Announcements

- A note on participation
- Reading results sections
Homework

- **Reading response** (due W 6/29 by 11:30 AM):
  - Questions posted on website (under Course Readings)

- **MIA: method of loci** (due W 6/29 by 11:30 AM):
  - Come to class prepared with a sequence *in order* of 10 unique and distinctive locations along a familiar route
  - Details posted on website (under Memory in Action)
Last time

- Neuroscience primer & experimental design:
  - Areas of the brain (sensory, control/attention networks, medial temporal lobe)
  - How to measure neural activity — fMRI
  - Double dissociations
  - Correlation vs. experiment

- How to read a paper — use the notes when reading the Owen et al. paper for Weds!
This time

• What is working ("short-term") memory (WM)?
• Why is WM important?
• Capacity limits of WM
• Contrasting WM and LTM
• Forms of WM
This time

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- Forms of WM
Multiple memory systems

Transient memory
- Sensory
- Working (short-term)

Long-term memory
- Declarative
  - Episodic
  - Semantic
- Non-declarative
  - Conditioning
  - Skill learning
  - Priming
Multiple memory systems

Transient memory
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Sensory memory

- Our sensory systems convert **sensory energy** (light, sound, etc.) into **neural representations**

- Sensory systems have a **brief “storage space”** for these representations

  - Sensory memories are **fleeting memories** of stimuli we just experienced
Demonstration!
Sperling task (1960)

• Classic study of sensory ("iconic") memory

1. Briefly presented with a grid of letters (50 ms)

2. Participants immediately reported which letters they had seen

Want to try the task yourself?
Demo on Course Demos page!
Sperling task (1960)

• Results
  • On average, participants reported ~4-5 items
  • Noted that they saw more letters than they were able to report
Sperling was interested in how much information was actually stored in sensory memory.

Soon after the grid was removed, played a tone indicating which row of letters to report ("partial report").

If participants could report the whole row, suggests that they must have briefly remembered the whole grid.
Sperling task (1960)

**full report**
- A, T, V, S, B, F, K, Q, Z
- A, F, K, Q, ...

**partial report**
- A, T, ...
- S, B, F!
- K, Q, Z!

4 letters
8 letters!
Sperling task (1960)

- Sensory memory seemingly contains all visual input!
- Suggests that sensory memory is fleeting
- Attentional capacity is limited

(reporting ~3 letters/row suggests that ~9 letters actually remembered for a brief period of time!)
Multiple memory systems

**Transient memory**
- Sensory
- **Working (short-term)**

**Long-term memory**
- **Declarative**
  - Episodic
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  - Conditioning
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Multiple memory systems

**Working memory**
- Contents are highly accessible
- Brief and fragile
- Limited in capacity
- Sustained neural firing

**Long-term memory**
- Contents are less accessible
- Enduring
- Limitless in capacity
- Changes in synapses
"Modal model" of memory

Atkinson-Shiffrin model (1968)

- **Working memory**: a system for maintaining and manipulating active representations, separate from sensory memory & LTM
  - Currently, we typically use a *functional* term (working memory) instead of a *descriptive* term (short-term memory)
This time

- What is working ("short-term") memory (WM)?
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Importance of working memory

- **Working memory capacity** is correlated with:
  - Reading comprehension
  - Reasoning and problem solving
  - General intelligence (ability to reason/solve new problems independently of previously acquired knowledge)
  - Academic success
    - WM capacity at 5 years of age is a better predictor of academic success than IQ!

- **Impairments in working memory** are associated with a number of clinical conditions
  - Specific language impairment
  - Attention deficit hyperactivity disorder (ADHD)
  - Schizophrenia
Importance of working memory

• Can WM training actually increase intelligence?

We’ll find out next class!
This time

• What is working ("short-term") memory (WM)?

• Why is WM important?

• **Capacity limits of WM**

• Contrasting WM and LTM

• Forms of WM
Capacity limits of WM

- WM capacity is frequently tested with span tasks
- Digits, letters, etc.
- **Example**: increase the number of digits incrementally; how many digits can you remember? Try the demo on the website!

Miller (1956): “Magic number 7, plus or minus 2”
Capacity limits of WM

- Visual WM capacity is related to the ability to focus attention on relevant information and filter out distractions ("filtering efficiency")

Remember red shapes on left:

- better WM!
- worse WM!

Adaptation of Vogel et al. (2005)
This time

- What is working ("short-term") memory (WM)?
- Why is WM important?
- Capacity limits of WM
- **Contrasting WM and LTM**
- Forms of WM
Contrasting WM & LTM

- Evidence for separate WM and LTM systems?

- Research looking at serial position in a free recall task has informed our understanding of multiple memory systems
  - **Free recall**: read/listen to a list of words, then recall as many as you can
  - **Serial position**: ordering of items within a list
Demonstration!
Demonstration!

horse
Demonstration!

window
Demonstration!

wheelbarrow
Demonstration!
eagle
Demonstration!

apple
Demonstration!
mug
Demonstration!
Contrasting WM & LTM

Percent Recalled

Serial Position

earlier items

horse  window  wheelbarrow  eagle  apple  mug

last items
Contrasting WM & LTM

Serial Position

Percent Recalled

earlier items

horse window wheelbarrow eagle apple mug

last items
Contrasting WM & LTM

- **Primacy effect (LTM)**: Items recalled better when presented earlier.
- **Recency effect (WM)**: Items recalled better when presented last.

- **Serial Position**

- **Percent Recalled**

- **Earlier items**: horse, window, wheelbarrow
- **Last items**: eagle, apple, mug
Contrasting WM & LTM

- **Serial Position**: beginning, middle, end
- **Proportion Recalled**

- **Condition**: Standard

- **Primacy Effect** (LTM)
- **Recency Effect** (WM)
Contrasting WM & LTM

Early on during study:

```
+----------------------------------------------------------+
| input                                                   |
| sensory registers                                       |
| visual                                                  |
| attention                                               |
| WM                                                      |
| horse                                                   |
| window                                                  |
| LTM                                                     |
| earlier items                                           |
| horse   window   wheelbarrow   eagle   apple   mug       |
| last items                                             |
```
Contrasting WM & LTM

In middle of study:

input -> sensory registers (visual) -> attention -> WM

WM: window, wheelbarrow, eagle

LTM: window, horse

earlier items: horse, window, wheelbarrow, eagle

last items: apple, mug
Contrasting WM & LTM

At the end of study:

input

sensory registers

visual

WM

attention

apple

mug

LTM

eagle

window

horse

wheelbarrow

earlier items

horse  window  wheelbarrow  eagle  apple  mug

last items
Contrasting WM & LTM

- Factors influencing primacy:
  - Rate of presentation

<table>
<thead>
<tr>
<th>Condition</th>
<th>Serial Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>beginning</td>
</tr>
<tr>
<td>Speeded</td>
<td>middle</td>
</tr>
<tr>
<td></td>
<td>end</td>
</tr>
</tbody>
</table>

Proportion Recalled

% of Words Recalled

slow (standard)
speeded
Contrasting WM & LTM

- Factors influencing primacy:
  - Rate of presentation
  - List length
  - Familiarity of materials
  - Medial temporal lobe (MTL) damage

Baddeley & Warrington (1970)
Contrasting WM & LTM

- Factors influencing recency:
  - Filled delay (articulatory suppression; e.g., saying “bah bah bah”) between study and test

Atkinson & Shiffrin (1971)
Contrasting WM & LTM

• Evidence for multiple memory systems
  • Behavioral double dissociation
    • Manipulation A influences behavior X but not behavior Y; manipulation B influences behavior Y but not behavior X
    • Quick presentation rate impairs primacy (LTM) but not recency (WM)
    • Filled delay impairs recency (WM) but not primacy (LTM)!
  • Lesion (neuropsychological) double dissociation
    • Patients with MTL damage show impaired primacy (LTM) but not recency (WM)
    • Patients with frontal/parietal damage show impaired recency (WM) but not primacy (LTM)!
Contrasting WM & LTM

Behavioral Double Dissociation

- Primacy (LTM) vs. Recency (WM)
- Performance
- Filled delay
- Fast presentation

Lesion Double Dissociation

- Primacy (LTM) vs. Recency (WM)
- Performance
- Frontal/Parietal patient
- MTL amnesic
Contrasting WM & LTM

The behavioral and lesion double dissociations are strong evidence for separate WM and LTM systems!
This time

• What is working (“short-term”) memory (WM)?

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• Forms of WM
Forms of WM

- Modal model
  - WM (STM) is separate from LTM
  - All sensory modalities pass through a unitary WM buffer

Atkinson & Shiffrin (1968)
Forms of WM

But behavioral, neuropsychological, and neuroimaging studies suggest WM might NOT be unitary!
Forms of WM

- Evidence from neuropsychological data: **Patient KF**
  - Left temporal/parietal lesion
  - **Impaired auditory span**, relative to visual span
  - Preserved auditory LTM!

![Brain Image](image)

<table>
<thead>
<tr>
<th>Modality</th>
<th>1 Letter</th>
<th>2 Letters</th>
<th>3 Letters</th>
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<tbody>
<tr>
<td>Auditory</td>
<td></td>
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<td></td>
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<tr>
<td>Visual</td>
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![Bar Chart](chart)
Forms of WM

- Evidence from neuropsychological data: Patient ELD
  - Right frontal/temporal lesion
  - Impaired visuospatial span, normal auditory span
Forms of WM

- Double dissociations between *types* of WM!

Lesion double dissociation

- Patient ELD
- Patient KF

Auditory WM  Visuospatial WM

Performance
Forms of WM

- Double dissociations between types of WM!

Lesion double dissociation
- Patient ELD
- Patient KF

Behavioral double dissociation
- Visuospatial distraction
- Auditory distraction

Performance

Auditory WM  Visuospatial WM  Auditory WM  Visuospatial WM
Forms of WM

- **Tripartite model** (three compartment model)

Baddeley & Hitch (1974)

- **Phonological loop**
  - holds acoustic and speech information

- **central executive**
  - (a) decides which information is maintained and
  - (b) manipulates information

- **Visuospatial sketchpad**
  - holds visual and spatial information
Forms of WM

- **Tripartite model** (three compartment model)

  - **Phonological loop**
    - holds acoustic and speech information
  - **central executive**
    - (a) decides which information is maintained and (b) manipulates information
  - **Visuospatial sketchpad**
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Baddeley & Hitch (1974)
Forms of WM

- Modal model
- Tripartite model

“Systems hypothesis” of WM
- Contents of WM stored in dedicated buffer(s)

But what about the maintenance of other types of information beyond visuospatial and phonological? Smell? Taste? Touch?

Is there really a separate WM buffer for each type of information? Or is there a simpler explanation?
Forms of WM

- Modal model
- Tripartite model

“Systems hypothesis” of WM
- Contents of WM stored in dedicated buffer(s)

Emergent hypothesis of WM
- There are *not* separate buffers for WM
- Information in WM is supported by the same regions that perceive that information!
- This information is maintained through attention
Forms of WM

• Evidence for the emergent hypothesis

• Find regions of the brain important for perceiving types of stimuli, and then use fMRI to see if these regions are more active when maintaining that type of information in WM
Forms of WM

- Evidence for the emergent hypothesis

Where is information maintained during the delay?

- Modal model
  - Both in short-term store
- Tripartite model
  - Both in visuospatial sketchpad
- Emergent hypothesis
  - Faces in face areas (FFA), scenes in scene areas (PPA)

Ranganath et al. (2004)
Forms of WM

- Evidence for the **emergent hypothesis**

Ranganath et al. (2004)

Maintaining information recruits the same regions involved in perceiving that information!
Forms of WM

- *How is perceptual information maintained?*

**Prefrontal cortex (PFC)** sends top-down projections to *perceptual regions*, and can help maintain representations in those regions.

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<th>Maintain (Delay)</th>
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<td><img src="image1" alt="Face Area" /></td>
<td><img src="image2" alt="Face Area" /></td>
</tr>
<tr>
<td><strong>Place Area (PPA)</strong></td>
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-Xu (2014); Ranganath et al. (2004)
Forms of WM

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<td><strong>Control Areas (Prefrontal Cortex)</strong></td>
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Xu (2014); Ranganath et al. (2004)
Forms of WM

• *How is perceptual information maintained?*

• Monkeys either need to remember *location* or *object*

• PFC lesions impair performance on both tasks

• What do you predict would happen after lesions to sensory areas important for processing locations vs. objects?

Jacobson et al., 1935
General Summary

• Sensory memory is fleeting, and attentional capacity limited

• WM capacity is related to the ability to focus attention on relevant information and filter out distractions

• Behavioral and lesion data support a distinction (double dissociation!) between WM and long term memory

• WM “emerges” when perceptual representations are maintained through persistent neural firing (in modality-specific regions)

• The prefrontal cortex is critical for maintaining these representations (across all modalities)
Homework

• **Reading response** (due W 6/29 by 11:30 AM):
  - Questions posted on website (under Course Readings)

• **MIA: method of loci** (due W 6/29 by 11:30 AM):
  - Come to class prepared with a sequence (*in order*) of 10 unique and distinctive locations along a familiar route
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Exit ticket

Questions?