Instructor: Sean Kang, Ph.D.
Email: sean.kang@dartmouth.edu
Class Meets: Weekdays 1:30-4:00pm @ 9B114

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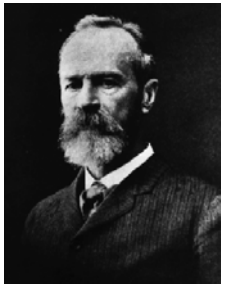
Myths and Mysteries of Human Learning and Memory

Short-Term Memory (STM) & Working Memory (WM)

28 Jun 2016

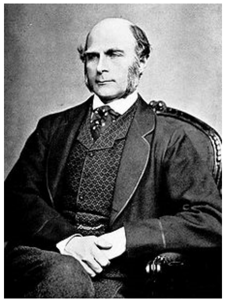
"The objects we feel in this directly intuited past differ from properly recollected objects. An object which is recollected, in the proper sense of the term, is one which has been absent from consciousness altogether, and now revives anew…. But an object of primary memory is not thus brought back; it was never lost; its date was never cut off in consciousness from that of the immediately present moment. In fact, it comes to us as belonging to the rearward portion of the present space of time, and not to the genuine past."

- William James (1890)



"There seems to be a presence-chamber in my mind where full consciousness holds court, and where two or three ideas are at the same time in audience, and an ante-chamber full of more or less allied ideas, which is situated just beyond the full ken of consciousness. Out of this ante-chamber the ideas most readily allied to those in the presence-chamber appear to be summoned in a mechanically logical way and to have their turn of audience."

- Sir Francis Galton (1883)



History of dividing memory into multiple stores, with one specialised for holding information briefly.

Short-term memory
Primary memory
Short-term store
(Working memory)

Different Attributes of STM and LTM (widely accepted in the 1970s)

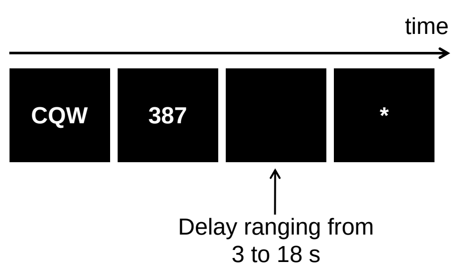
	STM	LTM
Maintenance of info	Rehearsal	Organisation
Format of info	Primarily acoustic	Primarily semantic
Capacity	7 ± 2 chunks	No known limit
Duration of info	Up to 1 min	Up to years
Retrieval	Probably automatic	Search process
Retrieval time	Fast	Slow

Short-Term Memory

1. Duration
2. Capacity
3. Retrieval from
4. Coding

"Brown-Peterson Distractor Paradigm"

Consonant trigram (i.e., 3 letters) presented, followed by a number. Subject asked to count backwards by 3s until they receive a prompt to recall the trigram.



"387, 384, 381, 378…"

(8 trials at each of 6 delays)

Memory for consonant trigrams declined as delay increased

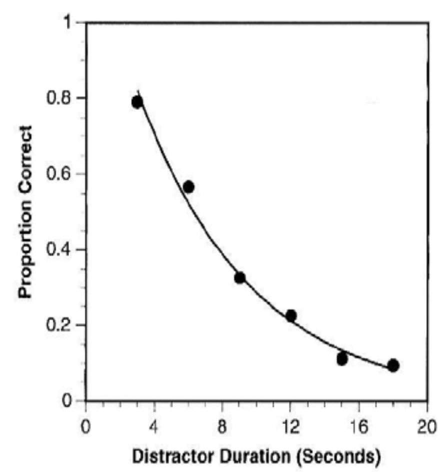


Figure 3.3 Proportion of consonant trigrams recalled correctly as a function of the distractor task duration.
SOURCE: Peterson & Peterson (1959).

Similar findings by Brown (1958)

Short-Term Memory

1. Duration
2. Capacity
3. Retrieval from
4. Coding

VOL. 63, NO. 2 MARCH, 1956

THE PSYCHOLOGICAL REVIEW

THE MAGICAL NUMBER SEVEN, PLUS OR MINUS TWO: SOME LIMITS ON OUR CAPACITY FOR PROCESSING INFORMATION [1]

GEORGE A. MILLER
Harvard University

My problem is that I have been persecuted by an integer. For seven years this number has followed me around, has intruded in my most private data, and has assaulted me from the pages of our most public journals. This number assumes a variety of disguises, being sometimes a little larger and sometimes a *little smaller than usual, but never* changing so much as to be unrecognizable. The persistence with which this number plagues me is far more than a random accident. There is, to quote a famous senator, a design behind it, some pattern governing its appearances. Either there really is something unusual about the number or else I am suffering from delusions of persecution.

Miller (1956)

Chunking

An integrated piece of information

1 4 9 1 6 2 5 3 6 4 9 6 4 8 1

1 4 9 16 25 36 49 64 81

1^2 2^2 3^2 4^2 5^2 6^2 7^2 8^2 9^2

Squares of digits 1–9

Ericsson, Chase, & Faloon (1980)

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.

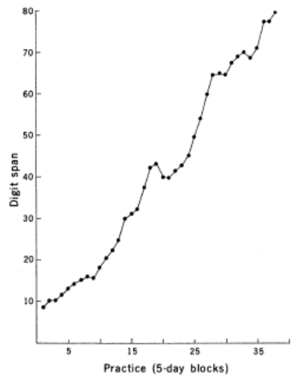


Fig. 1. Average digit span for S.F. as a function of practice. Digit span is defined as the length of the sequence that is correct 50 percent of the time; under the procedure followed, it is equivalent to average sequence length. Each day represents about 1 hour's practice and ranges from 55 trials per day in the beginning to 3 trials per day for the longest sequences. The 38 blocks of practice shown here represent about 190 hours of practice; interspersed among these practice sessions are approximately 40 hours of experimental sessions (not shown).

Ericsson, Chase, & Faloon (1980)

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.

chunking

Did S.F. increase his STM capacity with training?

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.

NO.

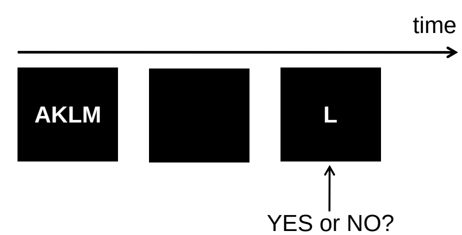
<u>Short-Term Memory</u>

1. Duration
2. Capacity
3. Retrieval from
4. Coding

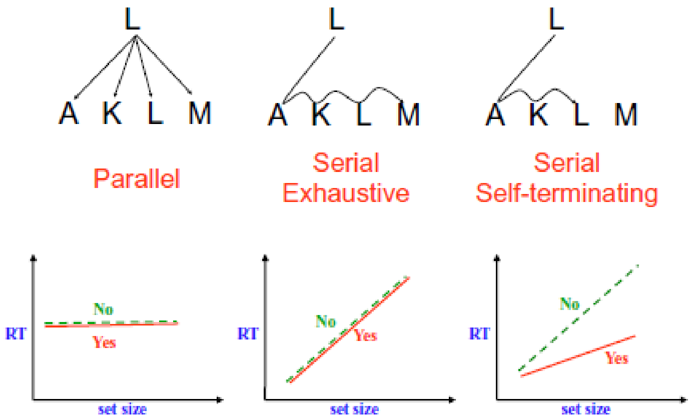
How do people "search" STM?

The "Sternberg" Task:

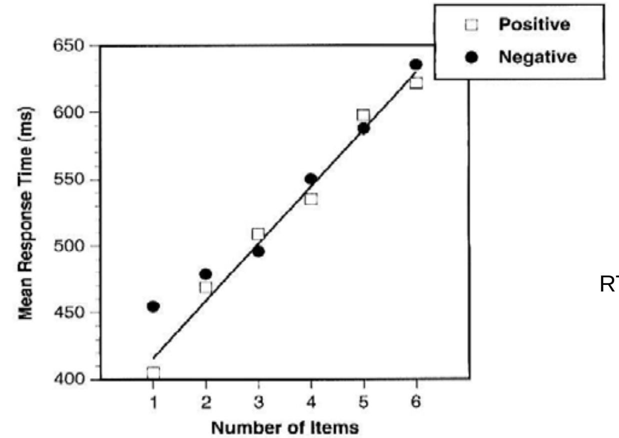
Subject presented with short list of items (1 to 6), followed by a "probe" item. Subject has to decide whether the probe item was part of the list.



PREDICTIONS



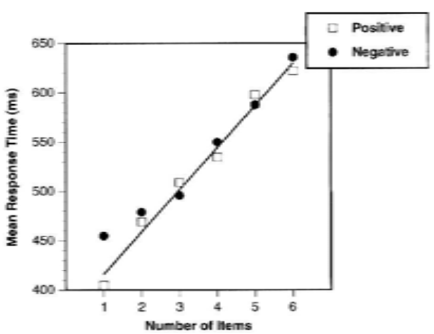
Sternberg (1966)



RT = 397 + 38n

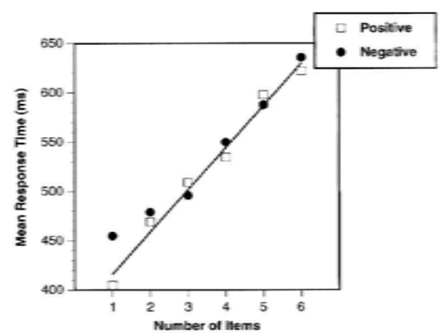
Figure 3.7 The mean time to determine whether a probe item was in the original list of items (positive probe) or was not in the original list (negative probe) as a function of the number of items in the list.
SOURCE: Reprinted with permission from "High Speed Scanning in Human Memory," by S. Sternberg, 1966, *Science*, *153*, 652–654. Copyright © 1966 American Association for the Advancement of Science.

Sternberg (1966)



RT increased by ~ 38ms for each additional item in the search set
→ **SERIAL**

Sternberg (1966)



It didn't matter whether the target was in the set or not
→ **EXHAUSTIVE**

Short-Term Memory

1. Duration
2. Capacity
3. Retrieval from
4. Coding

Evidence for acoustic code in STM

Conrad (1964)

Subjects presented visually with lists of 6 letters each (750ms/letter). Some letters looked similar but sounded quite different (e.g., V and X); others looked quite different but sounded similar (e.g., V and C).

After each list, subjects had to recall the letters in the right order (i.e., immediate serial recall).

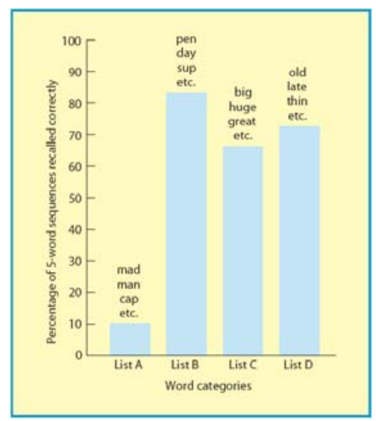
Conrad (1964)

Table 2. *Recall confusions*

Response letter	Stimulus letter: B	C	P	T	V	F	M	N	S	X
B	.	18	62	5	83	12	9	3	2	0
C	13	.	27	18	55	15	3	12	35	7
P	102	18	.	24	40	15	8	8	7	7
T	30	46	79	.	38	18	14	14	8	10
V	56	32	30	14	.	21	15	11	11	5
F	6	8	14	5	31	.	12	13	131	16
M	12	6	8	5	20	16	.	146	15	5
N	11	7	5	1	19	28	167	.	24	5
S	7	21	11	2	9	37	4	12	.	16
X	3	7	2	2	11	30	10	11	59	.

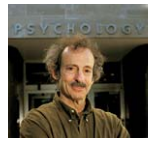
Errors in recall tended to be based on acoustic similarity rather than visual similarity

…similar findings by Baddeley (1966)

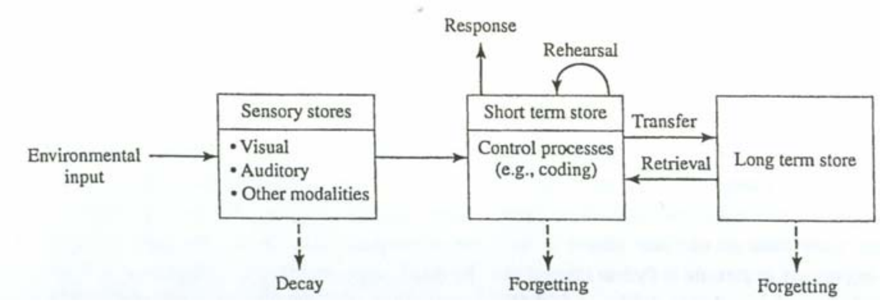


The effect of phonological and semantic similarity on immediate serial recall of five-word sequences. Phonological similarity leads to poor immediate recall whereas similarity of meaning has little effect.

Two-Store Model



Atkinson & Shiffrin's (1968) "Modal" model

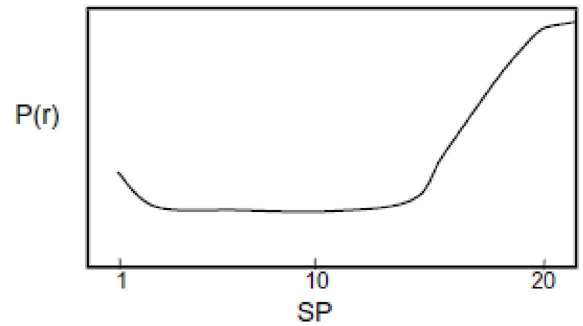


Information must pass through (and be rehearsed in) STS in order to reach LTS.

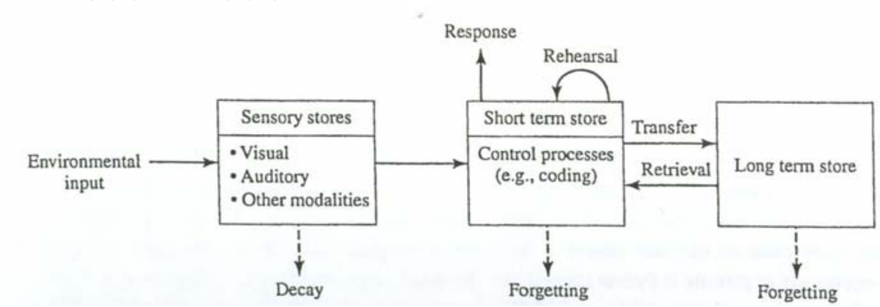
Serial Position Curve in Single-Trial **Free Recall**

Present List (of words)

Immediate recall in **any order**



"Modal" model



How does this model explain the serial position curve?

Primacy: early items receive more rehearsal (greater likelihood of transfer to LTS)

Recency: late items are "dumped" from STS

Effect of List Length

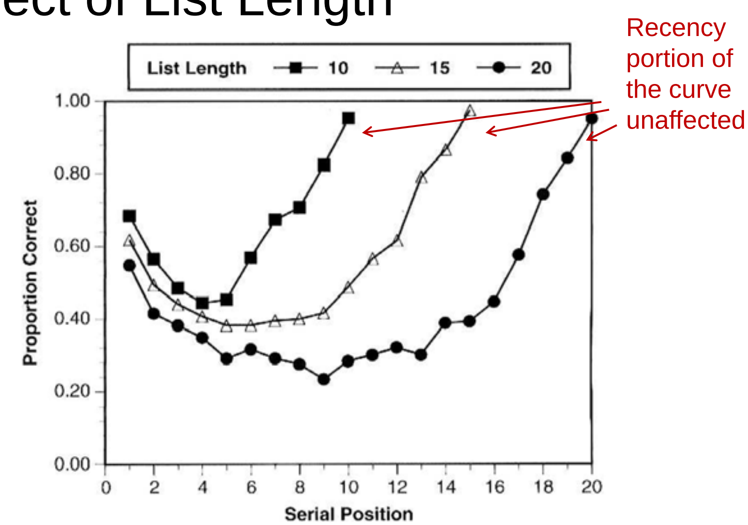


Figure 3.8 Serial positions curves showing the proportion of items recalled correctly in a free recall test as a function of input position for three different list lengths. SOURCE: Data from Murdock (1962).

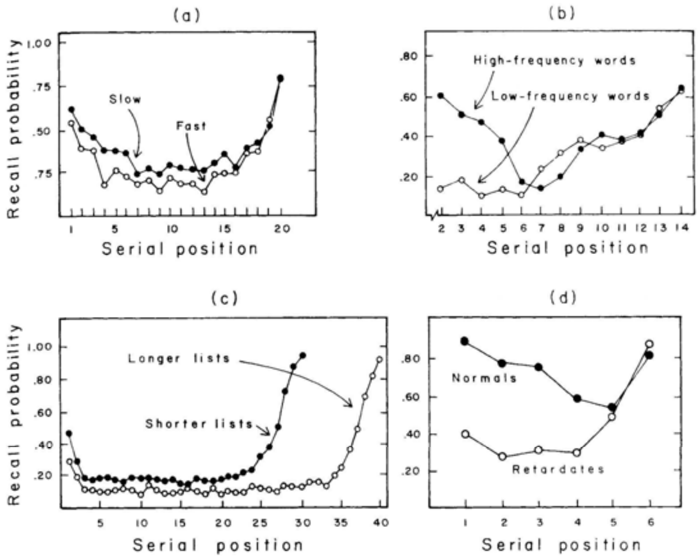
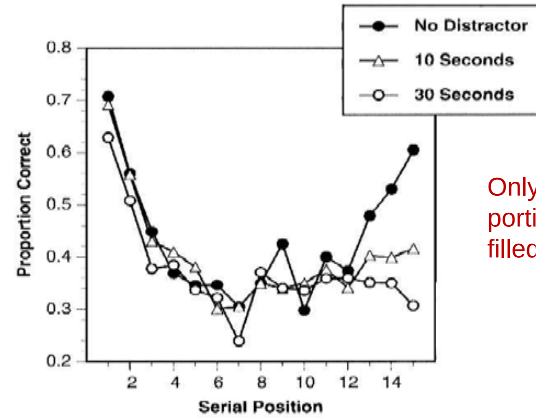


FIGURE 6.3 The effects of four independent variables on the serial position function. (a) Performance as a function of persentation rate, either three or nine seconds per item (after Glanzer & Cunitz, 1966). (b) The effect of word frequency (after Sumby, 1963). (c) The effect of list length, 30 versus 40 items (after Murdock, 1962). (d) An experiment on probe memory for position with normal and mentally retarded subjects (after Belmont & Butterfield, 1971).

Effect of Filled Delay



Only recency portion affected by filled delay

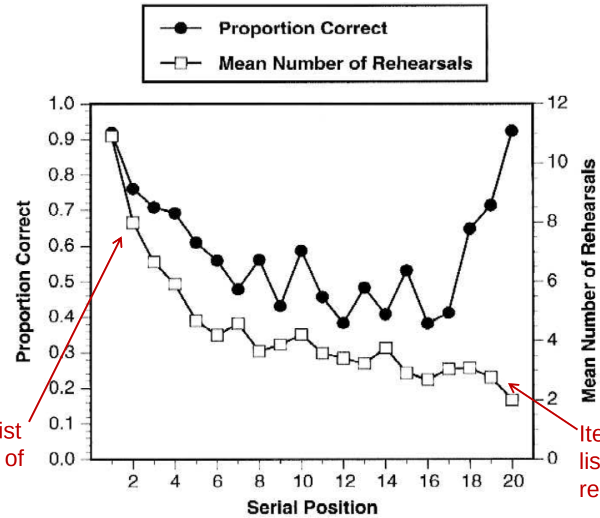
Figure 3.10 The proportion of items recalled correctly as a function of serial position in a free recall test when there is no distractor task, or when subjects are required to count backward for 10 or 30 seconds before recalling the items. SOURCE: From "Two Storage Mechanisms in Free Recall," by M. Glanzer and A. R. Cunitz, 1966, *Journal of Verbal Learning and Verbal Behavior*, 5, 351–360. Copyright © 1966 Academic Press, Inc. Reprinted with permission.

The modal model posits that the primacy effect occurs b/c items at the beginning of the list receive extra rehearsals (which increases transfer into LTM).

Is there a way to look at rehearsals directly?

Rundus & Atkinson (1970) asked subjects to rehearse aloud. 20 words/list, each word presented for 5 s.

ITEM	WORDS REHEARSED
1 Cattle	*cattle, cattle, cattle, cattle*
2 Tribute	*tribute, cattle, tribute, cattle*
3 Hint	*hint, tribute, cattle, cattle*
4 Golf	*golf, hint, tribute*
…	
20 Wrench	*wrench, …*



Items at beginning of list received a lot of rehearsal

Items at end of list received few rehearsals

Figure 3.9 The proportion of items recalled correctly as a function of serial position and the mean number of rehearsals devoted to each item at each serial position. SOURCE: From "Rehearsal Processes in Free Recall: A Procedure for Direct Observation," by D. Rundus and R. C. Atkinson, 1970, *Journal of Verbal Learning and Verbal Behavior*, 9, 99–105. Copyright © 1970 Academic Press, Inc. Reprinted with permission.

Negative Recency (Craik,1970)

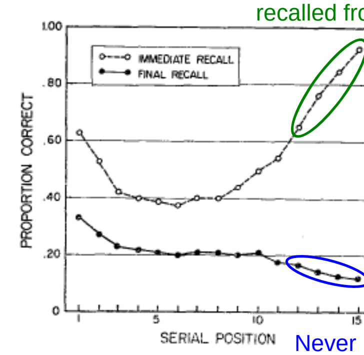
10 lists, 15 words/list.

Immediate free recall (IFR) after each list.

After recall of the last list, a break then a surprise "final free recall" (FFR) test.

Positive recency in IFR but ***negative*** recency in FFR.

Received few rehearsals; recalled from STS



Never made it to LTS b/c not rehearsed enough

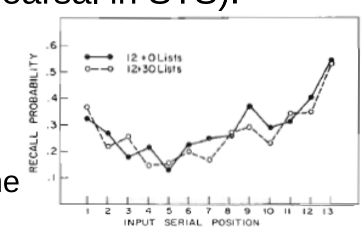
But the modal model can't account for…

- Recency effect even with a continual distractor task
- Neuropsychological patients
- Rehearsal doesn't guarantee transfer to LTM
- Long-term recency effects

PROBLEMS WITH THE MODAL MODEL

The recency effect occurs even when using a *continual distractor task*

Distractor task after *each* item in a list.
(Continual distraction from rehearsal in STS).



Why a problem?

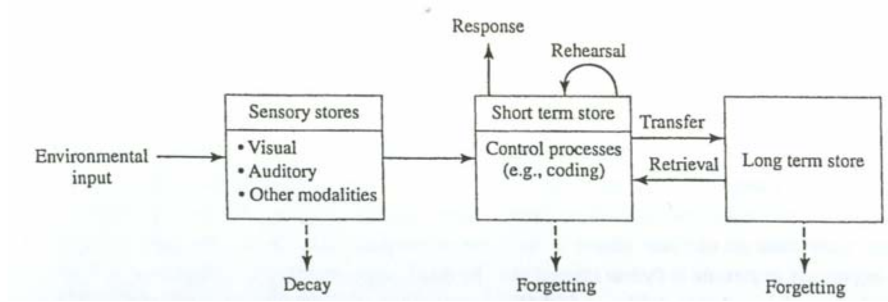
The to-be-remembered words at the end of the list should have been gone from STS by the time the test occurred.

Bjork and Whitten (1974)

But the modal model can't account for…

- Recency effect even with a continual distractor task
- Neuropsychological patients
- Rehearsal doesn't guarantee transfer to LTM
- Long-term recency effects

ANOTHER PROBLEM WITH THE MODAL MODEL



Information must pass through (and be rehearsed in) STS in order to reach LTS.

But patients exist with very poor STM but intact LTM.

Patient K.F. had a digit span of only 2 items, but otherwise normal LTM (Shallice & Warrington, 1970)

But the modal model can't account for…

- Recency effect even with a continual distractor task
- Neuropsychological patients
- Rehearsal doesn't guarantee transfer to LTM
- Long-term recency effects

Amount of rehearsal not necessarily associated with transfer to LTM

Lists of words with different initial letters.

Before presentation of each list, subjects told that words beginning with a certain letter were critical, and at any time they should be ready to report the last word beginning with the specified letter.

E.g., if B is the critical letter…

dog	bat	clock	desk	wall	car	bear	cup	leaf

Signal to report word. "bear"

(Craik & Watkins, 1973)

On a surprise free recall test later, subjects' probability of recall of the critical words was unrelated to the amount of rehearsal given to the words earlier.

# of intervening (non-critical) words

PERCENTAGE RECALL AS A FUNCTION OF EXPERIMENTAL CONDITION, *i* VALUE, AND PRESENTATION RATE

Condition	Presentation rate	*i* value: 0	1	2	3	4	5	6	8	12	Mean
Replaced	Slow	12	13	22	10	21	19	19	18	19	17
	Medium	10	15	22	12	14	19	09	12	11	14
	Fast	14	07	11	06	06	14	09	16	15	11
	Mean	12	12	19	10	14	17	13	15	15	14
Reported	Slow	19	20	20	20	31	39	22	26	28	25
	Medium	20	22	19	19	31	26	20	28	20	23
	Fast	26	15	22	26	20	31	19	11	20	21
	Mean	22	19	20	22	28	32	20	22	23	23

Therefore, maintenance rehearsal may serve to keep information in STM, but it doesn't necessarily promote transfer to LTM.

(Craik & Watkins, 1973)

But the modal model can't account for…

- Recency effect even with a continual distractor task
- Neuropsychological patients
- Rehearsal doesn't guarantee transfer to LTM
- Long-term recency effects

Long-term Recency Effects

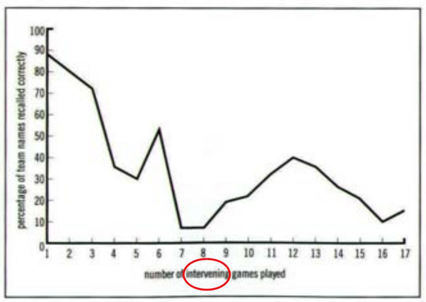
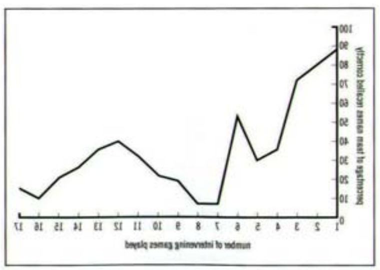


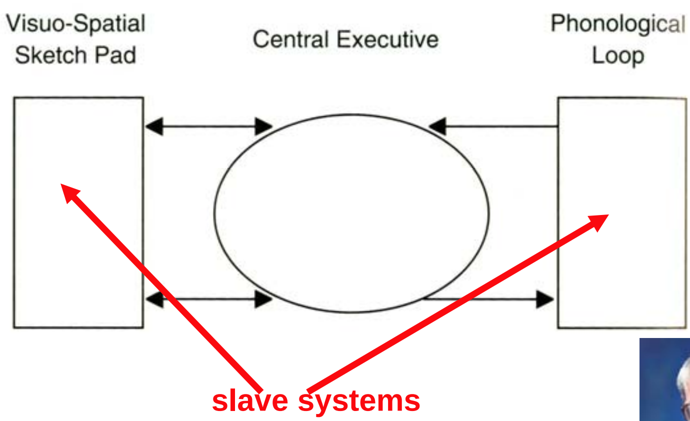
FIG. 6.5.
This graph, showing rugby players' memory for the names of teams recently played, demonstrates the general tendency for recent events to interfere with memory of similar but less recent events.
(Baddeley & Hitch, 1977)



WORKING MEMORY– a temporary memory system in which information is maintained and manipulated for a short period of time.

The most influential model of WM has been the one proposed by Alan Baddeley (e.g., Baddeley & Hitch, 1974).

WORKING MEMORY: The Baddeley model



Simplified version of Baddeley's (1990) model

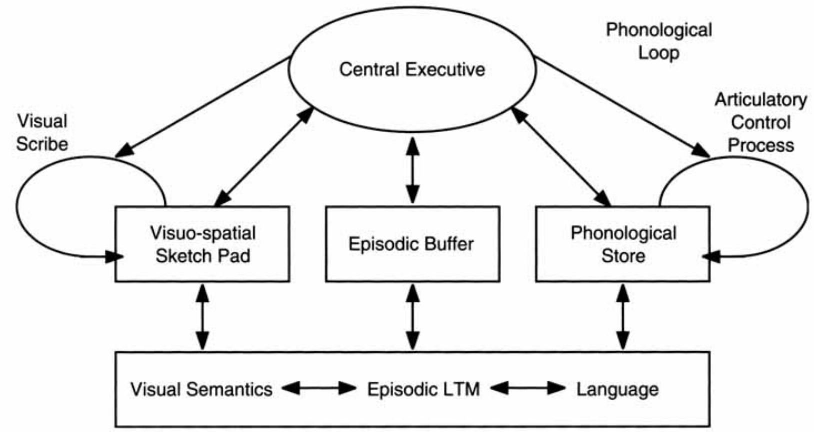
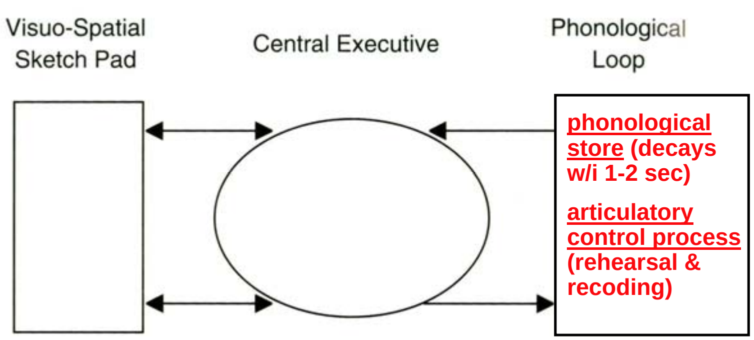


Figure 4.1 A schematic representation of Baddeley's working memory. The phonological loop is made up of the articulatory control process and the phonological store; the corresponding process and store for visuo-spatial information are the visuo-spatial sketch pad and the visual scribe. SOURCE: Based on descriptions from Baddeley (2000) and Baddeley & Logie (1999).

WORKING MEMORY: The Baddeley model



Simplified version of Baddeley's (1990) model

2 COMPONENTS OF THE PHONOLOGICAL LOOP

<u>Phonological store</u> – memory store that can hold speech-based information for a brief period (i.e., 1-2 sec).

<u>Articulatory control process</u> –

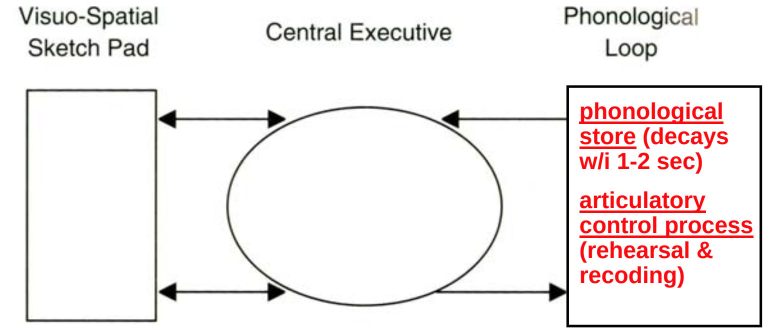
translates visual information (e.g. a visual word) into a speech-based code and puts this information into the phonological store

refresh a trace in the phonological store. This refreshing process offsets the decay process. Controls subvocal rehearsal, which is analogous to overt rehearsal.

WORKING MEMORY: The Baddeley model

Central executive
Slave systems
-- phonological loop
Evidence:
the phonological similarity effect
the irrelevant speech effect
the word length effect
articulatory suppression effects
-- visuo-spatial sketch pad
Evidence:
interference effects/imagery suppression
the unattended picture effect

Evidence for the Phonological Loop:



1. Phonological Similarity Effect
2. Irrelevant Speech Effect
3. Word-length Effect
4. Articulatory Suppression Effect

Phonological Similarity Effect

Immediate serial recall of visually-presented 6-letter sequences (Conrad & Hull, 1964)

BDGPTV < FHLNYZ

Immediate serial recall of auditorily-presented 5-word sequences (Baddeley, 1966)

mad, man, cap, mat, cat < pen, day, sup, cow, bar

Irrelevant Speech Effect

Immediate serial recall of visually-presented 9-digit sequences (Salamé & Baddeley, 1982)

- Recall performance impaired if study/presentation of the digits accompanied by spoken words (e.g., cat, gap, pad, bed, etc.) or nonsense syllables (e.g., cag, dak, tad, bep, etc.)
- Recall not disrupted by white noise
- Vocal music more disruptive than instrumental music (Salamé & Baddeley, 1989)

Word-Length Effect

Immediate serial recall of 5-word lists. Each list consisted of either 1-, 2-, 3-, 4-, or 5-syllable words.

Number of syllables 1	2	3	4	5
Stoat	Puma	Gorilla	Rhinoceros	Hippopotamus
Mumps	Measles	Leprosy	Diphtheria	Tuberculosis
School	College	Nursery	Academy	University
Greece	Peru	Mexico	Australia	Yugoslavia
Crewe	Blackpool	Exeter	Wolverhampton	Weston-Super-Mare
Switch	Kettle	Radio	Television	Refrigerator
Maths	Physics	Botany	Biology	Physiology
Maine	Utah	Wyoming	Alabama	Louisiana
Scroll	Essay	Bulletin	Dictionary	Periodical
Zinc	Carbon	Calcium	Uranium	Aluminium

(Baddeley, Thomson, & Buchanan, 1975)

Word-Length Effect

Memory span is greater for short than for long words.

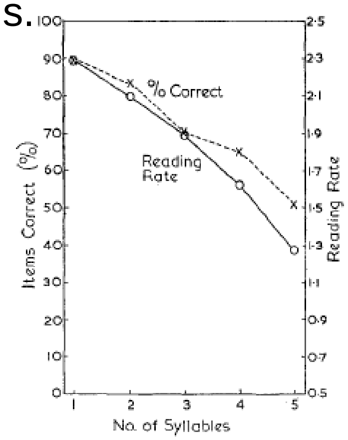
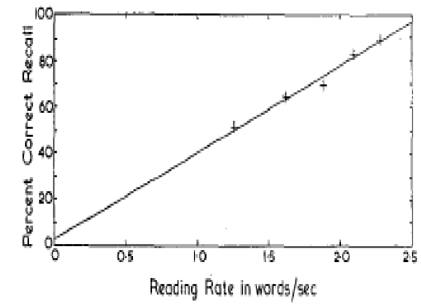


FIG. 3. Mean reading rate and percentage correct recall of sequences of five words as a function of word length.



(Baddeley, Thomson, & Buchanan, 1975)

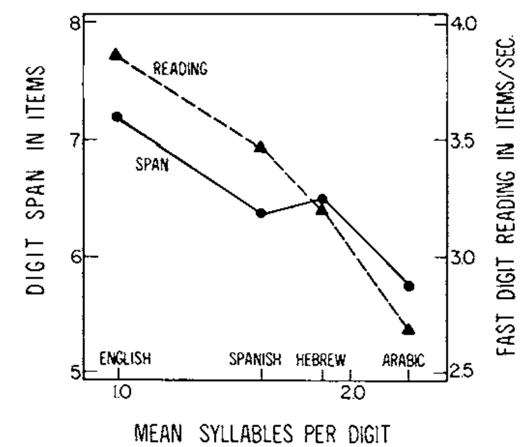
Word-Length Effect

Memory span is greater for short than for long words.

Memory span is correlated with rate of articulation

- across individuals
- across words in a language
- across languages (e.g., Welsh/English differences)
- developmentally

Differences in memory span across languages can be explained in terms of differences in reading times



(Naveh-Benjamin & Ayres, 1986)

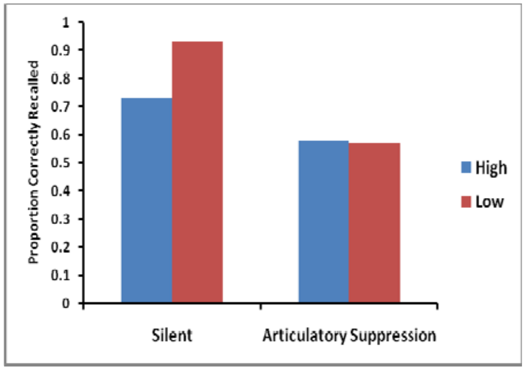
Articulatory Suppression Effect

If subjects are forced to rehearse/repeat aloud a sound, such as “lalalalala”, then the phonological loop will not be available for

- rehearsing
- recoding to-be-remembered information

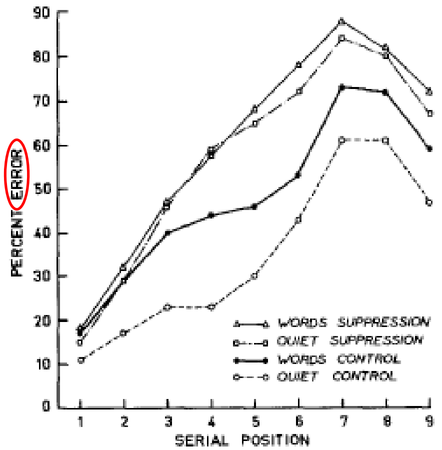
Articulatory suppression removes the phonological similarity effect for visual items b/c it disrupts the conversion of the visual code into a phonological code

Immediate serial recall of 5-letter sequences. Letters were either of high or low phonological similarity.



(Peterson & Johnson, 1971)

Articulatory suppression does the same thing to the irrelevant speech effect…



(Salamé & Baddeley, 1982)

FIG. 3. The effect of articulatory suppression on memory for sequences of visually presented digits accompanied by silence or unattended spoken words.

PHONOLOGICAL LOOP SUMMARY

Phonological store - holds info for ~ 2 s

Articulatory control process

Refreshes (via subvocal rehearsal)

Translates visual information to phonological store (i.e., recoding)

PHONOLOGICAL LOOP: WHAT USE IS IT?

Learning to read

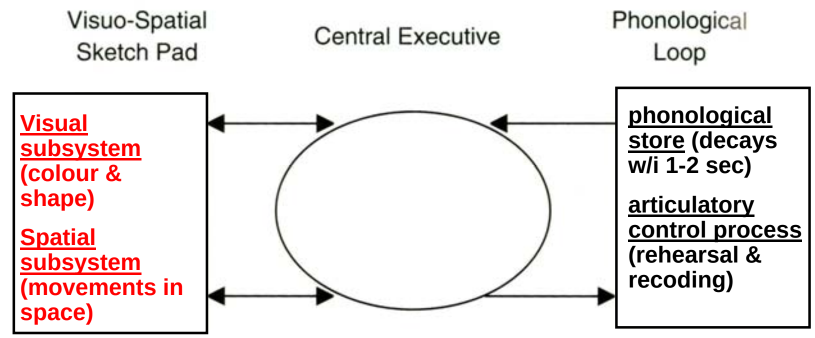
Language comprehension

Acquiring vocabulary

A familiar example used to illustrate the function of working memory is the storage of a telephone number between the time when it is looked up in a phone directory and the time when it is dialled.

anaphora

WORKING MEMORY: The Baddeley model



Logie (1995) proposed two subcomponents of the VSSP (analogous to Phonological Loop): visual cache & inner scribe

Simplified version of Baddeley's (1990) model

What would show there is a distinct visuo-spatial slave system?

For the phonological loop, one critical finding was interference from similar sounds.

Likewise, for the visuo-spatial sketchpad, critical evidence would be interference from similar visuo-spatial tasks/items.

Interference in the visuo-spatial sketchpad

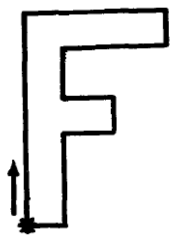
2 (task: visuo-spatial or verbal) x

2 (mode of responding: pointing or verbal)

Brooks (1968)

Visual task

Imagine the outline of a letter, such as F, then imagine a marker in the lower left corner that moves around the outside. At each corner, say whether it is an extreme top/bottom corner (YES) or not (NO).



Brooks (1968)

Verbal task

A sentence is presented auditorily. Subject's task is to categorise each word in that sentence.

E.g., "a bird in the hand is not in the bush"

Categorise each word as a noun or a non-noun.

No, Yes, No, No, Yes, No, No, No, No, Yes

Brooks (1968)

Two modes of responding

Verbal: say "YES" or "NO" aloud.

Visuo-spatial: point to YES or NO.

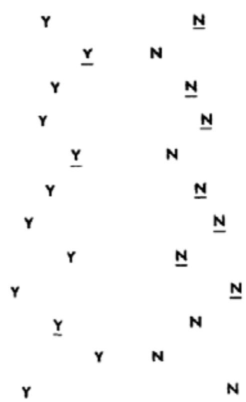
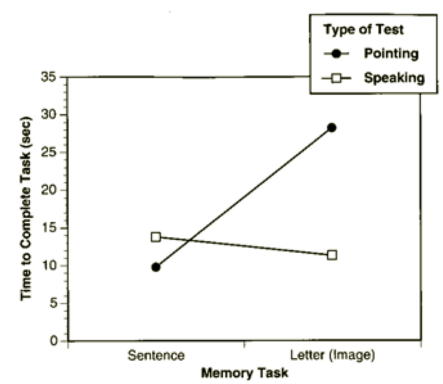


FIGURE 1. A sample output sheet for the pointing condition of Experiment I. The underlined letters are those which would be pointed to in categorizing the sentence "a bird in the hand is not in the bush." The letters are staggered to force close visual monitoring of pointing.

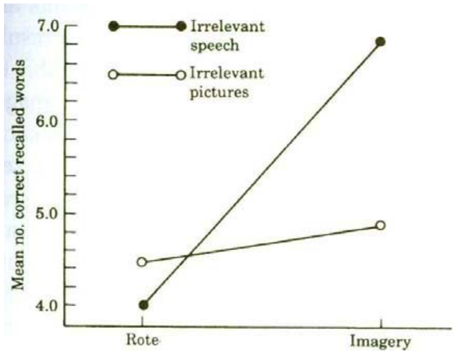
Brooks (1968)

Subjects were faster at responding when the mode of responding differed from the type of task



Brooks (1968)

UNATTENDED PICTURE EFFECT

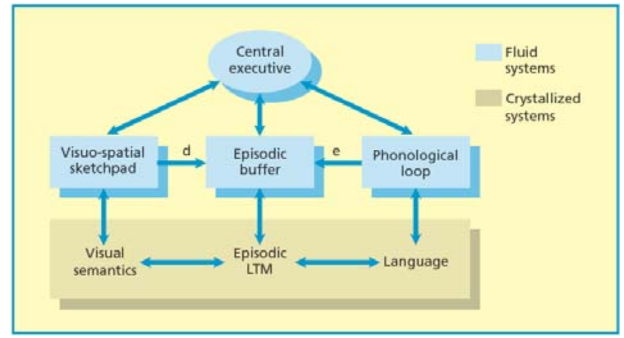


Logie (1986)

Some unanswered questions:

- Why is memory still pretty decent in the articulatory suppression condition?
- How is WM linked to LTM?

The episodic buffer. (Baddeley, 2000)



The episodic buffer: a new component of working memory?

Alan Baddeley

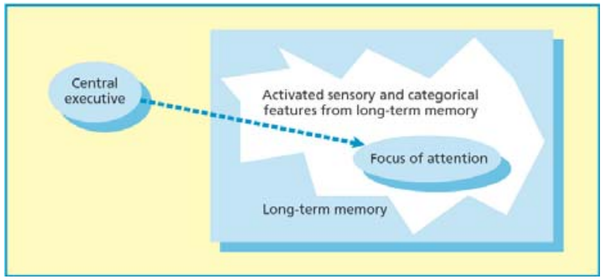
In 1974, Baddeley and Hitch proposed a three-component model of working memory. Over the years, this has been successful in giving an integrated account not only of data from normal adults, but also neuropsychological, developmental and neuroimaging data. There are, however, a number of phenomena that are not readily captured by the original model. These are outlined here and a fourth component to the model, the episodic buffer, is proposed. It comprises a limited capacity system that provides temporary storage of information held in a multimodal code, which is capable of binding information from the subsidiary systems, and from long-term memory, into a unitary episodic representation. Conscious awareness is assumed to be the principal mode of retrieval from the buffer. The revised model differs from the old principally in focussing attention on the processes of integrating information, rather than on the isolation of the subsystems. In doing so, it provides a better basis for tackling the more complex aspects of executive control in working memory.

(Baddeley, 2000)

Other ways of thinking about WM

1. Cowan's activation model
2. Engle's conception of WM "capacity"

Embedded processes model



(Cowan, 1999)

Subset of info in LTM in heightened state of activation

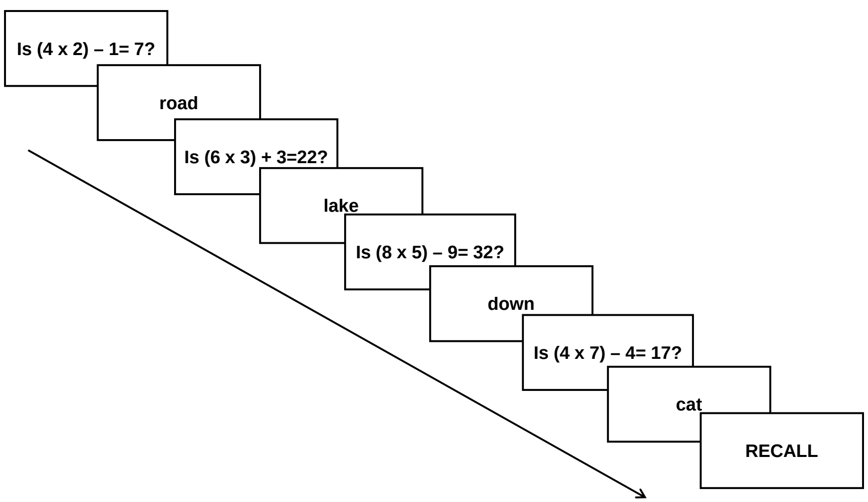
Similarities to Baddeley's model
- Decay (time-based limits), Interference (item-based limits)
- Place of cognitive work/mental workspace

WM Capacity

"WM capacity tasks measure a construct… distinguishable from STM and at least related to, maybe isomorphic to, general fluid intelligence and executive attention. One crucial function of the WM system is keeping information quickly retrievable when the task context provides interfering information that would lead to an inappropriate response."

(Engle, 2002)

WM Capacity (Operation Span)



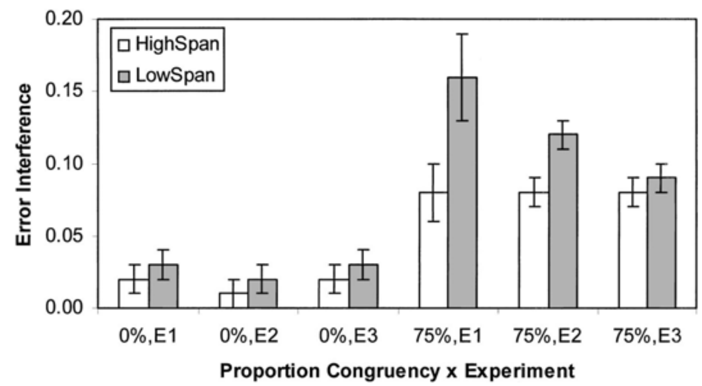
Stroop Task: Name the **font/ink** colour

Blue
Red
Green
Yellow
Red
Blue
Yellow
Green

Proportion of congruent trials

0%	75%
Blue	Blue
Red	Red
Green	Green
Yellow	Yellow
Red	Red
Blue	Blue
Yellow	Yellow
Green	Green

When it's hard to maintain task goals, high span individuals perform better



(Kane & Engle, 2003)

What about ignoring irrelevant information?

Individuals with low WM span have a hard time ignoring irrelevant information

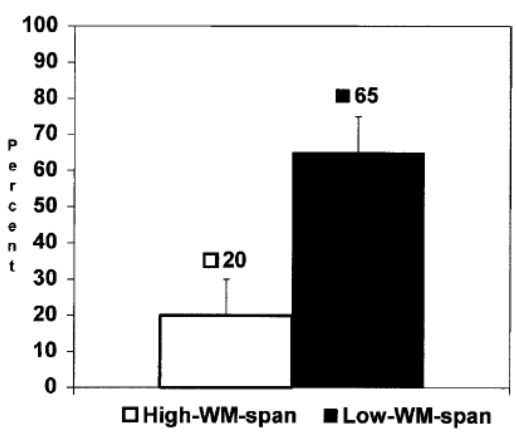


Figure 1. The proportion of high- and low-span subjects who reported hearing their name in the irrelevant message.

(Conway, Cowan, & Bunting, 2001)

WM capacity (but not STM capacity) strongly related to general fluid intelligence

WM Span & Verbal SAT: $r = +.59$ (Daneman & Carpenter, 1980)

WORKING MEMORY IS NECESSARY FOR…

Language comprehension

Ability to follow directions

Vocabulary learning

Note-taking

Writing

Reasoning

Playing chess, bridge, etc.