TEMPORARY MEMORY: SHORT-TERM AND WORKING MEMORY

Learning & Memory
Arlo Clark-Foos, Ph.D.
## Support for a Multi Store Model

**Distinctions between STM and LTM**

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Biological</th>
<th>Neurological</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ebbinghaus – no effort to recall 1-5 nonsense syllables; considerable effort to recall &gt;5 syllables</td>
<td>• Inhibiting protein synthesis does not impair within-session memory but prevents build-up of memory across sessions.</td>
<td>• Neurological patients can show specific deficits in STM, LTM, or in transition from STM to LTM (e.g., HM).</td>
</tr>
</tbody>
</table>

What are these systems, and how do they interact?
Fig. 1. A flow chart of the memory system. (Solid lines indicate paths of information transfer. Dashed lines indicate connections which permit comparison of information arrays residing in different parts of the system; they also indicate paths along which control signals may be sent which activate information transfer, rehearsal mechanisms, etc.)
Short-Term Memory

- Ability to store information in current consciousness without active rehearsal

- Tasks to measure capacity
  - Span (Digit, Letter, etc.)
  - n-back
  - Operation Span
  - Serial Addition
    - PASAT

- Working Memory?
  - We’ll come back to this...
How many memory systems are there?

- Support for Multi-Store Models (e.g., Atkinson & Shiffrin)
  - Capacity
  - Forgetting
  - Components and Functions
  - Animal WM?
  - Neural representations of WM

Do we have evidence for this distinction?
How Short is Short-Term Memory?

- **Echoic Memory**
  - Partial Report Procedure (Darwin et al., 1972)
  - < 2-3 sec

![Diagram of stimulus presentation procedure for auditory partial report experiment]

<table>
<thead>
<tr>
<th>Left</th>
<th>Both</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>8</td>
<td>F</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>R</td>
</tr>
<tr>
<td>L</td>
<td>U</td>
<td>10</td>
</tr>
</tbody>
</table>

**Darwin, Turvey, and Crowder (1972)**

**Darwin et al. Results**

![Graph showing decrease in items correct with increasing ISI (seconds)]
SHORT-TERM MEMORY CAPACITY

- Miller’s Magic Number 7 ± 2 (1956)
  - Persecuted by a number
  - Digit Span

- Other Span Tests (Reading, Sentence, O-Span, etc.)

- Free Recall
  - Serial Position Effects
    - Primacy
    - Recency
  - Role of long-term vs. short-term memory?
SERIAL POSITION EFFECTS

(A) Immediate recall

(B) Recall delayed by 30 seconds
IMPROVING STM CAPACITY

- Chunking

K. Anders Ericsson
William G. Chase

Exceptional Memory

Extraordinary feats of memory can be matched or surpassed by people with average memories that have been improved by training.

- Ericsson, Chase, & Faloon (1980)
HERMANN EBBINGHAUS & FORGETTING CURVES

- Ubiquitous!
FORGETTING CURVES AGAIN...

- Different Modalities
- Similar patterns

- Single cause of forgetting?
Duration of Short-Term Memory

- Brown-Peterson Task
  - Brown (1958) & Peterson and Peterson (1959)
  - Forgetting Curve
  - Decay?
Duration of Short-Term Memory

- Proactive Interference
  - Keppel & Underwood (1968)
  - Decay or Interference? Final word?

![Graph](image)

**Fig. 3.** Mean recall after 48 hr on five recall trials as a function of successive blocks of three lists.
SHORT-TERM MEMORY AND INTERFERENCE

- Jenkins & Dallenbach (1924)

- Reducing interference or disrupting consolidation?

*Image with graphs and text boxes.*
Atkinson & Shiffrin (1968): STS

Environmental input → Sensory registers → Short-term store → Long-term store

- Visual
- Auditory
- Touch

Temporary working memory
Control processes:
Rehearsal
Coding
Decisions
Retrieval strategies

Response output

Permanent memory store
SHORT-TERM VS. LONG-TERM

○ Distinctions
  - Capacity/Forgetting
  - Representational Coding
  - Anatomical (more later)

○ Similarity
  - Interactions (e.g., proactive interference)
  - Spreading Activation (more later)
REPRESENTATIONAL CODING

- Kintsch & Buschke (1969)
  - Serial Position & Errors
  - Synonyms vs. Homophones
  - Semantic vs. Perceptual Similarity

**Fig. 1.** Probability of recall of synonyms and unrelated words as a function of serial position.

**Fig. 3.** Probability of recall of homophones and unrelated words as a function of serial position.
ANATOMICAL DISTINCTIONS

- **Amnesics** (Baddeley & Warrington, 1970)
  - Hippocampus
  - H.M.
  - Korsakoff’s
  - etc.

- **Temporoparietal Damage** (Shallice & Warrington, 1970)
  - No STM (recency of one), intact LTM

![Brain Diagram](image)
**Short-Term Store vs. Working Memory**

Baddeley (2000)

Baddeley & Hitch (1974)

Atkinson & Shiffrin (1968)
Working Memory

- Baddeley & Hitch (1974)
  - Central Executive
  - Visuospatial Sketchpad
  - Phonological Loop
  - Subvocal Rehearsal
  - Rehearsal Rates
- Ode on WM (Keenan)

Evidence for separate visual and verbal coding in memory. Subjects attempted to learn a list of words using either visual imagery or rote verbal repetition, while trying to ignore either a flickering visual pattern or background speech. When subjects used imagery, only the flickering light impaired performance; when they used rote repetition, the opposite pattern was found \([32^{**}]\).
WORKING MEMORY

- Stores about 2 s of auditory information
- Example: 7 numbers will be presented for 2 s; remember them!
  - Learn: 5 6 2 8 1 7 3
  - Delay...
  - Remember: 5 6 2 8 1 7 3

Did you repeat the numbers mentally? This is the phonological loop!
WORKING MEMORY

- Properties of the Phonological Loop

### TABLE 2

Experiment 2: Mean Percentage Error-rate as a Function of Musical Background

<table>
<thead>
<tr>
<th>Vocal</th>
<th>Instrumental</th>
<th>Silent Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Mozart (♀)</td>
<td>(a) The Shadows</td>
<td>(a) 24.2</td>
</tr>
<tr>
<td>(b) Rossini (♂)</td>
<td>(a) Mike Oldfield</td>
<td>(b) 22.9</td>
</tr>
<tr>
<td>(c) Schubert (♂)</td>
<td>(c) Duke Ellington</td>
<td>(c) 21.4</td>
</tr>
<tr>
<td>(d) Mozart (♀)</td>
<td>(d) Human League</td>
<td>(d) 21.3</td>
</tr>
<tr>
<td>Mean</td>
<td>29.7</td>
<td>25.3</td>
</tr>
</tbody>
</table>

(♂) Male singer  (♀) Female singer
**Visuospatial Sketchpad: Example**

- Imagine a $4 \times 4$ grid (16 squares) with a 1 in the second column of the second row.
- Place a 2 to the right of the 1.
- In the square above the 2, put a 3.
- To the right of the 3, put a 4.
- Below the 4, put a 5.
- Below that, put a 6.
- Then to the left of that, a 7.
- What number is above the 7?

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<table>
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<tr>
<td>3</td>
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<td></td>
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<tr>
<td>1</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>6</td>
<td></td>
</tr>
</tbody>
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**Answer: 2!**

*Getting this right (or near right) requires a visuospatial sketchpad.*
WORKING MEMORY

- Properties of the Visuospatial Sketchpad
  - Baddeley et al. (1975)

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<td>6</td>
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<td>8</td>
<td></td>
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</tbody>
</table>

**Spatial material**
- In the starting square put a 1.
- In the next square to the right put a 2.
- In the next square up put a 3.
- In the next square to the right put a 4.
- In the next square down put a 5.
- In the next square to the left put a 7.
- In the next square down put an 8.

**Nonsense material**
- In the starting square put a 1.
- In the next square to the quick put a 2.
- In the next square to the good put a 3.
- In the next square to the quick put a 4.
- In the next square to the bad put a 5.
- In the next square to the slow put a 7.
- In the next square to the bad put an 8.
Do Animals Have Working Memory?

- Serial Probe Recognition Task (Wright et al. 1985)

Also: rats can remember up to 17 arms in win-shift!
VISUOSPATIAL SKETCHPAD

- Delayed nonmatching to sample task:
  - Novel object shown
  - Delay
  - Choose the nonmatching object

- Requires visual memory of object to be held in mind during short delay—a function of the visuospatial sketchpad
PLACE VS STATE MODELS OF MEMORY

- Multi-Store

- Unitary-Store

![Diagram showing the multi-store model of memory](image1)

![Diagram showing Cowan's model of working memory](image2)
Place vs State models of Memory
Cognitive (Executive) Control and the Central Executive

- Manipulating the contents of STM

<table>
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<th>Behaviors</th>
<th>Tasks used to explore these behaviors</th>
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<tbody>
<tr>
<td>Controlled updating of short-term memory</td>
<td>N-back task, self-ordered search</td>
</tr>
<tr>
<td>Setting goals and planning</td>
<td>Tower of Hanoi</td>
</tr>
<tr>
<td>Task switching</td>
<td>Wisconsin Card Sorting Test</td>
</tr>
<tr>
<td>Stimulus attention and response inhibition</td>
<td>Stroop task</td>
</tr>
</tbody>
</table>
Executive Function: Updating

- N-back Task
  - Update contents of WM to keep up with task.

- Self-Ordered Tasks
  - Mental “To Do” Lists
EXECUTIVE FUNCTION: SETTING GOALS AND PLANNING

- Edouard Lucas and the Tower of Hanoi Legend
  - 64 gold disks @ 1 per second = 580 bn years!

- Setting subgoals, tracking completed and remaining goals, planning next goal...
**EXECUTIVE FUNCTION: TASK SWITCHING**

- **Wisconsin Card Sorting Test (WCST)**

  - Sorting rule changes without warning
    - Maintaining and then switching a rule
  - Frontal patients and perseveration (Roberts et al., 1996)
EXECUTIVE FUNCTION: STIMULUS SELECTION & RESPONSE INHIBITION

- Driving and Crossing Roads in England and Australia
- Stroop Task (Stroop, 1935)

<table>
<thead>
<tr>
<th></th>
<th>control</th>
<th>compatible</th>
<th>incompatible</th>
</tr>
</thead>
<tbody>
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<tr>
<td></td>
<td>fence</td>
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<td>red</td>
</tr>
</tbody>
</table>
EXECUTIVE FUNCTION AND INTELLIGENCE

- Daneman & Carpenter
  - Correlations between WM (Delayed Recall) and...
    - Verbal SAT
    - Raven’s Progressive Matrices (Mensa)
NEUROLOGICAL BASIS OF WM
Prefrontal Cortex (PFC)
The Case for the Prefrontal Cortex

- 300 World War II Vets (Pfiefer, 1922)

- Wilder Penfield’s Sister
  - Disexecutive Syndrome
    - Disrupted ability to think/plan

- Baddeley’s (1986) patient RJ
  - Bilateral Frontal Lesions
  - Tower of London & String Cutting

- N-back, Span, Delayed Recall, WCST
THE CASE FOR THE PREFRONTAL CORTEX

- Jacobsen et al. (1937): Bilateral PFC Lesions
  - Delayed Response Task
DIVIDING THE PREFRONTAL CORTEX

- Orbital, Medial, and Lateral PFC
  - Lateral ➔ Dorsolateral (DLPFC)
  - Ventrolateral (VLPFC)
**Delay Cells**

- **Fuster (1995)**
  - Delay cells in DLPFC
  - “holding in mind”

- **Goldman-Rakic (1995)**
  - Occular motor delayed response task
    - Sensory and Motor Response Info
  - DLPFC lesions

- **Miller (2000)**
  - Maintain activity, despite distractions, until needed
BADDELEY’S MODEL AND BRAIN ANATOMY

- DLPFC lesions impair monitoring, not maintaining
  - Self-Ordered Delayed Response Tasks (Petrides, 1995)
It’s a Big DLPFC After All

- Phonological Loop and Visuospatial Sketchpad
  - $n$-back task (Spatial vs. Verbal)
    - (Smith et al., 1996)
    - Left is Specialized and Right is not?

- Reconciliation of Baddeley’s Model and Unitary Store?
**Smith et al.’s (1996) n-Back Tasks**

Baddeley & Hitch (1974)

Right Hemisphere

Left Hemisphere (Broca’s area?)

Figure 4. PET images of statistically significant activation sites in the spatial memory condition (top) and the verbal memory condition (bottom). Each image is superimposed on an MRI image of a composite brain. Note that in the verbal memory task the activation is greater in the left than the right hemisphere, whereas in the spatial memory task the activation is greater in the right hemisphere in key regions (see text). Stereotaxic coordinates of all significant foci of activation are given in Table 1 (Experiment 2).
GOAL ABSTRACTION

- *Making PBJ Sandwiches*
  - *Broad Abstraction Starts at the Front*

  “*Make your own breakfast this morning*”
- Developmental changes in frontal lobes support abstract planning
  (Shaw et al., 2008)
USING PFC TO CONTROL LTM

- Frontal Patients and Observing Activity in Controls
  - Meta-Memory (underconfident JOL; TOT)
  - Source Memory (Dobbins et al., 2002)
PFC-Hippocampus Interactions

**Encoding Interactions**

- **DLPFC**: Organization of material to be remembered
  - Progressively higher-level representations of perceived information formed in posterior cortex

- **VLPFC**: Semantic/phonological elaborative processing of MTL representations to ensure traces are distinct

- **MTL**: Different features bound into episodic representation

**Retrieval Interactions**

- **APFC**: Higher-level mnemonic control operations

- **DLPFC**: Monitoring and verification of retrieved information

- **VLPFC**: 1. Cue specification, strategic search of MTL stored representations 2. Maintenance of retrieved information

- **MTL**: Comparison of retrieval cue and stored representations using pattern completion
SCHIZOPHRENIA AND THE PFC

- Weinberger et al. (1996)
  - WCST and DLPFC in Schizophrenic and Control

- Activity in DLPFC lower in Sz. during N-back (Barch et al., 2002)
- Post-mortem neural pathologies

- COMT gene
  - Degrading dopamine
ATTENTION DEFICIT/HYPERACTIVITY DISORDER (ADHD)

- At least 5% children diagnosed*
- Decreased PFC activity and weaker connections in PFC
  - Is the problem in the PFC or elsewhere (basal ganglia)?