Individual Differences in Working Memory and Mathematical Ability in Primary School Children

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Why is Maths Important?

“According to the most recent Skills for Life survey, almost 17 million people in the UK have numeracy skills below those needed for the lowest grade at GCSE.”

(National Numeracy, 2012)
Why is Maths Important?

• “Adults who struggle with numeracy are twice as likely to be unemployed as those who are competent.”
• “Recent studies have shown that numeracy is a bigger indicator of disadvantage than literacy.”

(National Numeracy, 2012)
Mathematical Cognition

The underlying skills relating to mathematical performance are diverse.
Drivers of Mathematical Ability

• Language
  (Cowan, Donlan, Newton & Lloyd, 2005; Donlan, Cowan, Newton & Lloyd, 2007; Henry & MacLean, 2003; Purpura & Ganley, 2014)

• Comorbidity with reading difficulties
  (Fuchs & Fuchs, 2002; Koponen, Aunola, Ahonen & Nurmi, 2007; but see Bull & Johnston, 1997)

• Maths anxiety
  (Passolunghi, 2011)
Underlying Drivers of Mathematical Ability

Considering these findings, the field of working memory (WM; Baddeley & Hitch, 1974) demonstrates its own immense relevance.
Working Memory and General Ability

WM has been linked to:

• Development of language
  (Alloway & Archibald, 2008; Newton, Roberts & Donlan, 2010)

• Reading ability
  (Gathercole, Alloway, Willis, & Adams, 2006)

• Maths Anxiety
  (Ashcraft & Moore, 2009 – a review)
Working Memory and General Ability

WM has been linked to:

• Learning difficulties
  (Gathercole & Pickering, 2000, Henry & MacLean, 2002; Henry & MacLean, 2003)

• Academic success
  (Alloway & Alloway, 2010)
Working Memory and Mathematical Ability

And, unsurprisingly, WM has been linked to mathematical ability.

Working Memory and Mathematical Ability

More specifically:

- WM’s potentially predictive nature
  (Bull, Espy & Wiebe, 2008; Krajewski & Schneider, 2009; Lee, Ng, Bull, Pe & Ho, 2011; Passolunghi & Lanfranchi, 2012)

- The impact of deficits in WM
Working Memory and Maths

Many studies have noted the importance of WM in maths learning. Notably, Swanson and Beebe-Frankenberger (2004):

• Assessed primary school children at-risk or not at risk for serious math difficulties.

• Working Memory found to be a unique predictor above IQ, general maths skills, algorithm knowledge, processing speed, short-term memory and inhibition.
Working Memory Capacity

WM capacity increases from infancy to adolescence. Why?:

• Faster processing speed results in more storage space. (Case, Kurland & Goldberg, 1982)

• Faster processing speed results in less memory decay. (Towse & Hitch, 1995; Towse, Hutton & Hitch, 1998)

• Developmentally acquired rapid micro-switching ability between processing and maintenance. (Camos & Barrouillet, 2007)
WM Capacity
A Time-Based Resource-Sharing Model

- Time-Based Resource-Sharing (TBRS) argues that both resource sharing and memory decay are at play in WM capacity. (Barouillet, Bernadin & Camos, 2004)

- They conducted a study in adults which manipulated both cognitive load of a task and the processing time available.
WM Capacity
A Time-Based Resource-Sharing Model

• They demonstrated that WM spans vary as a function of cognitive load (within a constant time period).

• This is due to a micro-switching between processing and maintenance during processing.

• A developmental study found the micro-switching ability to be efficient from 7 yrs. of age. (Barrouillet, Gavens, Vergauwe, Gaillard & Camos, 2009)
WM Capacity
A Time-Based Resource-Sharing Model

Camos & Barrouillet (2011) decided to test this developmental shift in maintenance strategy.

Using the same methodology as for their earlier TBRS research, they manipulated cognitive load and task duration.
They found:

• The recall of 6 yr. olds depended only on processing task duration.
• That is, the longer the delay between processing and recall, the lower their span.
• Indicates decay.
Camos & Barrouillet, 2011

• For 7 yr. olds the cognitive load of the processing task determined recall performance.
• They argue the cognitive load reduces the time available for refreshing.
• This differentiates passive maintenance from active refreshing.
Summary

• WM is important with regard to mathematical ability.
• There is indication of developmental changes of WM and how they may contribute to maths ability.
The Current Study

The purpose of the current study was to further investigate the TBRS model from a developmental perspective.

• Improve on methodology in Barrouillet et al., (2009)

• Identify to what extent maintenance strategy contributes to maths performance
The Current Study

Experiment One:

- 92 primary school children in Year 3 (7 – 8 yr. old)
- 3 x WM CSTs (two conditions)
- 3 x Switching (TEA-Ch, DCCS, CNS)
- 3 x Inhibition (TEA-Ch, VIMI)
- IQ
- BAS III Reading measure
- SAT Maths (year 3)
The Current Study

Experiment Two:

• Subset of 52 children in Year 5 (9-10 yr. old)
• Standardised curriculum-based maths measure (Access)
Measuring Working Memory

Year 3: Three complex span tasks (CSTs):

• Listening span (LS)
• Odd One Out span (OOO)
• Counting span (CS)
Measuring Working Memory

Counting Span
Recall: number of dots per trial

Listening Span
Recall: Last word of sentence per trial

Odd One Out Span
Recall: OOO location per trial

Counting Span
Recall: number of dots per trial

Listening Span
Recall: Last word of sentence per trial

Odd One Out Span
Recall: OOO location per trial
Measuring Working Memory

3 x CSTs

Participant led processing

Display until participant response given

Maths Ability

Titrated processing

Display based on individual processing speed
Titrated Working Memory Measure

20 Non-memory trials

Counting Span
Listening Span
Odd One Out
Titrated Working Memory Measure

- Calculated individual mean response time (RT) across 20 trials
- Processing stimuli presented for duration of individual mean RT (+ 2.5 SD)
- Therefore time/cognitive load based on individual ability (not group)
Measuring Mathematical Ability

Year 5: Standardised maths test:

• Using & applying mathematics (e.g. money)
• Counting & understanding number (e.g. number line)
• Knowing & using number facts (e.g. times table)
• Calculating (arithmetic)
• Understanding shape (e.g. mental rotation)
• Measuring (e.g. time, distance, size)
• Handling data (e.g. charts, probability)
Comparing Tasks

Comparison of mean total trials correct for each span task in each condition:
Processing Speed

Response time for the processing component of the CST:

NB: Processing speed for CS. However, LS and OOO have show similar results.
Counting Span

Correlations between span score and standardised maths score.
Listening Span

Correlations between span score and standardised maths score.

[Graphs showing correlations between span score and standardised maths score.]
Odd One Out Span

Correlations between span score and standardised maths score.

![Graph 1: Total trials Correct Standard vs Maths Score](#)

![Graph 2: Total trials Correct Titrated vs Maths Score](#)
# Maths and CSTs

Correlations between standardised maths and complex span task scores

<table>
<thead>
<tr>
<th>Maths</th>
<th>Counting</th>
<th>Listening</th>
<th>Odd One Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Participant Led</td>
<td>Titrated</td>
<td>Participant Led</td>
</tr>
<tr>
<td>Maths</td>
<td>.492**</td>
<td>.387**</td>
<td>0.27</td>
</tr>
</tbody>
</table>

*<.05, **<.001 (2-tailed)
## Counting Span

Correlations between standardised maths components and complex span task scores

<table>
<thead>
<tr>
<th></th>
<th>Participant Led</th>
<th>Titrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using &amp; Applying Mathematics</td>
<td>0.572**</td>
<td>0.417**</td>
</tr>
<tr>
<td>Counting &amp; Understanding Number</td>
<td>0.530**</td>
<td>0.418**</td>
</tr>
<tr>
<td>Knowing &amp; Using Number Facts</td>
<td>0.444**</td>
<td>0.326*</td>
</tr>
<tr>
<td>Calculating</td>
<td>0.524**</td>
<td>0.364**</td>
</tr>
<tr>
<td>Understanding Shape</td>
<td>0.324*</td>
<td>0.270</td>
</tr>
<tr>
<td>Measuring</td>
<td>0.363**</td>
<td>0.437**</td>
</tr>
<tr>
<td>Handling Data</td>
<td>0.361**</td>
<td>0.226</td>
</tr>
</tbody>
</table>

*<.05, **<.001 (2-tailed)
## Listening Span

Correlations between standardised maths components and complex span task scores

<table>
<thead>
<tr>
<th></th>
<th>Listening</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Participant Led</td>
<td>Titrated</td>
<td></td>
</tr>
<tr>
<td>Using &amp; Applying Mathematics</td>
<td>.252</td>
<td>.397**</td>
<td></td>
</tr>
<tr>
<td>Counting &amp; Understanding Number</td>
<td>.337*</td>
<td>.445**</td>
<td></td>
</tr>
<tr>
<td>Knowing &amp; Using Number Facts</td>
<td>.242</td>
<td>.409**</td>
<td></td>
</tr>
<tr>
<td>Calculating</td>
<td>.306*</td>
<td>.557**</td>
<td></td>
</tr>
<tr>
<td>Understanding Shape</td>
<td>.108</td>
<td>.429**</td>
<td></td>
</tr>
<tr>
<td>Measuring</td>
<td>.275</td>
<td>.446**</td>
<td></td>
</tr>
<tr>
<td>Handling Data</td>
<td>.213</td>
<td>.405**</td>
<td></td>
</tr>
</tbody>
</table>

*<.05, **<.001 (2-tailed)
Odd One Out Span

Correlations between standardised maths components and complex span task scores

<table>
<thead>
<tr>
<th>Math Component</th>
<th>Participant Led</th>
<th>Titrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using &amp; Applying Mathematics</td>
<td>.254</td>
<td>.379*</td>
</tr>
<tr>
<td>Counting &amp; Understanding Number</td>
<td>.120</td>
<td>.355*</td>
</tr>
<tr>
<td>Knowing &amp; Using Number Facts</td>
<td>.182</td>
<td>.239</td>
</tr>
<tr>
<td>Calculating</td>
<td>.151</td>
<td>.325*</td>
</tr>
<tr>
<td>Understanding Shape</td>
<td>.194</td>
<td>.278</td>
</tr>
<tr>
<td>Measuring</td>
<td>.256</td>
<td>.435**</td>
</tr>
<tr>
<td>Handling Data</td>
<td>.205</td>
<td>.276</td>
</tr>
</tbody>
</table>

*<.05, **<.001 (2-tailed)
Why are computer-paced span tasks so predictive of high-level cognition?

Interestingly this ties in with the work of Barrouillet and colleagues with 11 year olds, despite the fact that we did not find a drop in span performance when limiting maintenance opportunities (Lepine et al, 2005)
Why are computer-paced span tasks so predictive of high-level cognition?

Time spent on processing components of self-paced tasks can reduce correlation between span and general cognitive ability (Engle et al, 1992; Turley-Ames & Whitfield, 2003).
Why are computer-paced span tasks so predictive of high-level cognition?

This is consistent with other findings that show unlimited processing times do not predict higher-order cognition compared to constrained CSTs (Friedman & Miyake, 2004)
Why are computer-paced span tasks so predictive of high-level cognition?

Similarly, St Clair-Thompson (2007) found that the time taken to implement strategies reduced the correlation between WM and reading and arithmetic measures.
Inhibition and Switching

As we saw, the titrated tasks held a much stronger correlation with Maths than the participant-paced tasks.

Now lets look at the other measures
# Maths, Switching and Inhibition

Correlations between school maths grade, switching and inhibition

<table>
<thead>
<tr>
<th></th>
<th>Switching 1</th>
<th>Switching 2</th>
<th>Inhibition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maths</td>
<td>0.41*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading</td>
<td>0.32*</td>
<td>0.25**</td>
<td></td>
</tr>
</tbody>
</table>

* p < .05  ** p < 0.01
Maths Regression Analysis

Measures of IQ, Counting and listening span were significantly predictive of maths ability

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.8</td>
<td>22.82</td>
<td></td>
</tr>
<tr>
<td>IQ</td>
<td>0.03</td>
<td>.29</td>
<td>.34*</td>
</tr>
<tr>
<td>Counting span</td>
<td>.08</td>
<td>.28</td>
<td>.28**</td>
</tr>
<tr>
<td>Listening span</td>
<td>.08</td>
<td></td>
<td>.18***</td>
</tr>
</tbody>
</table>

Note: $R^2 = .51 \ (p < .001) \ * \ p < .001 \ ** \ p < .005 \ *** \ p < .05$
Reading Regression Analysis

Measures of switching and listening span were significantly predictive of reading ability.

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.58</td>
<td>22.82</td>
<td></td>
</tr>
<tr>
<td>Listening span</td>
<td>0.7</td>
<td>.29</td>
<td>.19*</td>
</tr>
<tr>
<td>Task Switching</td>
<td>.67</td>
<td>.28</td>
<td>.25**</td>
</tr>
</tbody>
</table>

Note: $R^2 = .29$ (* $p < .001$) ** $p < .05$
Summary

• Restricting processing time (and possibly rehearsal) does not lead to a drop in recall

• Children with higher spans will increase processing speed if required (high WM span as a mediator for anxiety)
Summary

• Not all span tasks are the same (odd one out and listening versus counting)

• Titrated tasks correlate better with academic performance

• Visual and phonological CSTs correlate with maths components
Summary

• Specifically, IQ, counting and listening span predict maths ability (different for reading)

• 50% variance explained. Will analysis of individual processing time, processing accuracy and recall time offer more?
The complexities of working memory span measurement


• Individual differences children and adults:
• CST performance dependent on domain-general processing efficiency
• But domain specific storage capacity
• Separate resource pools support processing and storage functions
• Not a shared resource pool
The complexities of working memory span measurement


• Residual task performance (coordination?) contributes to maths and reading independent from processing and storage abilities alone.

• Domain specific storage and domain general processing (multi-component model)
The complexities of working memory span measurement


- There is a need to consider processing and storage when considering how/why working memory capacity predicts high-level cognition.
The complexities of working memory span measurement


• Showed a complex pattern of shared and unique variance among processing speed, processing accuracy, storage and higher-order cognition

• Across domains
The complexities of working memory span measurement


• Relationship between span scores and gF not mediated by P.speed or P.accuracy.
• But processing plays a role as it strengthens the predictive power of span task to gF
• Something else is at play.
Next step

• Analyse P.speed, P.accuracy
• Incorporate recall timing as well as accuracy
• Understand individual differences at a fine-grained level
• How to they contribute to maths and reading ability.
Any questions?