Baddeley & Hitch (1974)

Diagram:
- **Phonological loop**
  - Storage (passive)
  - Rehearsal (active)
- **Central executive**
- **Visuospatial sketch pad**
  - Visual information
  - Spatial information

Baddeley's working memory model
Recall the words

BEAR, SPOT, TRAIL, LOW, TEAR, GOOD
CogLab: Operation span

- Spring ‘12  N=14
- Span score: sum of all sequence lengths recalled correctly while processing math
- Max score = 60
- Math accuracy needs to be > 85%
- Class data:
  - Math accuracy = 97.7%
  - O-span score = 43.1 (SD =11.46)
WM span tasks

- Span tasks
  - Measure capacity while processing
- Examples:
  - Forward digit span, letter span, word span
  - Backward digit span
  - Visual memory span
  - Size judgment span
  - Computation span
  - Reading span
  - ETC!
CogLab: Memory Span

- Class results: N = 10 (Fall ‘09)
- Span score (sd)
  - Numbers: 6.2 (1.87)
  - Letters (sound different): 5.4 (1.35)
  - Letters (sound similar): 5.0 (1.56)
  - Words (short): 5.3 (1.06)
  - Words (long): 4.3 (0.95)
WM and individual differences

Question:
- Why is there a relationship between WM span and higher-level cognitive tests?
- What accounts for the correlations?

http://www.stat.berkeley.edu/~stark/Java/Html/Correlation.htm
Correlation between WM span and:

- Reading and listening comprehension
- Vocabulary and new vocabulary learning
- Computer-language learning
- Following directions
- Note taking
- Writing
- Reasoning
- Bridge playing
- Verbal scholastic aptitude test
- Verbal and quantitative SAT
WM and individual differences
Daneman & Carpenter (1980)

Method: Tasks given to yng adults
- Reading span
- Nelson-Denny reading comprehension test
- Pronoun reference test

Results: Examine correlations
- Reading span and reading comprehension $r = 0.55$
- WM span and verbal SAT $r = .59$
- WM span and pronoun reference test $r = 0.9$
- WM correlates with overall measures of intelligence! ($r$'s = 0.3 to 0.4) ... WHY??
WM span processes (if O-span task)

- Processing (of math)
  - Central executive
  - Use long-term memory for math knowledge
- Encoding and storage (of words)
  - Phonological loop
- Recall (retrieve) words

- Dual-task: simultaneous processing and storage
- Switching: between math/memory tasks
- Keep information “active” (rehearsal process)
- Resist interference (or decay of info)
Higher cognitive processes
e.g. Reading comprehension

- **Focused attention**
  - On words, sentence structure, paragraph
  - Keep certain information “active”

- **Comprehension**
  - Processing meaning by using long-term memory
  - Storage of previous information for context
  - Compute semantic and syntactic relations among words to create representation of information
  - Dual-task: simultaneous processing and storage

- **Selective attention: Block distractions**
  - Resist interference due to previous sentences
  - Environmental interference
  - Extraneous thoughts
Theories for WM correlations

- What is the source of individual differences?
  - General processing hypothesis
    - Low WM span: Inefficient processing
    - Trade-off of resources for processing & storage
    - If processing automatic, more resources for storage
  - Task specific hypothesis
    - Specific cognitive process is more efficient/automatic
  - General capacity hypothesis
    - High WM span: more attentional resources
    - WM capacity separate from STM capacity
Conway & Engle (1996)

Methods

- **Session 1**
  - **Original Ospan**
    - y/n math; say word out-loud; recall (write) words at end
    - Series varies from 2-6 words to remember (x3)
    - Randomized series (max score = 60)
    - Math must be 85% or greater
  - **Backward letter task**
    - Auditory presentation (1/sec); recall reverse order

- **Session 2**
  - **Mathematical operations**
    - 15 types: e.g. (a+b) vs (a*b)-c
    - Operation type for: 92% acc, 80-88% acc, 68-76% acc

- **Session 3**: 3 Ospan tasks (w/ math difficulty equated)
  - Also recorded “viewing time”
Predictions by each theory

- General processing hypothesis
  - No correlation between VSAT and Ospan when processing demand equated

- Task specific hypothesis
  - No correlation between VSAT and Ospan

- General capacity hypothesis
  - Correlation between VSAT and Ospan even when processing demand equated
  - “regardless of the demand of the processing component of the task, individual diffs in span remain”
Conway & Engle (1996)

# words recalled on O-span

<table>
<thead>
<tr>
<th></th>
<th>Original</th>
<th>Easy</th>
<th>Moderate</th>
<th>Difficult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Words</td>
<td>15</td>
<td>20</td>
<td>21</td>
<td>22</td>
</tr>
</tbody>
</table>

Viewing time of math problems

<table>
<thead>
<tr>
<th></th>
<th>Easy</th>
<th>Moderate</th>
<th>Difficult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>5000</td>
<td>6000</td>
<td>7000</td>
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</table>
Conway & Engle (1996)

This suggests that individual differences in span are not accounted for by differing ability on the processing component of complex span tasks

<table>
<thead>
<tr>
<th></th>
<th>VSAT</th>
<th>Original</th>
<th>Easy</th>
<th>Moderate</th>
<th>Difficult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>0.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easy</td>
<td>0.62</td>
<td>0.54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>0.49</td>
<td>0.68</td>
<td>0.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficult</td>
<td>0.54</td>
<td>0.68</td>
<td>0.72</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>Backward Letter</td>
<td>0.44</td>
<td>0.41</td>
<td>0.33</td>
<td>0.43</td>
<td>0.37</td>
</tr>
</tbody>
</table>

All $p<.01$
Table 5: correlations w/ and w/o viewing time partialled out - unchanged
Conway & Engle (1996)

- Equate processing (math) demands on O-span
  - Easy, Med, Hard
- Correlate VSAT performance
- Results: $r = 0.49$ to $0.62$
  - Unchanged compared to original ($r = .59$)
- Conclusions:
  - Individual differences due to “general controlled effortful attentional resources”
  - Individual diff’s only when engage in effortful processing
- But, what IS “attentional capacity”?
  - Individual diff’s in ... Resist inhib? Shifting? Controlled att?
Conway & Engle (1996)

- Support for general capacity hypothesis
  - # of words recalled does not vary with math difficulty
  - All span tasks (original and modified) correlate with VSAT
  - Easy O-span accounted for majority of variance in VSAT

- Why?
  - O-span requires attention switching
  - Existence of processing component beyond storage capacity measures WM – and predicts individual diff’s!

- Conclusions:
  - Differences in attention capacity is reason for individual differences in WM capacity
  - WM capacity changes performance on many tasks
WM span and...

- Attention
  - Dichotic listening
  - Stroop

- Inhibition
  - Posner’s cueing task
  - Eye movements
  - Intrusive thoughts questionnaire

- Memory (STM and LTM)
  - Verbal fluency
  - Brown-Peterson
  - Memory search
WM and dichotic listening

- Conway, Cowan, and Bunting (2001)
- Operation span
  - Low and High WM span groups
- Selective listening procedure
  - Male versus female voice reciting words
  - Shadow right ear
  - After shadowing asked about irrelevant message
- Results
  - Low WM span: detected name 65%
  - Hi WM span: detected name 20%
WM span and Stroop

Percentage of errors

Percentage of congruent trials

- High span
- Low span

- 0% cond
- 50% cond
- 75% cond
WM and inhibition

- **Kane, Bleckley, Conway, & Engle (2001)**
  - WM span and spatial cueing
    - Valid and invalid cueing (Posner task)
    - Hi span Ss better performance than low span Ss on invalid trials

- **Roberts, Hager, & Heron (1994)**
  - Antisaccade task (invalid cue to move eyes) with dual-task
  - Hi span better performance
  - Hi span allocate attention to whole display; Low span focused attentional spotlight
WM and LTM

- Rosen & Engle (1997)
  - WM span and verbal fluency
    - Generate as many words as possible that start with “F”
  - High span better than Low span
  - Add dual-task (monitor digits for 3 odd #s in row)
    - Result: Hi span perform like low span (w/o dual-task)

- Kane & Engle (2000)
  - WM span and Brown-Peterson task
  - Low span greater proactive interference

- Conclusions?
WM and intelligence

- WM Span and VSAT
  - $r = 0.6$

- Carpenter, Just, & Shell (1990)
  - Raven’s progressive matrices
  - O-span

- WM overall measures of intelligence
  - $r = 0.3$ to $0.5$
WM model: Engle (2001)
Other theories and questions...

- **Time-based forgetting theory**
  - More time processing → more decay/interference
  - “Speed of processing” theory

- **Strategy theory of individual differences**
  - Train storage strategy (e.g. rehearsal)

- **Can we change overall capacity of WM?**
  - Verhaeghen, Cerella, & Basak (2004)
  - Training on WM task for 10 hours!
  - Increase “Focus of Attention” from 1 to 4 items
Jaeggi et al. (2008)


Examine “transfer effects” to fluid intelligence (Raven’s progressive matrices)