What is Working Memory?

Written in March 2015 by Debbora Hall and Chris Jarrold

Theoretical background

Working memory is the ability to keep information in mind in the face of distraction. Many people are familiar with Baddeley's (1986) model of working memory, which states that there are separate storage systems for verbal and visuo-spatial material, which are controlled by a domain general 'central executive system' (Figure 1).

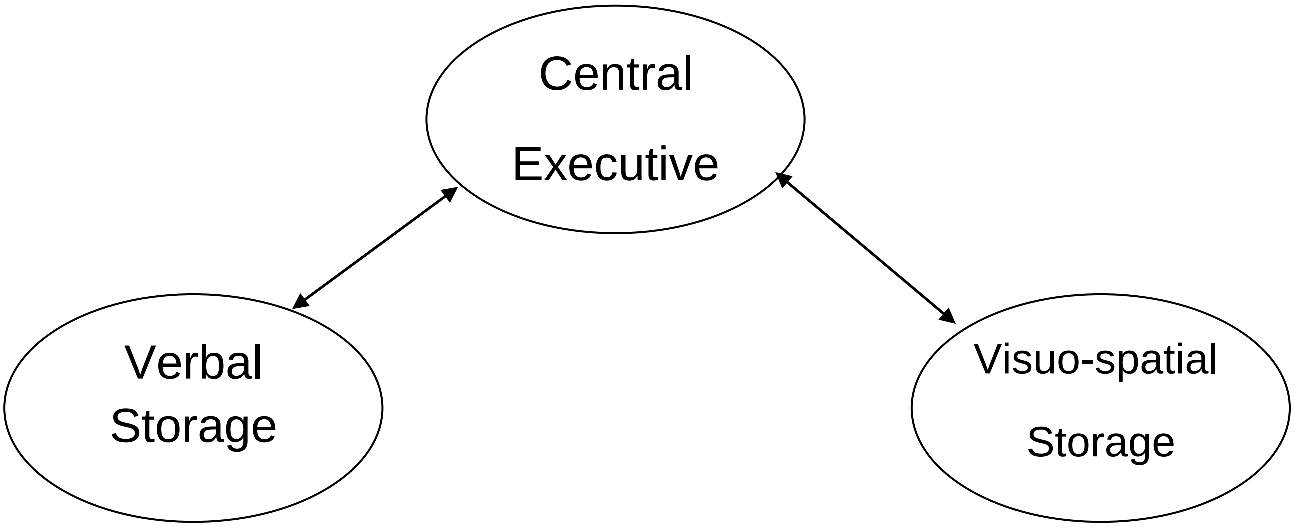

Figure 1: Baddeley's (1986) model of working memory

Baddeley's model (1986) has provided a useful framework for understanding working memory in both children and adults. Pickering and Gathercole (2001) developed the Working Memory Test Battery for Children, which includes tasks based on Baddeley's model, testing verbal short-term memory, visuo-spatial short-term memory, and central executive capacity. This set of tasks was computerised by Alloway et al. (2008) as the Automated Working Memory Test Battery (AWMA), and was comprehensively tested in over 700 children aged between 4 and 15 years old (Alloway et al., 2004). They found that Baddeley's structural approach to working memory could be upheld in all age groups, suggesting that it is correct to think of working memory as composed of different factors, in all age groups.

However, Baddeley's central executive, and tasks proposed to tap the central executive, were not well understood (Baddeley, 1996). Tasks tapping 'working memory' and the 'central executive' require that individuals remember memory items in the face of competing distraction. For example, this holds true of one of the earliest known complex span tasks, which is the counting span task. This was developed by Robbie Case and colleagues (Figure 2 and 3), and is demonstrated in Video 1. This task requires memory to be retained in the face of distracting processing activity (counting). The listening span task

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(Daneman & Carpenter, 1980) is another early version of a complex span task, and requires remembering words while completing a sentence comprehension task. Both counting span and listening span are highly correlated with one another (Pickering & Gathercole, 2001). Furthermore, both tasks are predictive of reading and mathematics in children and college age students (e.g., Daneman & Carpenter, 1980; Hutton & Towse, 2001; Kyllonen & Christal, 1990).

Figure 2: Robbie Case (image courtesy of Nancy Link).

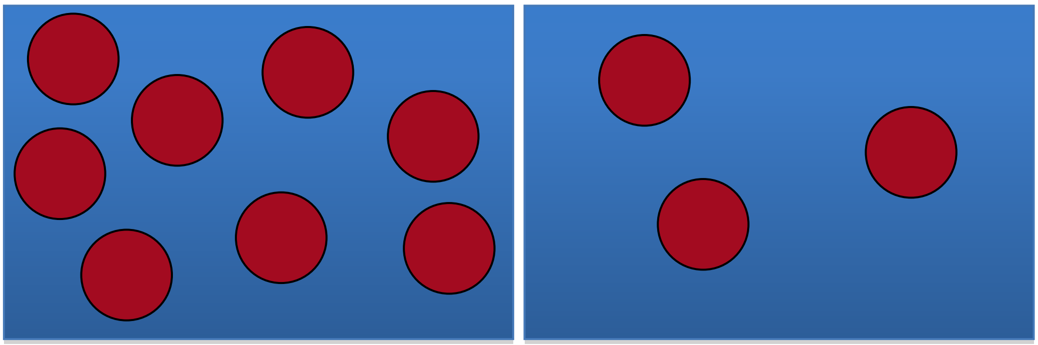

Figure 3: Count the dots on each screen and remember the totals (8, 3). This is the Counting Span Task.

So what makes complex span tasks, or measures of working memory, predictive of academic achievement (even more so than intelligence tests, Alloway & Alloway, 2010), when complex span tasks themselves vary? What is the common element in these complex span tasks? Since Case et al.'s (1982) work, a huge amount of research has examined how working memory works, and which processes are most important when understanding the links between working memory and classroom attainment.

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So what is working memory? Deconstructing complex span

We, and others, have worked to understand working memory by attempting to decompose complex span tasks into their components. We then examine how these components relate to one another, and how they independently relate to academic measures.

Bayliss et al. (2003) designed four complex span tasks which could be deconstructed into component parts to gauge verbal short-term memory, visuo-spatial short-term memory, verbal processing, and visual processing (Figure 4).

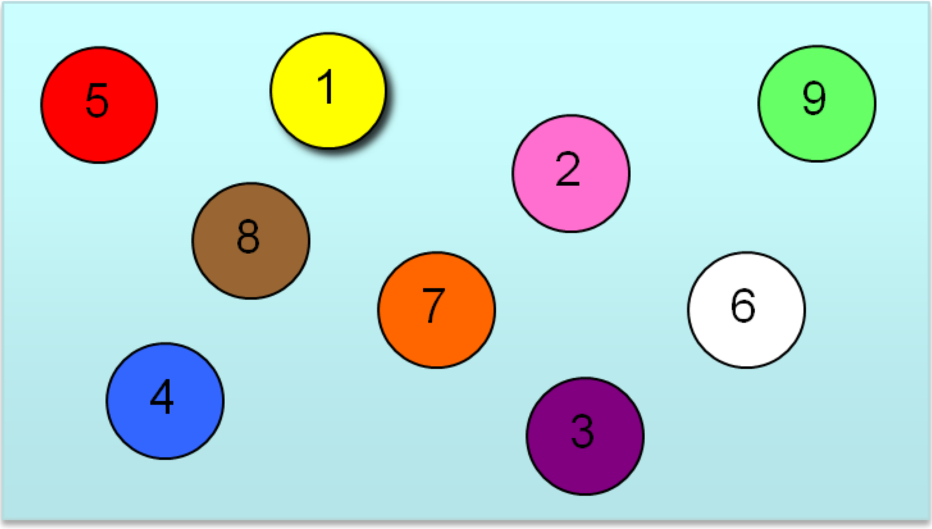

Figure 4: The presentation screen from Bayliss et al., (2003).

The verbal storage-verbal processing complex span task required that children pick a coloured circle corresponding to a verbal name (e.g. 'snow' –verbal processing). A number was inside each circle (6), and they were required to remember the number that was in the circle they picked. After several word choices, they were asked to recall the numbers in the order they saw them (verbal memory). In the visual storage – visual processing complex span task, individuals were asked to point to the circle with the bevelled edge (e.g. the white circle - visual processing) and remember the position of that coloured circle on an array (visual memory). When they were asked to recall, they recalled the positions of the circles in the order they were identified. Verbal storage-visual processing and visual storage-verbal processing versions of these tasks were also created.

In addition, the way these tasks were designed allowed Bayliss et al. to include additional, parallel, tasks to test:

1. Verbal memory separately (ONLY remember numbers in order);

2. Visual memory separately (ONLY remember positions);

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3. Verbal speed of processing separately (ONLY point to the circle corresponding to the colour as quickly as possible);

4. Visual speed of processing separately (ONLY point to the circle with the bevelled edge) and;

5. Combined storage and processing (in the complex span tasks).

Using factor analysis, these various tasks were shown to separate into distinct groupings. There were separate groupings of tasks involving verbal storage, tasks involving visuo-spatial storage, and tasks that had a processing component. Furthermore, using regression analysis, storage and speed of processing tasks were shown to both predict complex span. This means that general speed of processing is a significant component of working memory performance. This has been found by other research groups (Redick et al., 2012; Unsworth et al., 2009) and has since been replicated in our own more recent work.

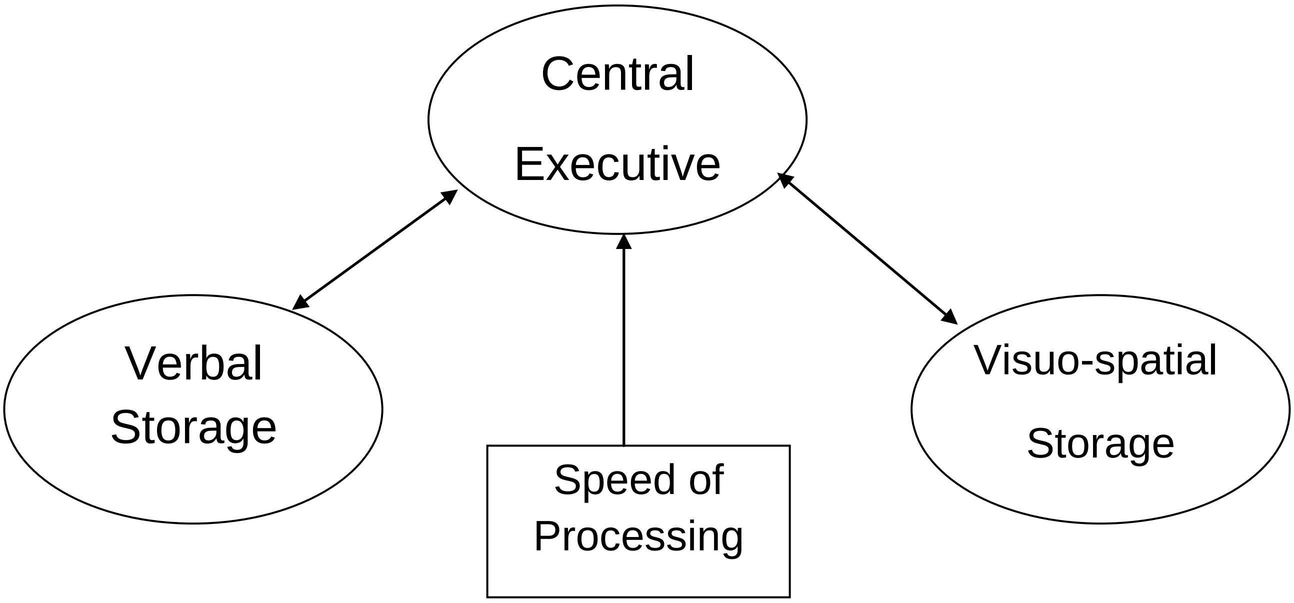

Figure 5: Revised model, based on Bayliss et al. (2003).

However, when storage capacity and processing speed were subtracted from complex span, Bayliss et al. (2003) found that there was more to complex span than simply short-term storage and speed of processing. There was something left over, which is termed ‘residual variance’. This residual variance may be the ability to combine remembering information with resisting distraction from the processing task.

It is known that when you combine storage and processing, storage affects processing speed (more memory load slows processing speed) and processing affects storage (greater processing demands impair memory) (Vergauwe et al., 2014). The effort to

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complete a working memory task may invoke processes such as the ability to resist distraction, which may affect the rate we forget information, maintaining attentional control, use of long term memory, or strategies such as rehearsal (see also Bayliss & Jarrold, 2015; Hall et al., 2014).

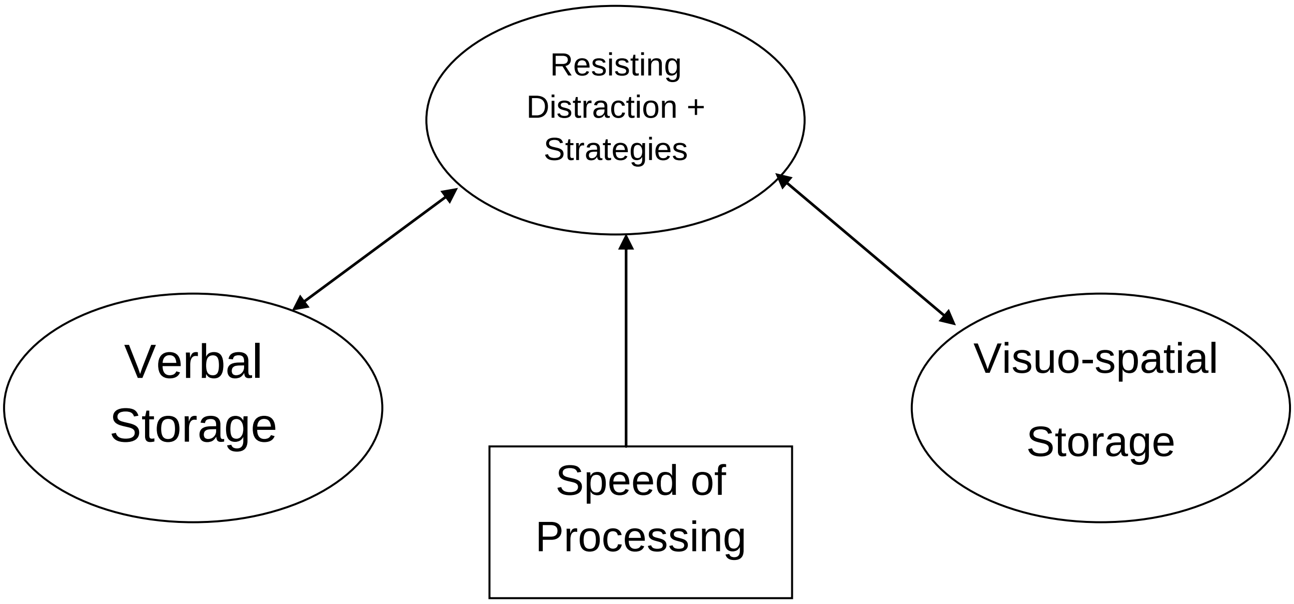

Figure 6: Revised model based on recent work by Bayliss & Jarrold, Hall et al.

In Factsheets 2 and 3 we will explore storage and resistance to distraction in more detail.

What does this mean for our understanding of working memory in the classroom?

Bayliss et al. (2003), Tam et al. (2010), and Hall et al. (2014) all found that complex span tasks were good predictors of reading and mathematics in 6 to 8 year olds.

Further, when they explored storage capacity and processing speed on their own, the storage measures were good predictors of reading and mathematics (see also Bull et al., 2008; Hall et al., 2014), as were the speed of processing measures However, neither were as good as complex span at predicting these academic abilities. This finding has been replicated in other research groups internationally (e.g. Unsworth & Engel, 2007).

If an individual presents with any, or a combination, of the following: low short-term memory span, slow speed of processing, fast rate of forgetting, and / or slow or no use of rehearsal, they may be at risk for classroom difficulties. What is important to note is that

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the different processes are differently related to abilities, and different patterns of strengths and weakness may be observed in each individual.

In summary

- Working memory is not a single process or ability
- We can measure working memory to determine which elements are at typical levels for a given child and which are more or less advanced than would be expected
- This may help us to target interventions and support more effectively

What is the average performance on a working memory task?

As Factsheets 2 and 3 will explore storage and processing in more detail, we will focus here *only* on performance on complex span tasks.

There are developmental improvements in performance on complex span tasks. This may be a result of a number of factors, including increased speed of processing, increased efficiency in using strategies and long term memory support, and basic increases in storage capacity.

On a complex span task such as the one featured in *Game 1 – Working Memory*, with distraction level, and speed, set at the lowest and slowest level, performance could be expected to be similar to that seen in studies discussed above. We have used these as reference points in Table 1 below.

Please note that these tests are not standardised assessments. We are basing our numbers on average performance of between 70 and 100 children tested in average schools around Bristol. For standardised scores on other complex span tasks (such as counting span and reading span) please see Pickering and Gathercole (2001), or Alloway et al. (2008).

Table 1: Mean span on a verbal complex span task from age 6 to 18. Span reflects the longest sequence recalled. Standard deviations give an idea of scores around the mean. 68% of children fall within 1 standard deviation of the mean. Scores above or below this are more unusual. Averages are rounded to the nearest 0.5.

Age band (average age)	Average (mean span)	Spans -1 standard deviation	Spans +1 standard deviation
6 [a]	1.5	1.0	2.0
7 [b]	2.5	1.0	4.0
8 [c]	3.5	2.5	4.5
9 [d]	4.5	3.5	5.0
18 (young adult) [c]	5.0	4.0	6.0

[a] Tam et al., 2010; [b]Jarrold et al., 2014; [c]Bayliss et al., 2003; [d]Bayliss & Jarrold, 2015.

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References

Alloway, T.P. & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. Journal of Experimental Child Psychology, 106, 20-29.

Alloway, T.P., Gathercole, S.E, Kirkwood, H.J., & Elliott, J.E. (2008). Evaluating the validity of the Automated Working Memory Assessment. *Educational Psychology, 7*, 725-734.

Baddeley, A.D. (1986) *Working Memory*. Oxford; Clarendon Press.

Bayliss, D.M. & Jarrold, C. (2015). 'How quickly they forget: The relationship between forgetting and working memory performance'. *Journal of Experimental Psychology: Learning, Memory and Language*, 41,163-177

Bayliss, D. M., Jarrold, C., Gunn, D. M., & Baddeley, A. D. (2003). The complexities of complex span: Explaining individual differences in working memory in children and adults. Journal of Experimental Psychology: General, 132, 71–92.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior. 19, 450-466.

Hall, D., Jarrold, C., Towse, J., Zarandi, A., Mackett, N. (2014). An exploratory approach to understanding working memory and classroom achievement in young children. Poster presented at the International Conference on Working Memory, Cambridge.

Hutton, U. M. Z. & Towse, J. N. (2001). Short-term memory and working memory as indices of children's cognitive skills. Memory, 9, 4-6, 383-394.

Jarrold, C.R., Mackett, N.G. & Hall, D. (2014). 'Individual differences in processing speed mediate a relationship between working memory and children's classroom behaviour'. *Learning and Individual Differences*, 30, 92-97.

Kyllonen, P., & Christal, R. (1990). Reasoning ability is (little more than) working memory capacity?! Intelligence, 14, 389 – 433.

Pickering, S.J. & Gathercole, S.E. (2001). *The Working Memory Test Battery for Children Manual*. London; The Psychological Corporation.

Redick, T.S., Unsworth, N., Kelly, A.J., & Engle, R.W. (2012). Faster, smarter? Working memory capacity and perceptual speed in relation to fluid intelligence. Journal of Cognitive Psychology, 24, 844-854.

Tam, H., Jarrold, C., Baddeley, A. D., & Sabatos-DeVito, M. (2010). The development of memory maintenance: Children's use of phonological rehearsal and attentional refreshment in working memory tasks. Journal of Experimental Child Psychology, 107, 306–324.

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and:

Vergauwe, E., Camos, V., & Barrouillet, P. (2014). The effect of storage on processing: How is information maintained in working memory? Journal of Experimental Psychology: Learning, Memory, and Cognition, 40, 1072-1095.

Unsworth, N., & Engle, R.W. (2007). On the division of short-term and working memory: An examination of simple and complex spans and their relation to higher-order abilities. Psychological Bulletin, 133, 1038-1066.

Unsworth, N., Redick, T.S., Heitz, R.P, Broadway, J.M., Engle, R.W., (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage Memory 17 (6), 635-654.

Further reading:

Gathercole, S. E., & Alloway, T. P. (2007). *Understanding working memory: A classroom guide.* London: Harcourt Assessment.

The CALM clinic is based in Cambridge, UK, and is run by Dr Joni Holmes and Professor Sue Gathercole. They have a set of resources available on the website at:

http://calm.mrc-cbu.cam.ac.uk/

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