Consolidating working memory: Enhancing cognitive performance through effective encoding

Donna Bayliss
Neurocognitive Development Unit
School of Psychology
University of Western Australia
Consolidation of LTM

- Wixted (2004; 2005)
  - memory traces become more durable and less vulnerable to interference over time
  - process of consolidation
  - new memories interfere with previously established memory traces that have not had a chance to consolidate
Consolidation of LTM
Consolidation of STM

- Jolicoeur and Dell’Acqua (1998)
  - sensory encoding
    - massively parallel, transmission of information about different attributes of stimuli, sensory persistence
  - perceptual encoding
    - pattern recognition, letter identification, representations remain active while sensory input is available, otherwise, subject to rapid decay
Consolidation of STM

- Jolicoeur and Dell’Acqua (1998)
  - short-term consolidation
    - the process of encoding information into a more durable form of memory, which allows for further processing and delayed report
  - time consuming, requires central mechanisms
Consolidation of STM

- Jolicoeur and Dell’Acqua (1998)

SOA
350, 500, 650, 800, 1200, & 1600 ms

Fixation
250 ms
Memory Array

HKM

$O$

100 ms
Mask Array

Auditory
Tone

RECALL
Consolidation of STM

- Jolicoeur and Dell’Acqua (1998)
Consolidation of STM

- Woodman & Vogel (2005)
Consolidation of STM

- Woodman & Vogel (2005)
Development of consolidation

- Is the process of memory consolidation evident in children?
- Is memory consolidation important for working memory performance?
- Is memory consolidation important for educational achievement?
Development of Consolidation

Visual Change-Detection Task

Delay Interval
50, 150, 350, 750, 1550 ms

3550 ms

1000 ms Fixation
200 ms Memory Array
100 ms Auditory CRT
200 ms Mask Array
Test Array
Development of Consolidation

Verbal Change-Detection Task

Delay Interval
50, 150, 350, 750, 1550 ms

3550 ms

1000 ms Fixation
400 ms Memory Item
100 ms Visual CRT
200 ms Mask Array
Test Array

12
Development of Consolidation

- Visual (N=39)
Development of Consolidation

- Verbal ($N=48$)
### Development of Consolidation

<table>
<thead>
<tr>
<th></th>
<th>Verbal 50ms</th>
<th>Verbal 150ms</th>
<th>Verbal 350ms</th>
<th>Verbal 750ms</th>
<th>Verbal 1550ms</th>
<th>Visual 50ms</th>
<th>Visual 150ms</th>
<th>Visual 350ms</th>
<th>Visual 750ms</th>
<th>Visual 1550ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal 50ms</td>
<td>1</td>
<td>.717**</td>
<td>.667**</td>
<td>.731**</td>
<td>.588**</td>
<td>-.052</td>
<td>-.013</td>
<td>-.113</td>
<td>-.162</td>
<td>-.200</td>
</tr>
<tr>
<td>Verbal 150ms</td>
<td>1</td>
<td>.758**</td>
<td>.768**</td>
<td>.716**</td>
<td></td>
<td>.049</td>
<td>-.017</td>
<td>.074</td>
<td>-.127</td>
<td>.071</td>
</tr>
<tr>
<td>Verbal 350ms</td>
<td>1</td>
<td>.758**</td>
<td>.728**</td>
<td></td>
<td></td>
<td>.145</td>
<td>.155</td>
<td>.100</td>
<td>.011</td>
<td>.087</td>
</tr>
<tr>
<td>Verbal 750ms</td>
<td>1</td>
<td>.748**</td>
<td></td>
<td></td>
<td></td>
<td>-.025</td>
<td>-.009</td>
<td>-.159</td>
<td>-.235</td>
<td>-.197</td>
</tr>
<tr>
<td>Verbal 1550ms</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.223</td>
<td>-.129</td>
<td>-.131</td>
<td>-.267</td>
<td>.016</td>
</tr>
<tr>
<td>Visual 50ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>.481**</td>
<td>.511**</td>
<td>.588**</td>
<td>.441**</td>
</tr>
<tr>
<td>Visual 150ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>.474**</td>
<td>.354*</td>
<td>.201</td>
<td></td>
</tr>
<tr>
<td>Visual 350ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>.643**</td>
<td>.550**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual 750ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>.619**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual 1550ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Development of Consolidation

- RT data consistent with a consolidation process in children
- similar RT functions evident for both verbal and visual information, albeit weaker for verbal
- partial support for a central attentional account
  - memory item and choice-RT task are from different modalities
  - but, no correlations across verbal and visual tasks
Consolidation and Working Memory

- Is the process of memory consolidation evident in children?
- Is memory consolidation important for working memory performance?
- Is memory consolidation important for educational achievement?
Consolidation and Working Memory

- Working memory often assessed using working memory span tasks that involve rapid switching between storage and processing.
- Consolidation is slowed in individuals with schizophrenia.
- Experiments showing an effect of processing pace on working memory performance have often confounded fast pace with less opportunity for consolidation.
Consolidation and Working Memory

Random Delayed

Canonical Immediate

+ N

+ L

T

C

?
Consolidation and Working Memory

Total Trials Correct

Trials Correct

Immediate

0

5

10

15

Canonical

Random

Delay

Immediate

Delay

0

5

10

15
Consolidation and Working Memory

Processing Accuracy

Proportion Correct

Immediate

Delayed

Canonical

Random
Consolidation and Working Memory

Response Time on the Processing Task

Processing Time

Immediate

Delayed

0

1000

1500

2000

2500

3000

3500

Canonical

Random

0

1000

1500

2000

2500

3000

3500

Immediate

Delayed

Delay
Consolidation and Working Memory

- providing an opportunity for consolidation does improve working memory performance, especially for difficult tasks
- processing of information presented immediately after a to-be-remembered stimulus is likely to be impaired
- processing of information presented immediately after a to-be-remembered stimulus is likely to be slowed
Consolidation and Educational Achievement

- Is the process of memory consolidation evident in children?
- Is memory consolidation important for working memory performance?
- Is memory consolidation important for educational achievement?
Consolidation and Educational Achievement

- working memory is predictive of educational achievement

- variation in working memory that remains once variation in processing and storage is removed is predictive of reading and mathematics (Bayliss et al., 2003; Jarrold & Bayliss, 2007)
Consolidation and Educational Achievement

- inserting pauses at syntactic boundaries improves older adults’ memory for stories (Holland & Fletcher, 2000)

  75 wpm
  Susan was excited. The present had arrived, at last!

  115 wpm
  Susan was excited. The present had arrived, at last!

  175 wpm
  Susan was excited. The present had arrived, at last!
Consolidation and Educational Achievement

- inserting pauses at syntactic boundaries improves older adults’ memory for stories

<table>
<thead>
<tr>
<th>Task</th>
<th>Speech Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75 wpm</td>
</tr>
<tr>
<td>Recall</td>
<td>50.6</td>
</tr>
<tr>
<td>Recognition</td>
<td>72.7</td>
</tr>
</tbody>
</table>

Consolidation and Educational Achievement

Visual Change-Detection Task

Delay Interval
100, 200, 400, 800 ms

1000 ms Fixation
200 ms Memory Array
100 ms Auditory CRT
200 ms Mask Array
Test Array

3300 ms
Consolidation and Educational Achievement
Consolidation and Educational Achievement

- Visual Change-Detection Task

![Graph showing the relationship between delay (ms) and mean RT (ms) for Encode and Ignore conditions.](image-url)
# Consolidation and Educational Achievement

<table>
<thead>
<tr>
<th></th>
<th>Reading Comp</th>
<th>Maths</th>
<th>Spatial STM</th>
<th>Spatial WM</th>
<th>Visual 100ms</th>
<th>Visual 200ms</th>
<th>Visual 400ms</th>
<th>Visual 800ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading Comp</td>
<td>1</td>
<td>.595**</td>
<td>.230</td>
<td>.306</td>
<td>.237</td>
<td>.043</td>
<td>.106</td>
<td>.111</td>
</tr>
<tr>
<td>Maths</td>
<td>1</td>
<td>.425**</td>
<td>.490**</td>
<td></td>
<td>-.092</td>
<td>-.162</td>
<td>-.068</td>
<td>.065</td>
</tr>
<tr>
<td>Spatial STM</td>
<td>1</td>
<td>.443**</td>
<td></td>
<td></td>
<td>-.141</td>
<td>-.071</td>
<td>-.250</td>
<td>-.065</td>
</tr>
<tr>
<td>Spatial WM</td>
<td>1</td>
<td></td>
<td>-.339**</td>
<td>-.317</td>
<td>-.289</td>
<td>-.112</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual 100ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>.773**</td>
<td>.757**</td>
<td>.625**</td>
</tr>
<tr>
<td>Visual 200ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>.704**</td>
<td>.640**</td>
</tr>
<tr>
<td>Visual 400ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>.660**</td>
</tr>
<tr>
<td>Visual 800ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

N = 37

*Note: ** denotes statistically significant correlations.*
Consolidation and Educational Achievement

- Working memory is associated with individual differences in reading and maths performance.
- Individual differences in short-term memory consolidation are associated with working memory performance in children.
- Individual differences in short-term memory consolidation do not appear to be associated with reading and maths performance.
Practical Implications

- consolidation of information into working memory is a time-consuming, attentionally demanding process

- this may impact on a child’s working memory performance and educational achievement

- learning situations that provide the opportunity for consolidation of information are likely to maximise the retention of that information
Practical Implications

- present information in small manageable chunks, in simple language or form
- provide pauses at natural boundaries to allow meaningful chunks of information to be consolidated
- teach children to control their own encoding strategies
Thanks to..

Collaborators

Chris Jarrold
Jade Bogdanovs

Funding

Australian Government
Australian Research Council
Experiment 2 - Method

- 51 children (mean age: 9 years, 0 months)
  - 36 met 70% accuracy criteria on CRT
- two visual change-detection tasks
  - encode and ignore conditions
  - 5 delay intervals (50, 150, 350, 750, 1550 ms)
  - visual memory stimuli (colours or symbols)
  - auditory choice-RT task
  - articulatory suppression throughout presentation
Experiment 2

Visual Change-Detection Task (colours)

Delay Interval
50, 150, 350, 750, 1550 ms

1000 ms Fixation
200 ms Memory Array
100 ms Auditory CRT
200 ms Mask Array
Test Array
Experiment 2

Visual Change-Detection Task (symbols)

Delay Interval
50, 150, 350, 750, 1550 ms

1000 ms
Fixation

200 ms
Memory Item

100 ms
Auditory CRT

200 ms
Mask Array

Test
Array
Experiment 1

- Visual Colours \((N=36)\)

![Graph showing response time against delay for Visual Encode and Visual Ignore conditions. The graph indicates a decreasing trend in response time as delay increases for both conditions.](image-url)
Experiment 1

- Visual Symbols ($N=36$)
# Experiment 2 (N=22)

<table>
<thead>
<tr>
<th></th>
<th>Symbol 50ms</th>
<th>Symbol 150ms</th>
<th>Symbol 350ms</th>
<th>Symbol 750ms</th>
<th>Symbol 1550ms</th>
<th>Visual 50ms</th>
<th>Visual 150ms</th>
<th>Visual 350ms</th>
<th>Visual 750ms</th>
<th>Visual 1550ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol 50ms</td>
<td>1</td>
<td>.816**</td>
<td>.726**</td>
<td>.304</td>
<td>.260</td>
<td>.530**</td>
<td>.210</td>
<td>.214</td>
<td>.404</td>
<td>.010</td>
</tr>
<tr>
<td>Symbol 150ms</td>
<td>1</td>
<td>.725**</td>
<td>.542**</td>
<td>.415</td>
<td>.380</td>
<td>.089</td>
<td>.138</td>
<td>.326</td>
<td>.061</td>
<td></td>
</tr>
<tr>
<td>Symbol 350ms</td>
<td>1</td>
<td>.522*</td>
<td>.301</td>
<td>.347</td>
<td>.183</td>
<td>-.018</td>
<td>.348</td>
<td>.290</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symbol 750ms</td>
<td>1</td>
<td>.535*</td>
<td>-.108</td>
<td>-.292</td>
<td>-.076</td>
<td>.144</td>
<td>.166</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symbol 1550ms</td>
<td>1</td>
<td>-.043</td>
<td>-.431*</td>
<td>-.435*</td>
<td>-.261</td>
<td>.303</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual 50ms</td>
<td>1</td>
<td>.652**</td>
<td>.589**</td>
<td>.586**</td>
<td>.345</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual 150ms</td>
<td>1</td>
<td>.588**</td>
<td>.778**</td>
<td>.211</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual 350ms</td>
<td>1</td>
<td>.690**</td>
<td>.076</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual 750ms</td>
<td>1</td>
<td>.380</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual 1550ms</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Consolidation of STM

- Woodman & Vogel (2005)