Acquisition of a Memory Skill

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Abstract. After more than 230 hours of practice in the laboratory, a subject was able to increase his memory span from 7 to 79 digits. His performance on other memory tests with digits equaled that of memory experts with lifelong training. With an appropriate mnemonic system, there is seemingly no limit to memory performance with practice.

One of the most fundamental and stable properties of the human memory system is the limited capacity of short-term memory. This limit places severe constraints on the human ability to process information and solve problems (1). On the other hand, this limit (about seven unrelated items) stands in apparent contrast to documented feats of memory experts (2). Whether these memory skills are the result of extensive practice or of exceptional ability has often been disputed. The goal of this research is to analyze how a memory skill is acquired.

An undergraduate (S.F.) with average memory abilities and average intelligence for a college student engaged in the memory span task for about 1 hour a day, 3 to 5 days a week, for more than 1½ years. S.F. was read random digits at the rate of one digit per second; he then recalled the sequence. If the sequence was reported correctly, the next sequence was increased by one digit; otherwise it was decreased by one digit. Immediately after half the trials (randomly selected), S.F. provided verbal reports of his thoughts during the trial. At the end of each session, he also recalled as much of the material from the session as he could. On some days, experiments were substituted for the regular sessions.

During the course of 20 months of practice (more than 230 hours of laboratory testing), S.F.'s digit span steadily improved from 7 to almost 80 digits (Fig. 1). Furthermore, his ability to remember digits after the session also improved. In the beginning, he could recall virtually nothing after an hour's session; after 20 months of practice, he could recall more than 80 percent of the digits presented to him. On one occasion (after 4 months of practice), we tested S.F.'s memory after the session with a recognition test (because recognition is a much more sensitive measure of retention than recall is); he not only recognized perfectly 3- and 4-digit sequences from the same day, but also recognized sequences from earlier in the week.

With only a few hundred hours of practice, S.F. would be classified as a beginner at most skills. However, in his field of expertise, memory for random digits, he compares favorably with the best-known mnemonists, such as Luria's S. and Hunt and Love's V.P. (2). For example, after about 6 months of practice, we set S.F. the task of recalling a matrix of 50 digits because data on this task are available for both S. and V.P. S.F.'s study times and recall times were at least as good as those of the lifetime memory experts.

The key to understanding this skill comes from analyses of S.F.'s verbal reports and his performance on various experimental tests. We will first describe two essential components of this skill: (i) his mnemonic associations and (ii) his retrieval structures. Then we will address the question of whether or not S.F. was able to increase his short-term memory capacity.

The most essential part of S.F.'s skill is his mnemonic associations, which he described in great detail in his verbal reports. The principle of a mnemonic is to associate unknown material with something familiar; the advantage is that it relieves the burden on short-term memory because recall can be achieved through a single association with an already-existing code in long-term memory. What S.F. did was to categorize 3- and 4-digit groups as running times for various races (3). For example, 3492 was recoded as "3 minutes and 49 point 2 seconds, near world-record mile time" (4). During the first 4 months, S.F. gradually constructed an elaborate set of mnemonic associations based initially on running times and then supplemented with ages (893 was "89 point 3, very old man") and dates (1944 was "near the end of World War II") for those sequences that could not be categorized as times. Running times (62 percent) and ages (25 percent) account for almost 90 percent of S.F.'s mnemonic associations.

There are several lines of evidence concerning the mnemonic associations. On the basis of S.F.'s verbal reports, we were able to simulate his mnemonic associations, that is, to abstract a set of rules that categorizes a sequence of digits as 3- and 4-digit running times. When we compared the simulation to the verbal reports, between 85 and 95 percent of the time the computer categorized the digit sequences as S.F. did. By means of the simulation, we were also able to determine which sequences of digits would be categorized as running times and
which would not. On the basis of this
analysis, we presented S.F. with se-
quencies that could not be associated
with running time categories. (This was
before S.F. started to use ages to supple-
ment his running times, after about 2
months of practice.) When S.F. was
faced with these uncodable sequences, his
performance dropped almost to his
beginning level. In another experimental
session we did the opposite: We present-
ed him with sequences that could all be
coded in terms of running times. His per-
formance jumped by 22 percent (from an
average of 16 to an average of 19.5 dig-
its).

The mechanism whereby S.F. recodes
single digits into 3- and 4-digit units is not
sufficient to account for his performance.
If S.F. originally had a digit span of 7 dig-
its, and he then learned to recode digits
into 4-digit groups, how could he remem-
ber the order of more than seven groups
of digits—that is, more than 28 digits? The
answer to this question comes from an
analysis of his retrieval structures.

Like most people, S.F. initially tried
to hold everything in a rehearsal buffer,
which stored material in a phonetic code.
When he first used his mnemonic associ-
ations (session 5), he demonstrated the
first rudimentary use of a retrieval struc-
ture. He recoded the first 6 digits as two
running times, if possible, and he held
the last 4 to 6 digits in his rehearsal buf-
fer. He then tried to recall the two run-
ning times in order while rehearsing the
last few digits. This strategy worked
well, and he gradually perfected it over
the course of the first 30 sessions until he
could recall as many as 18 digits by re-
coding three groups of 4 digits each as
running times and holding the last 6 dig-
its in his rehearsal buffer. At this point,
he began to experience real difficulty in
keeping the order straight for more than
three or four running times (Fig. 1,
blocks 8 and 9).

The next important advance came
when S.F. introduced organization into
his retrieval structure by segmenting his
groups into subgroups: He used two 4-
digit groups followed by two 3-digit
groups and the rehearsal group. From
this point, S.F. improved his perfor-
ance rapidly by increasing the number of
groups within each supergroup, until he
began to experience the same difficulty
as before. The second plateau in his per-
formance curve (around block 21 in Fig.
1) is associated with difficulty in remem-
bering the order of more than four
groups within a supergroup. Introducing
another level of organization by sub-
dividing these supergroups allowed
S.F.'s performance to improve rapidly
so that he now averages almost 80 digits.
His current retrieval organization can be
described as a hierarchy with three lev-
els, and his retrieval structure for 80 dig-
its can be illustrated in the following
way, with spaces corresponding to levels
in the hierarchy:

  444 444 333 333 444 333 444 5

Besides the verbal descriptions, there
is a great deal of additional evidence that
S.F. uses hierarchical retrieval struc-
tures. Probably the most straightforward
evidence comes from his speech patterns
during recall, which almost invariably
follow the same pattern. Digit groups are
recalled rapidly at a normal rate of
speech (about 3 digits per second) with
pauses between groups (about 2 seconds
between groups, on average, with longer
pauses when he has difficulty remember-
ing). At the end of a supergroup, how-
ever, there is a falling intonation, gener-
ally followed by a longer pause (3).

In several experiments, we verified
that groups are retrieved through the hi-
erarchical structure rather than through
direct associations between groups. In
one experiment, instead of asking for re-
call after presenting the digits, we pre-
sented S.F. with a 3- or 4-digit group and
asked him to name the group that pre-
ceded it or followed it in the sequence.
He required more than twice as long, on
the average, if the preceding or following
group crossed a supergroup boundary
(10.0 seconds) than if it did not (4.4 sec-
onds). In another experiment, after an
hour's session, we presented S.F. with
3- and 4-digit groups from that session
and asked him to recall as much as he
could about each group. He invariably
recalled the mnemonic associations he
had generated, and he often recalled a
great deal about the location of the group
within the hierarchy, but he was virtually
never able to recall the preceding or fol-
lowing group.

After all this practice, can we con-
clude that S.F. increased his short-term
memory capacity? There are several rea-
sons to think not. (i) The size of S.F.'s
groups were almost always 3 and 4 dig-
its, and he never generated a mnemonic
association for more than 3 digits (6). (ii)
He almost never allowed his rehearsal
group to exceed 6 digits. (iii) He general-
ly used three groups in his supergroups
and, after some initial difficulty with five
groups, never allowed more than four
groups in a supergroup. (iv) In one ex-
perimental session, S.F. was switched
from digits to letters of the alphabet after
3 months of practice and exhibited no
transfer: His memory span dropped back
to about six consonants.

These data suggest that the reliable
working capacity of short-term memory
is about three or four units, as Broadbent
describes because it is hard to increase the
capacity of short-term memory with extended
practice. Rather, increases in memory span
are due to the use of mnemonic associa-
tions in long-term memory. With an ap-
propriate mnemonic system and retrieval
structure, there is seemingly no limit to
improvement in memory skill with prac-
tice.

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References and Notes

1 G. A. Miller, Psychol. Rev. 63, 81 (1956); A. Newell and H. A. Simon, Problem Solv-

2 A. R. Luria has documented the case history of
one exceptional person, S., who seemed to re-
member large amounts of trivial information for
years by means of visual imagery [The Mind of a
Mnemonist (Avon, New York, 1968)], and E.
Hunt and T. Love have described another ex-
ceptional person, W.P., who could remember
large amounts of material by means of elaborate
linguistic associations in several languages [in
A. W. Melton and E. Martin, Eds., Coding Pro-
cesses in Human Memory (Winston, Washing-
ton, D.C., 1972), p. 233].

3 S.F. is a good long-distance runner who com-
petes in races throughout the eastern United
States. He classifies running times into at least
11 major categories, from half-mile to marathon,
with several subcategories within each.

4 The category label by itself was not sufficient to
retrieve the exact digits presented. A complete
understanding of the precision of mnemonic as-
sociations will require an answer to the more
general question of how meaningful associations
work.

5 Pauses, intonation, and stress patterns are well-
known indicators of linguistic structures [M. A.
K. Halliday, Intonation and Grammar in British
English (Mouton, The Hague, 1967); K. Pike,
The Intonation of American English (Univ. of
Michigan Press, Ann Arbor, 1949)]. In one
memory span study, we compared the grouping
patterns indicated by the prosodic features in re-
call with the grouping patterns reported by S.F.
in his verbal protocols, and agreement was vir-
tually perfect.

6 The mnemonic associations of lightning calcul-
ators appear to be limited to 3 or 4 digits (G. E.
Müller, Z. Psychol. Ergänzungsbld 5 (1911)).

7 D. A. Broadbent, in Studies in Long Term Mem-
ory, A. Kennedy and A. Wilkes, Eds. (Wiley,
New York, 1975), p. 3

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