Cognitive Neuroscience of Human Memory

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Why study memory?

What is Memory?

"Memory proper…is the knowledge of a former state of mind after it has already once dropped from consciousness; or rather it is the knowledge of an event, or fact, of which meantime we have not been thinking, with the additional consciousness that we have thought or experienced it before."

William James (1892)
Principles of Psychology

Remember the following words

THREAD

PIN

EYE

SEWING

SHARP

POINT

PRICK

THIMBLE

HAYSTACK

THORN

HURT

INJECTION

SYRINGE

CLOTH

KNITTING

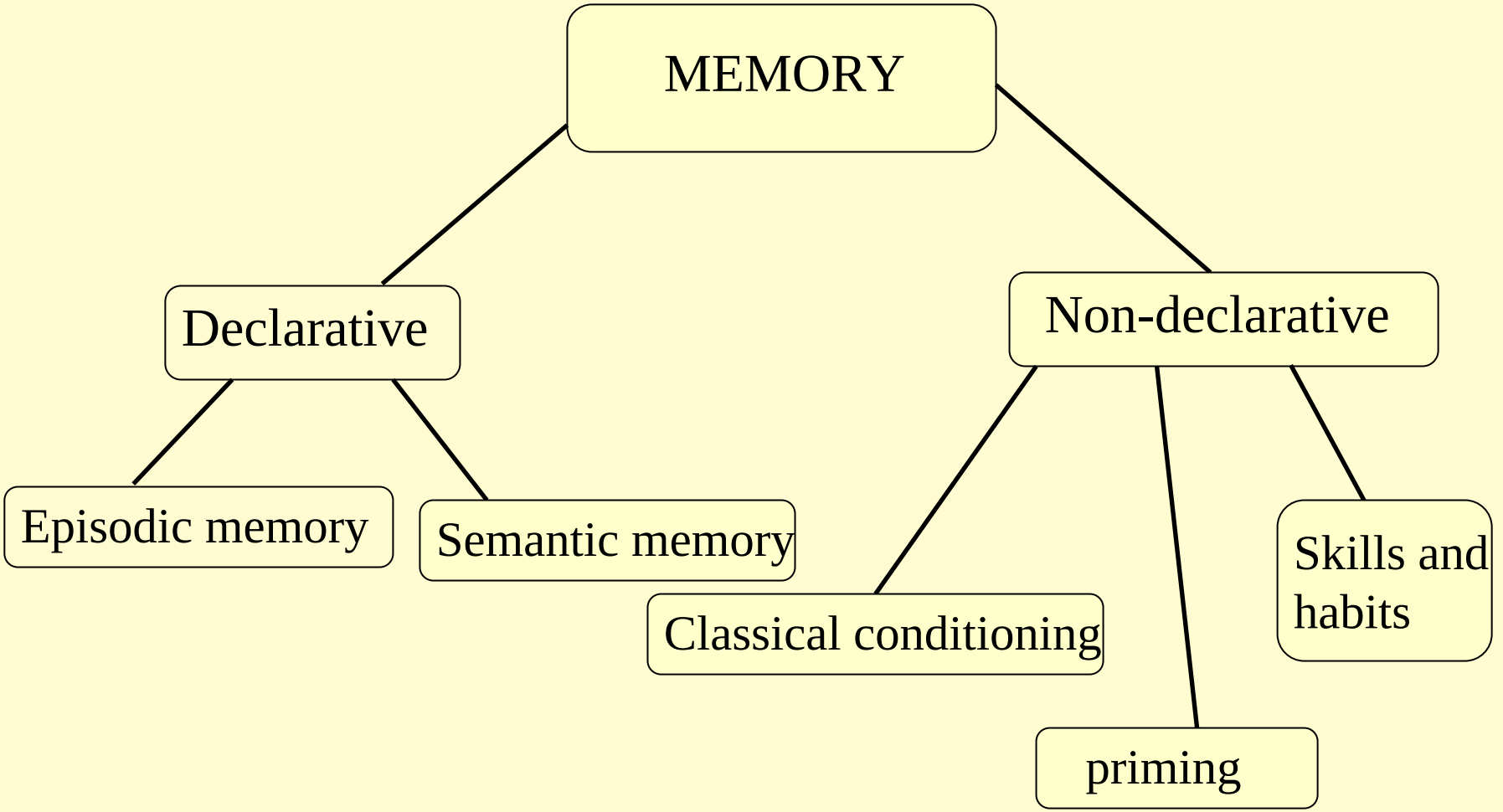
How do we define memory?

Types of memory:

- Recollection of a specific event – episodic
- Knowledge of facts - semantic
- Holding information “in mind” - working
- Feeling that something is familiar - episodic
- “Remembering” to do something - prospective
- Improvement with experience (learning) - priming
- Habits, skills, conditioning

- *These are each associated with different types of brain processes*

Long-term Memory Systems



My General Approach

- Memory is complicated
- To understand memory, we need to look at it from several angles:
  - Functional
  - Neural
- Research Methods:
  - Behavioral studies
  - Lesion studies
  - Brain imaging studies

Do you remember learning the following words?

NURSE

PIN

FISH

THREAD

BIKE

PIE

NEEDLE

CLOTH

Test List

NURSE
PIN
FISH
THREAD
BIKE
PIE
NEEDLE
CLOTH

Study List

THREAD
PIN
EYE
SEWING
SHARP
POINT
PRICK
THIMBLE
HAYSTACK
THORN
HURT
INJECTION
SYRINGE
CLOTH
KNITTING

Memory is not faithful!

History of Memory Research

- Ebbinghaus
- Pavlov
- Skinner
- Thorndike
- Bartlett

Memory: The Basic Puzzles

What are the cognitive and neural architectures of memory?

What are the memory systems?

What are the contents of memory?

What are the cognitive operations underlying memory?

What are the neural mechanisms of memory?

Overview

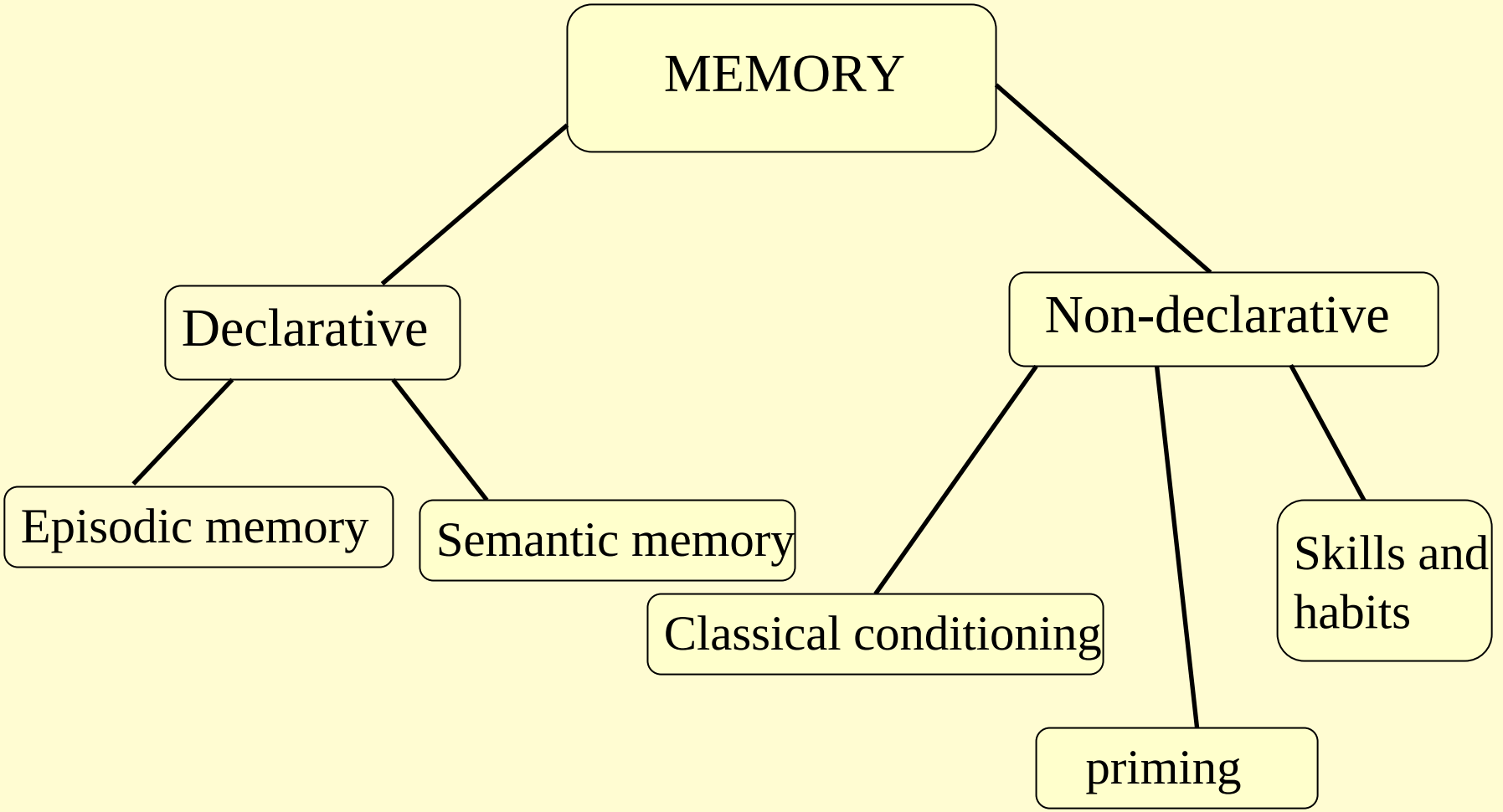
Cognitive Psychology

Neuropsychology

Animal Models

Functional Imaging

Long-term Memory Systems



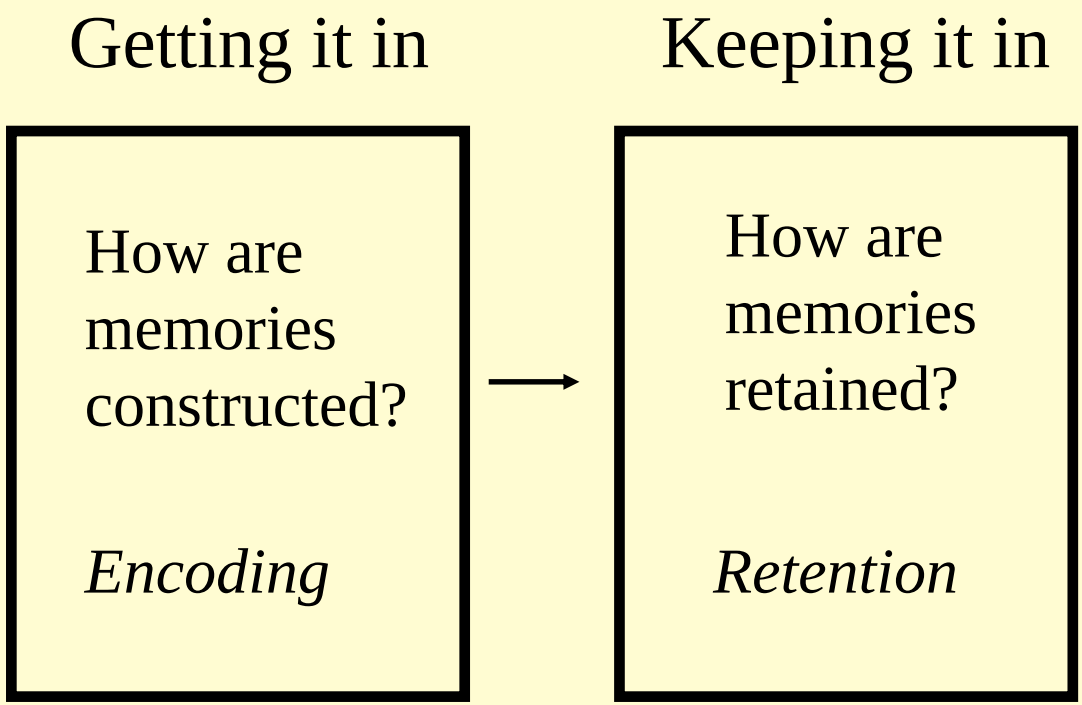
Stages of Long-Term Memory

Getting it in

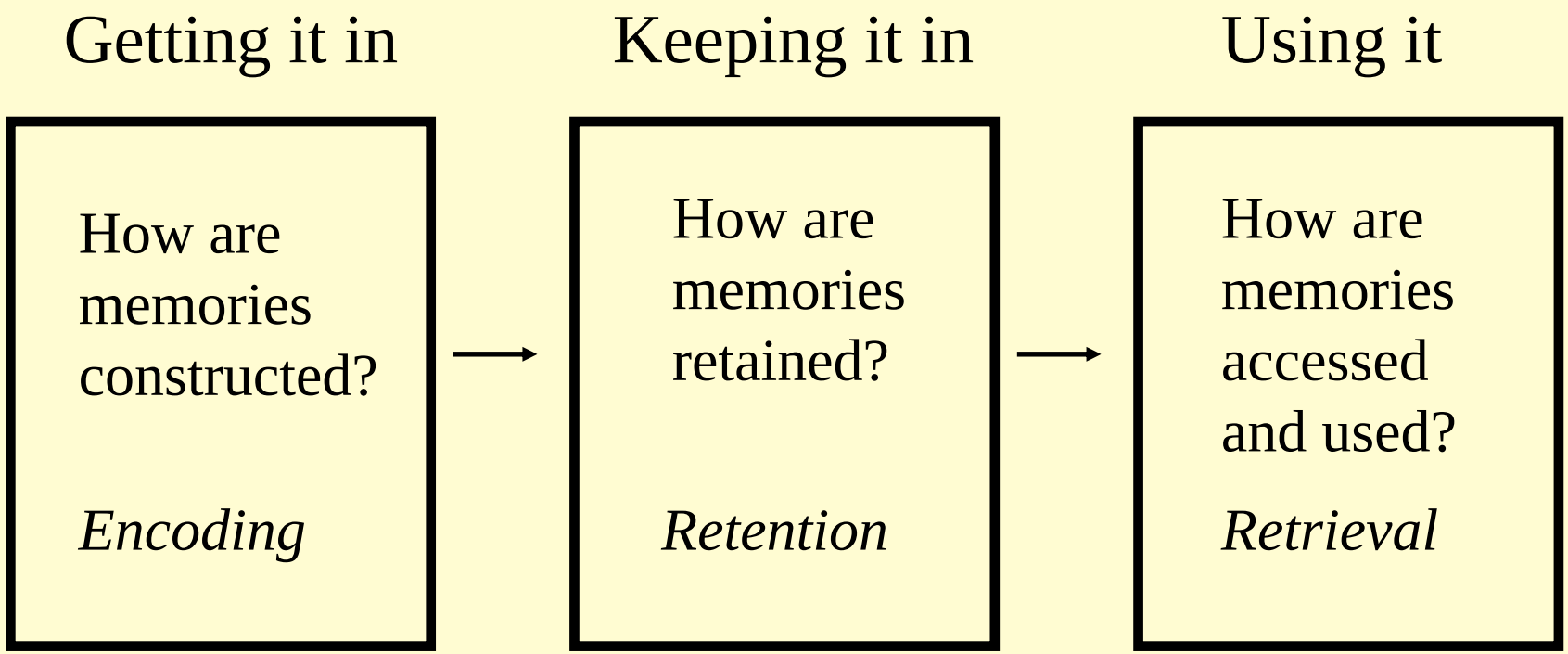
How are memories constructed?

Encoding

Stages of Long-Term Memory



Stages of Long-Term Memory



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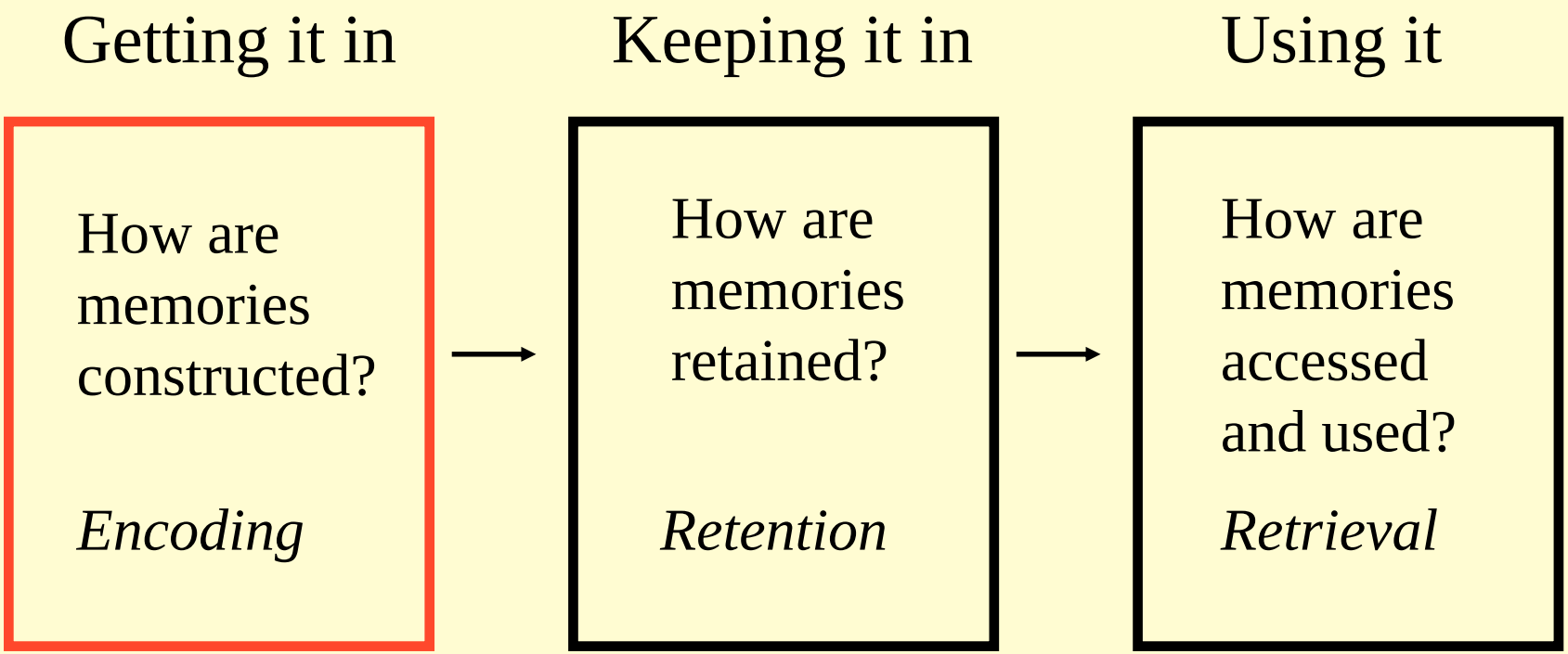

Episodic Encoding

- encoding: the processes that initially transform an experience into a durable memory trace

- consists of a structural change in the nervous system
  - unit–to–unit changes in synaptic strength

- episodic encoding: processes that yield a durable memory trace such that an event can be subsequently consciously retrieved

Can be understood at the neural and at the psychological levels

Principles of Episodic Encoding

Attention

Levels of Processing (LoP)

Transfer Appropriate Processing (TAP)

Relation of Episodic & Semantic Memory

Effects of Prior Knowledge

Distribution of Practice

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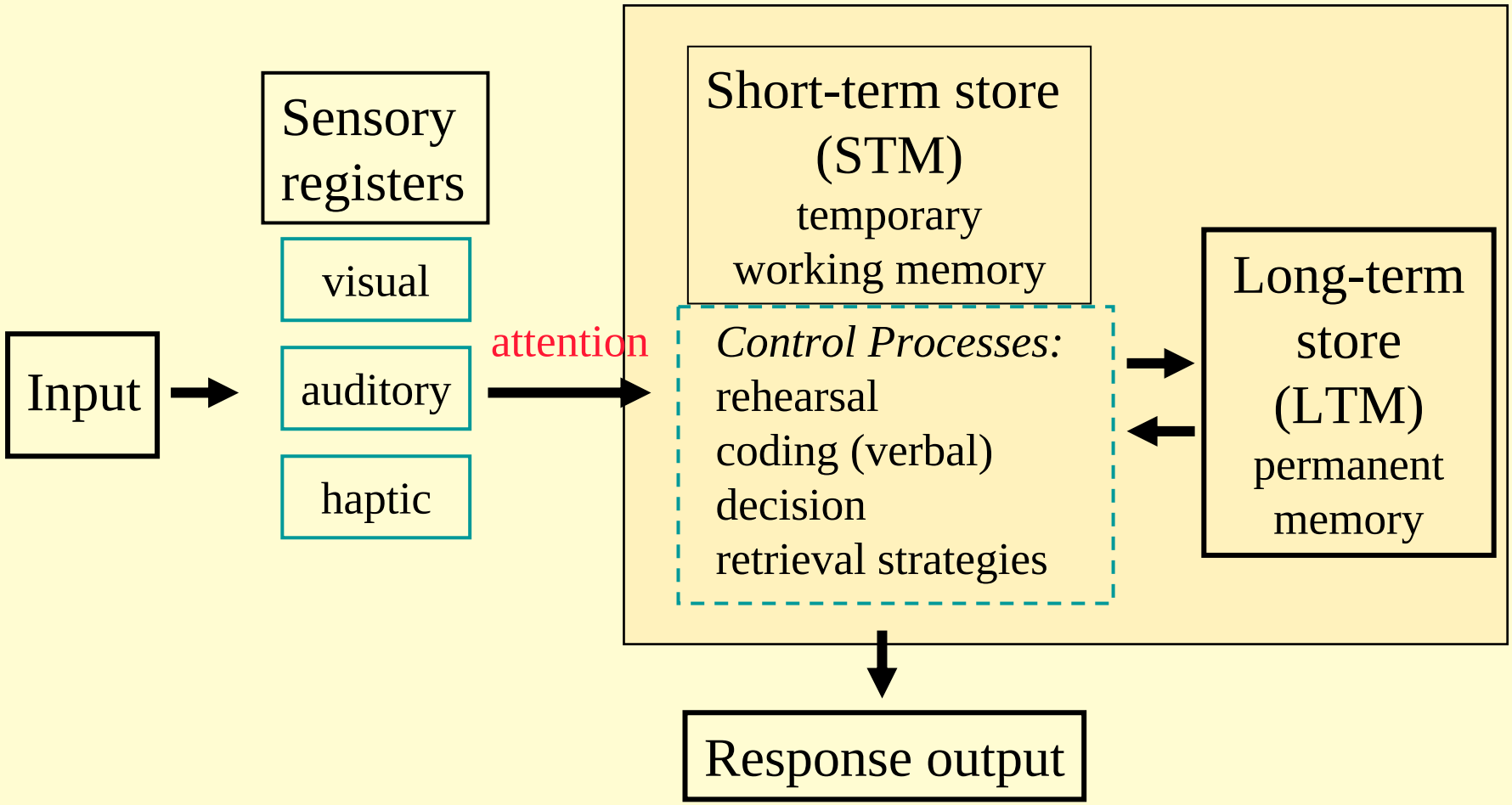
Modal Two-Store Model of Memory

Atkinson & Shiffrin (1968)



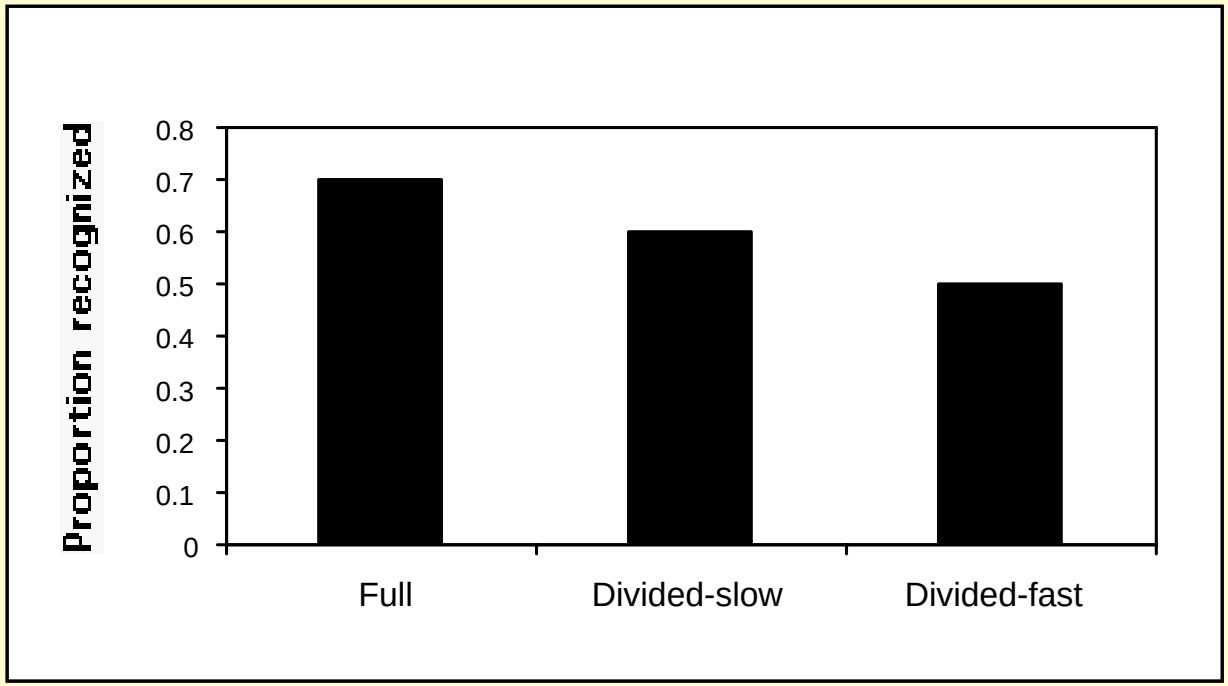
Attention & Encoding

Attending to an item is important for memory formation

Full-attention: intentional learning of visually presented words

Divided-attention: visual word learning plus a secondary task

- monitor auditory tones, indicating whether the current tone has a “high”, “medium”, or “low” pitch
- rate of tone presentation was “slow” or “fast”



(Gardiner & Parkin, 1990)

Attention, Encoding, & The Brain

Encoding: intentional learning of 15 paired-associates
e.g., *Poet–Browning*

Distractor-Tasks:

- Easy: move joystick around 4 boxes, order is predictable
  1,2,3,4….
- Difficult: move joystick around 4 boxes, order is random
  1,4,3,2,4,2,1,3….

Test: cued–recall *Poet–?*

TABLE 1 Description of tasks

Experiment 1 (acquisition)

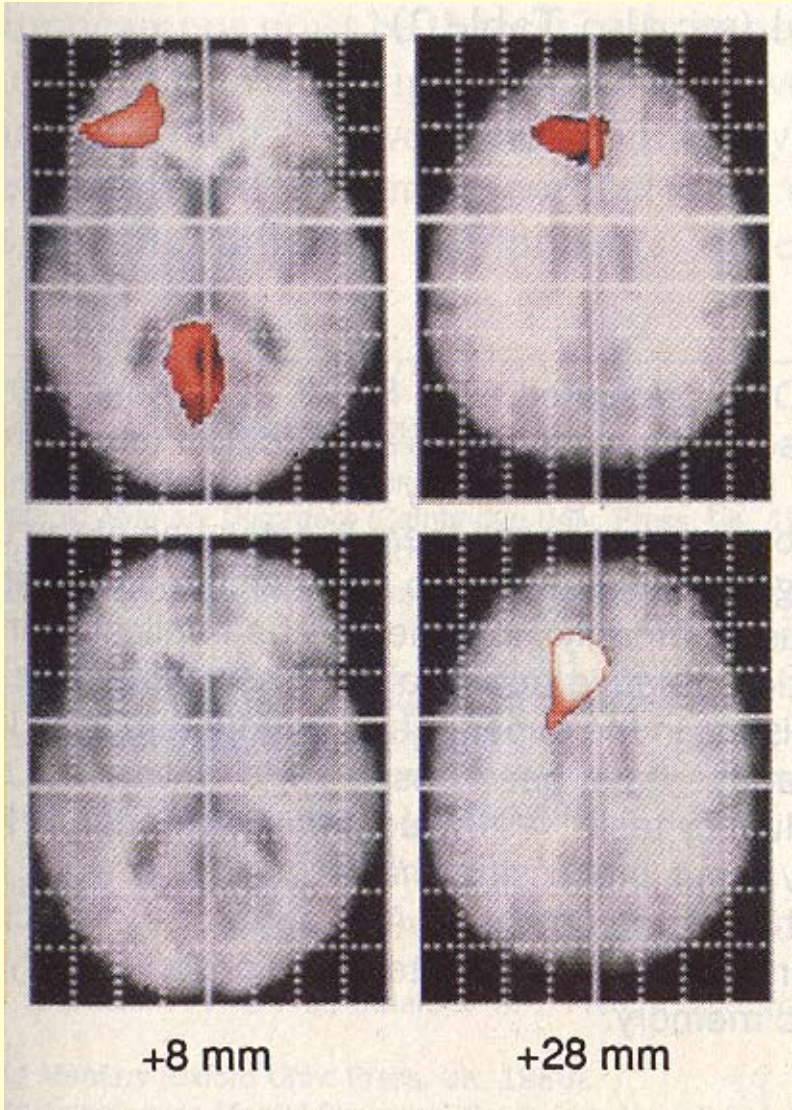
	Paired-associate task	Memory performance	Distractor task*
I	Encoding†	83 ± 4%	Easy
II (control)	Passive listening‡	—	Easy
III	Encoding†	68 ± 4%§	Difficult
IV (control)	Passive listening‡	—	Difficult

(Shallice et al., 1994)

Attention, Encoding, & the Brain

Easy distraction –
Passive listening

Difficult distraction –
Passive listening



(Shallice et al., 1994)

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Levels of Processing

(Craik & Lockhart, 1972; Craik & Tulving, 1975)

Encoding = incidental by-product of the active perceptual and cognitive processing carried out during an event

Stimuli / Events can be processed at different “levels”

Shallow (sensory aspects)

structural: perceptual features of the presented stimulus
phonological/lexical: convert stimuli to speech-based codes
semantic: access and evaluate the meaning of the text

Deep (derived aspects)

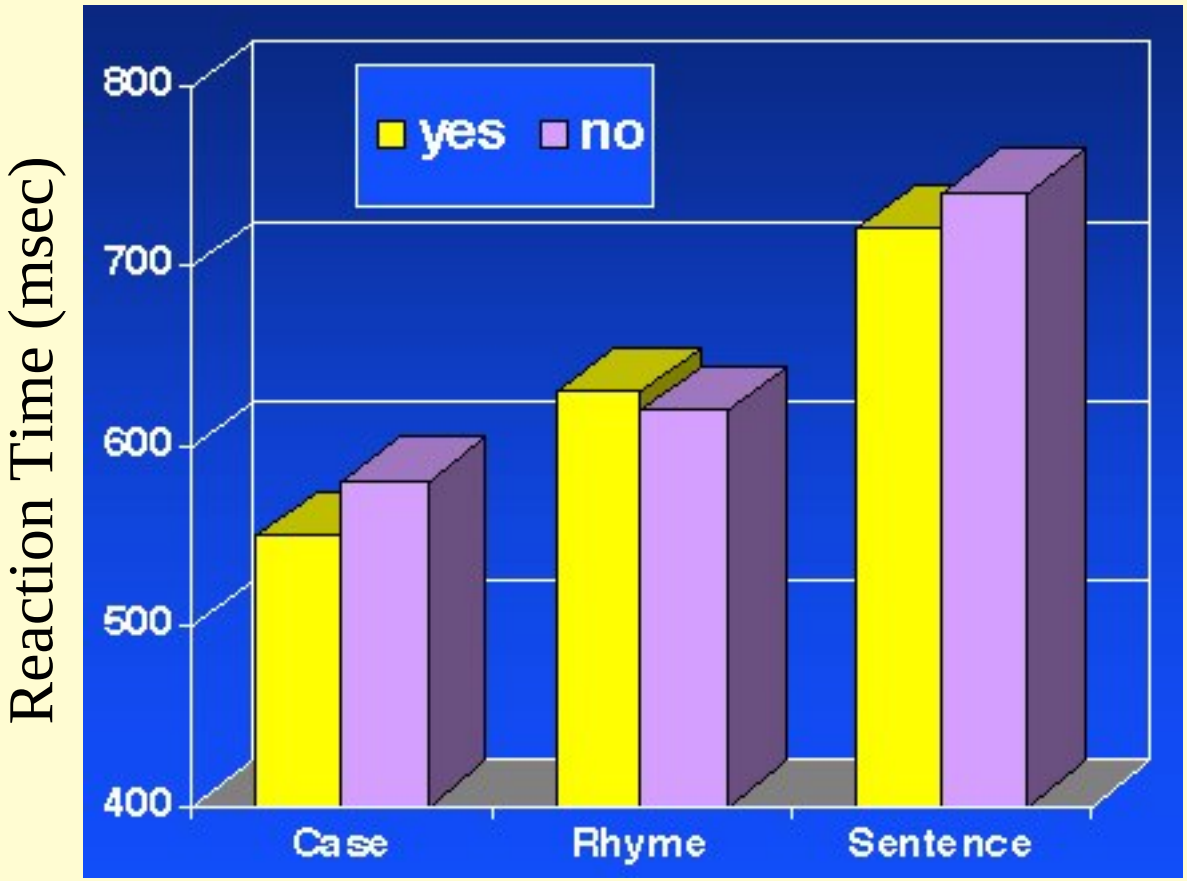
“Deeper” processing = more effective encoding

Levels of Processing Paradigm

	Yes	No
Structural		
Is the word in capital letters?	TABLE	table
Phonological		
Does the word rhyme with WEIGHT?	crate	MARKET
Semantic		
Would the word fit the sentence: "He met a _____ in the street?"	FRIEND	cloud

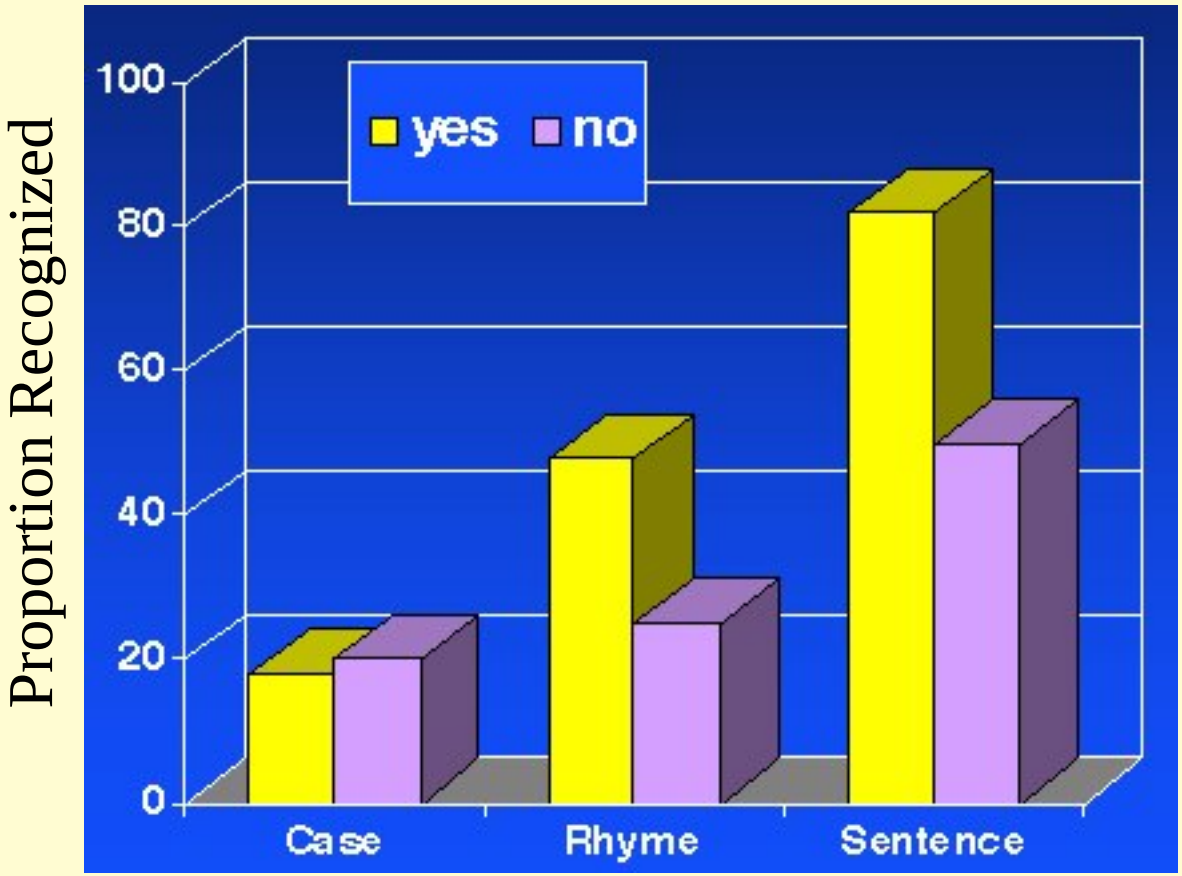
(Craik & Tulving, 1975)

Levels of Processing: Time to Process Item



(Craik & Tulving, 1975)

Levels of Processing: Subsequent Memory



Perhaps indicates "deeper" is better

BUT…

"deeper" is processed longer, could just be processing time

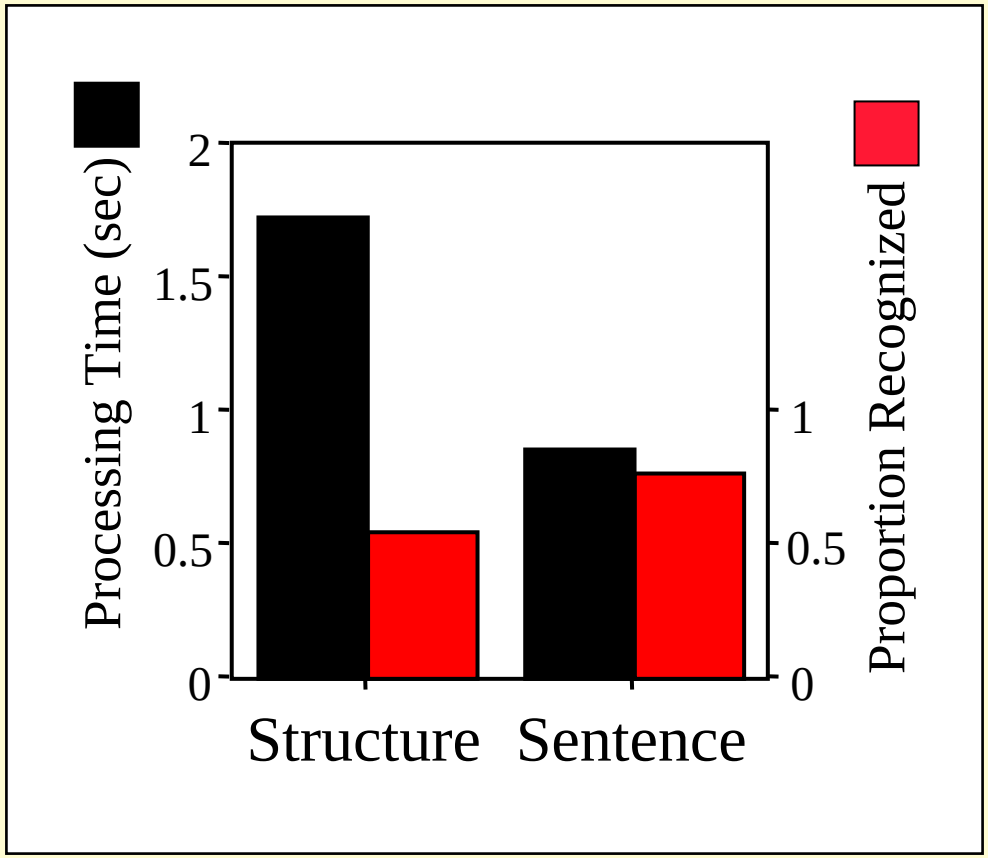
(Craik & Tulving, 1975)

Levels of Processing Paradigm

	Yes	No
Structural		
CCVVC?	BRAIN	UNCLE
Semantic		
Would the word fit the sentence: "The man threw the ball to the _____?"	CHILD	CLOCK

(Craik & Tulving, 1975)

Levels of Processing: Subsequent Memory



(Craik & Tulving, 1975)

Levels of Processing

- Useful, consistent results
- However, slightly circular reasoning…

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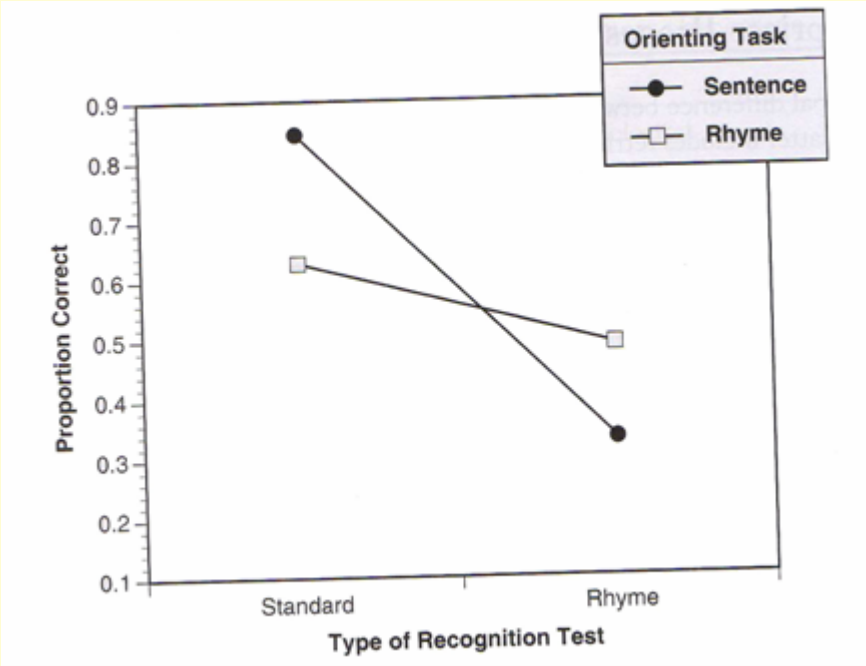
Transfer Appropriate Processing

TAP: A process leads to better memory NOT because it is deeper, but because it is *appropriate* for the kind of test that will be conducted.

How different from LOP?

- TAP includes a role for retrieval..



But semantic encoding followed by semantic cue BEST, thus semantic encoding may lead to better cue specificity.. (Watkins (1979) cue overload principle..)

Encoding Specificity

- Tulving (1972)

- The experience of recollection relies on the interaction between a cue and a memory trace
  - "Ecphory"

- You can't say that one type of encoding is better than another because you need to consider the interaction between the retrieval cue and the trace that was produced at encoding.

- Example: "weak" vs. "strong" cues
  - Weak: fruit--> flower
  - Strong: bloom-->flower

Encoding Specificity Experiment

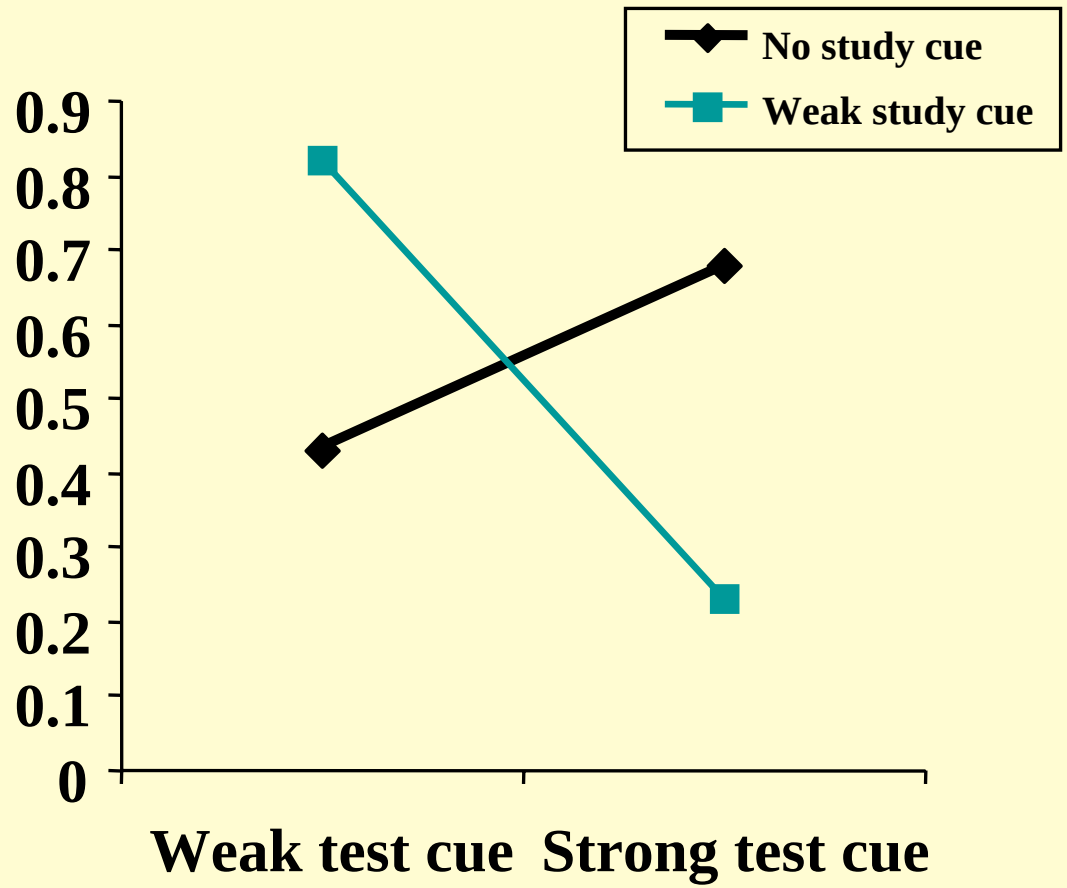
- 2 study conditions:
  - Weak cue: fruit--> bloom
  - No cue: bloom

- 2 cued-recall conditions:
  - Weak cue: fruit: _____
  - Strong cue: flower: _____

- *Are strongly associated words always better retrieval cues?*

Encoding Specificity Principle

Memory depends on an interaction between what is encoding processing and conditions at retrieval .



Context-dependent memory

- *Information is remembered best when retrieval and encoding contexts match*

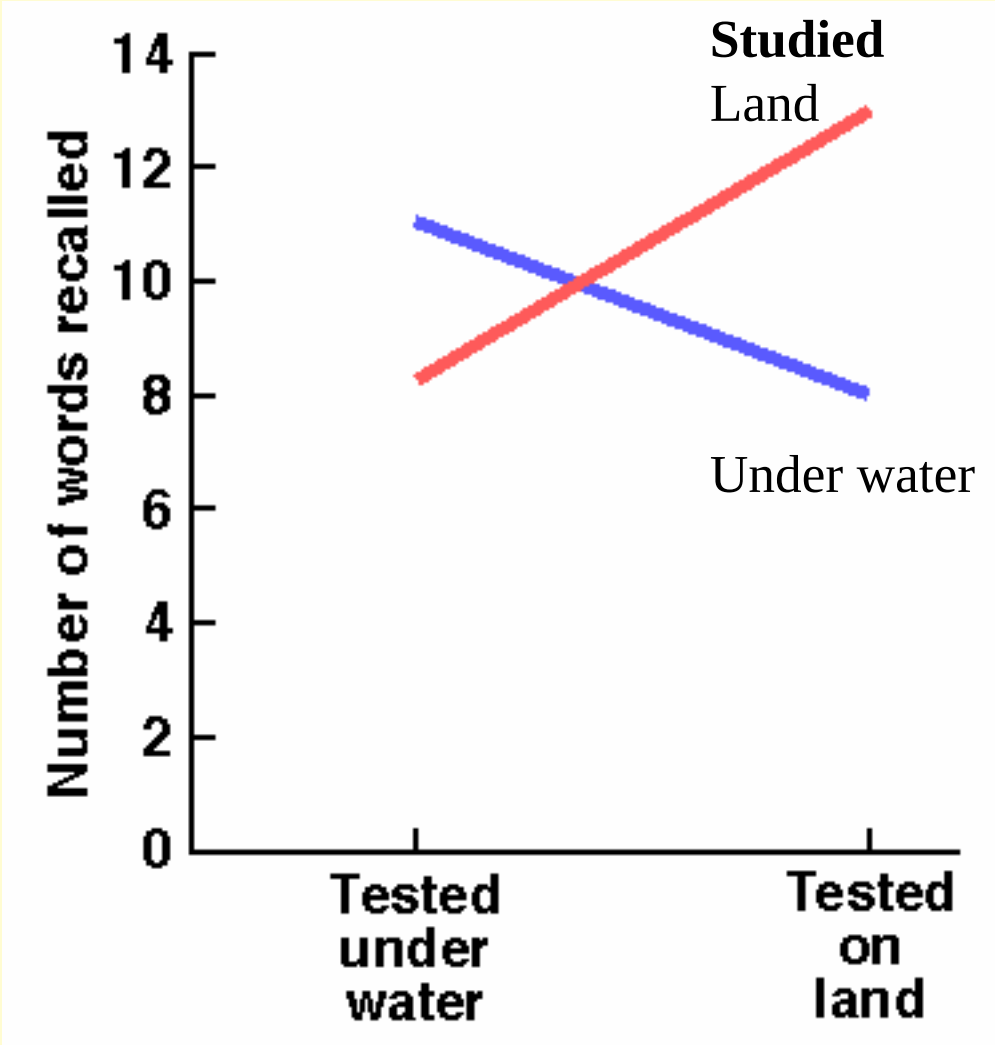
- Example: Smith (1979) had subjects learn 80 words in a basement. Surprise recall test either
  - in same room
  - in soundproof booth on 5th floor
  - in soundproof booth on 5th floor, with instructions to visualize basement room before learning items.

Context-dependent memory

- *Information is remembered best when retrieval and encoding contexts match*

- Example: Smith (1979) had subjects learn 80 words in a basement. Surprise recall test either
  - in same room. Mean recall = 18 words
  - in soundproof booth on 5th floor = 12 words
  - in soundproof booth on 5th floor, with instructions to visualize basement room before learning items = 17.2 words

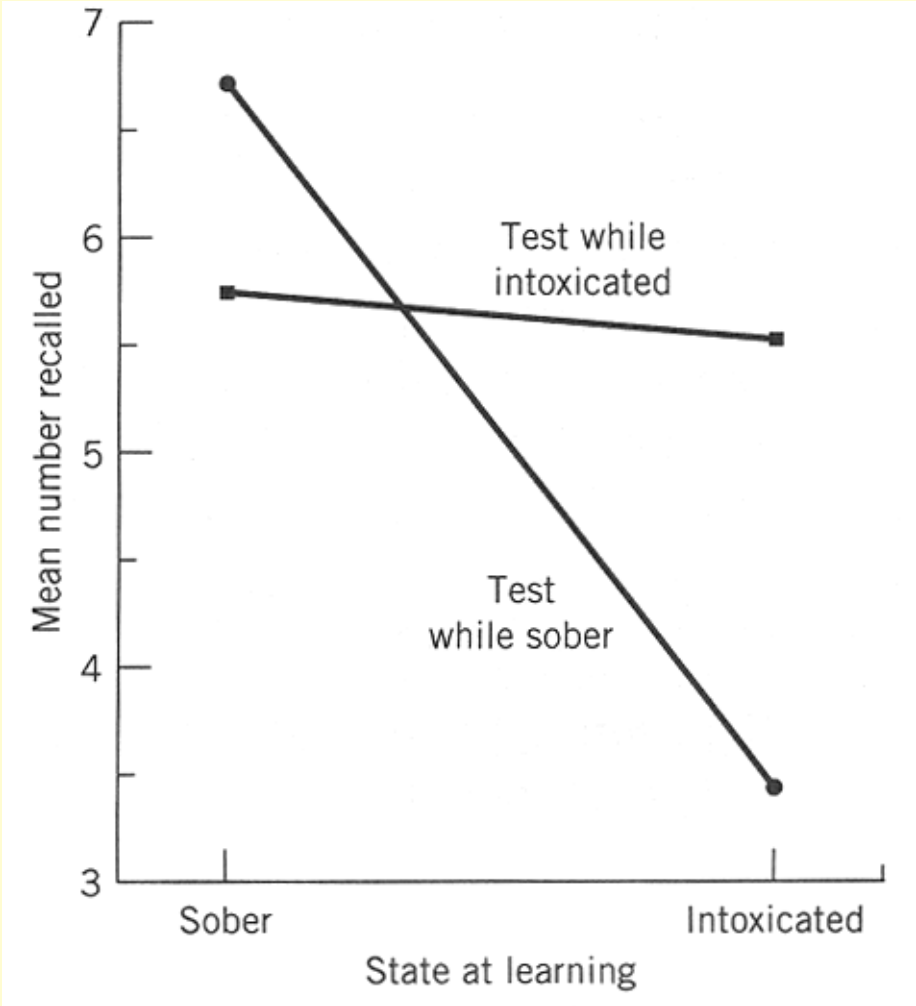
Context–Dependent Memory



External context contains stimuli that become associated with the learned material and that are useful cues for eliciting retrieval of these memories

(Godden & Baddeley, 1975)

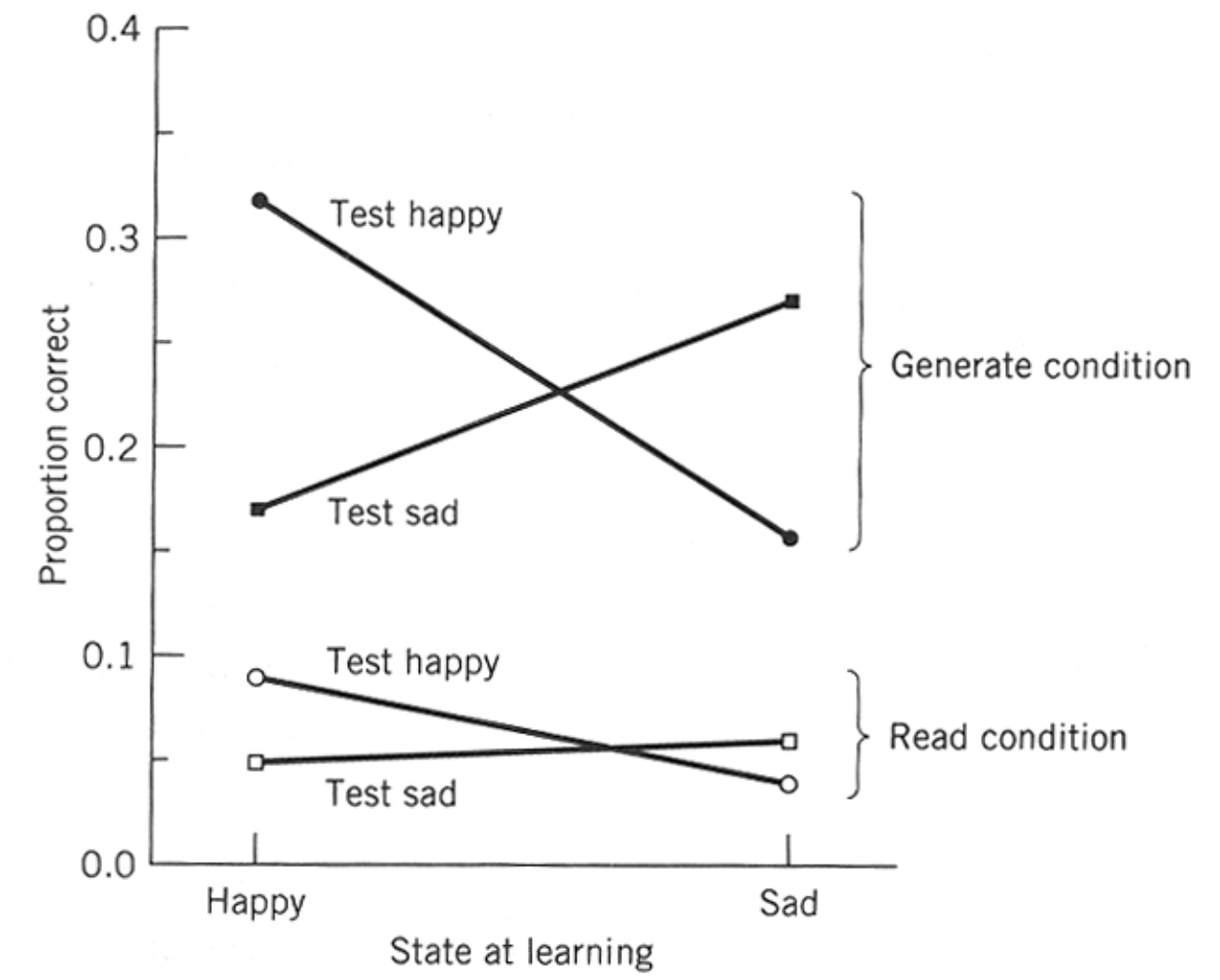
State–Dependent Memory



Internal context or states also are associated with learned information and serve as useful cues for eliciting retrieval of these memories

(Goodwin et al., 1969)

Mood–Dependent Memory



(Eich & Metcalfe, 1989)

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Distribution of Practice

Organization and Encoding

- Deese (1959):
  - 3 Lists of words: highly related, less related, unrelated
  - Relatedness facilitates recall

High Related: 7.35

Moth

Insect

Wing

Bird

Fly

Yellow

…

Unrelated: 5.5

Book

Tulip

Government

Sofa

Early

Velvet

…

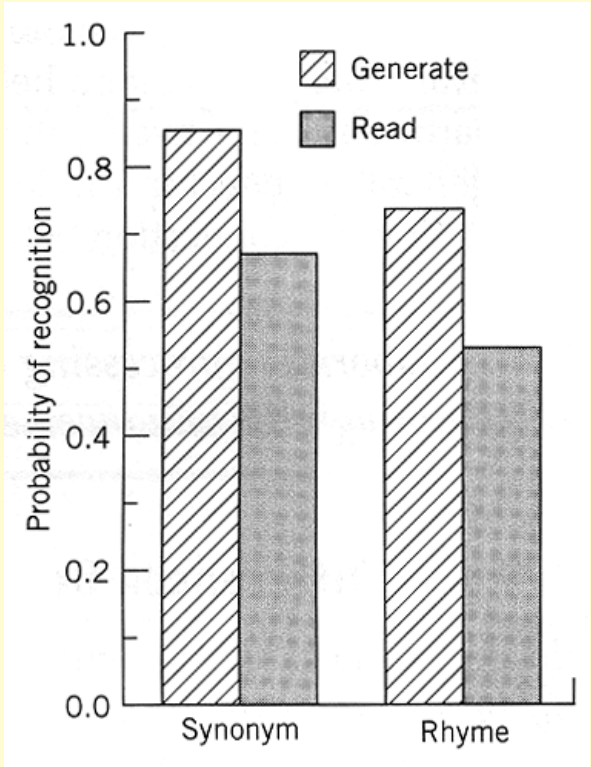
Encoding is More Effective When Information is Generated Rather than Presented: Generation Effect

READ Conditions:

Synonym	Unhappy – SAD
Rhyme	Pad – SAD

GENERATE Conditions:

Synonym	Unhappy – S___?
Rhyme	Pad – S__?

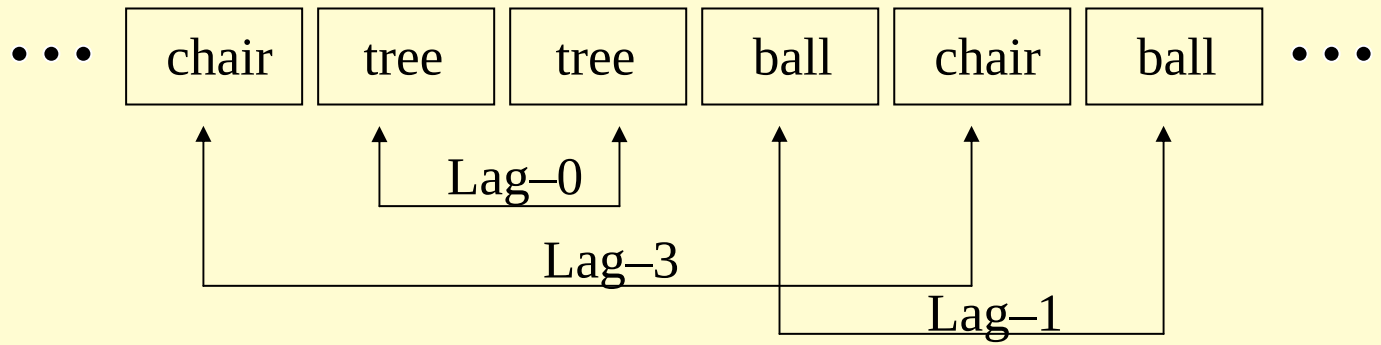


- greater elaboration/processing of meaning or phonology
- greater engagement of **retrieval processes** during study that are likely to be engaged at test

Distribution of Practice

Not all encoding events are created equal

"with any considerable number of repetitions a suitable distribution of them over a space of time is decidedly more advantageous than the massing of them at a single time" (Ebbinghaus, 1885)



Spacing / Lag effect

- greater lags between practice/study trials yield better memory

Understanding Distributed Practice

Deficient processing: during massed/short lag trials, the second occurrence of an item is not processed fully

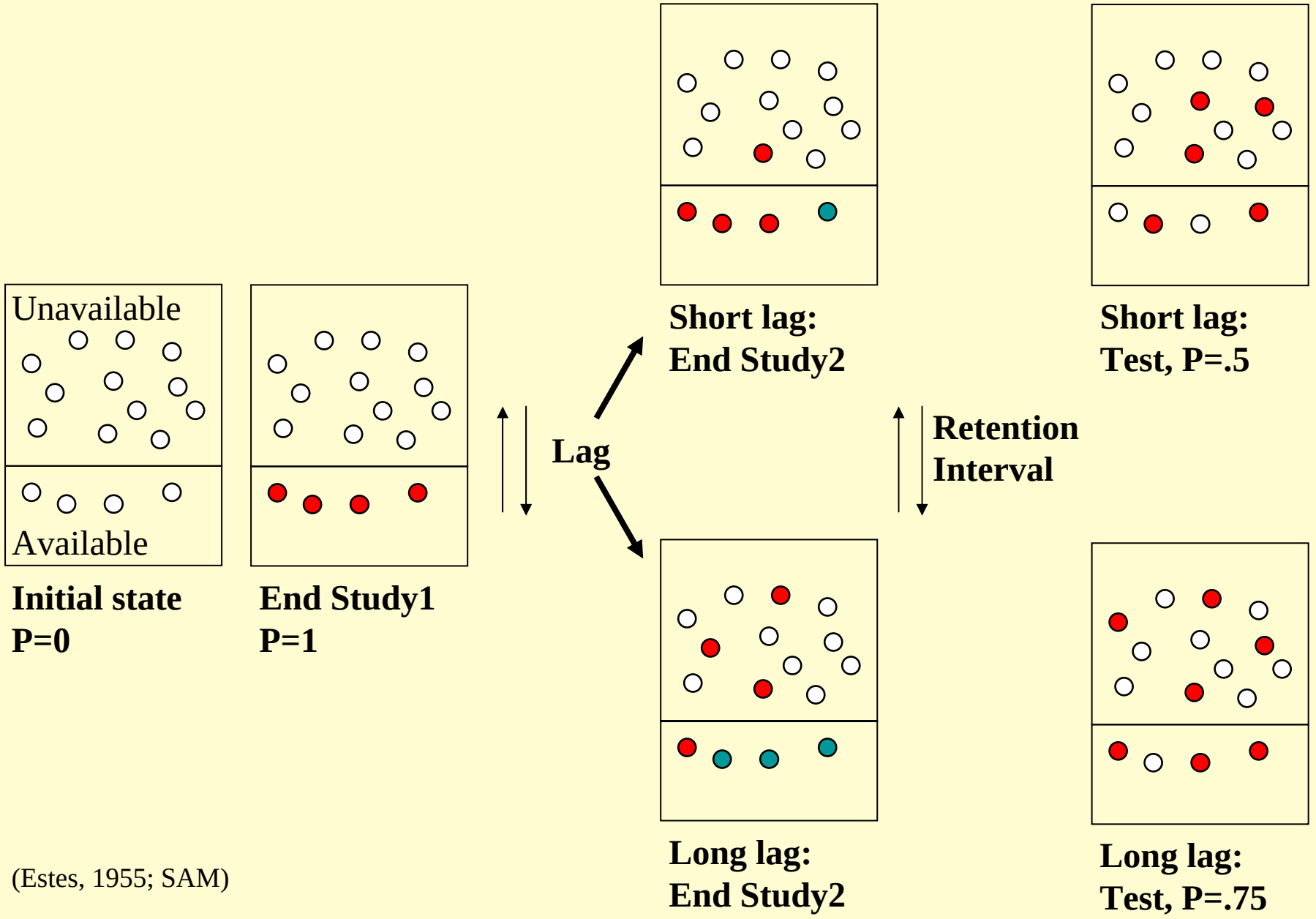
- less attention to items just processed

Encoding variability: longer lags result in more variable encoding

- variable encoding yields a richer memory trace permitting access from multiple routes
- variability may derive from random stimulus fluctuations across time (Estes' stimulus sampling theory)

Consolidation – distributing practice may enhance subsequent memory because initial trace has had time to consolidate

Stimulus Sampling Theory & Lag Effects



(Estes, 1955; SAM)

Von Restorff Effect

Fox
Lion
Cow
Giraffe
Motorcycle
Sheep
Deer
Mouse
Horse

Von Restorff Effect

Fox
Lion
Cow
Giraffe
Motorcycle
Sheep
Deer
Mouse
Horse

- Derived from an experiment by von Restorff (1933)

- In these experiment, a list of items is presented and one item deviates in some way from the others

- "Isolate" item is typically remembered better than other items

- This suggests that distinctiveness also influences memory encoding

Focus on similarities or differences?

- Craik and Lockhart's LOP view suggests that deep encoding produces a more distinctive record of each event, thereby leaving a stronger memory

- Effects of organization on memory suggest that focusing on similarities among multiple events also facilitate memory

- Hunt & Einstein (1981):
  - Relational and item-specific information help boost memory

Hunt & Einstein (1981)

- List of words from 6 categories

- 3 tasks:
  1. Relational: sort words into each category
  2. Item-specific: rate each word for pleasantness
  3. Combined: Do both

- Results:
  - Recall much better in combined than in either relational or item-specific encoding conditions
  - Clustering greater in relational and combined than item-specific conditions

- These findings suggest that relational and item-specific processing both enhance encoding, but in different ways

Conclusions

- LOP highlights role of type of encoding, not merely time spent encoding, in successful memory formation

  - However, slightly circular reasoning..
  - No role for retrieval..

-TAP highlight role of the match between encoding and retrieval

  - However, semantic encoding still wins out..

- What gets encoded?
  - Distinction between the nominal stimulus and the functional stimulus *(Carmichael et al, 1932)*

Overview

Cognitive Psychology

Neuropsychology

Animal Models

Functional Imaging

How does the brain support memory?

Amnesia

- What is it? (retrograde, anterograde)
- Characteristic patterns of spared and impaired performance in amnesia.
- Role of MTL regions in long-term memory formation
- Theories of long-term memory consolidation

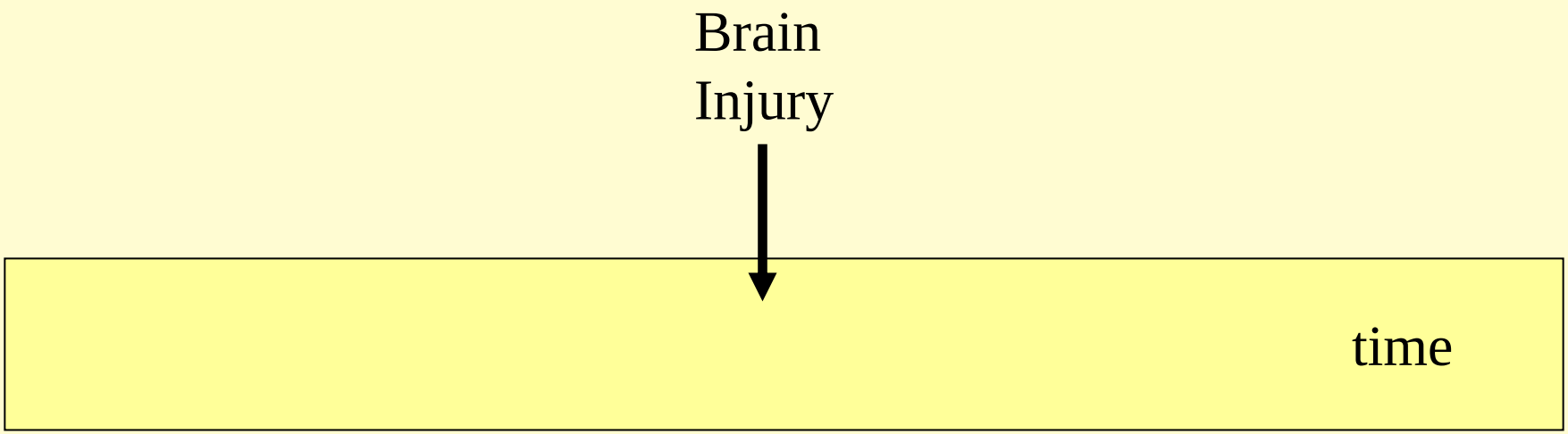
Definition of Global Amnesia

- Profound forgetfulness

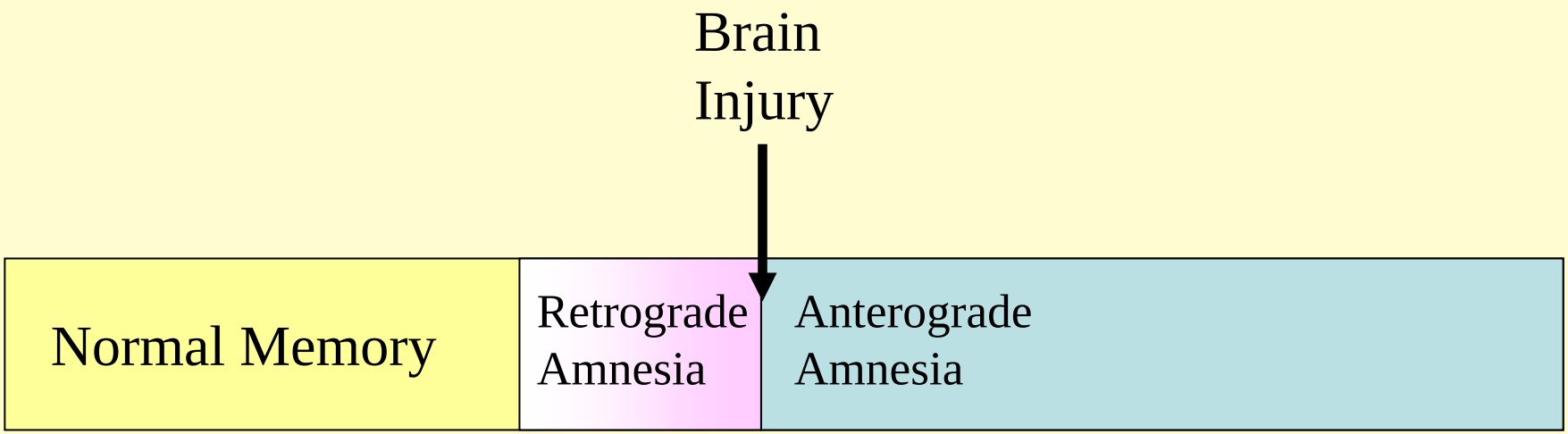
  - Regardless of modality of information (names, faces, places, odors, music are all forgotten)

  - Regardless of information presentation (visual, auditory, olfactory)

Definition of Amnesia

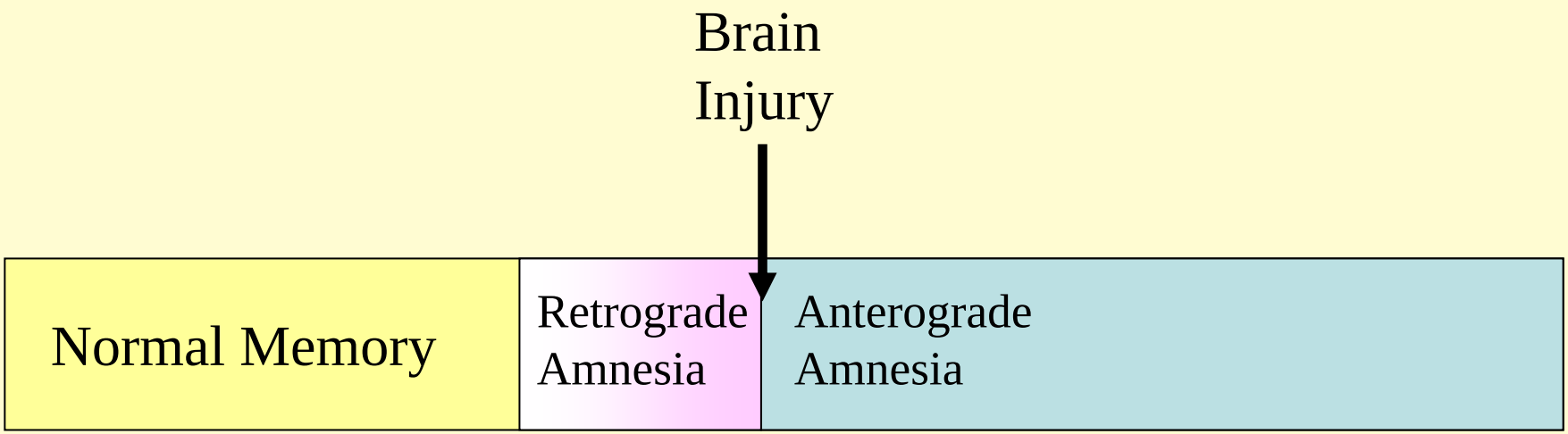


Definition of Amnesia



- Anterograde Amnesia – the inability to form new memories
- Retrograde Amnesia – the inability to recollect old memories

Definition of Amnesia



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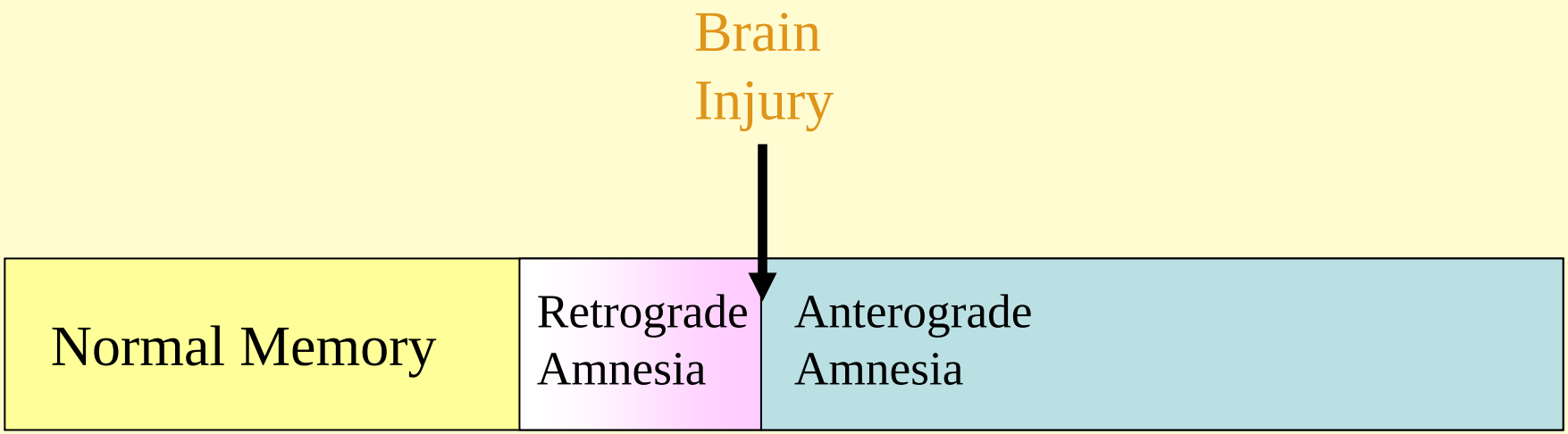

- Medial temporal-lobe damage

Amnesia

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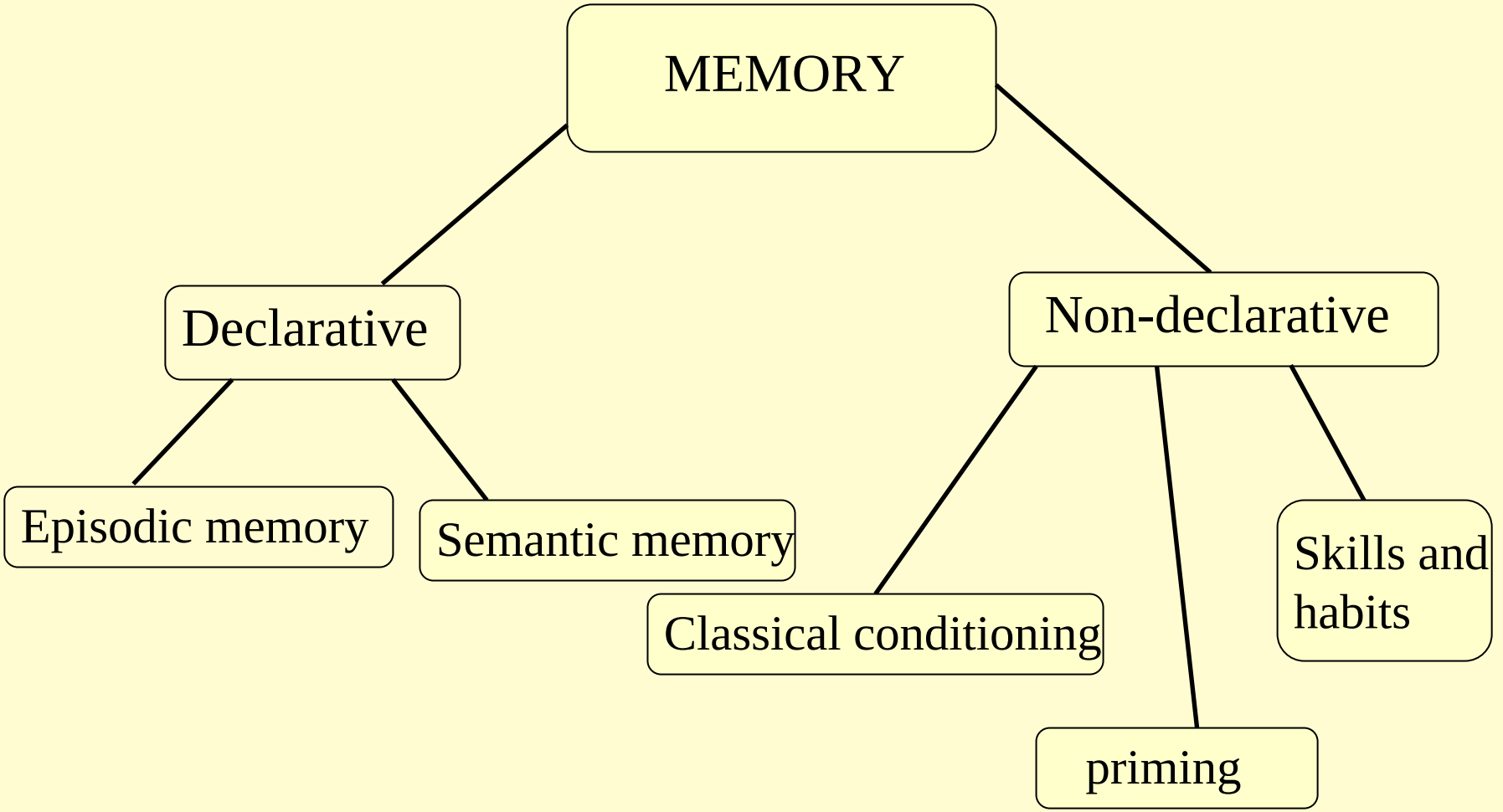
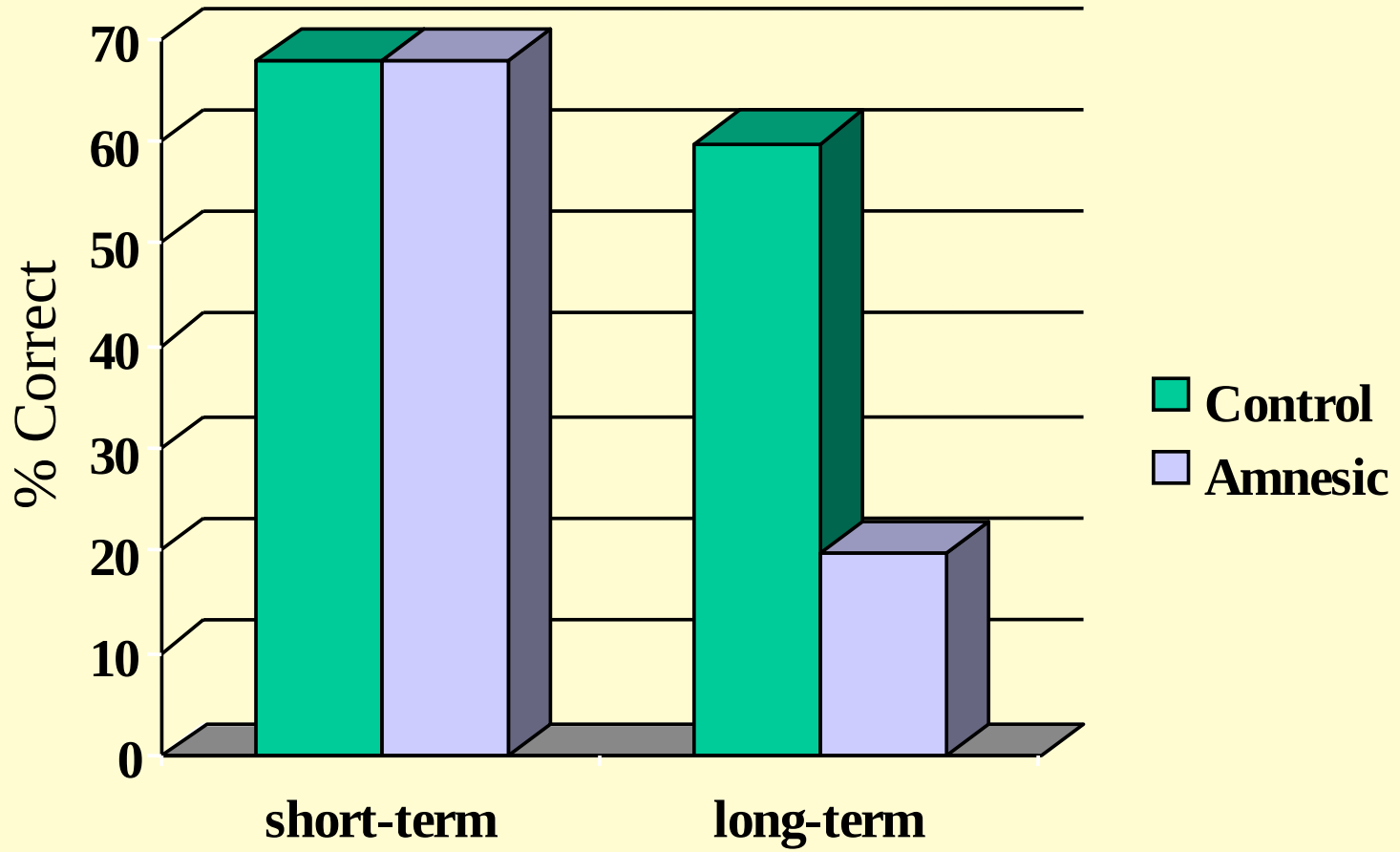
Long-term Memory Systems

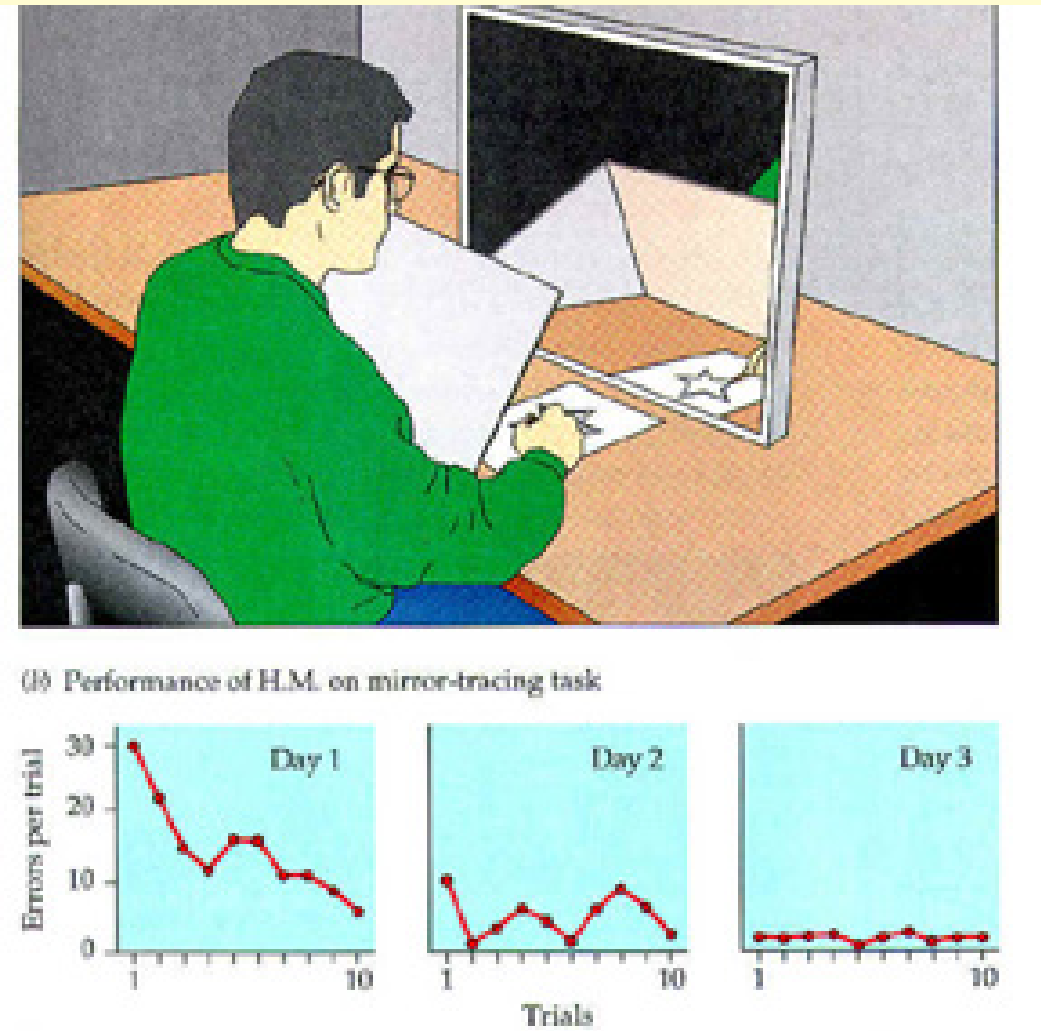


Short-term versus Long-term Memory

- spared short-term memory; impaired long-term memory



Skill Learning



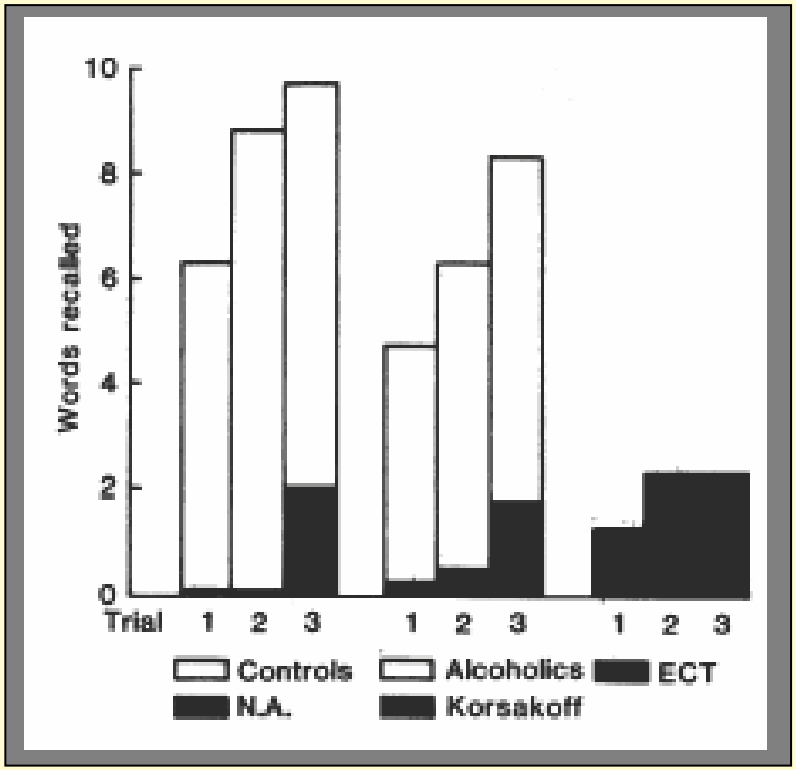
H.M.’s mirror tracing performance improves across trials, although he cannot recall previously performing the task

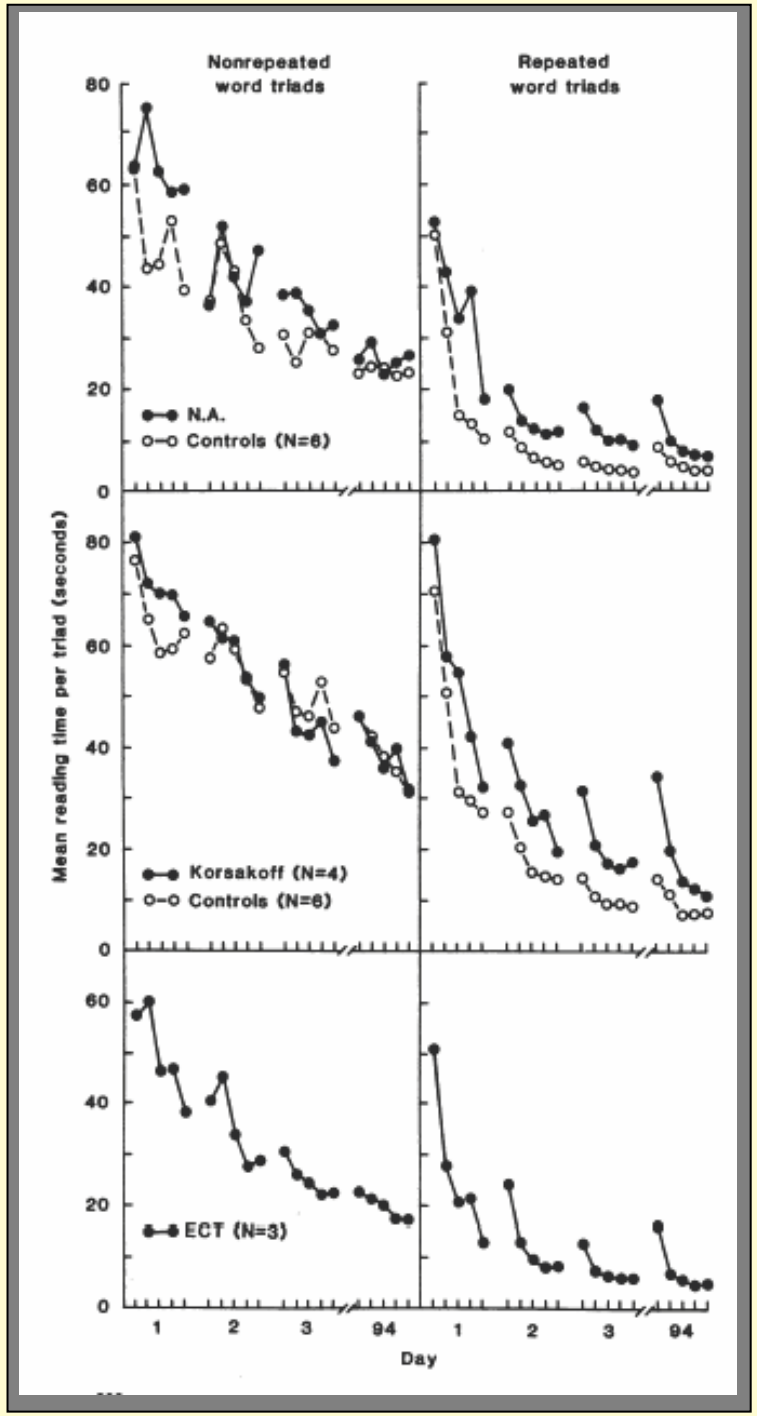
Milner , 1962

Procedural vs Declarative

nepjious sauerkraut vagueness

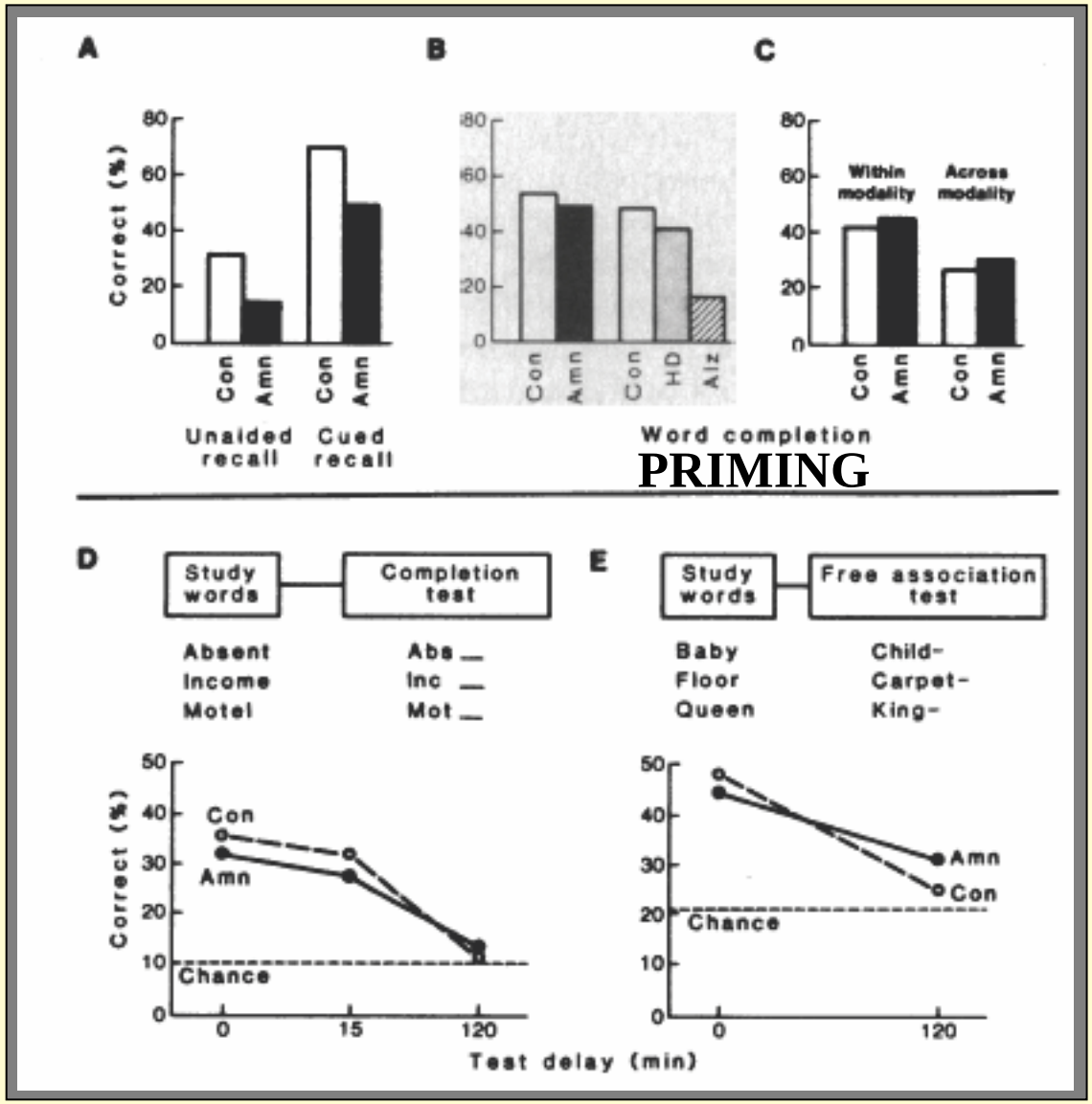
Cued recall test





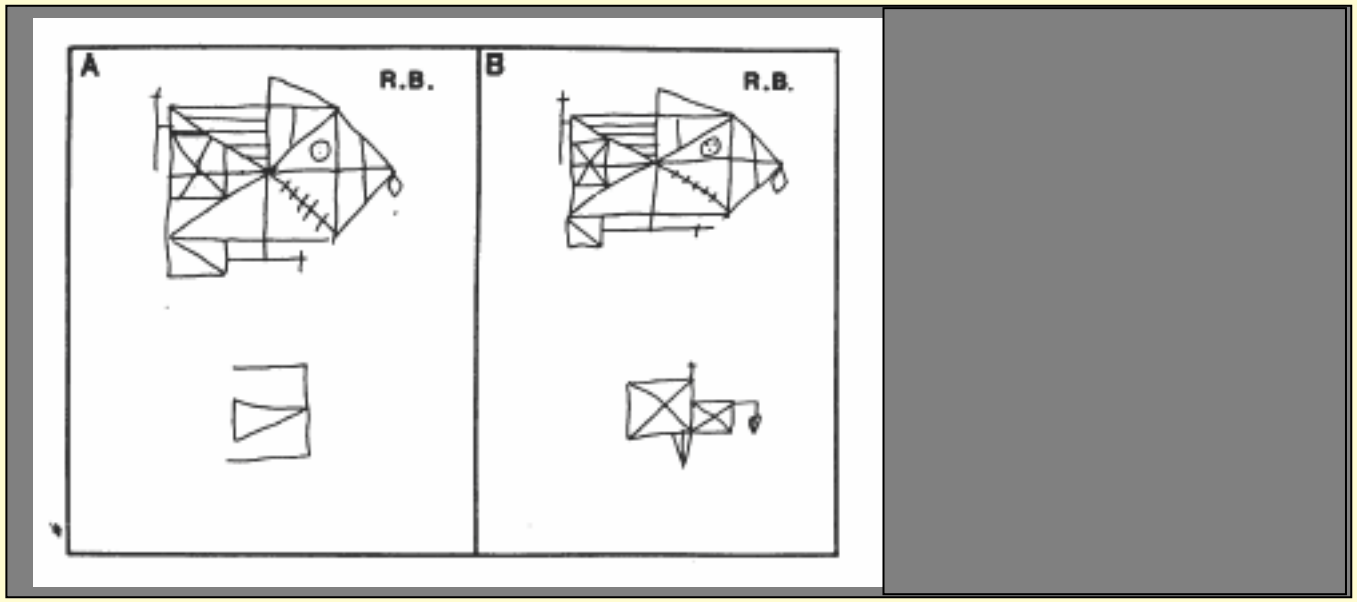
Cohen and Squire 1980

Procedural vs Declarative



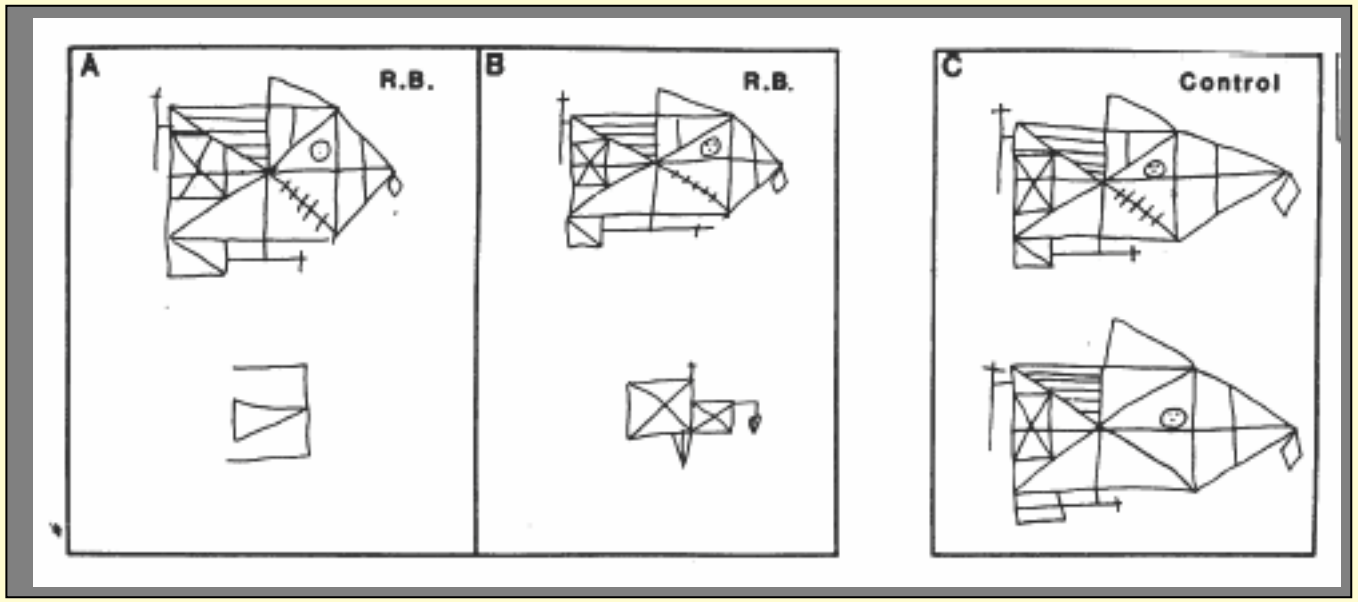
Cohen and Squire 1980

Immediate vs. Long term recall



Patient R.B.

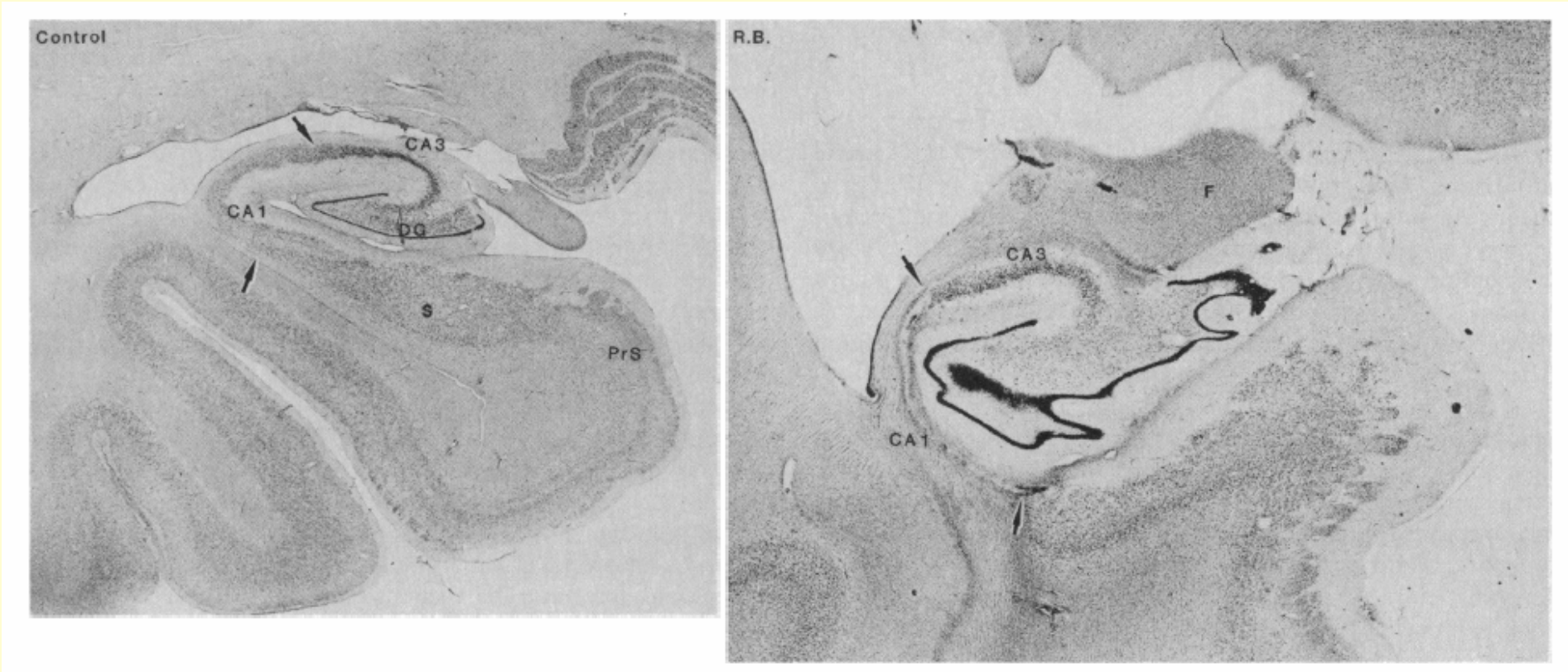
Immediate vs. Long term recall



Patient R.B.

Patient R.B.

- *selective damage to hippocampus leads to amnesia*



H.M. and New Semantic Learning

H.M. demonstrates poor memory for words and phrases that entered the language after the onset of his amnesia

Word/phrase	Free Recall
angel dust	“dust made by angels, we call it rain”
biodegradable	“two grades”
flower child	“a young person who grows flowers”
Watergate	“a city or town in Pennsylvania or Ohio”

Word/phrase	Four-choice Recognition
brain wash	the fluid that surrounds and bathes the brain
granola	a portable keyboard wind instrument
software	expensive clothing made of a soft, twilled fabric

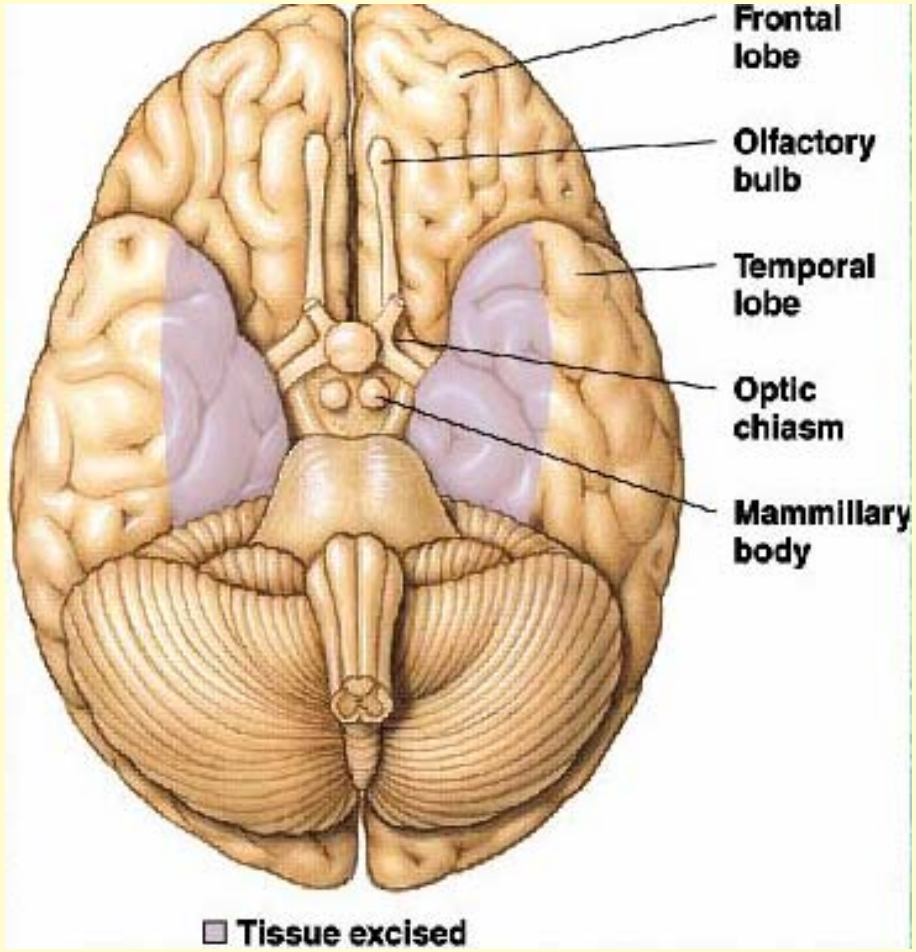
Amnesia

- What is it? (retrograde, anterograde)
- Characteristic patterns of spared and impaired performance in amnesia.
- Role of MTL regions in long-term memory formation
- Theories of long-term learning and long-term memory consolidation.

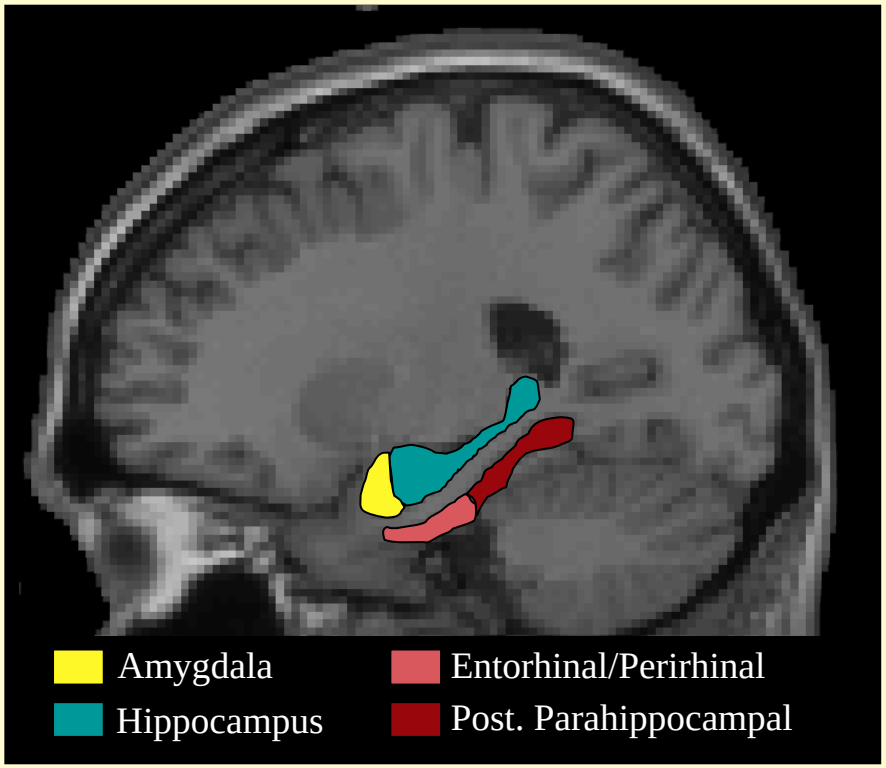
Location of H.M.’s lesion

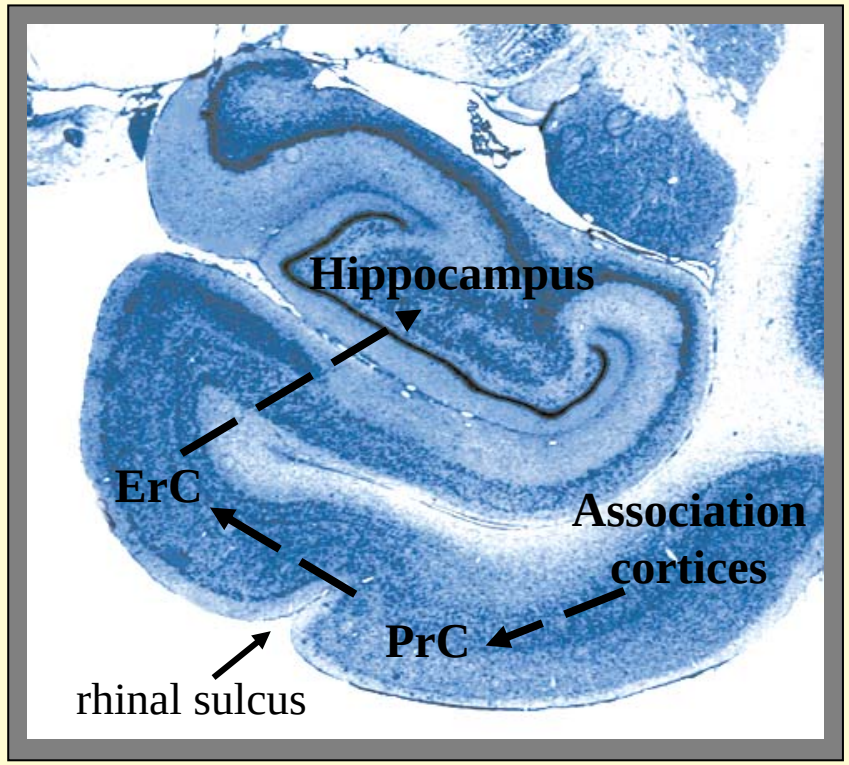
- In an attempt to cure his epilepsy, H.M. had his medial temporal lobes removed bilaterally

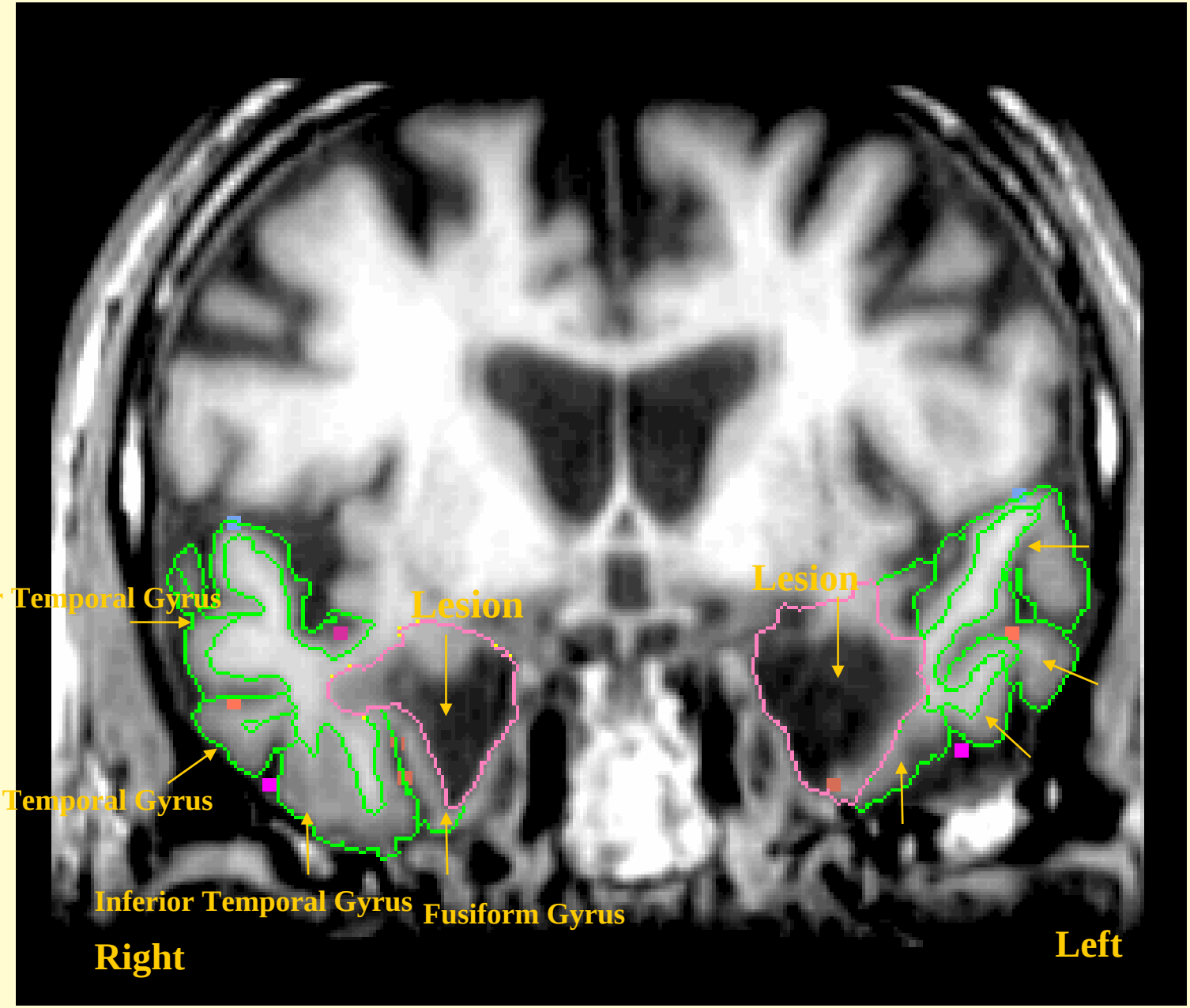
- While this surgery did reduce the frequency of his epileptic seizures, it also left him with a profound *global amnesia*



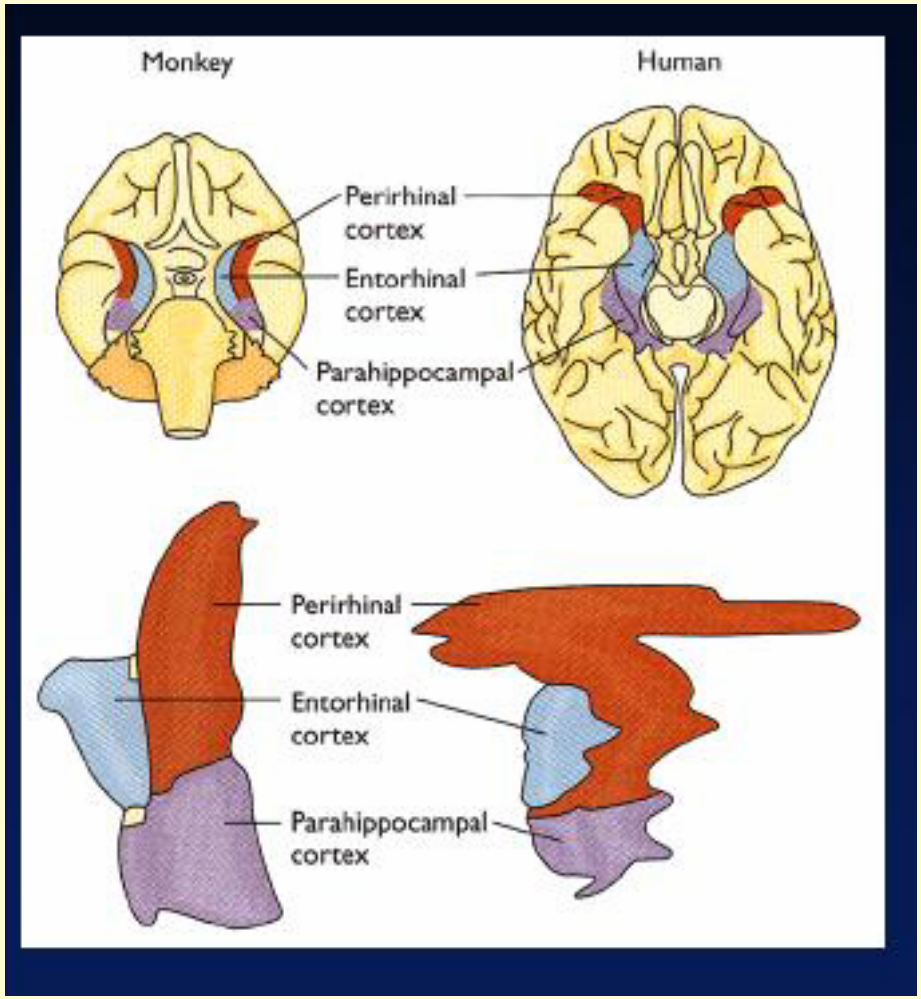
Medial Temporal Lobe Substructures



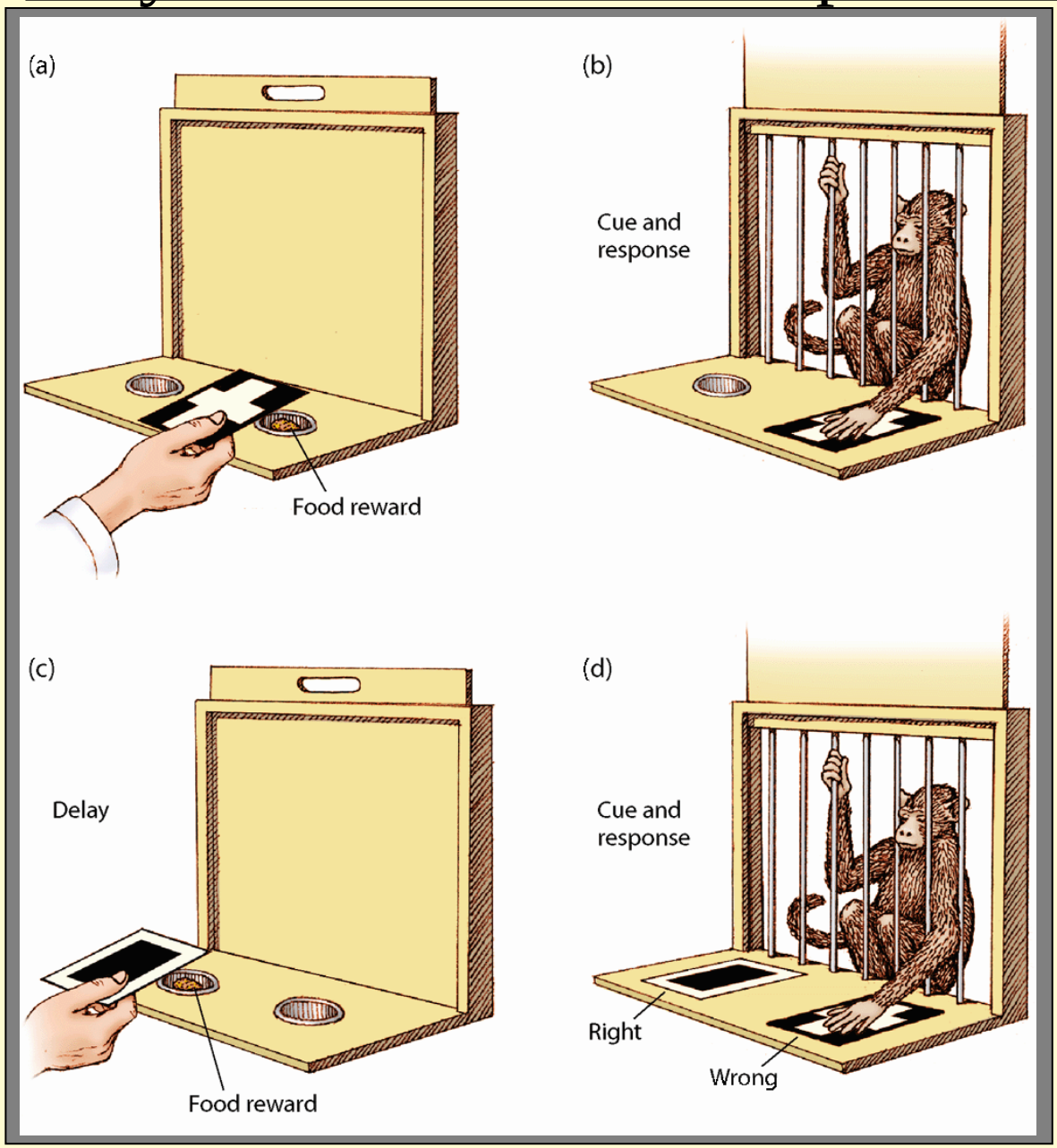



Superior Temporal Gyrus
Lesion
Lesion
Middle Temporal Gyrus
Inferior Temporal Gyrus
Fusiform Gyrus
Right
Left

Animal Models of Memory

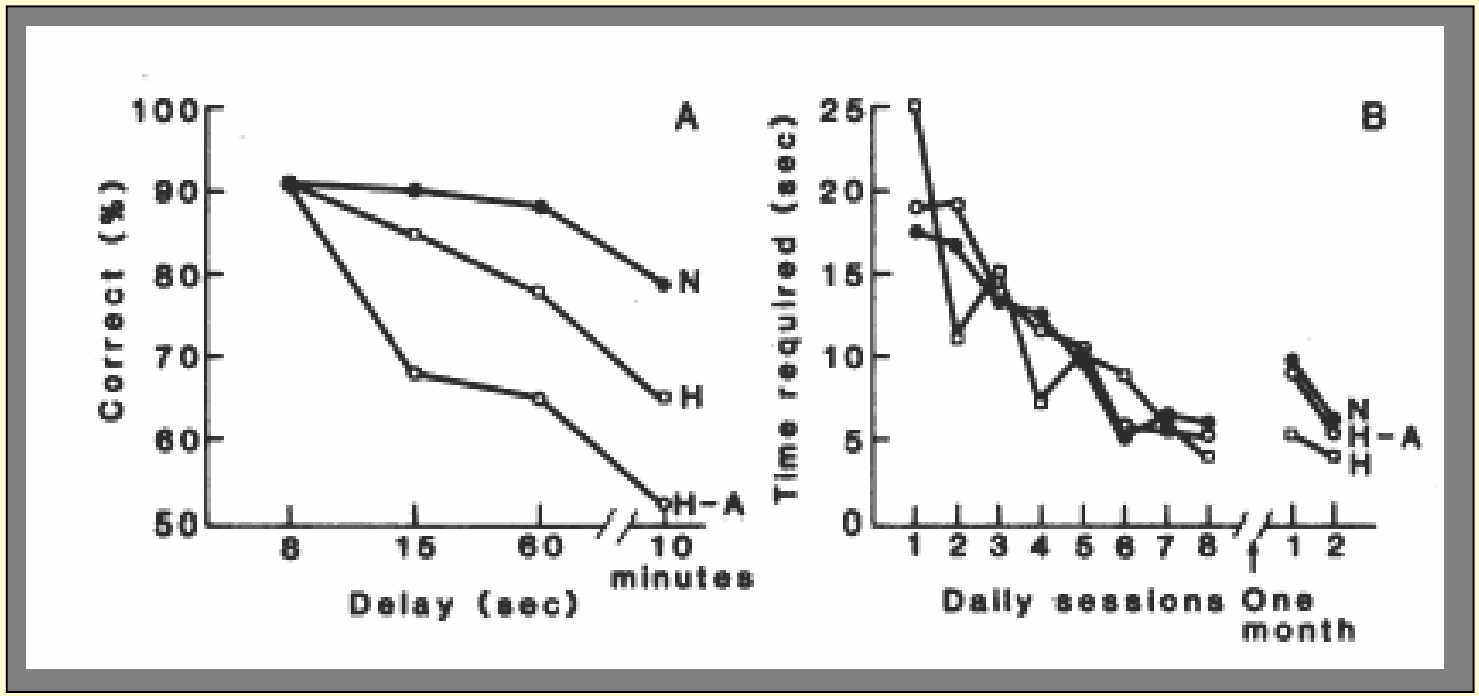


Delayed non-match to sample tasks



Monkey Models of Amnesia

DNMS impaired but other forms of learning (e.g. visual discrimination, motor skills..) are intact.



(Squire, Science, 1986)

Medial Temporal Lobe structures and long-term learning: Evidence from humans

- H.M. had the entire MTL resected bilaterally

  - Do you have to have this much damage to have resulting amnesia, or are there particular MTL regions responsible for the amnesia?

  - What is the hippocampus needed for? What about rhinal cortex?

Medial Temporal Lobe structures and long-term learning: Evidence from humans

- Two amnesic patients studied by Squire and colleagues had damage to only one region (CA1) of the hippocampus

  - suggests that damage limited to the hippocampus can cause a specific memory impairment (Zola-Morgan et al., 1986).

- As add more damage (to other regions of the hippocampus and to the surrounding MTL regions) the amnesic syndrome becomes more severe.

However, doesn't mean that all MTL structures mediate the same function!!

Medial Temporal Lobe structures and long-term learning: Evidence from humans

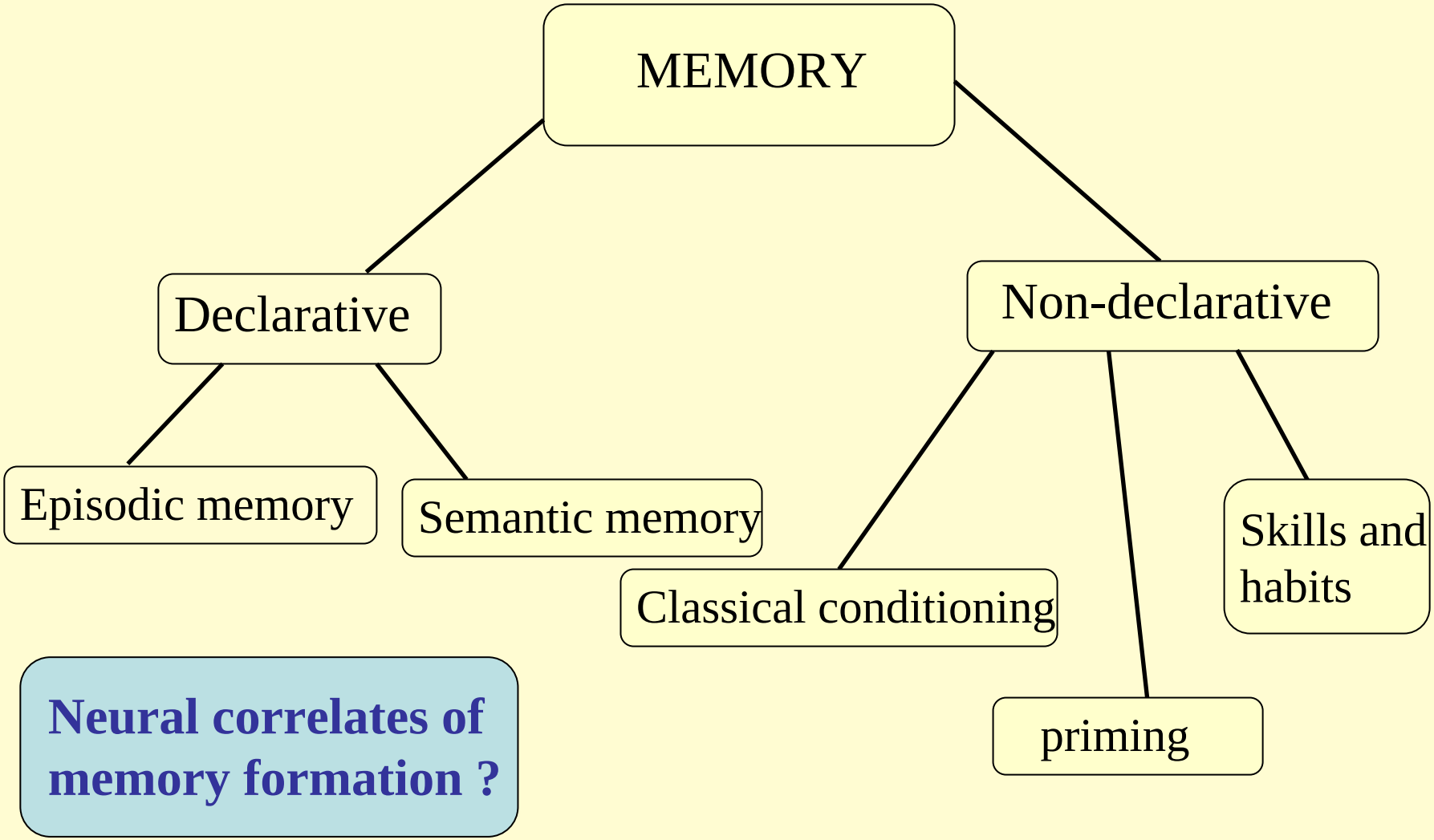
Is the hippocampus required for semantic learning?

- 3 patients with *early*, selective hippocampal insult
- Anterograde amnesia for everyday, episodic events
- Relative sparing of semantic learning abilities
  - competent in speech & language
  - learned to read, write, & spell
  - in normal range on tests of verbal intelligence

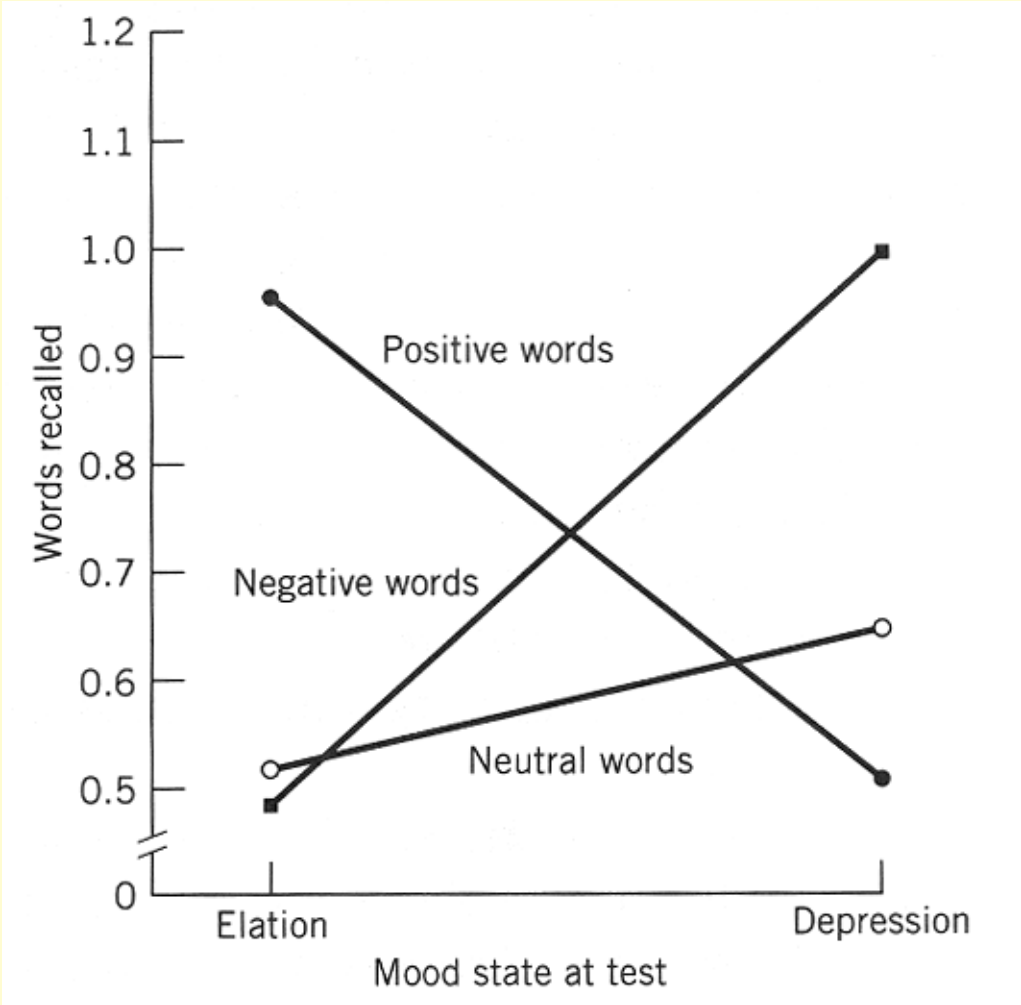
Considered in conjunction with H.M.'s performance, these results suggest that it may be the rhinal cortex and not the hippocampus that is important for semantic learning

(Vargha-Khadem et al., 1997)

Long-term Memory Systems



Mood–Congruent Memory



(Teasdale & Russell, 1983)

Cue–dependent nature of memory has important implications for mental health. Biases to retrieve mood–congruent experiences can create “snowball” effects.

Process Dissociation

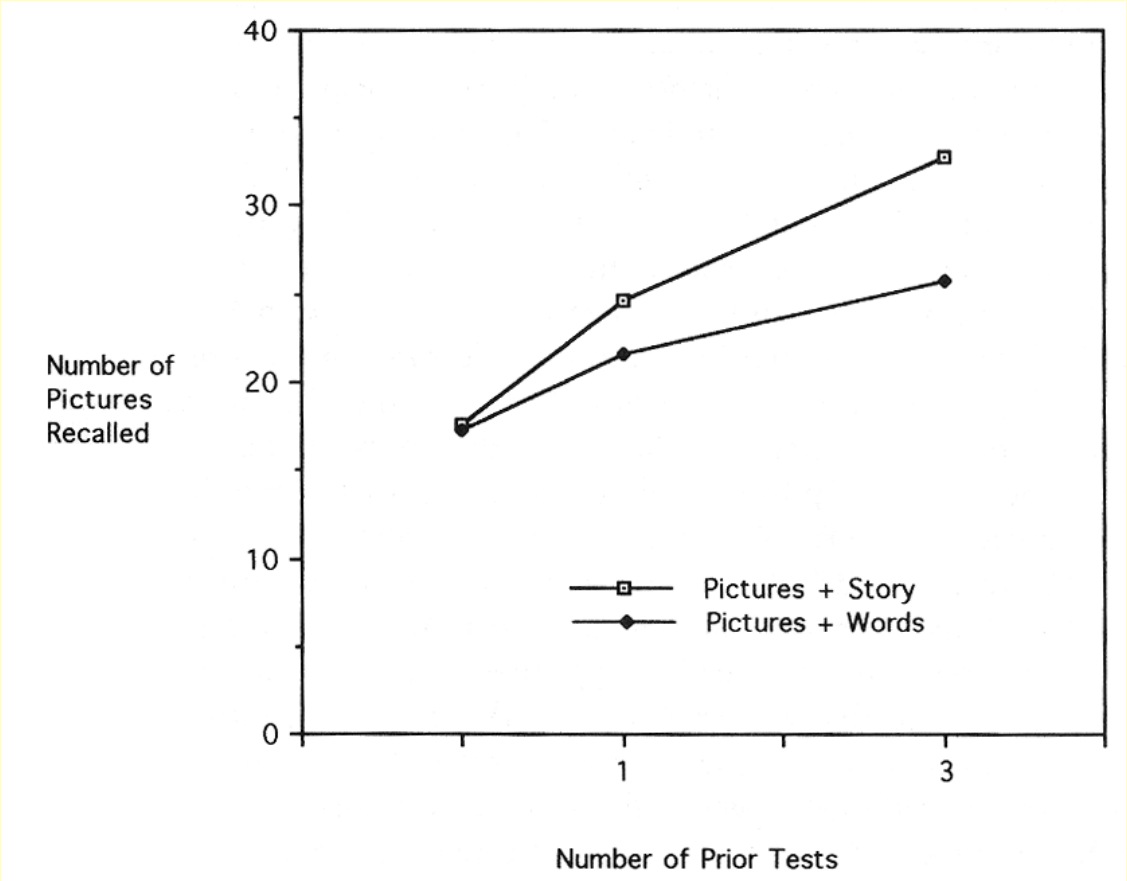
Assumptions: different processes can contribute to memory
- Automatic
- Intentional (recollective)

Method: Phase 1 - Hear list of words
Phase 2 - FULL - read list of words
DIVIDED - read list + distraction task

TEST - Word stem completion
Inclusion - fill in with word from either phase, or any word
Exclusion - Do not fill in a word from the study

Analysis:
Inclusion = R + A(1-R)
Exclusion = A(1-R)
Inclusion = R + *Exclusion*
R = Inclusion - Exclusion
A = Exclusion/1-R

Retrieval Yields a Robust Encoding Effect



- increasing the # of free recall tests immediately after learning yields superior recall 1 week later
- retrieval is an effective encoding event

Retrieval is Superior When There is Contextual / Cue–Support

STUDY:

- Lists of words from a category
- Study N lists

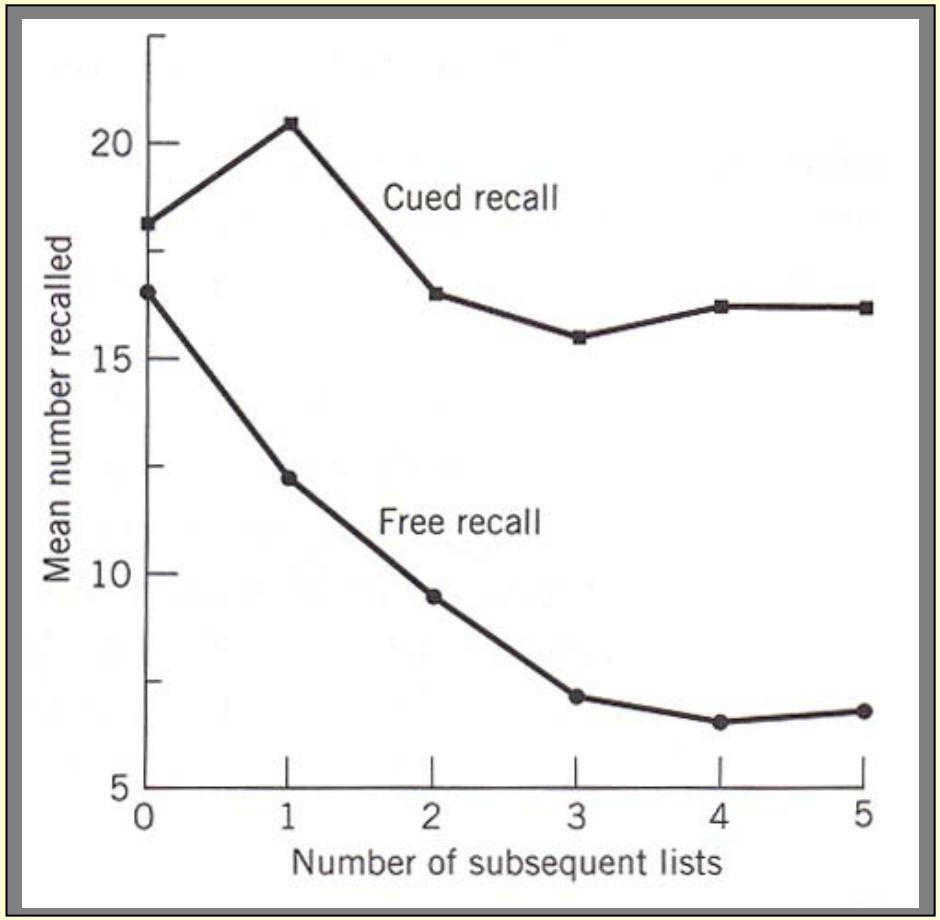
RECALL:

- Free recall

  Context–?
- Category–cued recall

  Context+Animals–?

  Context+Fruits?

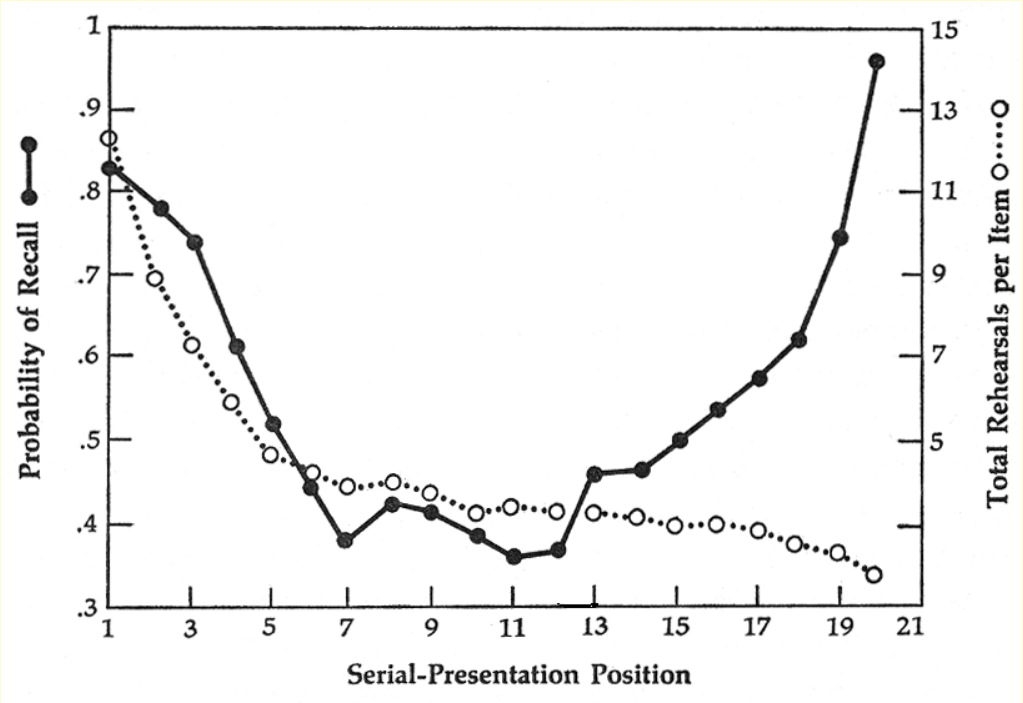


(Tulving & Psotka, 1971)

Memory failure can be attributed to loss of access to appropriate retrieval cues

Rehearsal and Free Recall

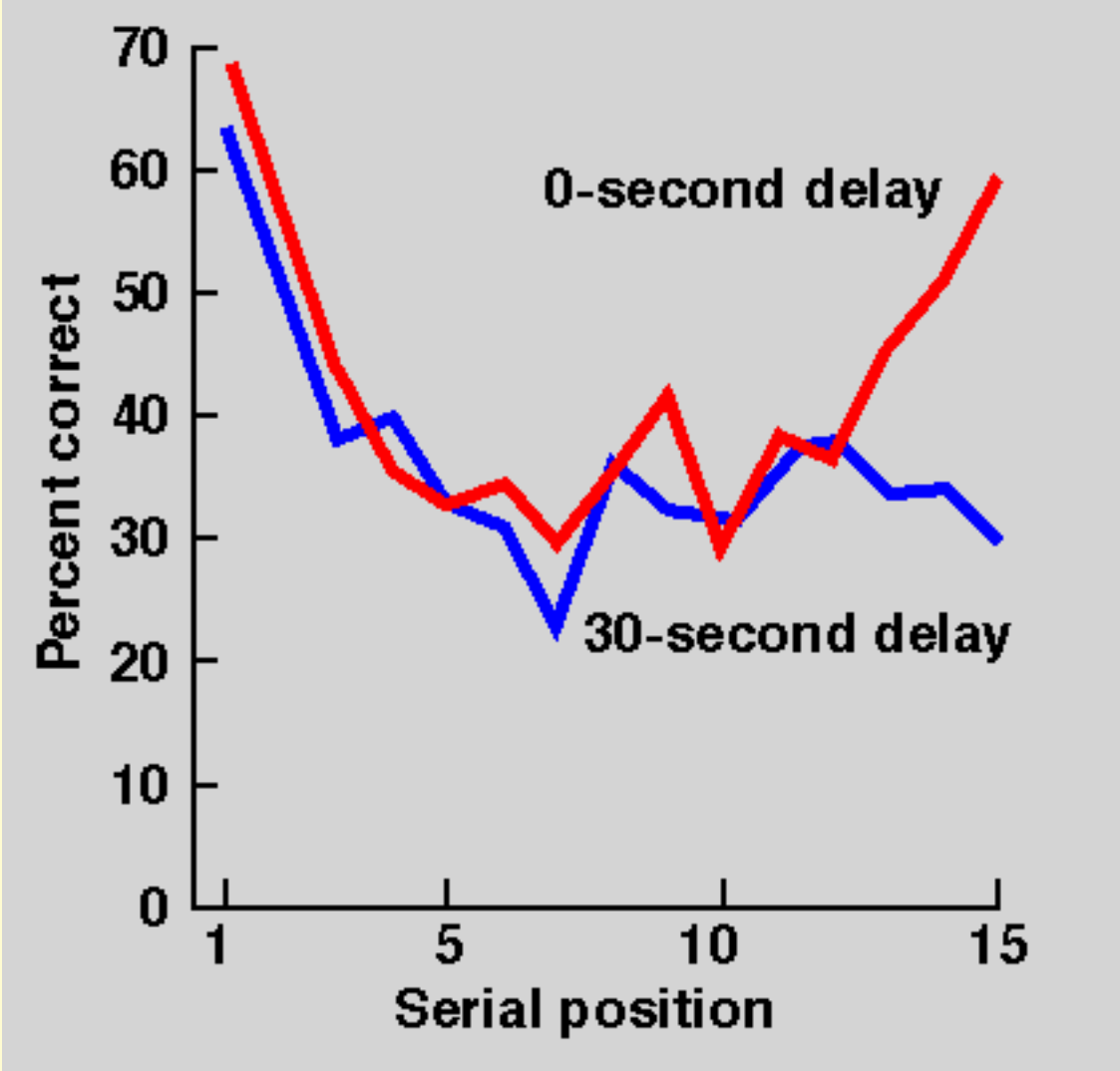
ITEM PRESENTED	ITEMS REHEARSED (REHEARSAL SET)
1 REACTION	REACTION, REACTION, REACTION, REACTION
2 HOOF	HOOF, REACTION, HOOF, REACTION
3 BLESSING	BLESSING, HOOF, REACTION
4 RESEARCH	RESEARCH, REACTION, HOOF, RESEARCH
5 CANDY	CANDY, HOOF, RESEARCH, REACTION
6 HARDSHIP	HARDSHIP, HOOF, HARDSHIP, HOOF
7 KINDNESS	KINDNESS, CANDY, HARDSHIP, HOOF
8 NONSENSE	NONSENSE, KINDNESS, CANDY, HARDSHIP
.	.
.	.
.	.
20 CELLAR	CELLAR, ALCOHOL, MISERY, CELLAR



(Rundus, 1971)

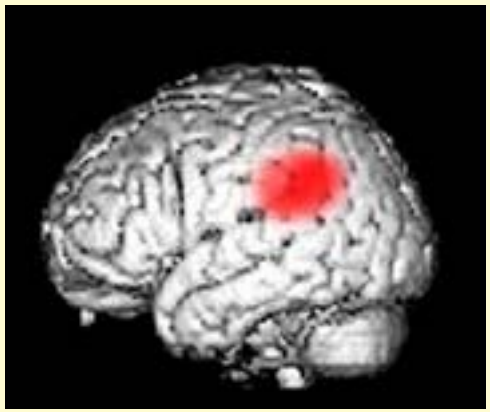
Recency Component – STM

Dissociable effects of filled delay



Evidence for Separate STM / LTM Stores

- H.M. → intact STM span, but impaired LTM
- K.F. → intact LTM, but impaired STM span



left inferior parietal lesion

limited span for auditory material

span 1: 19/20 trials correct
span 2: 7/20 trials correct
span 3: 2/20 trials correct

STM and LTM depend on different systems or processes

STM = Active Portion of LTM

Control mechanisms maintain or keep active different memory representations such that they can be worked with in a goal-directed manner: Working Memory