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Investigating the predictive roles of working memory and IQ in academic attainment

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ABSTRACT

There is growing evidence for the relationship between working memory and academic attainment. The aim of the current study was to investigate whether working memory is simply a proxy for IQ or whether there is a unique contribution to learning outcomes. The findings indicate that children's working memory skills at 5 years of age were the best predictor of literacy and numeracy 6 years later. IQ, in contrast, accounted for a smaller portion of unique variance to these learning outcomes. The results demonstrate that working memory is not a proxy for IQ but rather represents a dissociable cognitive skill with unique links to academic attainment. 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 intervention.

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Introduction

Working memory, our ability to process and remember information, is linked to a range of cognitive activities from reasoning tasks to verbal comprehension (Kane & Engle, 2002). Working memory is composed 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 (Baddeley, 2000). This model also includes two domain-specific stores responsible for the temporary storage of verbal and visuospatial information and has been supported in studies of children (Alloway,

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Gathercole, & Pickering, 2006; Bayliss, Jarrold, Gunn, & Baddeley, 2003), adults (Kane et al., 2004), and neuroimaging research (Jonides, Lacey, & Nee, 2005).

Although working memory can be tested reliably from as young as 4 years of age (Alloway, Gathercole, Willis, & Adams, 2004), performance on working memory tasks is subject to large degrees of individual variation (Alloway & Gathercole, 2006). Individual differences in working memory capacity have important consequences for children's ability to acquire knowledge and new skills (see Cowan & Alloway, 2008, for a review). In typically developing children, scores on working memory tasks predict reading achievement independent of measures of phonological skills (Swanson & Beebe-Frankenberger, 2004). Working memory is also linked to math outcomes; low working memory scores are closely related to poor performance on arithmetic word problems (Swanson & Sachse-Lee, 2001) and poor computational skills (Bull & Scerif, 2001; Geary, Hoard, & Hamson, 1999). Working memory capacity also has a significant impact on learning in various developmental disorders such as reading disabilities (Gathercole, Alloway, Willis, & Adams, 2006), language impairments (Alloway & Archibald, 2008), and motor difficulties (Alloway, 2007b).

Given the strong links between working memory and learning, the objective of the current study was to investigate whether working memory is simply a proxy for IQ with respect to academic attainment. There are two opposing positions regarding the theoretical relationship between working memory and IQ. One view is that these two constructs are so highly correlated that they could be considered as isomorphic properties (Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Jensen, 1998; Stauffer, Ree, & Carretta, 1996). An alternative account is that working memory shares psychometric properties with IQ yet is dissociable (Alloway et al., 2004; Conway, Cowan, Bunting, Theriault, & Minkoff, 2002). In a recent meta-analysis, Ackerman, Beier, and Boyle (2005) pointed out that working memory and general fluid intelligence share on average 20% of their variance (but see Kane et al., 2004). This modest overlap suggests that these two constructs are not synonymous (see also Conway, Kane, & Engle, 2003).

The relationship between working memory and IQ has implications for learning. Some researchers have suggested that the key factor underlying the relationship between working memory and learning is IQ (Nation, Adams, Bowyer-Crane, & Snowling, 1999; Stothard & Hulme, 1992). Contrasting evidence suggests that working memory shares unique links with learning after statistically accounting for IQ (e.g., Cain, Oakhill, & Bryant, 2004; Gathercole, Alloway, et al., 2006).

As an extension of existing cross-sectional studies, the aim of the current study was to investigate the respective contributions of working memory and IQ to academic attainment over a 6-year period. It is possible that working memory plays a critical role in predicting learning outcomes when children are young because they have very few knowledge-based resources to draw on to support learning (Alloway et al., 2005). As children get older, they build up more knowledge; thus, tests that tap crystallized intelligence such as vocabulary might be better predictors of learning outcomes. We assessed typically developing children first at 5 years of age and then again at 11 years of age. Working memory was assessed using tasks where the individual is required to both 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. 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.

We included measures of fluid intelligence (object assembly and block design) and crystallized intelligence (vocabulary). The use of nonverbal IQ tests at Time 1 and verbal IQ test at Time 2 is in line with Horn and Cattell's (1967) suggestion that nonverbal IQ skills are precursors to verbal IQ and facilitate the acquisition of crystallized knowledge (see Blair, 2006, for a discussion). Similarly, it is possible that nonverbal IQ skills at Time 1 would predict learning outcomes 6 years later. Academic attainment was measured using standardized tests of reading, spelling, and math.

Method

Participants

There were 98 children (51% boys and 49% girls) in this study, tested at two time points. At Time 1 (September 2001), children were 4.3 to 5.7 years of age and attending kindergarten full-time (mean

age = 5 years 0 months, $SD = 2.6$ months). They were retested 6 years later (Time 2, September 2007) on standardized measures of memory, IQ, and learning. These children were 10.0 to 11.3 years of age (mean age = 10 years 11 months, $SD = 2.3$ months). Schools were selected on the basis of a poverty (income) index used in the United Kingdom, eligibility for free school meals, and represented a range of low (3–7%), middle (15–25%), and high (34–45%) indexes on the basis of national rates. Information was provided by each child's principal caregiver about maternal educational level (i.e., completed high school, vocational training, or higher education) and the age at which the mother left school. Parental consent was obtained, and children were tested individually in a quiet area of the school on both occasions.

Measures

Memory

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 Time 2. Tests were taken from the Automated Working Memory Assessment (AWMA) (Alloway, 2007a) at Time 2 and from the Working Memory Test Battery for Children (Pickering & Gathercole, 2001), a paper-and-pencil analogue of the AWMA, at Time 1. In the verbal short-term memory tests, the child hears a sequence of verbal items (digits and one-syllable words, respectively) and needs to recall each sequence in the correct order. In the verbal working memory test, backward digit recall, the child is required to recall a sequence of spoken digits in the reverse order. In the listening recall test, the child is presented with a series of spoken sentences, needs to verify each sentence by stating "true" or "false," and must recall the final word for each sentence in sequence. Standard scores, with a mean of 100 and a standard deviation of 15, were recorded. Composite scores were calculated by averaging standard scores of the two measures in each memory component. Test reliability of the AWMA was reported by Alloway and colleagues (2006), and test validity was reported by Alloway, Gathercole, Kirkwood, and Elliott (2008).

It is worth noting that the current study included forward digit recall as a measure of verbal short-term memory and backward digit recall as a measure of verbal working memory. This decision was based on findings that in forward digit recall, the processing load is minimal given that the child immediately recalls number sequences. In contrast, in the backward digit recall task, there is an added requirement to recall the digits in reverse sequence that imposes a substantial processing load on the child, as illustrated by the finding that forward digit spans are higher than backward digit spans (Isaacs & Vargha Khadem, 1989; see also Vandierendonck, Kemps, Fastame, & Szmalec, 2004). Correspondingly, short-term memory skills such as forward digit recall are much more weakly associated with general academic and cognitive performance than working memory skills as measured by backward digit recall (e.g., Daneman & Merikle, 1996; see also Gathercole & Alloway, 2006, for a review).

General ability

IQ tests at Time 1 consisted of block design and object assembly subtests from the Wechsler Preschool and Primary Scale of Intelligence – Revised (Wechsler, 1990). At Time 2, the children completed the vocabulary subtest from the Wechsler Intelligence Scale for Children–Third Edition (Wechsler, 1992). Standard scores, with a mean of 100 and a standard deviation of 15, were recorded.

Academic attainment

Two standardized measures of learning ability were administered at Time 2 only. The Wechsler Objective Reading Dimensions (WORD) (Wechsler, 1993) consists of tests of basic reading, reading comprehension, and spelling for children. The Wechsler Objective Numerical Dimensions (WOND) (Wechsler, 1996) assesses mathematical reasoning and number operations. Standard scores, with a mean of 100 and a standard deviation of 15, were recorded. Composite scores of literacy and numeracy were calculated by averaging standard scores of the respective learning subtests.

Results

Descriptive statistics for the working memory tests are shown in Table 1. For all memory measures, standard scores ($M = 100$, $SD = 15$) are reported. At both time points, mean scores were within the average range for working memory and IQ.

The correlation coefficients among all measures are shown in Table 2. Of interest was whether the age at which the mother left school and the maternal educational level, indexes of socioeconomic level, correlated with working memory, IQ, and/or academic attainment. The age at which the mother left school was significantly related to literacy scores ($r = .25$), and the maternal educational level was significantly related to IQ at Time 2 ($r = .23$), but these were not related to working memory at either Time 1 or Time 2 ($r_s = .10$ – $.17$). This pattern of association suggests that working memory performance was not strongly impacted by such socioeconomic indexes. Looking next at the relationship among memory, IQ, and learning outcomes, r_s ranged from .22 (numeracy and IQ at Time 2) to .45 (numeracy and working memory at Time 1). Working memory appears to be a relatively stable construct, as evidenced by the coefficients between Time 1 and Time 2 ($r = .62$ for short-term memory and $r = .54$ for working memory).

Displayed in the upper triangle in Table 2 are the attenuation-corrected correlations among working memory, IQ, and learning outcomes. Correction for attenuation accounts for measurement error and provides an estimation of the relationship between IQ and working memory with learning if reliability values were perfect (see Jensen, 1998). The pattern of the attenuation-corrected correlations is similar; working memory tasks are more closely associated with learning outcomes than IQ tests.

It is possible that the working memory measures capture learning potential as well as prior learning, as indexed by maternal education. In contrast, the short-term memory measures may represent the more education-free measure and, thus, be more closely linked to learning outcomes. To investigate this issue, we looked at the relationship between working memory and short-term memory with learning outcomes (literacy and numeracy) after statistically partialling out variation due to maternal education. Looking first at working memory at Time 1, it was significantly related to both literacy ($r = .27$) and numeracy ($r = .30$). Working memory at Time 2 was also significantly related to literacy ($r = .31$) and numeracy ($r = .22$). Next, short-term memory at Time 1 was significantly related to both literacy ($r = .34$) and numeracy ($r = .33$). Short-term memory at Time 2 was also significantly related to literacy ($r = .39$) and numeracy ($r = .35$). A comparison of the two correlation coefficients indicated

Table 1

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

Measure	Time 1		Time 2	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>Memory</i>				
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
<i>IQ</i>				
Block design	100.56	14.16		
Object assembly	104.08	16.39		
Vocabulary			87.13	23.45
<i>Learning outcomes</i>				
Reading			98.67	12.10
Spelling			98.91	12.52
Literacy composite			99.30	10.77
Math reasoning			101.28	17.65
Numerical operations			100.51	11.86
Numeracy composite			98.81	14.74

Table 2

Correlation coefficients among all measures.

Measure	1	2	3	4	5	6	7	8	9	10
1. Age at which mother left school	1									
2. Maternal educational level	.69	1								
3. Verbal STM (Time 1)	.05	-.04	1							
4. Verbal STM (Time 2)	.02	-.07	.62	1						
5. Verbal WM (Time 1)	.17	.15	.55	.46	1				.51	.61
6. Verbal WM (Time 2)	.10	.17	.51	.61	.54	1			.45	.45
7. Nonverbal IQ (Time 1)	.10	.17	.34	.28	.37	.41	1		.35	.52
8. Verbal IQ (Time 2)	.08	.23	.17	.16	.18	.38	.23	1	.41	.28
9. Literacy (Time 2)	.25	.11	.33	.38	.40	.36	.29	.33	1	
10. Numeracy (Time 2)	-.08	.10	.35	.37	.45	.35	.41	.22	.59	1

Note. The environmental factors, working memory, IQ, and learning outcomes are displayed in the lower triangle ($n = 98$), and the attenuation-corrected correlations are displayed in the upper triangle. STM, short-term memory; WM, working memory. For coefficients greater than .20, $p < .05$.

that there was no significant difference in the correlation values between working memory and short-term memory at Time 1 for literacy ($z = .45$, $p = .65$) or numeracy ($z = .19$, $p = .85$). A similar pattern is evidenced between working memory and short-term memory at Time 2 for literacy ($z = .52$, $p = .60$) and numeracy ($z = .82$, $p = .41$). It appears that the short-term memory measures were not more education free and that the working memory measures were able to capture learning potential independent of prior learning, as indexed by maternal education.

The next step was to find the best set of predictor variables (working memory or IQ) in academic attainment in the current sample ($n = 98$). Two forced-entry regression analyses were performed on both learning outcomes: composite literacy scores (WORD) and composite numeracy scores (WOND). The six predictor variables (short-term memory, working memory, and IQ at both 5 and 11 years of age) were entered simultaneously to explore which variable would best predict attainment at 11 years of age. Model statistics, as well as standardized beta values and t statistics, are provided in Table 3. In the first model, literacy, the outcome measure, consisted of the WORD composite score comprising reading, spelling, and comprehension tests. Working memory at Time 1 accounted for the highest proportion of variance in literacy (16%), and IQ at Time 2 accounted for additional significant variance (7%). In the second model, numeracy, the outcome measure, consisted of the WOND composite score

Table 3

Forced-entry regression analyses predicting learning outcomes at Time 2.

	R^2	β	t
<i>Model 1: Literacy</i>			
All six variables	.28		
Verbal STM (Time 1)		.01	0.08
Verbal STM (Time 2)		.22	1.56
Verbal WM (Time 1)		.23	1.83*
Verbal WM (Time 2)		-.05	-0.36
Nonverbal IQ (Time 1)		.13	1.17
Verbal IQ (Time 2)		.25	2.35*
<i>Model 2: Numeracy</i>			
All six variables	.30		
Verbal STM (Time 1)		.01	0.06
Verbal STM (Time 2)		.18	1.42
Verbal WM (Time 1)		.29	2.53*
Verbal WM (Time 2)		-.06	-0.43
Nonverbal IQ (Time 1)		.25	2.51*
Verbal IQ (Time 2)		.11	1.10

Note. STM, short-term memory; WM, working memory.

* $p < .05$.

comprising numerical operations and math reasoning tests. Working memory at Time 1 accounted for the highest proportion of variance in numeracy (21%), and IQ at Time 1 accounted for additional significant variance (6%). The regression analyses indicate that verbal working memory at 5 years of age accounted for the largest proportion of variance in both literacy and numeracy skills 6 years later. Although IQ skills at 5 years of age also contributed to academic attainment, the proportion of variance it accounted for was lower.

The next step was to explore which cognitive abilities (working memory or IQ) shared unique variance with the two measures of academic attainment. For example, the relations between working memory and learning were assessed after taking into account the variance shared with IQ. Any final steps that account for significant additional portions of variance, thus, share unique links with the dependent variable. It should be noted that this fixed-order hierarchical regression procedure is a highly conservative means of assessing unique relations when different variable sets are themselves highly correlated with one another, as in the current case. However, it does have the advantage of providing stringent tests of specificity of relations that are valuable for interpretation of the data; any residual associations that do meet the criterion for statistical significance, therefore, are of particular note (see Cohen, Cohen, West, & Aiken, 2003).

In light of the findings from the regression analysis that working memory at Time 1 and IQ at Time 2 accounted for the largest significant variance in literacy, only these two measures were included as predictor variables (see Table 4). These predictor variables were entered in one order (IQ followed by working memory) and then the reverse order (working memory followed by IQ) to examine the variance accounted for by each variable in addition to the other. In the first model, with literacy as the outcome measure, IQ at Time 2 was entered at the first step, followed by working memory at Time 1. IQ accounted for a reasonably high proportion of variance (11%), whereas working memory at Time 1 accounted for additional variance in reading (12%). In Model 2, working memory at Time 1 was the first step and accounted for 21% of the variance. IQ at Time 2 followed and accounted for an additional significant variance of 7%.

In the next two models tested, numeracy was the outcome measure. On the basis of findings from the stepwise regression analysis that working memory and IQ at Time 1 accounted for the largest significant variance in numeracy, only these two measures were included as predictor variables (see Table 4). Here also, these predictor variables were entered in one order (IQ followed by working memory) and then the reverse order (working memory followed by IQ) to examine the variance accounted for by each variable in addition to the other. In Model 3, IQ as the first step accounted for a significant proportion of variance in numeracy (17%). The additional variance accounted for by working memory as the next step was also significant (10%). In Model 4, working memory as the first step accounted for 21% of the variance. The additional variance of IQ as the final step was significant (6%).

Table 4
Hierarchical regression analyses predicting learning outcomes at Time 2.

Dependent variable	R^2	R^2 change	F change	β	t
<i>Model 1: Literacy</i>					
Step 1: Verbal IQ (Time 2)	.11	.11	10.27*	.26	2.69*
Step 2: WM (Time 1)	.23	.12	12.90*	.35	3.59*
<i>Model 2: Literacy</i>					
Step 1: WM (Time 1)	.16	.16	16.17*	.35	3.59*
Step 2: Verbal IQ (Time 2)	.23	.07	7.25*	.26	2.69*
<i>Model 3: Numeracy</i>					
Step 1: Nonverbal IQ (Time 1)	.17	.17	18.90*	.28	2.95*
Step 2: WM (Time 1)	.27	.10	14.00*	.35	3.74*
<i>Model 4: Numeracy</i>					
Step 1: WM (Time 1)	.21	.21	24.77*	.35	3.74*
Step 2: Nonverbal IQ (Time 1)	.27	.06	8.70*	.28	2.95*

Note. WM, working memory.

* $p < .05$.

Thus, although IQ and working memory skills shared a substantial amount of variance with learning outcomes, both cognitive skills uniquely predicted outcomes in literacy and numeracy.

Discussion

The aim of the current study was to investigate the predictive power of working memory and IQ in learning in typically developing children over a 6-year period. This issue is of importance for two reasons. First, it can shed new light on the debate relating to the theoretical associations between IQ and working memory by investigating their unique links to academic attainment. Second, distinguishing between the cognitive skills underpinning success in learning is crucial for early screening and intervention. The findings from the current study provide new information on the contributions of working memory and IQ to literacy and numeracy. Specifically, working memory skills were uniquely linked to learning outcomes 6 years later. The 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 during the early years.

Some researchers suggest that the link between IQ and learning is greatest when the individual is learning new information rather than at later stages when it is suggested that gains made are the result of practice (see Jensen, 1980). Yet the current findings that working memory capacity predicted subsequent skills in reading, spelling, and math suggest that some cognitive skills contribute to learning beyond practice effects. This corresponds with research in children with learning difficulties that working memory capacity predicted subsequent learning outcomes independent of prior domain-specific knowledge (Alloway, 2009b). One caveat was the use of a crystallized intelligence test at Time 2 that allowed us to investigate the contribution of knowledge-based skills in academic attainment. Although previous research has established the unique predictive value of working memory when both fluid and crystallized intelligence tests were included (Alloway, 2007b; Alloway, 2009b; Gathercole, Alloway, et al., 2006), future research may benefit from including both measures at all time points in longitudinal studies.

The large contribution of working memory to subsequent learning extends findings from cross-sectional studies indicating that the specificity of associations between working memory and attainment persist after statistically controlling for differences in IQ in children with learning difficulties (Alloway, 2007b; Gathercole, Alloway, et al., 2006; Nation et al., 1999; Stothard & Hulme, 1992; Swanson & Saez, 2003). Further evidence that verbal working memory taps more than general ability is provided by reports of differences in working memory scores in children with reading comprehension problems and other learning disabilities even after accounting for verbal IQ (Cain et al., 2004; Siegel & Ryan, 1989). In the current study, the finding that the contribution of working memory to learning is strong even over a 6-year period suggests that working memory is a relatively stable construct, and the strong relationship between memory scores at Time 1 and Time 2 is consistent with previous research (Alloway et al., 2006; Alloway et al., 2008). Although cross-sectional studies have established that working memory does increase with age (Alloway et al., 2006; Swanson, 1999), it appears that its relative capacity remains constant. This suggests that children in the bottom 10 percentile compared with their same-age peers are likely to remain at this level throughout their academic careers.

Also of interest was the relationship of socioeconomic indexes to working memory, IQ, and learning outcomes. The mother's educational level was significantly associated with the student's literacy skills and IQ (Time 2). These links correspond with research indicating that the home life exerts a strong influence on vocabulary development (Hart & Risley, 1995; Hoff & Tian, 2005; Walker, Greenwood, Hart, & Carta, 1994). Various factors, such as how much a mother talks to her children and her attitudes toward education, have been identified as possible explanations for the observed low performances of children from deprived economic backgrounds on standardized literacy and vocabulary tests (Brody & Flor, 1998; Hoff, 2003; Walker et al., 1994). In contrast, the lack of a significant association between maternal education and working memory indicates that whether the mother left high school or went on to earn a higher degree did not have as strong an impact on the child's working memory performance as it had on IQ and literacy. Moreover, the significant relationship between

working memory and learning remained even after statistically accounting for the contribution of maternal education. This pattern fits well with emerging evidence that working memory is relatively impervious to environmental influences such as the number of years spent in preschool education (Alloway et al., 2004) and economic background (Engel, Heloisa Dos Santos, & Gathercole, 2008). One explanation for this is that working memory is a relatively pure measure of a child's learning potential and indicates a child's capacity to learn (Alloway et al., 2005; Dollaghan, Campbell, Needleman, & Dunlosky, 1997; Weismer et al., 2000). In contrast, academic attainment and even IQ tests measure knowledge that the child has already learned.

The finding that working memory, rather than IQ, accounted for the largest amount of statistical variance has valuable implications for education. In the classroom, students frequently need 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 that involve storing and processing information and keeping track of progress in difficult tasks (Gathercole, Lamont, & Alloway, 2006). Working memory impairments lead to learning deficits as well as difficulty in performing daily classroom activities. One explanation for this is that working memory acts like a bottleneck for learning (Gathercole, Alloway, et al., 2006). Because learning is an incremental process, building gradually over time, any disruption such as an inability to retain early learning episodes resulting from poor working memory can jeopardize subsequent learning success. Working memory may also be related to mind wandering (Kane et al., 2007) and self-discipline (Duckworth & Seligman, 2005), which affect academic performance.

Without early intervention, working memory deficits cannot be made up over time and will continue to compromise a child's likelihood of academic success (Alloway, 2009b). The first crucial step in supporting working memory is proper diagnosis. However, currently working memory problems often go undetected in children or are misdiagnosed as attentional problems (Gathercole, Alloway, et al., 2006). One useful tool to identify and support children with working memory impairments is the AWMA (Alloway, 2007a). It is the first standardized tool for nonspecialist assessors such as classroom teachers to screen their pupils for significant working memory problems quickly and effectively. The likelihood that children with poor working memory capacity will face academic problems in school was recently investigated using the AWMA (Alloway, Gathercole, Kirkwood, & Elliott, 2009). These students were more likely to perform very poorly in key learning outcomes such as reading and math. They were also more likely to be inattentive, forgetful, and easily distracted, leading to careless mistakes, especially in writing, and difficulty in solving problems. Targeted strategies may help (Gathercole & Alloway, 2008), and there is growing evidence that working memory capacity can be increased by training (Jaeggi, Buschkuhl, Jonides, & Perrig, 2008; Verhaeghen, Cerella, & Basak, 2004), which also transfers to academic attainment (Alloway, 2009a).

In summary, the current findings provide new evidence on the importance of working memory in learning outcomes over time. The practical implications suggest that early screening to identify the strengths and weaknesses of a student's working memory profile can lead to effective management and support to bolster learning.

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