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Working Memory and Recollection Contribute to Academic Achievement

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Abstract

The contributions of working memory and recollection to academic achievement are typically examined separately and most often with children who have learning difficulties. This study is the first to observe both types of memory in the same study and in typically developing children. Academic achievement focused on standardized assessments of math fluency, calculation, reading fluency, and passage comprehension. As noted in previous studies, working memory was associated with each assessed measure of academic achievement. Recollection, however, specifically contributed to math fluency and passage comprehension. Thus, recollection should be considered alongside working memory in studies of academic achievement.

Keywords

working memory; recollection; children; math; reading; academic achievement

1. Introduction

There are wide ranging individual differences in children's academic achievement. Variations in reading and math performance between children with and without learning difficulties are quite apparent to classroom teachers and parents alike. Even in typically developing children with no learning difficulties, individual differences in reading and math performance can be readily observed (e.g., Hecht, Torgesen, Wagner, & Rashotte, 2001; Jenkins, Fuchs, van den Broek, Espin, & Deno, 2003). Researchers have reported various distal contributors to these performance level differences (e.g., family socio-economic status, Aikens & Barbarin, 2008; parental interaction style, Mattanah, Pratt, Cowan, & Cowan, 2005; classroom instruction technique, Kilbanoff, Levine, Huttenlocker, Vasilyeva, & Hedges, 2006). More proximal contributors (e.g., working memory, Gathercole, Alloway, & Willis, 2006; Swanson, Jerman, & Zheng, 2008) have also been the focus of attention and with good reason. Academic-based processes rely on the formation and use of representations, a complex process that requires many cognitive skills, including memory.

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A comprehensive connection between memory and academic skills is lacking because of the literature's focus on contributions from a single cognitive process, such as working memory (e.g., Daneman & Hannon, 2001) or components from a single process, such as the factors that make up working memory (e.g., Nevo & Breznitz, 2010). The ability to comprehend and produce representations requires many mechanisms (Paivio, 1990); thus, there is a need to examine multiple cognitive processes and how they differentially contribute to academic achievement. The purpose of our study was to examine contributions of two different memory processes (recollection and working memory) to performance on standardized measures of academic achievement in children. Other studies tend to examine executive memory in relation to academic achievement; we took a more comprehensive view of memory in our study.

Associations between working memory (WM) and numerous aspects of learning and academic achievement in children are well established (e.g., Bourke & Adams, 2003; Bull, Johnson, & Roy, 1999; Gathercole, Brown, & Pickering, 2003; Nevo & Breznitz, 2011; Stevenson, Bergwerff, Heiser, & Resing, 2014; Swanson, 1993, 1994). WM is a complex cognitive process consisting of several components (Baddeley, 1992) that differ in their contributions to complex reading and math abilities (Nevo & Brenitz, 2011). One of the WM components, the episodic buffer, integrates information for short and long term memory use (Baddeley & Wilson, 2002). The episodic buffer allows for short term binding of contextual and item information that is later consolidated, allowing for the formation of episodic memories (EM) (Tulving, 1972). Because of these associations between WM and EM, we examined the contributions of both types of memory processes to academic achievement in math and reading. In the following paragraphs we highlight literature relating WM and EM to academic achievement. We then explain how the episodic buffer is connected to.

1.1 Working Memory: Development and Academic Achievement

WM is the ability to simultaneously maintain and manipulate information (Baddeley, 1992). WM capacity increases throughout childhood and into adolescence (for review see Gathercole, Pickering, Ambridge, & Wearing, 2004). Substantial improvements in WM during middle childhood may be attributed to the emergence of successful rehearsal techniques (Hulme, Thompson, Muir, & Lawerence, 1984) and increased processing speed (Cowan, Wood, Wood, Keller, Nugent, & Keller, 1998) found during this period.

WM contributes to reading achievement in children (for a meta analysis see Carretti, Borella, Cornoldi, & De Beni, 2009) because it aids in the conceptualization of words and the ability to maintain the words online for comprehension (Baddeley, 2003; Siegel, 1994). Thus, WM is related to skills necessary for reading fluency and comprehension, such as production of grammatical fluency (Ellis, 1996), syntactic comprehension (Santi & Grodzinsky, 2007), and phonological processing (Da Fontoura & Siegel, 1995). This has led to training programs designed to enhance WM. For example, preschool aged children have shown improvements in WM after training (Holmes, Gathercole, & Dunning, 2009). WM training with older children (9–11) has resulted in improvements in reading performance (Loosli, Buschkuehl, & Perrig, 2012).

In addition to benefits associated with achievements in reading, WM performance has been connected to benefits in mathematics (for review see Raghubar, Barnes, & Hecht, 2010). Specifically, WM is associated with the ability to retrieve arithmetic facts from LTM (Kaufman, 2002) and maintain numerical representations (Geary, 1993). These relations also explain why WM plays a crucial role in the ability to calculate and solve math-based word problems (Logie, Gilhooly, & Wynn, 1994; Swanson & Beebe-Frankenberger, 2004). In sum, the literature connecting WM to academic achievement is well developed.

1.2 Episodic Memory: Development and Academic Achievement

EM refers to memory for specific items and their contextual information (Tulving, 1972) and is often discussed in the adult cognition literature from a dual-process prospective, separating EM into recollection and familiarity (Yonelinas, 2002). Recollection refers to the detail-rich memory for items and contextual information. Recollection is typically what is brought to mind when we think of EM and the process of retrieving information from our past. To elaborate, recognizing an object is not sufficient to require recollection; we must retrieve details regarding other contextual factors of the information. Familiarity is a global evaluation of memory strength. Research with adults supports the notion that recollection and familiarity are dissociable processes (Diana, Yonelinas, & Ranganath, 2007).

Very young children's recollection is far less complex or detailed than that of adults. This is likely due to the lack of experience recollecting past events and continuation of neural development (Ghetti & Lee, 2013; Riggins, 2012). Familiarity, however, appears to remain stable by age six (Ghetti & Angelini, 2008). The literature also suggests that familiarity develops far earlier than recollection. A study exploring recollection and familiarity in 8–19 year olds found that while familiarity remained constant with age, recollection increased with age (Billingsley, Smith, & McAndrews, 2002), suggesting that recollection continues to develop into adolescence. Ghetti and Angelini (2008) found similar results in 6–18 year olds using confidence ratings and receiver operating curves (i.e., plotted hits in relation to false alarms as confidence changed).

In a rare study of academic achievement examining the EM dichotomy of recollection and familiarity, Mirandola and colleagues (2011) reported on adolescents with and without reading difficulties, Adolescents with learning difficulties displayed a deficit in recollection, but not familiarity, suggesting that only recollection was associated with academic success in reading. We are aware of no studies exploring this dichotomy in relation to math achievement. Associations between recollection and math have been found through use of recall tasks (e.g., Fletcher, 1985; Stevenson & Newman, 1986). Recall tasks elicit recollection processes, especially if recall of contextual information is required (Yonelinas, 2002, 1994). However, the studies focused on recollection did not consider other critical contributors to reading or math achievement, such as WM.

By examining the unique contributions of WM and recollection, we can broaden our understanding of cognitive contributors to academic achievement. Increasing our understanding of how childhood memory operates could have practical implications in educational settings. Our study focused on WM and the recollection aspect of EM during middle childhood.

1.3 Episodic Buffer and Episodic Memory

As previously noted, one of the components of the WM model is the episodic buffer (Baddeley, 2000). This element allows for information to be integrated across time and space, allowing for short term binding of contextual and item information. The episodic buffer is further believed to aid in the sending and receiving of information from EM (Baddeley, 2000). The other elements of WM, visuospatial sketchpad and phonological loop, are thought to aid in visual and verbal semantics, respectively. In a study exploring these aspects of WM, all three components were correlated with reading achievement (Nevo & Berznitz, 2011), suggesting that each WM component also associated with EM plays a role in reading achievement. It may be, however, that EM and WM contribute uniquely to academic achievement. This idea is supported by brain imagining evidence suggesting that the prefrontal cortex is associated with WM (Curtis & D'Esposito, 2003), whereas the medial temporal lobe, specifically the hippocampus, is associated with EM (Squire & Cave, 1991). As the literature currently stands, it could be argued that relations between EM and academic achievement are actually attributed to WM because of the episodic buffer's role in EM. And indeed, EM and WM are correlated (Schneider & Weinert, 1995). We propose, however, that recollection plays an independent role in academic achievement because of the separate neural process associated with EM and WM.

1.4 Current Study

We took a comprehensive view of memory by examining the unique contributions of WM and recollection (i.e., an aspect of EM) to reading and math achievement. As we have noted, most research examining recollection is focused on children with learning difficulties (Mirandola et al., 2011; Spring & Capps, 1974; Swanson, 1994; Weekes, Hamilton, Oakhill, & Holliday, 2008). A good deal of the literature examining WM contributions to academic achievement likewise focuses on school-aged children with learning difficulties (e.g. Carretti, Borella, Cornoldi, & De Beni, 2009; Raghubar, Barnes, & Hecht, 2010). Understanding how WM and recollection processes contribute to the reading and math performance of typically developing children without reading or math difficulties is critical for a more complete picture of individual differences in academic achievement.

Therefore, we examined the contributions of two memory processes to achievement in typically developing children. We hypothesized that WM and recollection would statistically predict reading and math achievement, as assessed by standardized tests. In our analyses, we simultaneously examined potential contributions of WM and recollection to account for unique variance associated with each memory process.

2. Method

2.1. Participants

Our sample was comprised of 81 children (52% female; 9–11 years, *M* =10.38, *SD* = .73) who made up one cohort from an on-going longitudinal study on cognition and emotion development. Some children had been participating since infancy (n = 57) and others were newly recruited for this visit (n = 24). Children were predominantly Caucasian (89%) with highly educated parents; 99% of mothers and 91% of fathers had at least some education beyond high school. As compensation for participation, parents received a $50 gift certificate and children received a small gift and a $10 gift certificate.

2.2. Recollection Memory Task

The recollection memory task was adapted from work by DeMaster and Ghetti (2013). Children viewed black and white line drawings surrounded by a color border. The stimuli were taken from an existing set of 244 line drawings (Szekely, et al., 2003). Four blocks, each with eight line drawings, were used; four drawings were altered to have a lower resolution and four unaltered. The four blocks comprised the categories of foods, vehicles, animals, and outdoor activities. The groupings were used to allow for the potential use of a mnemonic technique (categorical clustering); however, this technique was not suggested to the children. The line drawings were surrounded by one of two colors with each block having a different pair: red/green, blue/yellow, purple/green, or brown/pink. The stimuli were displayed on a computer monitor one at a time, each for 4 seconds with an inter-trial interval of 1.5 seconds.

Prior to the encoding phase, children were instructed to attend to the drawings as well as the color of the surrounding borders. They were also told that they would later be asked to name the drawings associated with each color border. During the encoding phase for each block the children viewed a total of 8 line drawings (4 clear, 4 altered; see figure 1). Immediately after each block, children were shown a color border from that block and prompted to verbally recall the drawings associated with that color. They were then shown the other color from that block and asked to recall those line drawings. The difference in performance between the altered and nonaltered images was not significant, $t(79) < .001$, $p = .99$, and correlated $r = .45$. A composite score was created combining total correct from both recall conditions, total possible was 32.

2.3. Working Memory Task

A backwards digit span (BDS) task was administered to assess working memory. Children were initially presented with two digits and instructed to repeat the sequence backwards. Two practice trials were given to ensure understanding and then the task began. Attempt at recall of the same digit span with at least one correct trial for two trials was required before lengthening the span by one digit. The digit span was lengthened until errors were produced on two consecutive trials of the same span. The variable of interest was digit span, which accounts for nonconsecutive errors.

2.5. Assessments of Math and Reading

Woodcock Johnson (WJ) III Tests of Achievement were used to measure math and reading ability (Woodcock, McGrew, & Mather 2001). Measures of math ability included calculation and math fluency. Measures of reading ability included passage comprehension and reading fluency. The variables of interest were number correct within each measure. The WJ III subtests demonstrate high reliabilities of .80 or higher (Woodcock, McGrew. Mather, & Schrank, 2003).

2.6. Verbal IQ

The Peabody Picture Vocabulary Test IV (PPVT; Dunn & Dunn, 2006) was administered as a proxy for verbal IQ. Because intelligence is typically correlated with WM, as well as reading and math performance, we controlled for this variable in all our analyses. The PPVT is a nationally standardized instrument, and the measure of interest was participants' standardized scores.

3. Results

3.1. Correlations

For descriptive statistics and correlations refer to Table 1. Two children did not complete the reading fluency assessment. All other tasks had data from 81 participants. All WJ III measures (reading fluency, math fluency, reading comprehension, calculation) were positively correlated with WM, recollection, and each other. Four hierarchical regressions were used to examine the contributions of memory (WM, recollection) to the four individual reading and math performance measures. Verbal IQ (i.e., PPVT) was entered into the first step of each equation. Because of our wide age range (9–12 years), we also entered age into the first step of each equation. WM and recollection performance were entered into the second step of each equation.

3.2. Reading Achievement

3.2.1. Reading fluency—Verbal IQ and age in Step 1 collectively accounted for 18% of the variance in reading fluency. The variables in Step 2 accounted for an additional 17% of the variance in reading fluency, with verbal IQ (6%) and working memory (12%), but not recollection, contributing unique variance.

3.2.2. Passage comprehension—Verbal IQ and age in Step 1 collectively accounted for 20% of the variance in passage comprehension. The variables in Step 2 accounted for an additional 23% of the variance in passage comprehension, with verbal IQ (7%), working memory (9%) and recollection (9%) contributing unique variance.

3.3. Math Achievement

3.3.1. Math fluency—Verbal IQ and age in Step 1 collectively accounted for 10% of the variance in math fluency. The variables in Step 2 accounted for an additional 12% of the variance in math fluency, with working memory (5%) and recollection (4%) contributing unique variance.

3.3.2. Calculation—Verbal IQ and age in Step 1 collectively accounted for 32% of the variance in calculation. The variables in Step 2 accounted for an additional 7% of the variance in calculation, with age (15%), verbal IQ (5%), and working memory (4%), but not recollection, contributing unique variance.

4. Discussion

We examined individual differences in reading and math achievement by assessing the contributions of two different memory processes. Our findings suggest that recollection and WM both contribute to math and reading performance, after controlling for the contributions of IQ and age. The WM and recollection results were not surprising individually, but our study is the first to examine them simultaneously; they each contribute unique variance. These results are consistent with past research separately examining contributions of WM (Alloway & Alloway, 2010; Swanson, 1994; St. Clair-Thompson & Gathercole, 2006) and recollection (Mirandola et al., 2011) to academic achievement.

Not surprisingly, WM contributed to all four measures of academic achievement. This finding is consistent with past research exploring WM's contributions to both math (Bull, Johnson, & Roy, 1999; Swanson & Beebe-Frankenberger, 2004) and reading (Bourke & Adams, 2003; Gathercole, Alloway, Willis, & Adams, 2006) achievement. Children needed to maintain formulas and sentences within working memory, and manipulate them to achieve the correct answers, in order to be successful on any of our measures of math or reading.

Our findings with respect to recollection and academic achievement were more variable. Previous studies comparing children with and without reading difficulties suggest that recollection is an important component to reading success (Mirandola et al., 2011; Paris & Myers, 1981; Spring & Capps, 1974). We found that recollection contributed unique variance to passage comprehension performance in typical readers. This is not surprising considering that reading requires the need to retrieve detailed information in order to accurately comprehend a passage. To understand a complex passage, children must retrieve information regarding the meaning of the words. Furthermore, the passage comprehension task required children to complete complex passages. Such a task would tax retrieval memory systems.

Recollection did not, however, contribute to reading fluency. The reading fluency task required children to read sentences and respond if they were accurate or not (e.g., *The sky is always pink.*). This task may rely on familiarity processes more so than recollection. Children may have used their familiarity with the statements as a way to determine their accuracy, rather than retrieval of similar events in their lives. Such a strategy would result in much faster results (Yonelinas & Jacoby, 1994), which would be an advantageous strategy in the reading fluency task since the children were given time constraints.

The children in our study also showed some associations between recollection and math. Although recollection contributed unique variance to math fluency, it did not contribute to calculation performance. It is possible that this is due to the large amount of variance attributed by age to calculation performance found in our study. The relation between age and calculation is not surprising considering the large range of difficulty found in math problems used in the calculation assessment. An age restrictive sample may allow for a better understanding of how recollection contributes to this process. The contribution of recollection to math abilities is not well known. A longitudinal study explored various predictors during preschool to the same sample's high school academic abilities (Stevenson & Newman, 1986). They found that preschool serial memory for pictures, numbers and words, as well as visual recall, was correlated with math and reading measures in grades 5 and 10. Further analyses suggested that verbal recall predicted math ability (computation). Considering that recall is related to recollection (Yonelinas, 2002), it may be that recollection would be related to math outcomes as well. However, Stevenson and Newman (1986) did not control for WM, nor control for IQ. Our study suggests that recollection is an important contributor to math fluency in particular over and above IQ and uniquely from WM.

There were some limitations to this work. EM is often segmented into recollection and familiarity (Ghetti, Lyons, & DeMaster, 2012; Yonelinas, 2002). For a more comprehensive picture of memory processes associated with academic achievement, further research could be conducted examining all three memory processes (recollection, familiarity, and WM). Future studies could use a remember/know or associative task design measuring both recollection and familiarity. However, we predict that familiarity will not contribute to academic achievement in studies of older school age children because the development of familiarity stabilizes by age 6 (Ghetti & Angelini, 2008). For younger children, familiarity may contribute to reading and math achievement.

Additionally, it would be beneficial to explore how various WM tasks contribute to math and reading abilities. The connection between recollection and WM is likely through the episodic buffer. However, we did not use a detailed WM task tapping into the complex systems involved in WM. Past work examines all three WM systems' relations to reading achievement (e.g., Nevo & Breznitz, 2011). However, the episodic buffer's unique contributions were not discussed, and math achievement was not examined. Future studies should include a detail rich WM task, such as a picture-based N-back, or an episodic buffer specific task, such as a sentence span task. Additionally, future studies should examine these WM tasks' contributions to both reading and math abilities.

Our study was done in the context of a large longitudinal study, necessitating that we only use one measure each of WM and recollection. Multiple measures have the potential to contribute to greater construct validity. In addition, the generalizability of our results may be limited because our participants were predominantly Caucasian and from upper middle class families. Given associations between socio-economic status and academic achievement (for meta-analysis see Sirin, 2005), replications with more diverse samples would be beneficial. Furthermore, although our study provided evidence for WM and recollection contributions to academic achievement over and above crystalized intelligence (i.e., the PPVT), it would be informative to examine these associations while also controlling for fluid intelligence (i.e., using a task like the Raven matrices). Fluid intelligence contributes to math achievement (Primi, Ferrao, & Almeida, 2010).

Overall, our study demonstrated that WM contributes unique variance to math and reading performance, even after controlling for IQ and age. Recollection contributed unique variance to math fluency and passage comprehension. Although the research on WM training with children who are low in WM performance is mixed with respect to transfer of skills to academic achievement (e.g., Dunning, Holmes, & Gathercole, 2013; Holmes, Gathercole, & Dunning, 2009), it may be that WM training (e.g., Holmes, Gathercole, Place, Dunning, Hilton, & Elliott, 2010) combined with recollection enhancement (e.g., Brehmer, Li, Muller, von Oertzen, & Lindenberger, 2007) may result in an increase in academic achievement. Both of these memory processes should be considered in future studies and interventions on reading and math achievement in children.

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Highlights

- We examine memory processes and academic achievement.
- Multiple memory processes contributed uniquely to achievement.
- Working memory predicted math and reading performance on all tasks.
- Recollection predicted math and reading performance.

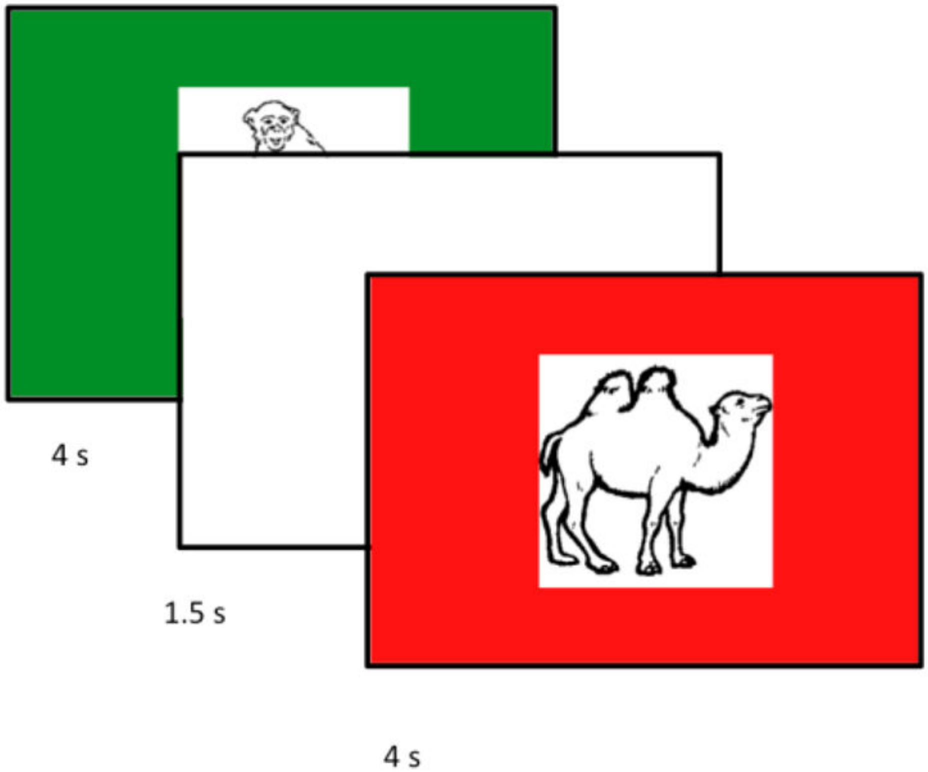

Figure 1.
Example of stimuli used in recollection task.

Table 1

Correlations and Descriptive Statistics

Task	1	2	3	4	5	6	7	8
1. Working Memory	--							
2. Recollection	.28*	--						
3. Verbal IQ	.08	.28*	--					
4. Reading Fluency	.46***	.38***	.32**	--				
5. Calculation	.35**	.37***	.27*	.58***	--			
6. Math Fluency	.33**	.36***	.17	.72***	.62***	--		
7. Passage Comprehension	.44***	.51***	.40***	.62***	.42***	.43***	--	
8. Age	.19	.27*	−.01	.26*	.49***	.28**	.18	--
n	81	81	81	79	81	81	81	81
M	4.08	16.20	112.56	48.19	20.19	61.23	29.83	10.38
SD	.73	4.44	13.69	13.59	3.85	23.89	4.78	.73
Minimum	2.00	7.00	85.00	23.00	12.00	8.00	15.00	9.05
Maximum	5.50	27.00	142.00	91.00	30.00	126.00	38.00	12.26

Note:

*** $p \leq .001$

** $p \leq .01$;

* $p \leq .05$.

Table 2

Hierarchical Regression Analyses of Memory Performance Predicting Reading Achievement

	R	R^2	$R^2\Delta$	$F\Delta$	F	β	t	sr^2
a. Dependent variable: Reading Fluency								
Step 1.	.42	.18			8.08^{***}			
Verbal IQ						.33	3.12^{**}	.11
Age						.27	2.57^{*}	.07
Step 2:	.59	.35	.17	9.84^{***}	9.90^{***}			
Verbal IQ						.25	2.54^{*}	.06
Age						.15	1.50	.02
Working Memory						.36	3.65^{***}	.12
Recollection						.17	1.65	.02
b. Dependent variable: Passage Comprehension								
Step 1.	.44	.20			9.52^{***}			
Verbal IQ						.40	3.97^{***}	.16
Age						.19	1.85	.03
Step 2:	.65	.43	.23	15.09^{***}	14.03^{***}			
Verbal IQ						.28	3.11^{**}	.07
Age						.03	.34	.001
Working Memory						.31	3.41^{***}	.09
Recollection						.33	3.43^{***}	.09

Note:

*** $p \le .001$;

** $p \le .01$;

* $p \le .05$.

Reading Fluency (n= 79), Passage Comprehension (n=81).

Table 3

Hierarchical Regression Analyses of Memory Performance Predicting Math Achievement

	R	R^2	$R^2\Delta$	***F*Δ**	***F***	***β***	***t***	sr^2
a. Dependent variable: Math Fluency								
Step 1.	.32	.10			4.52*			
Verbal IQ						.17	1.57	.03
Age						.28	2.58*	.08
Step 2:	.47	.22	.12	5.45**	5.46***			
Verbal IQ						.09	.80	.01
Age						.17	1.56	.03
Working Memory						.23	2.11*	.05
Recollection						.23	1.99*	.04
b. Dependent variable: Calculation								
Step 1.	.56	.32			18.12***			
Verbal IQ						.28	2.99**	.08
Age						.49	5.26***	.24
Step 2:	.62	.39	.07	4.17*	11.88***			
Verbal IQ						.22	2.37*	.05
Age						.41	4.33***	.15
Working Memory						.20	2.14*	.04
Recollection						.14	1.40	.02

Note:

*** $p \leq .001$;

** $p \leq .01$;

* $p \leq .05$.

Math Fluency (n= 81), Calculation (n= 81).