The Neuroscience of Learning

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Key Information

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Course Outline

Week One: How We Learn
- Topic 1. Repetition and Hebbian Learning
- Topic 2. Feedback and Types of Learning

Week Two; How We Learn
- Topic 1. Long Term Potentiation and Synaptic Plasticity
- Topic 2. Dopamine and the Basal Ganglia

Week Three: What We Learn
- Topic 1. Explicit Memory
- Topic 2. Implicit Memory

Week Four: What We Learn
- Topic 1. Neural Basis of Memory
- Topic 2. Internal Models

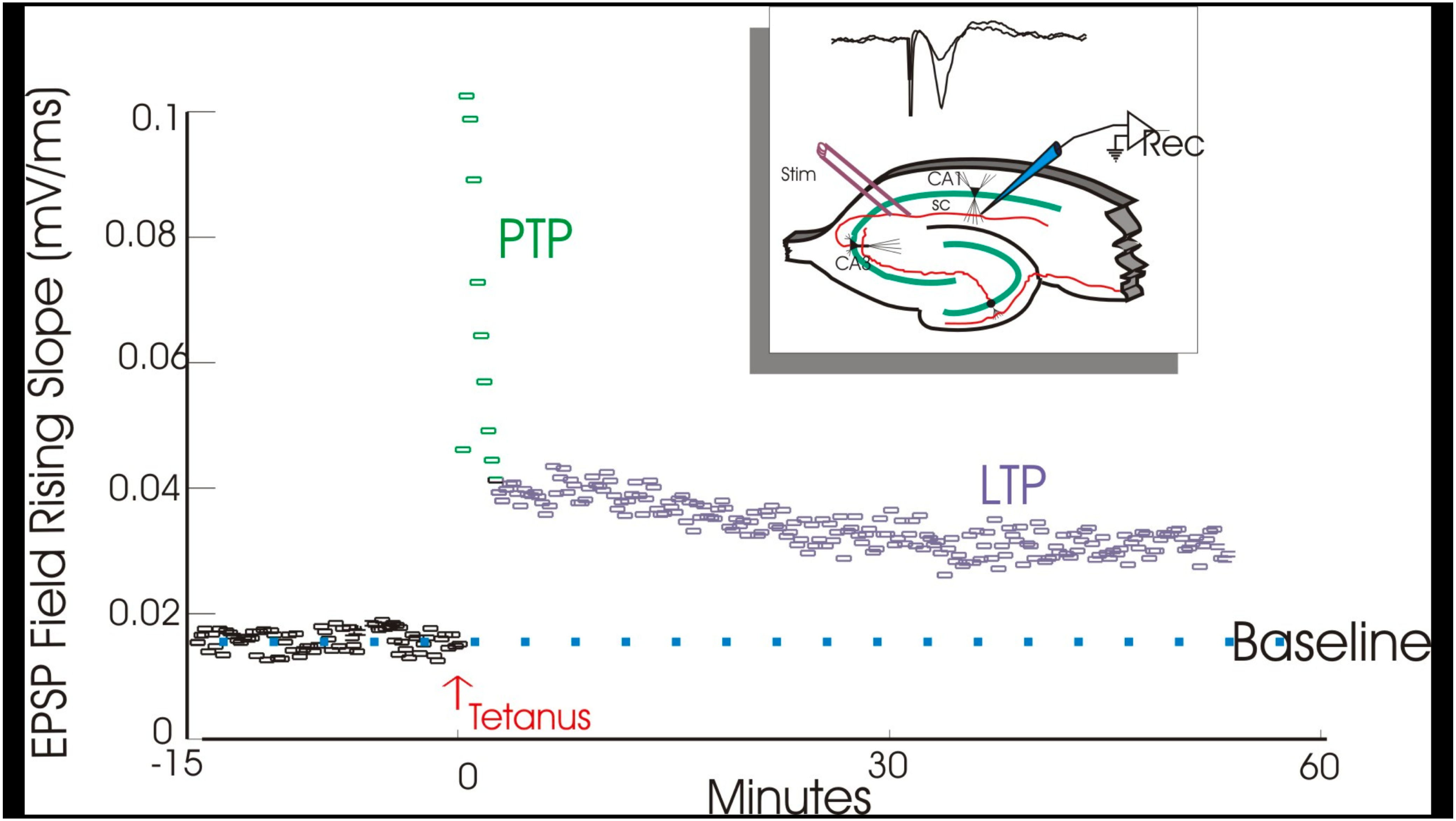
Week Five: How We Can Improve Learning
- Topic 1. Distributed Practice, Random Practice, Variable Practice
- Topic 2. Specificity of Practice, Part-Whole Practice, Mental Imagery

Week Six: How We Can Improve Learning
- Topic 1. Sleep, Diet, and Exercise
- Topic 2. Age, Learning Disorders

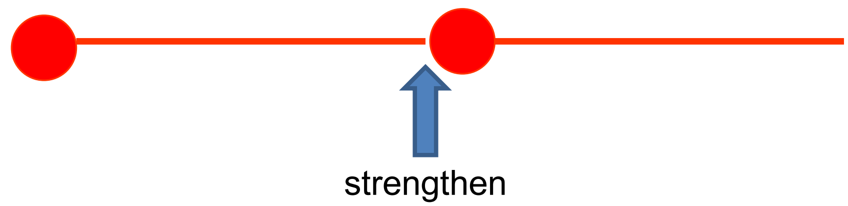
How do we learn?

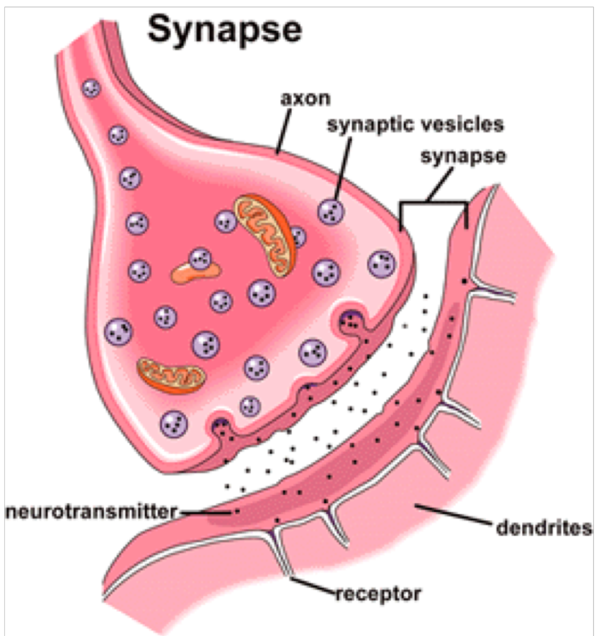
REPETITION and FEEDBACK

How do we learn?



EPSP Field Rising Slope (mV/ms)
0.1
0.08
0.06
0.04
0.02
0
-15
0
30
60
Minutes
PTP
LTP
Baseline
Tetanus
Stim
Rec
CA1
SC
CA3





HOW?

Increased neurotransmitter release
Increase receptors
Structural changes

But what do we learn?

MEMORIES

Definition of memory

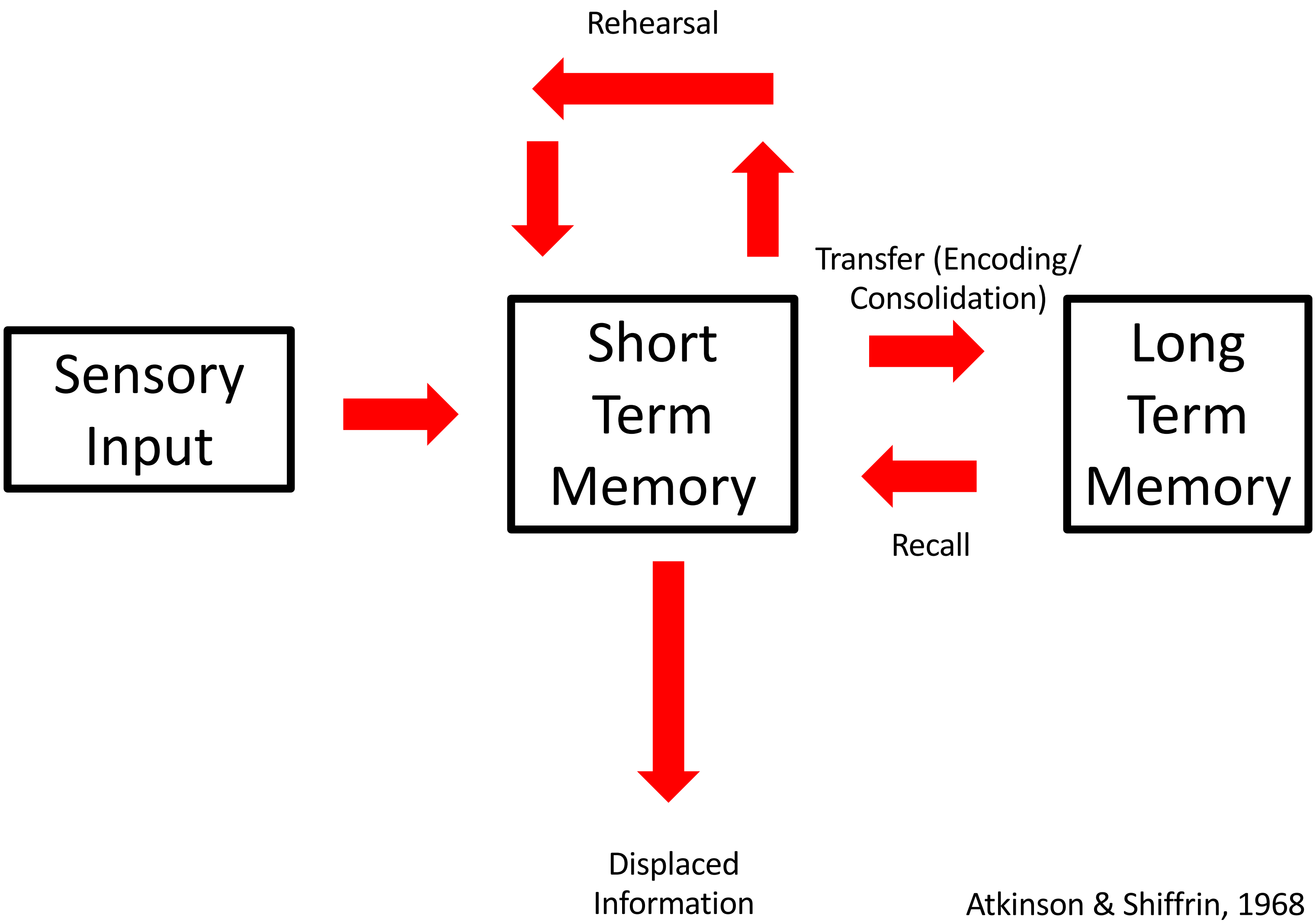
- The processes involved in retaining, retrieving, and using information about stimuli, images, events, ideas and skills after the original information is no longer present.

- Important implications of this definition:
  - Memory includes learning
  - Memory involves a variety of processes that can function with autonomy

Importance of memory

- Obviously being able to remember past experiences and learned skills is important for ability to make decisions, etc. in the present

- Memory also important in predicting the future. Much of what we know about the future results from our knowledge of the past



Rehearsal
Sensory Input
Short Term Memory
Transfer (Encoding/ Consolidation)
Long Term Memory
Recall
Displaced Information
Atkinson & Shiffrin, 1968

Working / Short Term Memory

Chair
Dress
Earrings
Bed
Counter
Shower
Floor
Shoes
Desk

What is the average of the following numbers?

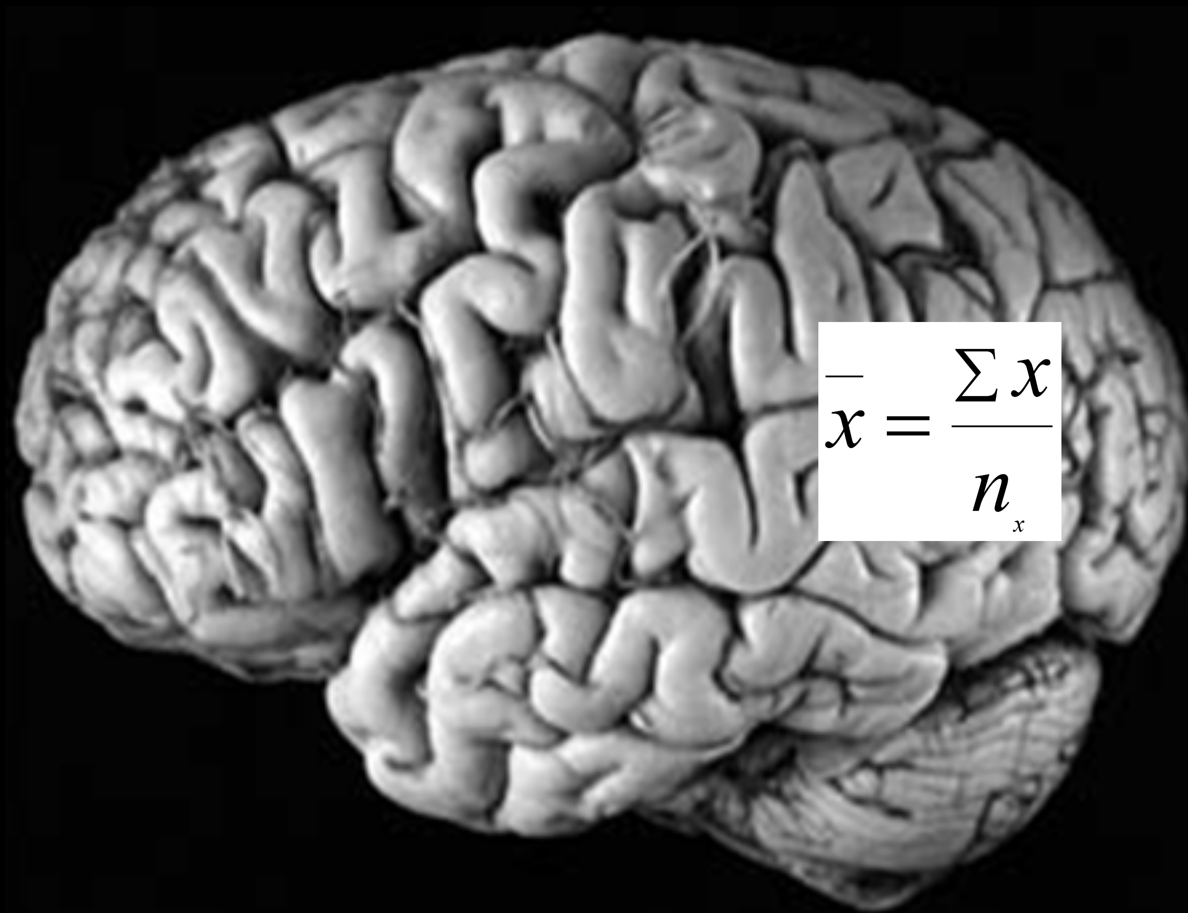
1

3

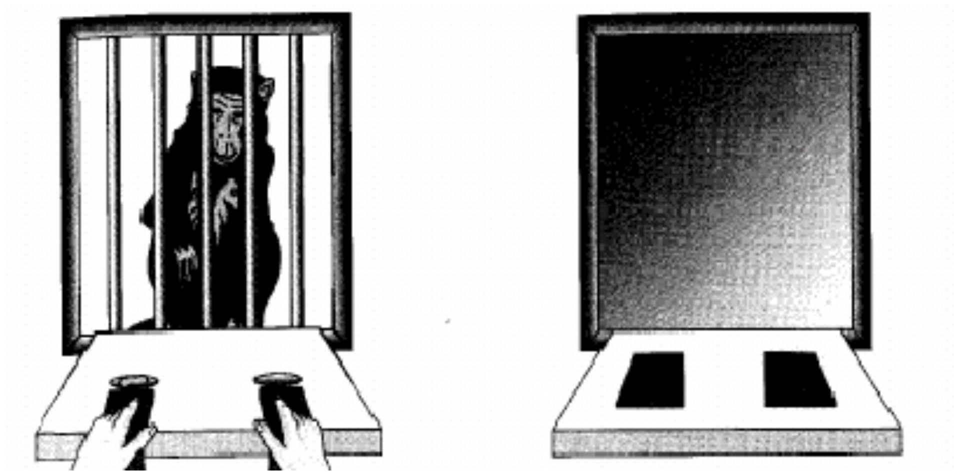
6

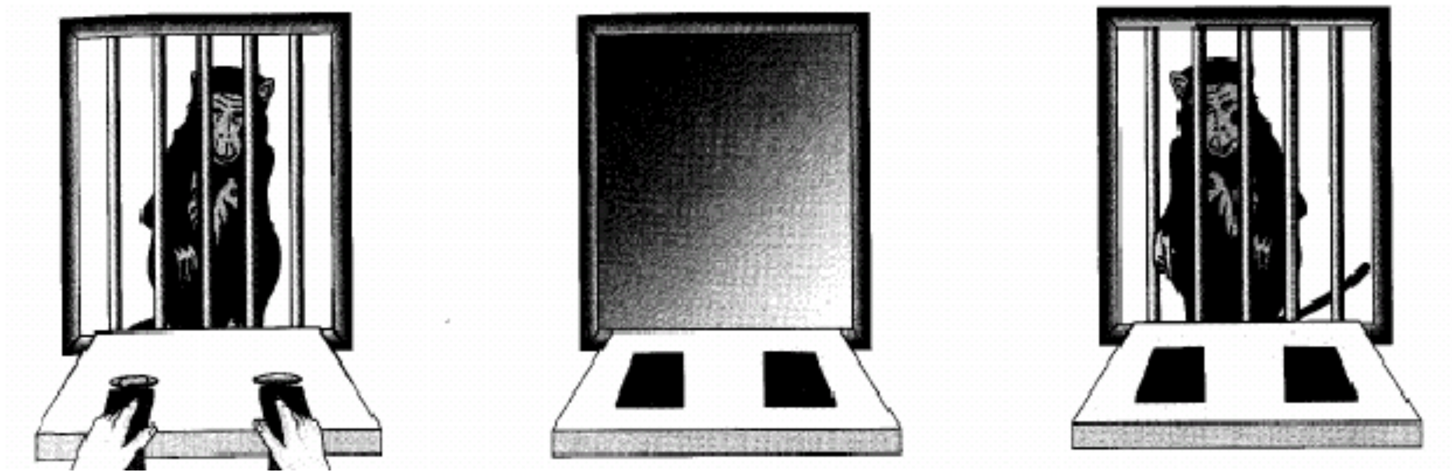
9

11

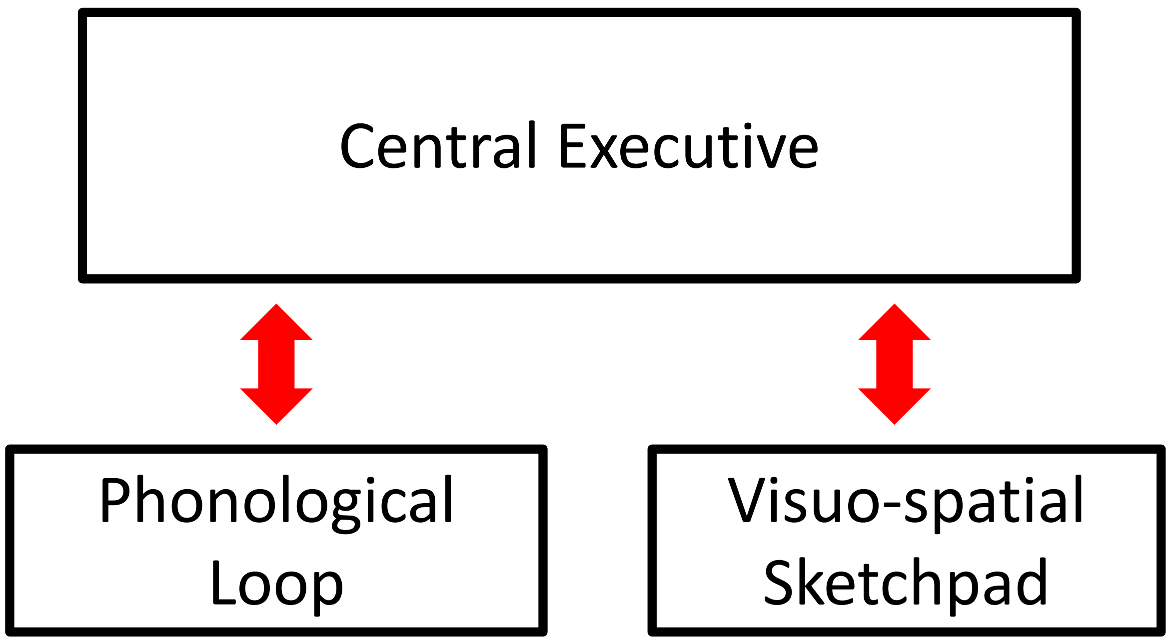


$$\bar{x} = \frac{\sum x}{n_x}$$





Working Memory



Baddeley & Hitch, 1974

The model defines important features:

1) Manipulation – requires central executive

2) Rehearsal – independent of central executive

3) The model is modality specific

maintains visual and spatial memories

Visuo-spatial
Sketchpad

Baddeley & Hitch, 1974

The Visuo-Spatial Sketchpad

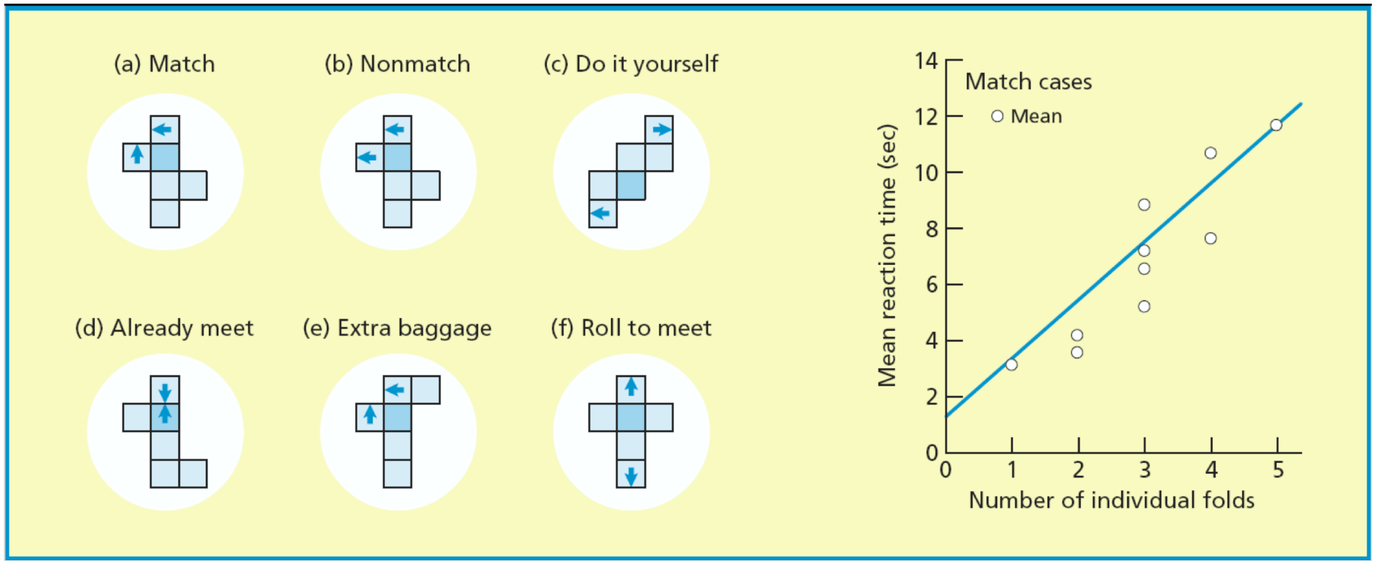
Imagine what you had for Breakfast.
How Vivid is Your Visual Imagery?

- People's subjective report of the vividness of their visual imagery is largely unrelated to their performance on visual tasks.
  - People who report more vivid imagery do not necessarily have better memories
    - They tend to use vividness as a sign of accuracy, sometimes mistakenly.
  - Subjective reports may reflect the way in which we choose to categorize and describe our subjective experiences, rather than their content/capacity.

The Visuo-Spatial Sketchpad

Image Manipulation

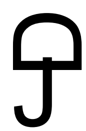
- Imagine folding the shapes below to create a solid, with the shaded area as the base. Will the arrows meet head on?



- Shepard and Feng (1972) found that the time it takes to answer the question depends on the number of folds required
- Men are typically better than women on spatial manipulation tasks, but this appears largely due to differences in strategies, which when taught to women eliminate the gender bias.

Sample Spatial Manipulation Task

- First, form an image of the capital letter J. Then imagine capital D. Now rotate the D through 90 degrees to the left and place it on top of the J. What does it look like?

J D  An umbrella

Articulatory suppression was used to disrupt the phonological loop and spatial tapping was used to disrupt the visuo-spatial sketchpad.

The Visuo-Spatial Sketchpad

Concurrent Tasks

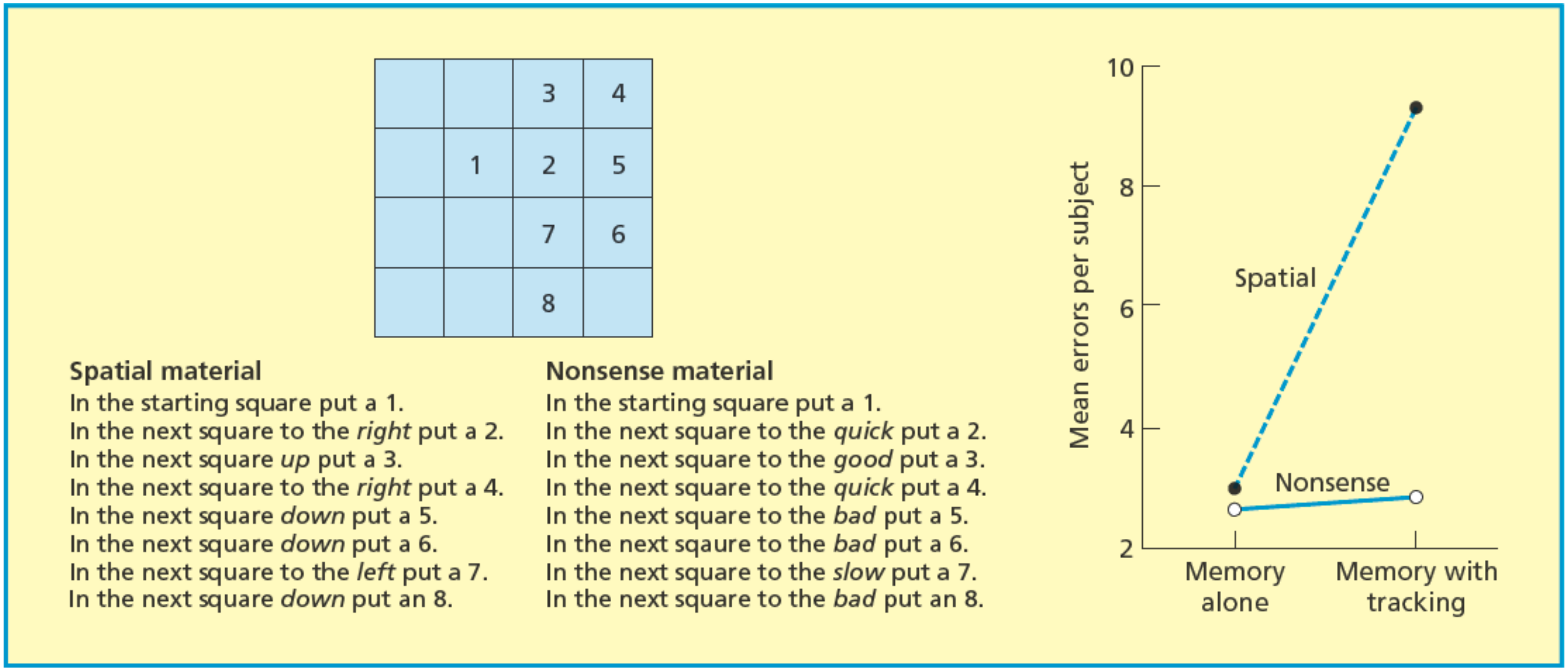
- Pearson et al. (1999) used one of two concurrent tasks while participants were attempting to spatially manipulate components to form a novel object (umbrella) and/or remember the individual components (e.g., J, D).
  - *Articulatory suppression* disrupted the capacity to remember the component shapes, suggesting that the phonological loop held the names of the components.
  - *Tapping a series of spatial locations* disrupted the capacity to create novel objects but spared the capacity to remember the component shapes, suggesting that the sketchpad is important for the former but not the latter.
- Concurrent spatial activity is especially disruptive to individuals who rely heavily on visuo-spatial imagery to perform specialized tasks (example: visualizing an abacus).

The Visuo-Spatial Sketchpad

Concurrent Tasks

- Just as spatial processing can interfere with imagery, imagery can interfere with spatial processing.
  - For example, imagining the sports events being reported on a car radio can disrupt one's ability to safely navigate the road ahead.
- Visual imagery can aid memory, but it can also be disrupted by the presentation of irrelevant pictures or colors which participants are instructed to ignore.

Disruption of Competing Tasks



Left above: Examples of the material developed by Brooks and used to study the visuo-spatial sketchpad. Participants must repeat the sentences from memory but can use the matrix to help them. Data from Brooks (1967). Right: The influence on recall of the Brooks sentences on a concurrent visuo-spatial tracking task. Data from Baddeley et al. (1973).

Vividness of Subjective Experience

Baddeley and Andrade (2000)

- *Hypothesis:*
  - Vividness of visual imagery reflects the operation of the sketchpad; auditory imagery reflects the phonological loop
- *Task:*
  - Participants asked to form and judge the vividness of visual or auditory images before being tested under one of the following:
    - Baseline conditions
    - Articulatory suppression conditions—predicted to reduce vividness of auditory imagery
    - Concurrent spatial tapping conditions—predicted to reduce vividness of visuo-spatial imagery

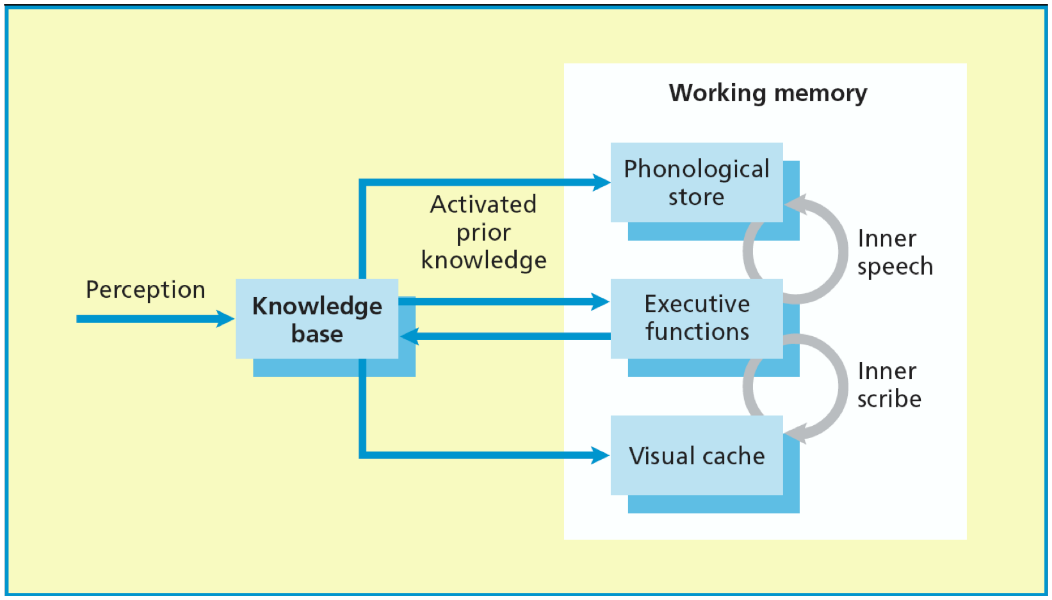
Working Memory and Visual Imagery

Baddeley and Andrade (2000)

- *Results:*
  - When images were novel, auditory imagery was less vivid under articulatory suppression and visual imagery was less vivid under spatial tapping, just as predicted.
  - When images were drawn from long-term memory, however, there was far less of an effect.
- *Interpretation:*
  - The loop and sketchpad only limit detail when the image depends on STM – fed by current experience.
  - When the image is based on LTM, it is much more reliant on a fourth component of working memory, the **episodic buffer**.

Proposed Structure of the Visuo-Spatial Sketchpad

- Logie (1995) suggests that the structure of the visuo-spatial sketchpad is similar to that of the phonological loop, in that it consists of:
  - The **visual cache**: A passive store.
  - The **inner scribe**: An active spatial rehearsal process
- Logie suggests that the sketchpad offers a mental workspace for complex tasks and (controversially) is always fed by LTM



maintains auditory memories

Phonological Loop

Baddeley & Hitch, 1974

The Phonological Loop

Aids Language Learning

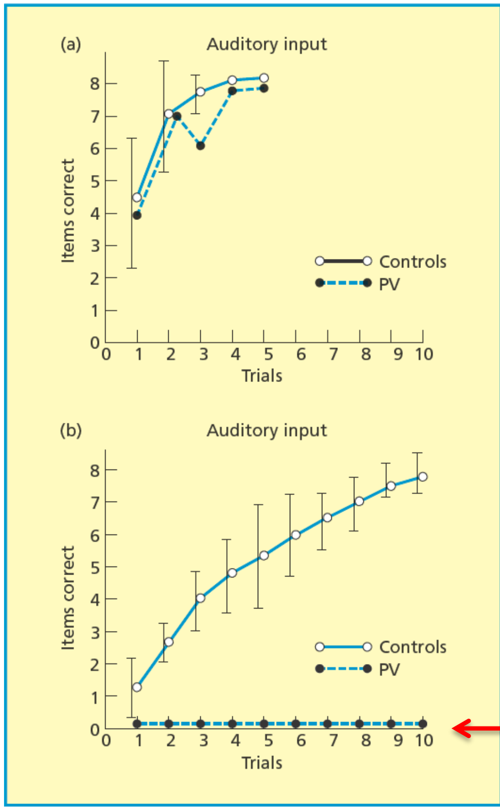
The Phonological Loop:

- Is the best studied component of WM
- Includes a temporary store and a verbal rehearsal process.
- What is it good for, besides letting people rehearse (repeat) items mentally and thereby increase their digit span by two to three items when repeating back numbers?

Neuropsychological Evidence suggests the loop is important to language learning because patients with impairments cannot learn a new language:

- Patient PV had acquired a pure phonological loop deficit as an adult, resulting in a digit span of two items.
- She had only relatively minor language comprehension problems with very long sentences but a profound inability to learn a new language.

PV was Unable to Learn a New Language



Rate of learning pairs of items by patient PV and controls. Her capacity to learn pairs of meaningful words was unimpaired (panel a), but she was not able to learn foreign language vocabulary (panel b).

From Baddeley, Papagano, and Vallar (1988). Copyright © Elsevier. Reproduced with permission.

PV's performance with new vocabulary words.

The Phonological Loop

What Happens with Normal Adults?

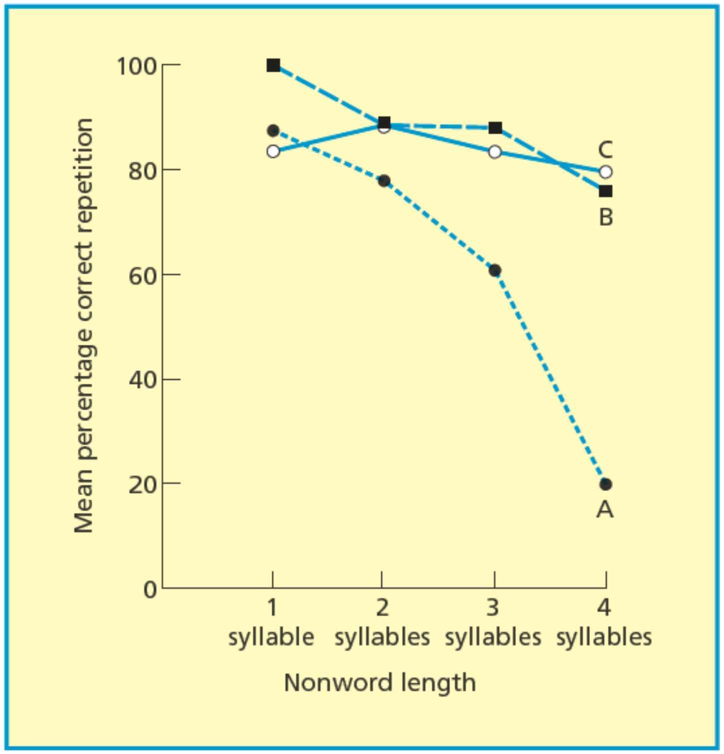
- Testing the language acquisition rationale with normal participants
  - Papagno, Valentine, and Baddeley (1991) found that:
    - Repeating an irrelevant sound disrupted foreign language learning without affecting learning native language word pairings – this showed the phonological loop was involved.
  - Papagno and Vallar (1992)
    - Varied either phonological similarity or the length of paired words – both known to influence the phonological loop.
      - When the response words were foreign, both factors impaired performance more than when the response words were from the native language.

The Phonological Loop

What Happens with Language-Impaired Children?

- Gathercole and Baddeley (1990) tested 8-year-old children with a specific language impairment.
  - *The Task*:
    - The **nonword repetition test**: Pseudo words of increasing length are heard and must be repeated (e.g. BALLOP, WOOGALAMIC, VERSATRATIONAL).
    - Ability to do this task well correlates with vocabulary development and is used to help diagnose dyslexia.
    - Studies reveal that phonological memory is crucial for early vocabulary acquisition (Gathercole & Baddeley, 1989)
  - *Results*:
    - Language-disordered children were impaired on the nonword repetition task, performing like 4-6 year old normal children.

Children with Specific Language Impairments



Percent correct repetition of nonwords by children with a specific language impairment (A), children of the same age (B), and children matched for language level but half their age (C). Adapted from Gathercole and Baddeley (1990).

The Phonological Loop and Action Control

- Vocally or subvocally reminding oneself of the relevant task often improves performance.
  - Articulatory suppression limits this ability and disrupts performance (example – alternation of addition & subtraction).
- Vygotsky (1962) and Luria (1959) emphasized the use of verbal **self-instruction** to control behavior.
  - Studied as a means to help brain-damaged patients rehabilitate and to understand childhood development.
  - Largely underappreciated and under-investigated currently.

Central Executive

add / delete items from working memory
selecting from items
recall from long term memory
transfer to long term memory

Baddeley & Hitch, 1974

The Central Executive

- The central executive is thought to be an attentional controller, with two main modes of operation (Norman & Shallice, 1986):
  - A **semi-automatic conflict-resolution system**, based on existing habits and requiring little attention.
    - Conflicts are routinely resolved without much conscious awareness.
  - The **supervisory attentional system (SAS)**, based on an attentionally limited executive.
    - Crucial to the central executive.
    - Able to intervene when automatic conflict resolution is not possible or when a new situation arises.

The Supervisory Attentional System (SAS)

- Occasionally, the SAS doesn't initiate when it should have. Patients with frontal lobe damage appear to have problems with **attentional control**, suggesting that SAS relies on this brain region.
  - They often **perseverate** (repeatedly perform the same action or mistake with difficulty stopping or changing behavior).
  - They often fail to ***focus*** attention, resulting in **utilization behaviors** (uninhibitedly making use of whatever cues are afforded by the environment to guide behavior).
  - They often fail to **monitor** behavior (fail to make sure they are behaving appropriately for the situation) or recognize when their statements don't make sense (**confabulation**).

The Central Executive

- A major function of the central executive is to *direct attention to the task at hand,* such as planning the next chess move or remembering positions.
- Robins et al. (1996) tested expert & novice chess players – similar factors affected performance:
  - Performance was unaffected by *articulatory suppression*, suggesting that the phonological loop wasn't involved.
  - A concurrent *visuo-spatial tapping task* impaired performance somewhat, indicating the involvement of the sketchpad.
  - Greatest disruption came from an attentionally demanding *random generation task* (producing a random stream of numbers), suggesting involvement of the central executive.

The Central Executive

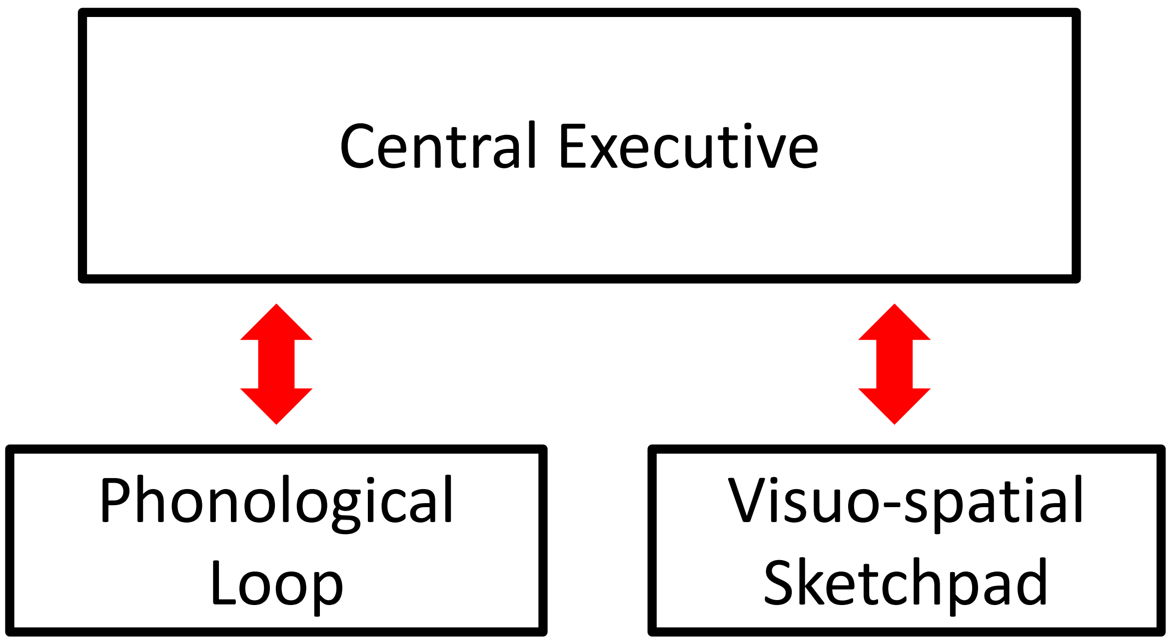
- Another major function of the Central Executive is to divide attention between two or more tasks.
  - Concurrent verbal reasoning tasks (e.g. talking on a cell phone in the car) can impair *judgment* while driving, even though driving skill remains intact.
  - Alzheimer's patients have particular difficulties dividing attention between simultaneous tasks, even when they are all very simple. A three-way conversation is difficult for them.
  - Some aspects of switching between more than one task can be relatively automatic, while others demand attention.

What was that list
of words?

Chair
Dress
Earrings
Bed
Counter
Shower
Floor
Shoes
Desk

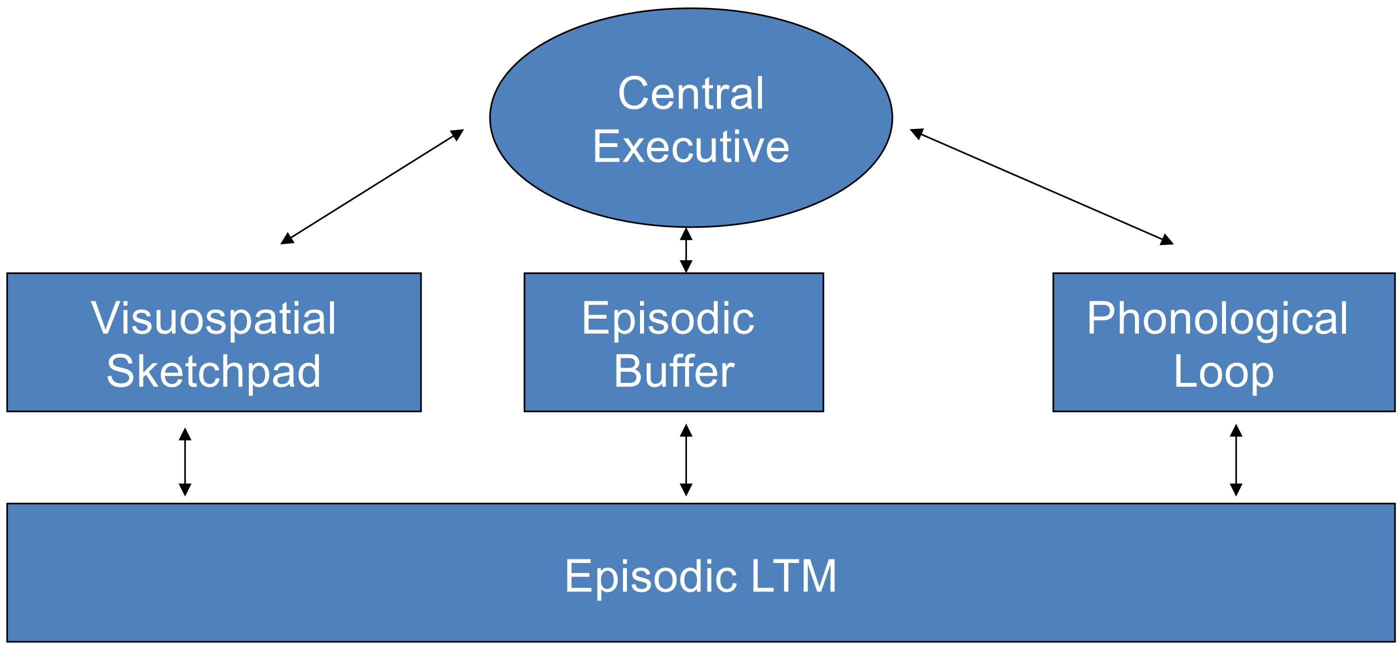
Central Executive

setting goals and planning
task switching
stimulus response selection (inhibition)
control of working memory



Baddeley & Hitch, 1974

4-Component Model of Working Memory



Problems with the Three-Component Model of WM

- The three-component model of WM cannot explain why memory span can sometimes exceed the capacity of the subsystems (as much as 15 words in a sentence).
    - for words in a sentence
        - Aspects of LTM (e.g. grammar) help to chunk the items; yet, we lack an explanation of how LTM and WM interact
    - for digit span (6 or 7 items)
        - If the phonological loop can store only about three items, where are the rest stored? If they are stored in visual STM, how does this interact with phonological STM?
- The model also cannot explain why images based on LTM do not depend on the sketchpad or phonological subsystems.

The Episodic Buffer

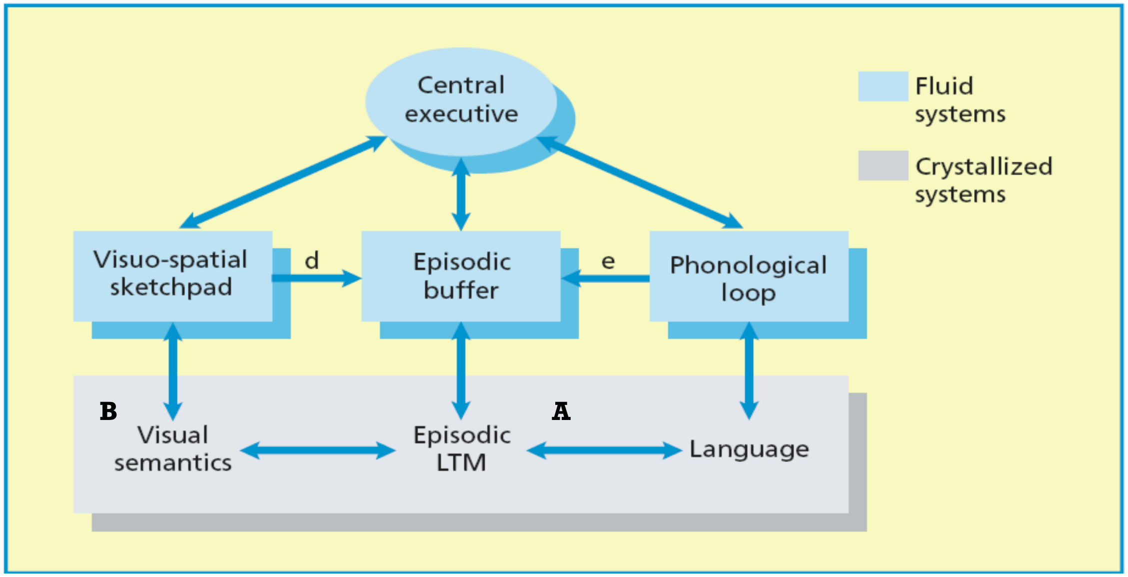
A Solution to the Problems with the WM Model?

- **Episodic Buffer** -- A newly proposed fourth component of the WM system.
  - Originally assumed to be controlled by the central executive.
  - A storage system with a capacity of around 4 chunks of information in a multidimensional code.
    - Multiple dimensions permit links between the subsystems, as well as with LTM & perception.
  - Information is retrieved through conscious awareness – consciousness pulls info together.
  - Allows for the binding of previously unrelated concepts -- disrupting the executive does not impair binding, so it may be automatic/passive.

The Current Model

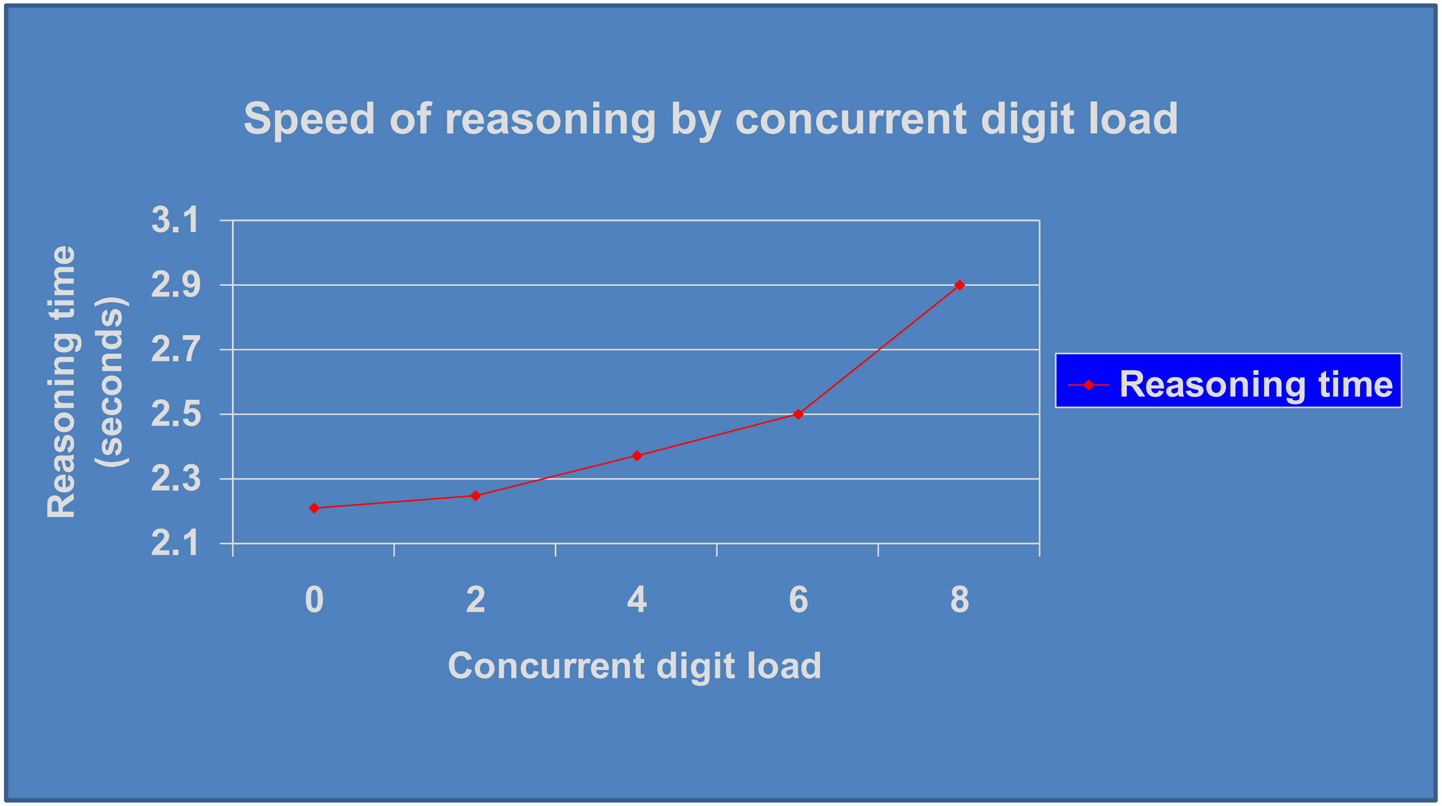
An elaboration of the original three-part model with a few major changes:

- Added two links from phonological and visuo-spatial subsystems to LTM
  - Arrow A: language acquisition
  - Arrow B: visual and spatial mapping
- Added the episodic buffer
  - Accessed through either subsystem and/or the central executive
  - Possibly linked to emotions



Other things to consider...

Why a central executive?



Baddeley (1986)

Limited capacity ofSTM

- Miller (1956) proposed the magic number 7 $\pm$ 2
- We can only receive, process, and retrieve approximately 7 pieces of information at a time
- His study asked people to recall in order lists of numbers of varying length

Short Term Memory Capacity 7+/- 2

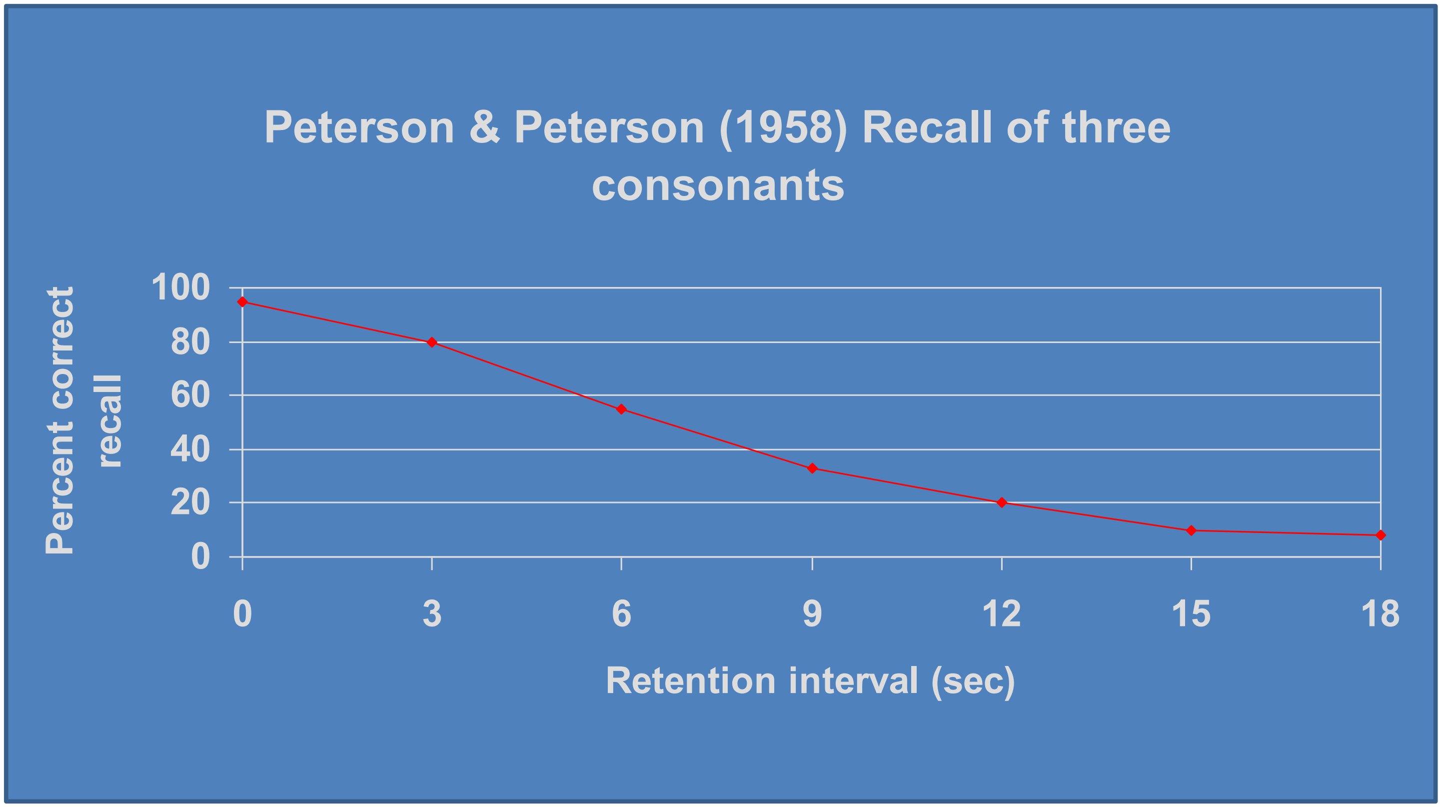
Miller's Magic 7 +/-2

Miller (1956) The magical 7 +/-2.
The STM can hold on average between 5 & 9 items of information.

Chunking: Grouping the items together into chunks.
Telephone number: when you remember it you often recite a group of the numbers as together e.g. 01253 720 742, rather than 01255364289.

Meaningful chunks are even easier to remember:
CBC, FBI, NBC

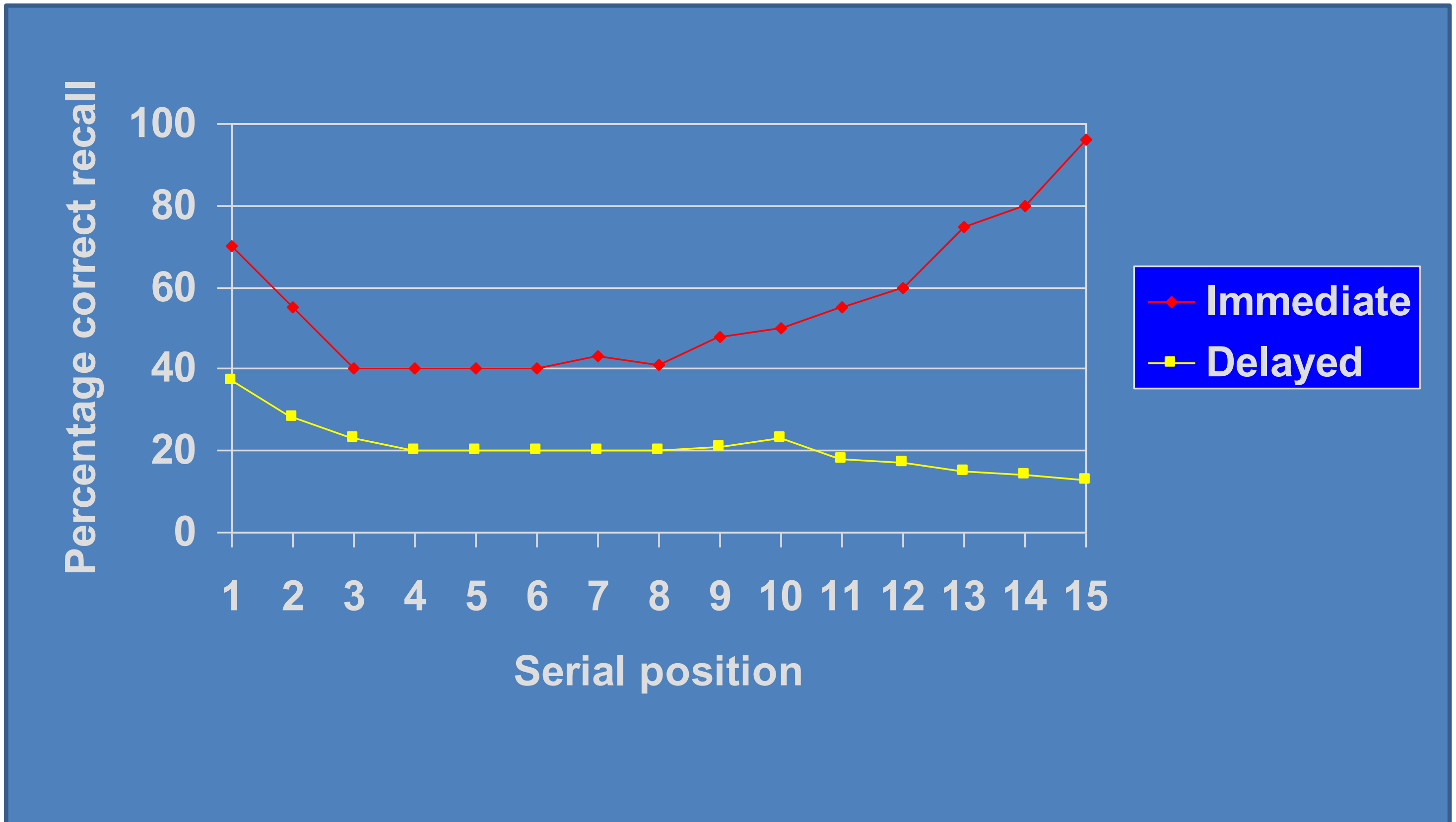
Rapid Forgetting: Distraction



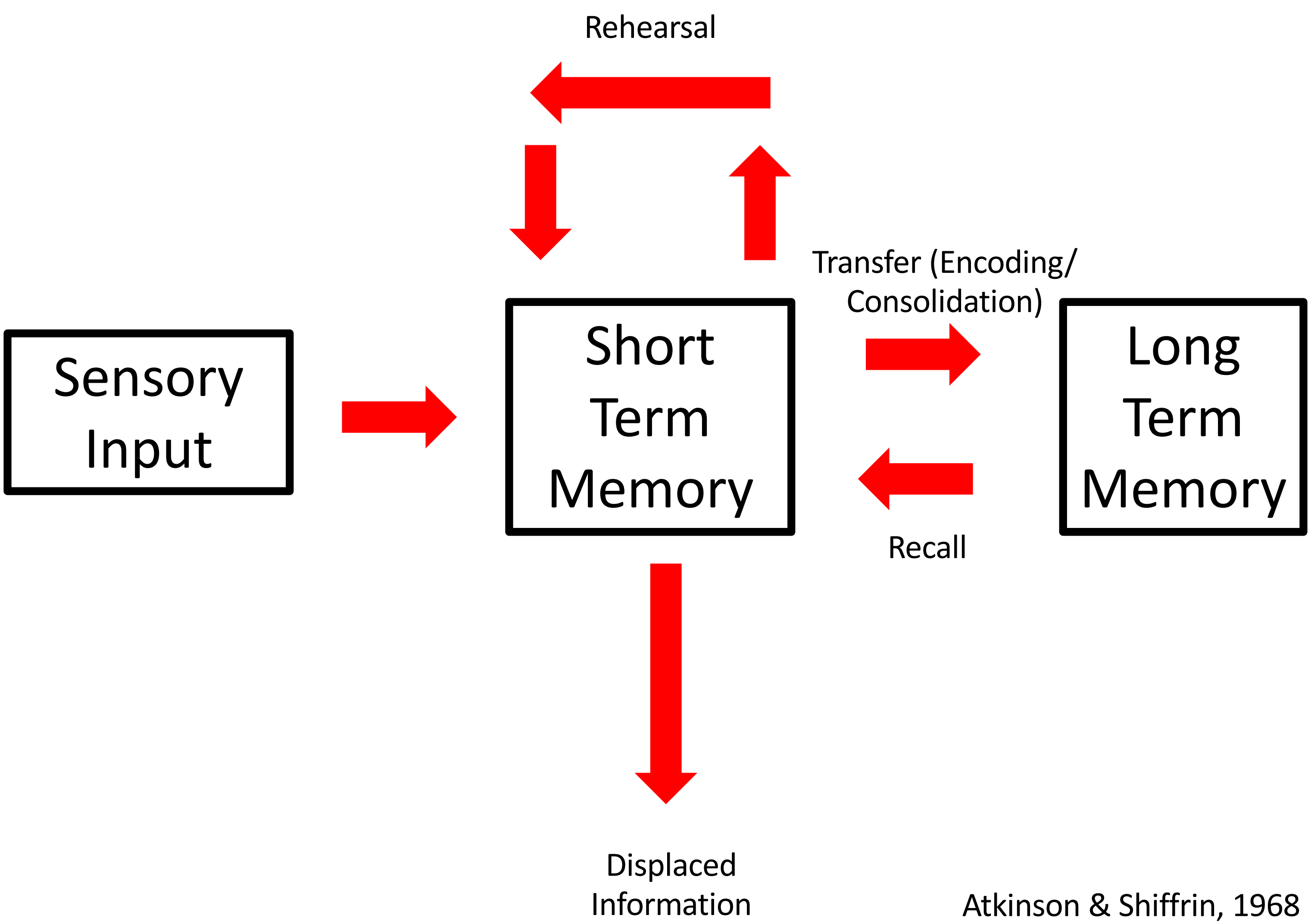
Interpretation of Peterson

- Memory loss in STM is the result of decay; "the memory trace decays" without rehearsal
- STM different than long-term because it was believed that forgetting in long-term memory results from interference

Primacy and Recency



Craik, 1970


Rehearsal
Sensory Input
Short Term Memory
Transfer (Encoding/ Consolidation)
Long Term Memory
Recall
Displaced Information
Atkinson & Shiffrin, 1968

Problems with modal model

- Modal model assumes that STS plays a critical role in the transfer of information into LTS
  - Specifically, this model suggests that the capacity of the STS should determine the probability that an item enters LTS and
  - The amount of exposure in STS should affect the likelihood that an item enters into LTS

Problems with modal model

- Both these implications are incorrect
  - several studies have shown that under some conditions the number of times material is rehearsed is a poor predictor that it will be recalled subsequently (shallow rehearsal)

Problems with modal model

– Shallice and Warrington (1970) and others have established that at least some people with poor memory span (this suggests that STS is damaged) have normal long-term memory
  - KF memory span WAIS score = 2, Mean = 10, Standard deviation = 3
  - established that KF understood spoken words by presenting a list of spoken words; task was to tap table when words were from a given category
  - KF also was impaired when RN STM test administered

Theories of WM

Cowan's Embedded Processes Theory

- WM depends on activation that takes place within LTM and is controlled by attentional processes.
- Activation is temporary and decays, unless maintained through active verbal rehearsal or continued attention.
- Activated memory is multidimensional, with some resemblance to the episodic buffer.
- WM capacity is limited to around four chunks (NOT six to seven, as suggested by Miller, 1956)