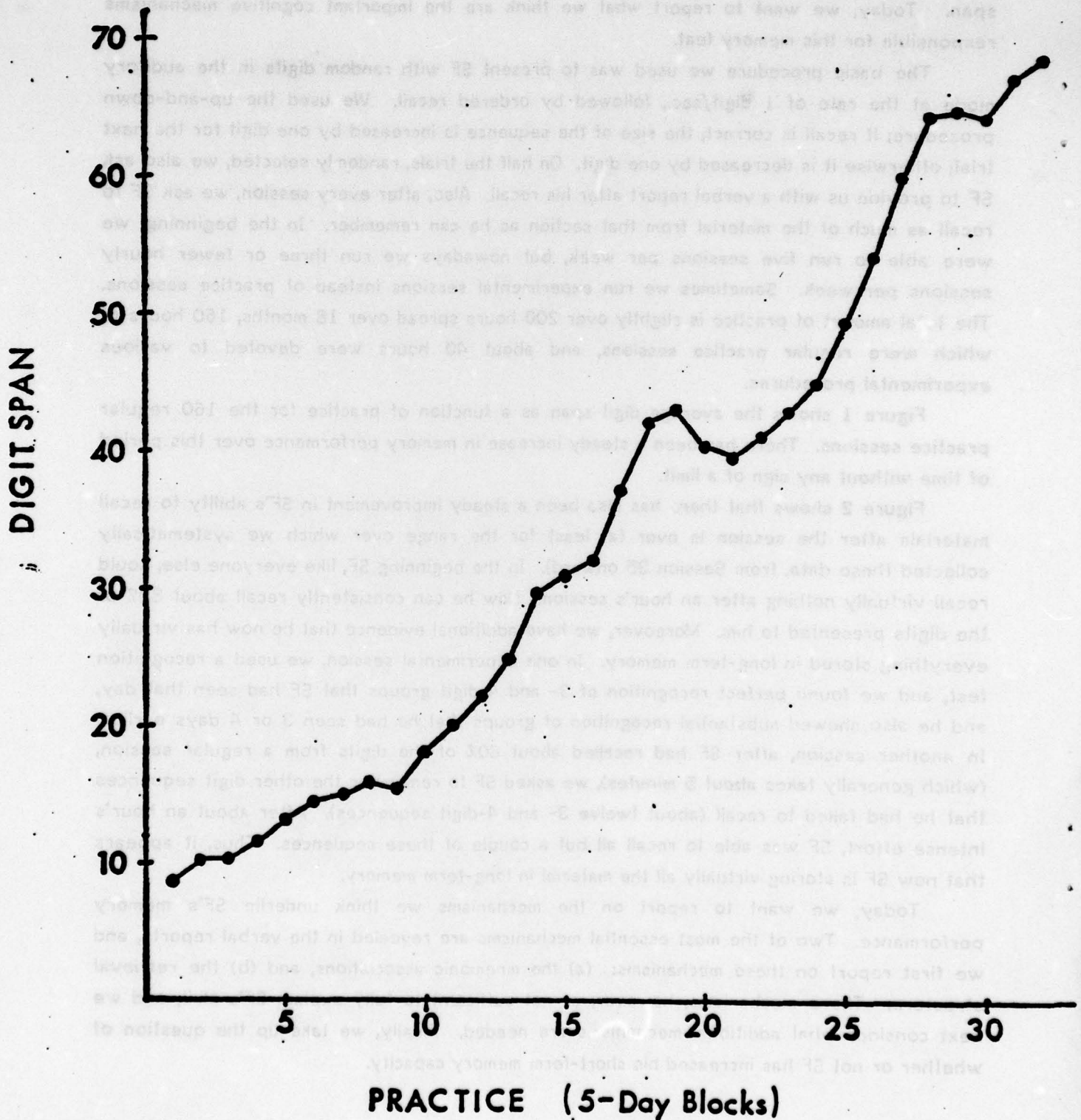


Figure 1

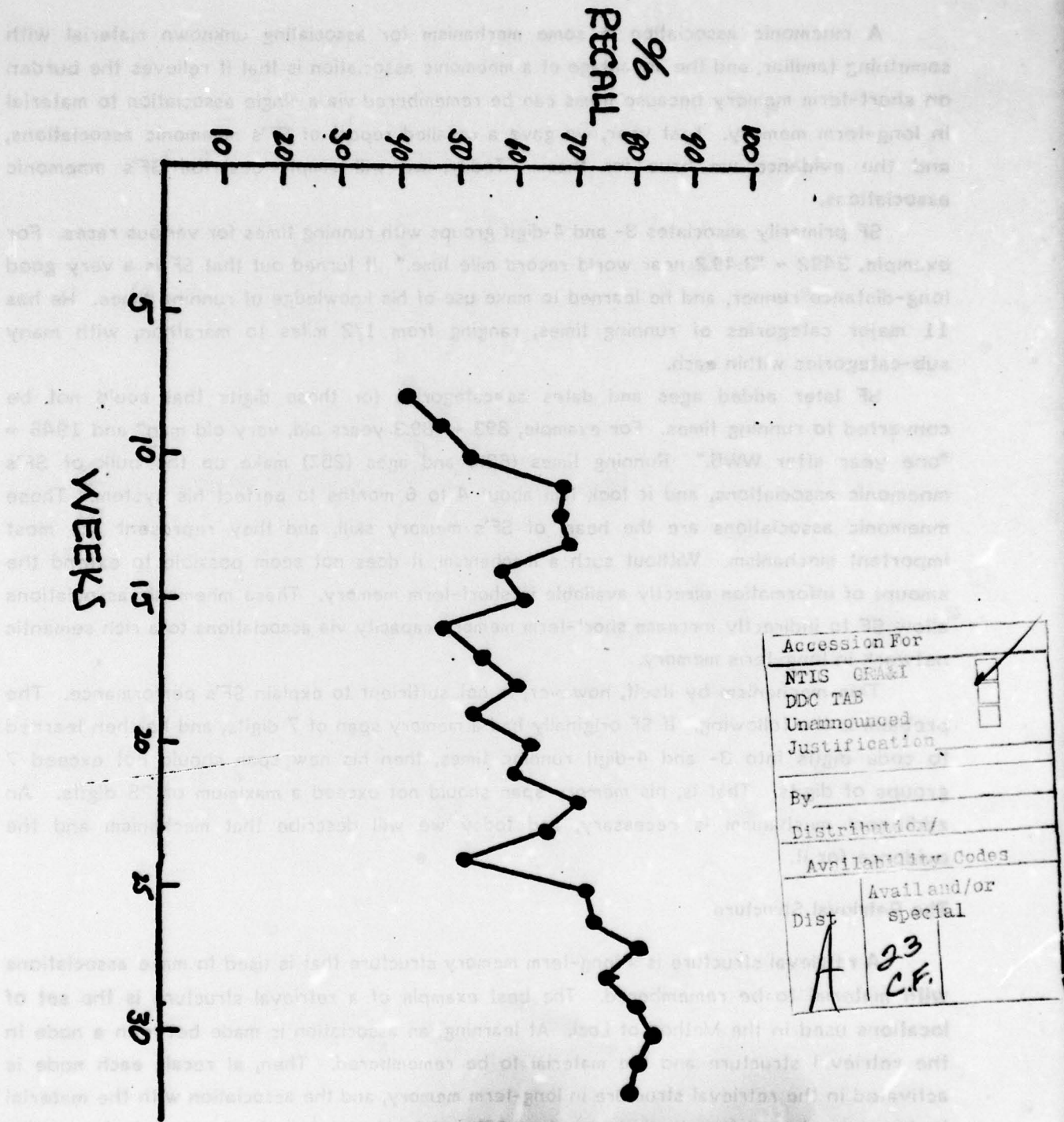


Figure 2

Mnemonic Associations

A mnemonic association is some mechanism for associating unknown material with something familiar, and the advantage of a mnemonic association is that it relieves the burden on short-term memory because items can be remembered via a single association to material in long-term memory. Last year, we gave a detailed report of SF's mnemonic associations, and the evidence we have for them. Today, we will simply describe SF's mnemonic associations.

SF primarily associates 3- and 4-digit groups with running times for various races. For example, 3492 = "3:49.2 near world-record mile time." It turned out that SF is a very good long-distance runner, and he learned to make use of his knowledge of running times. He has 11 major categories of running times, ranging from 1/2 miles to marathon, with many sub-categories within each.

SF later added ages and dates as categories for those digits that could not be converted to running times. For example, 893 = "89.3 years old, very old man" and 1946 = "one year after WWII." Running times (62%) and ages (25%) make up the bulk of SF's mnemonic associations, and it took him about 4 to 6 months to perfect his system. These mnemonic associations are the heart of SF's memory skill, and they represent the most important mechanism. Without such a mechanism, it does not seem possible to extend the amount of information directly available in short-term memory. These mnemonic associations allow SF to indirectly increase short-term memory capacity via associations to a rich semantic network in long-term memory.

This mechanism by itself, however, is not sufficient to explain SF's performance. The problem is the following. If SF originally had a memory span of 7 digits, and he then learned to code digits into 3- and 4-digit running times, then his new span should not exceed 7 groups of digits. That is, his memory span should not exceed a maximum of 28 digits. An additional mechanism is necessary, and today we will describe that mechanism and the evidence for it.

The Retrieval Structure

A retrieval structure is a long-term memory structure that is used to make associations with material to be remembered. The best example of a retrieval structure is the set of locations used in the Method of Loci. At learning, an association is made between a node in the retrieval structure and the material to be remembered. Then, at recall, each node is activated in the retrieval structure in long-term memory, and the association with the material to be remembered is activated. Most of SF's retrieval structure is apparent in his verbal protocols.

Figure 3 illustrates the development of SF's retrieval structure, as revealed in his

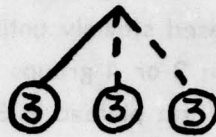
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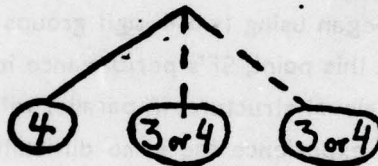


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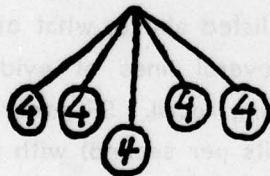


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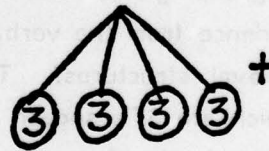
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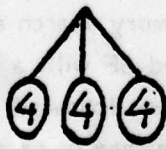
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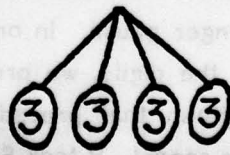
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Figure 3

verbal protocols. In the beginning, like everyone else, SF tried to hold everything in a phonemically based rehearsal buffer (R). Within the first 5 sessions, however, SF demonstrated the first rudimentary use of a retrieval structure. Instead of holding everything in a rehearsal buffer, he tried to separate one or two groups of three digits each from the rehearsal group, and recall these groups while rehearsing the last 4-6 digits. On the 5th day of practice, SF first invented his mnemonics, and he tried to code the first two groups as running times. This technique worked well, and he was able to expand this retrieval structure to hold up to three groups of 3- or 4-digit running times plus a rehearsal group. His performance increased steadily until he reached 18 digits, and then he ran into difficulties in holding more than 3 or 4 groups in his retrieval structure. We believe these difficulties are reflected in the first plateau in SF's acquisition curve (around Blocks 8 and 9 of Figure 1).

At this point, SF introduced an important advancement in his retrieval structure: hierarchical organization. He began using two 4-digit groups followed by two 3-digit groups, and the rehearsal group. From this point, SF's performance improved rapidly as he perfected the use of this hierarchical retrieval structure, in parallel with improvements in his mnemonic associations, until he began to experience the same difficulties as before. We believe that the second plateau in SF's performance curve (around Block 21 of Fig. 1) is associated with difficulties in remembering the order of more than 4 groups of 4 digits followed by more than 4 groups of 3 digits. At this point, SF first tried unsuccessfully to tag the middle item of 5 groups as a "hitching post" or "peg." Then he finally introduced another level in the hierarchy by breaking these groups up into subgroups, and his performance has improved rapidly ever since. SF is currently averaging about 70 digits, and his grouping structure for 70 digits is illustrated in Figure 4 for a typical trial. This figure illustrates our best guess about the hierarchical grouping structure, based on several sources of evidence.

Besides the evidence from the verbal protocols listed above, what other evidence is there for these retrieval structures? There are several lines of evidence, the most straightforward of which are SF's speech patterns during recall. SF generally recalls digit groups rapidly at a normal rate of speech (about 3 digits per second) with pauses between groups (about 2 sec. between groups, on average, with longer pauses when he has difficulties in remembering). At the end of a hierarchical group, however, there is a falling intonation, generally followed by a longer pause. In one memory search experiment, instead of asking for recall after presenting the digits, we presented SF with a 3-digit or 4-digit group and asked him to name the group that preceded it or followed it in the sequence, and we measured the latency of his report. It took SF more than twice as long, on the average, if the preceding or following group crossed a hierarchical boundary than if it did not (10.0 vs 4.4 sec). In another experiment, after an hour's session we presented SF with 3- and 4-digit groups from that session and asked him to recall as much as he could about each group. SF

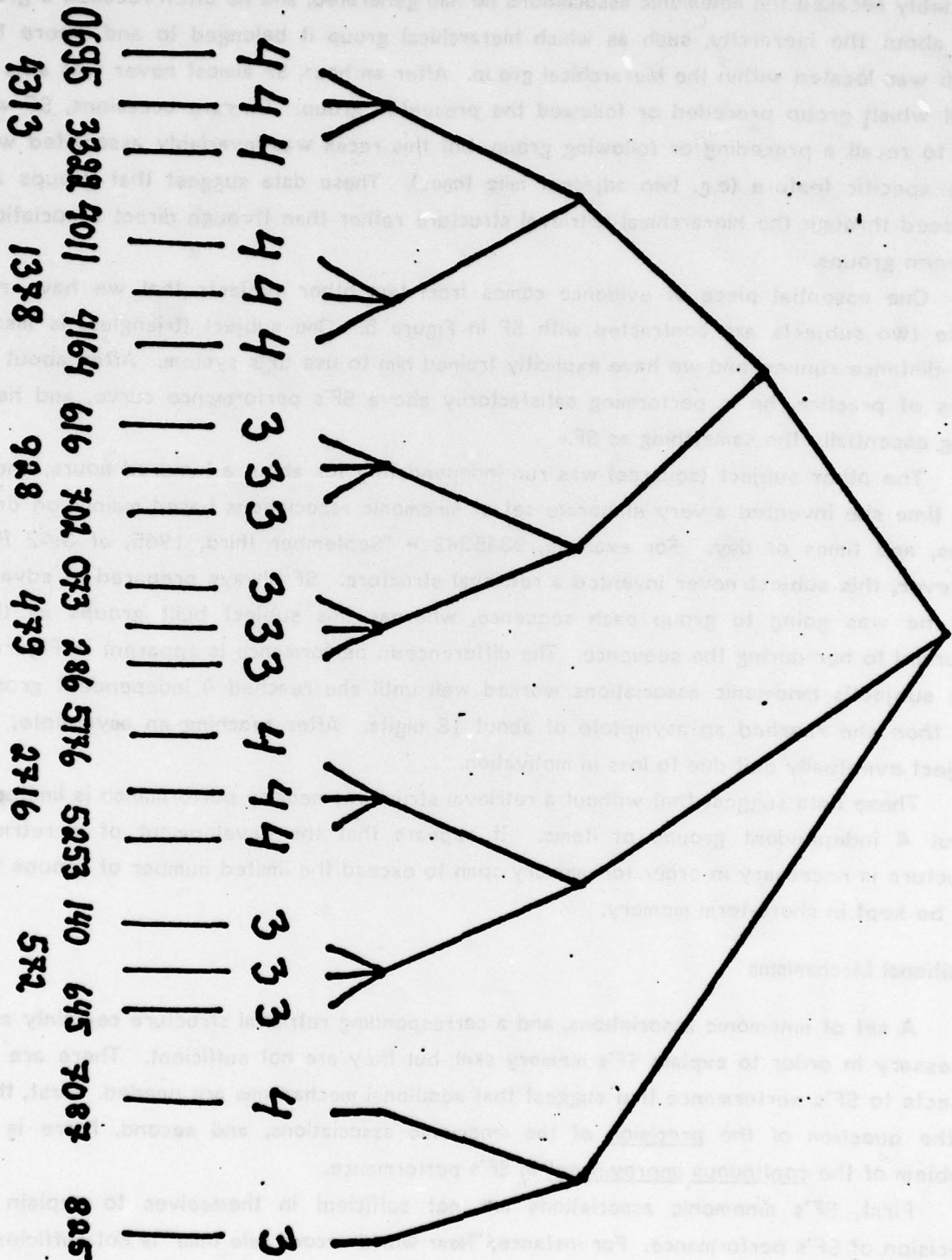


Figure 4

invariably recalled the mnemonic associations he had generated, and he often recalled a great deal about the hierarchy, such as which hierarchical group it belonged to and where the group was located within the hierarchical group. After an hour, SF almost never was able to recall which group preceded or followed the presented group. On rare occasions, SF was able to recall a preceding or following group, but this recall was invariably associated with some specific feature (e.g. two adjacent mile times). These data suggest that groups are accessed through the hierarchical retrieval structure rather than through direct associations between groups.

One essential piece of evidence comes from two other subjects that we have run. These two subjects are contrasted with SF in Figure 5. One subject (triangles) is also a long-distance runner, and we have explicitly trained him to use SF's system. After about 75 hours of practice, he is performing satisfactorily above SF's performance curve, and he is doing essentially the same thing as SF.

The other subject (squares) was run independently for about a hundred hours, and in that time she invented a very elaborate set of mnemonic associations based mainly on days, dates, and times of day. For example, 9365342 = "September third, 1965, at 3:42 P.M." However, this subject never invented a retrieval structure. SF always prepared in advance how he was going to group each sequence, whereas this subject built groups as they occurred to her during the sequence. The difference in performance is apparent in Figure 5. This subject's mnemonic associations worked well until she reached 4 independent groups, and then she reached an asymptote of about 18 digits. After reaching an asymptote, this subject eventually quit due to loss in motivation.

These data suggest that without a retrieval structure, memory performance is limited to about 4 independent groups of items. It appears that the development of a retrieval structure is necessary in order for memory span to exceed the limited number of groups that can be kept in short-term memory.

Additional Mechanisms

A set of mnemonic associations, and a corresponding retrieval structure certainly seem necessary in order to explain SF's memory skill, but they are not sufficient. There are two aspects to SF's performance that suggest that additional mechanisms are needed. First, there is the question of the precision of the mnemonic associations, and second, there is the problem of the continuous improvement in SF's performance.

First, SF's mnemonic associations are not sufficient in themselves to explain the precision of SF's performance. For instance, "Near world-record mile time" is not sufficient to retrieve 3:49.2. We believe that there must be some mechanism, not apparent in the verbal protocols, that binds the more abstract mnemonic associations to more precise information. We believe that this mechanism involves the redundancy and uniqueness of the memory trace

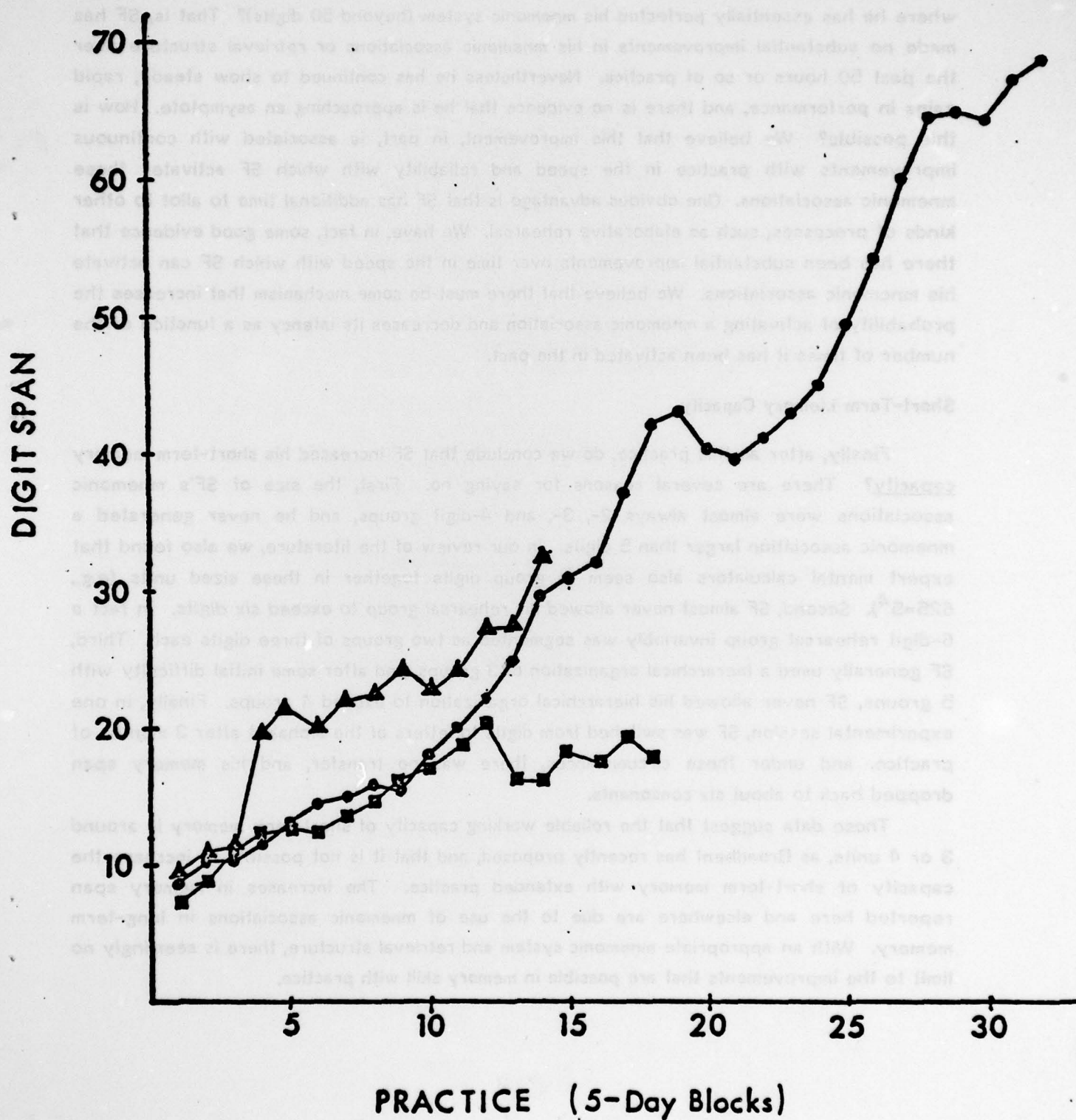


Figure 5

induced by meaningful associations.

Second, how is SF able to show further continuous improvement beyond the point where he has essentially perfected his mnemonic system (beyond 50 digits)? That is, SF has made no substantial improvements in his mnemonic associations or retrieval structure over the past 50 hours or so of practice. Nevertheless he has continued to show steady, rapid gains in performance, and there is no evidence that he is approaching an asymptote. How is this possible? We believe that this improvement, in part, is associated with continuous improvements with practice in the speed and reliability with which SF activates these mnemonic associations. One obvious advantage is that SF has additional time to allot to other kinds of processes, such as elaborative rehearsal. We have, in fact, some good evidence that there has been substantial improvements over time in the speed with which SF can activate his mnemonic associations. We believe that there must be some mechanism that increases the probability of activating a mnemonic association and decreases its latency as a function of the number of times it has been activated in the past.

Short-Term Memory Capacity

Finally, after all this practice, do we conclude that SF increased his short-term memory capacity? There are several reasons for saying no. First, the size of SF's mnemonic associations were almost always 2-, 3-, and 4-digit groups, and he never generated a mnemonic association larger than 5 digits. In our review of the literature, we also found that expert mental calculators also seem to group digits together in these sized units (e.g., $625=5^4$). Second, SF almost never allowed his rehearsal group to exceed six digits. In fact a 6-digit rehearsal group invariably was segmented as two groups of three digits each. Third, SF generally used a hierarchical organization of 3 groups, and after some initial difficulty with 5 groups, SF never allowed his hierarchical organization to exceed 4 groups. Finally, in one experimental session, SF was switched from digits to letters of the alphabet after 3 months of practice, and under these circumstances, there was no transfer, and his memory span dropped back to about six consonants.

These data suggest that the reliable working capacity of short-term memory is around 3 or 4 units, as Broadbent has recently proposed, and that it is not possible to increase the capacity of short-term memory with extended practice. The increases in memory span reported here and elsewhere are due to the use of mnemonic associations in long-term memory. With an appropriate mnemonic system and retrieval structure, there is seemingly no limit to the improvements that are possible in memory skill with practice.

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