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Working memory: Is it the new IQ?

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Working memory, our ability to process and remember information, is linked to a range of cognitive activities from reasoning tasks to verbal comprehension[1]. There is also extensive evidence of the relationship between working memory and learning outcomes[2]. However, some researchers suggest that working memory is simply a proxy for IQ and does not make a unique contribution to learning outcomes[3-4]. Here we show that children's working memory skills at 5 years of age was the best predictor of reading, spelling, and math outcomes six years later. IQ, in contrast, accounted for a smaller portion of unique variance to reading and math skills, and was not a significant predictor of spelling performance. Our results demonstrate that working memory is not a proxy for IQ, but rather represents a dissociable cognitive skill with unique links to learning outcomes. Critically, we find that working memory at the start of formal education is a more powerful predictor of subsequent academic success than IQ. This result has important implications for education, particularly with respect to developing intervention and training. It appears that we should target our efforts in developing working memory skills in order to see gains in learning.

Working memory is comprised of multiple components whose coordinated activity is responsible for the temporary storage and manipulation of information. According to one widely used model, working memory is a domain-general component responsible for the control of attention and processing that is involved in a range of regulatory functions including the retrieval of information from long-term memory[5]. This model also includes two domain-specific stores responsible for the temporary storage of verbal and visuo-spatial information and has been supported in studies of children[6-7], as well as adults[8], and neuroimaging research[9].

While working memory can be tested reliably from as young as four years of age[10], performance on working memory tasks is subject to large degrees of individual variation[11]. This is illustrated in Figure 1, which presents data from a verbal working memory test (listening recall) in 4 to 11 year olds. *Z*-scores were calculated using the trials correct measure of each test from all participating children; a score of 0 represents average performance on that measure across the entire age range. There was a steady developmental improvement in performance between 4 and 11 years. Equally notable is that there is a substantial degree of variability at each age, as reflected in the distance between the 10th and 90th centile bars for each measure. At 7 years, for example, the 10th centile is close to the mean for the 4 year old sample, and the 90th centile approximates to the mean performance level for 10 year old children. Thus within an average class of 30 children, we would expect to see working memory capacity differences corresponding to 6 years of normal development between the three highest and three lowest scoring individuals.

<Figure 1 here>

Individual differences in working memory capacity have important consequences for children's ability to acquire knowledge and new skills. In typically developing children, scores on working memory tasks predict reading achievement independently of measures of phonological skills[12]. Working memory is also linked to math outcomes: low working memory scores are closely related to poor performance on arithmetic word problems[13] and poor computational skills[14-15]. Working memory capacity also has a significant impact on learning, independent of IQ, in various developmental disorders such as reading disabilities[16] and Developmental Coordination Difficulties[17].

Given the strong links between working memory and learning, we addressed whether working memory is simply a proxy for IQ. One view is that working memory shares psychometric properties with IQ, yet is dissociable[18.] An alternate account is that these two constructs are so highly correlated that they could be considered as isomorphic properties[19]. We tested these competing views in a longitudinal study with children. We assessed typically developing children first at 5 years old and then again at 11 years old on standardized measures of working memory, IQ, and learning. We assessed working memory using tasks where the individual is required both to process and store increasing amounts of information. An example of such a task is listening recall, in which the participant hears a sentence, verifies it, and remembers the final word. Tasks of short-term memory, in contrast, place minimal demands on processing and are often described as storage-only tasks. Verbal short-term memory was assessed using tasks that require the participant to recall a sequence of verbal information, such as digit recall and word recall. In order to test the predictive power of IQ in learning, we included measures of fluid intelligence (object assembly and block design) and crystallized intelligence (vocabulary). We measured learning outcomes with standardized measures of reading, spelling, and math (Methods).

Looking first at the relationship between working memory and IQ, we found that fluid intelligence tested at 5 years old was significantly correlated with verbal working memory skills at 5 years ($r = .37$, $p<.001$) and 11 years ($r = .41$, $p<.001$). Crystallized intelligence tested at 11 years old was only significantly linked with verbal working memory skills at 11 years ($r = .38$, $p<.001$). This indicates that while working memory and IQ are moderately associated, there is not substantial overlap between these cognitive constructs. Of additional interest was whether maternal educational level, an index of socio-economic levels, correlated with either working memory or IQ performance. We found that the mother's educational level was significantly related to IQ scores (vocabulary; $r = .28$, $p<.05$); but not working memory, which suggests that working memory performance is not strongly impacted by socio-economic factors.

In order to find the best set of predictor variables (working memory or IQ) in learning outcomes, we conducted a series of stepwise regression analyses. We entered six predictor variables: verbal short-term memory and verbal working memory at 5 years and at 11 years; fluid intelligence at 5 years; and crystallized intelligence at 11 years. Model statistics, as well as standardized beta values and *t*-statistics, are provided in the supplementary information. In each aspect of learning, we found that verbal working memory at 5 years was the best predictor of success. IQ at 5 years was the next best predictor of math outcomes, while IQ at 11 years was linked to reading. We found that verbal short-term memory at 11 years was the next most important predictor of spelling success, which can be explained by the nature of spelling tests. Students are required to dissect the letters and sounds of a word while they keep it active in their mental workshop, which relies on verbal short-term memory. Figure 2 illustrates the amount of unique variance captured by working memory and IQ for each learning outcome (reading, spelling, and math).

<Figure 2 here>

We conclude that working memory represents a dissociable cognitive skill that is more important than IQ in predicting learning outcomes. This finding is important as it addresses concerns that general intelligence, once viewed as a reliable predictor of academic success, is unreliable as an individual can have an average IQ score, yet perform poorly in learning outcomes. We also establish a key difference between working memory and IQ is that the former is relatively impervious to environmental influence such as the quality of social and intellectual stimulation in the home, including financial background[20] and the number of years spent in pre-school education[21].

The finding that working memory, rather than IQ, is the best predictor of learning has valuable implications for education. In the classroom, students frequently have to rely on working memory to perform a range of activities. Poor working memory leads to failures in simple tasks such as remembering classroom instructions to more complex activities involving storage and processing of information and keeping track of progress in difficult tasks[22]. The first crucial step in supporting working memory is proper diagnosis using standardized tests developed for non-specialist assessors such as classroom teachers[23]. Working memory impairments lead to learning deficits, as well as difficulty in performing daily classroom activities. Without early intervention, working memory deficits cannot be made up over time and will continue to compromise a child's likelihood of academic success[24]. Targeted strategies may help[22] and there is now growing evidence that working memory capacity can be increased by intensive training[25]. By supporting working memory in the classroom, we can considerably improve learning outcomes.

Methods

Participants. Children were recruited from a larger study, involving a wide range of cognitive measures[21]. At Time 1 (September, 2001), children were aged 4.3 to 5.7 years and attending kindergarten full-time (*M* = 5 years; *SD* = 2.6 months). Six years later, 98 children from the original cohort were retested on standardized measures of memory, IQ, and learning (Time 2; September, 2007). These children were aged 10 to 11.3 years (*M* = 10.11 years; *SD* = 2.3 months; 51% boys). Schools were selected on the basis of a poverty (income) index used in the UK, eligibility for free school meals, and represented a range of low (7—3%), middle (15—25%), and high (34—45%) indices on the basis of national rates. Parental consent was obtained and children were tested individually in a quiet area of the school on both occasions.

Measures. Verbal short-term memory (digit recall and word recall) and working memory (backward digit recall and listening recall) tests were administered at both Time 1 and 2. Tests were taken from the Automated Working Memory Assessment[23] at Time 2, and the Working Memory Test Battery for Children[26], a paper and pencil analogue of the AWMA, at Time 1. Composite scores were calculated by averaging standard scores of the two measures in each memory component.

IQ tests at Time 1 consisted of block design and object assembly subtests from the Wechsler Preschool and Primary Scale of Intelligence-Revised[27]. At Time 2, the children completed the vocabulary subtest from the Wechsler Intelligence Scale for Children – III[28]. Learning was assessed using reading and spelling tests from the Wechsler Objective Reading Dimensions[29] and numerical operations and mathematical reasoning tests from the Wechsler Objective Numerical Dimensions[30]. Means and standard deviations in all cognitive measures as a function of testing times are provided in the supplementary information.

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Supplementary Information. Means and standard deviations in all cognitive measures as a function of testing times, as well as model statistics for the regression analyses, are provided in the supplementary information.

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Author Information. Reprints and permissions information is available at npg.nature.com/reprintsandpermissions. The authors declare competing financial interests: details accompany the full-text HTML version of the paper at (URL). Correspondence and requests for materials should be addressed to t.p.alloway@durham.ac.uk.

Table 1. Descriptive statistics of standard scores for cognitive measures as a function of testing times (n=98)

	Time 1		Time 2	
Measures	Mean	Std. Deviation	Mean	Std. Deviation
Memory				
Digit Recall	94.71	12.80	98.11	13.05
Word recall	100.19	15.52	102.47	16.33
Verbal short-term memory composite	97.45	12.18	100.29	12.97
Backward digit recall	97.97	15.12	97.06	17.35
Listening recall	103.32	16.96	96.36	19.42
Verbal working memory composite	100.64	13.88	96.71	15.78
IQ				
Block Design	100.56	14.16		
Object Assembly	104.08	16.39		
Vocabulary			87.13	23.45
Learning				
Reading			98.67	12.10
Spelling			98.91	12.52
Math reasoning			101.28	17.65
Numerical Operations			100.51	11.86
WOND Composite			98.81	14.74

Table 2. Stepwise regression analyses predicting learning outcomes

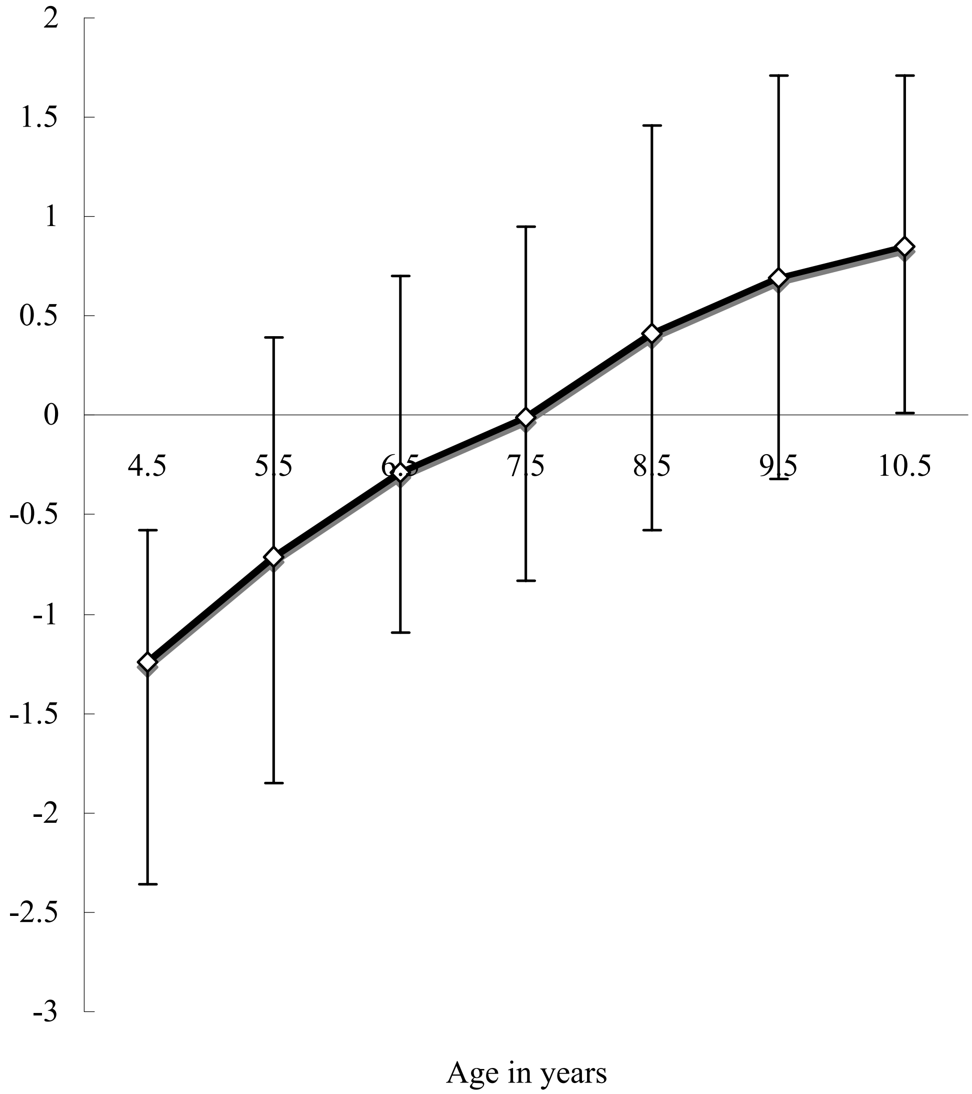
Dependant variables		Independent variables	*R2*	*ΔR2*	*ΔF*	*β*	*t*
Reading	1	Verbal WM: Time 1	.108	.108	11.56*	.329	3.40*
	2	IQ-Vocabulary: Time 2	.117	.068	7.77*	.265	2.79*
Spelling	1	Verbal WM: Time 1	.176	.176	18.10*	.419	4.26*
	2	Verbal STM: Time 2	.232	.056	6.13*	.270	2.48*
Math	1	Verbal WM: Time 1	.205	.205	24.77*	.453	4.98*
	2	IQ-Block Design: Time 1	.267	.062	7.99*	.285	2.83*

Note: WM=working memory; STM=short-term memory; * $p < .05$.

Figure 1.

Mean *z*-scores on a verbal working memory test from the Automated Working Memory Assessment as a function of age group; end points of bars denote 10th and 90th centile points.

Figure 2. The percentage of unique variance of working memory and IQ in predicting learning outcomes


2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
4.5
5.5
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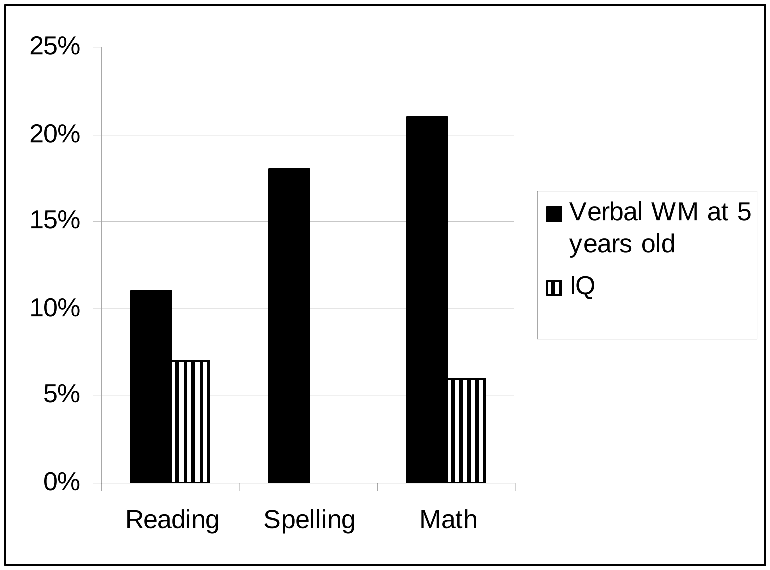
7.5
8.5
9.5
10.5
Age in years


25%
20%
15%
10%
5%
0%
Reading
Spelling
Math
Verbal WM at 5 years old
IQ