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The Relationships of Working Memory, Secondary Memory, and General Fluid Intelligence: Working Memory *is* Special

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Abstract

Recent efforts have been made to elucidate the commonly observed link between working memory and reasoning ability. The results have been inconsistent, with some work suggesting the emphasis placed on retrieval from secondary memory by working memory tests is the driving force behind this association (Mogle, Lovett, Stawski, & Sliwinski, 2008), while other research suggests retrieval from secondary memory is only partly responsible for the observed link between working memory and reasoning (Unsworth & Engle, 2006, 2007b). The present study investigates the relationship between processing speed, working memory, secondary memory, primary memory, and fluid intelligence. Although our findings show all constructs are significantly correlated with fluid intelligence, working memory, but not secondary memory, accounts for significant *unique* variance in fluid intelligence. Our data support predictions made by Unsworth and Engle, and suggest that the combined need for maintenance and retrieval processes present in working memory tests makes them "special" in their prediction of higher-order cognition.

Keywords

working memory; fluid intelligence; secondary memory; primary memory

Research examining individual differences in working memory function has led to numerous discoveries about how the human memory system operates. These insights hold important theoretical and practical utility. Theoretically-based research has revealed that working memory is a system that operates via a dynamic interaction between memory and executive

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attention processes (Cowan 1995), allowing individuals to maintain task goals in the face of interference (Conway, Cowan, & Bunting, 2001; Kane & Engle, 2000), update memory contents to meet current demands (Friedman et al., 2006), and to integrate distinct memory elements to form novel relationships (Oberauer, Süβ, Wilhelm, & Wittman, 2008). Working memory research has also yielded results with far-reaching practical implications. For example, working memory dysfunction is highly sensitive to the presence of various psychoneurological disorders, such as schizophrenia (Barch, 2003), Parkinson's disease (Altgassen, Phillips, Kopp, & Kliegel, 2007), and Alzheimer's dementia (Collette, Van der Linden, & Salmon, 1999). Additionally, laboratory working memory tests can be used to identify individuals who have genetic risk factors for developing Alzheimer's dementia (Rosen, Bergeson, Putnam, Harwell, & Sunderland, 2002).

The widespread predictive utility of the working memory construct makes it a powerful tool for both scientists and practitioners. One of the most reliable demonstrations of the predictive power of working memory is its ability to account for variation in higher-order cognitive functioning, such as fluid intelligence (Engle, Tuholski, Laughlin, & Conway, 1999; Friedman et al., 2006; Kane et al., 2004; Shelton, Elliott, Hill, Calamia, & Gouvier, 2009). Understanding the nature of this relationship is critical in determining why working memory is especially useful in predicting how well people can reason and adapt to an increasingly complex environment. Recent work, spearheaded by Unsworth and Engle, has focused on the possibility that the key element linking working memory and fluid intelligence is the combination of active maintenance in primary memory and retrieval from secondary memory. Unsworth and Engle (2006, 2007b) have argued that traditional working memory tasks (complex span tasks comprising both storage and processing demands) force people to actively maintain memoranda until they engage in the processing component of the task, at which point the memoranda must be displaced to secondary memory (see also McCabe, 2008). When it is time to retrieve the items, individuals must conduct a controlled search of the contents of secondary memory. One study revealed that participants who performed in the highest quartile on working memory tasks recalled more actual items and fewer erroneous items in a delayed free recall test, and produced faster retrieval rates (Unsworth, 2007). These findings suggested that people who perform well on working memory tests could better constrain their search set and more effectively retrieve items from secondary memory. This ability would also be useful for the novel problem-solving component inherent to tests of fluid intelligence. For example, when trying to decide which pattern segment will best complete a matrix design (e.g., Raven's Progressive Matrices; Raven, Raven, & Court, 1998) it is necessary to maintain separate pieces of the design to determine how they fit together. As the designs increase with complexity, it becomes more difficult to hold these items in the limited space of primary memory, leading to some of the items being displaced into secondary memory. Ultimately, pertinent items must be retrieved from secondary memory to determine which option will best solve these complex problems.

Several recent studies have demonstrated that the link between working memory and fluid intelligence is, at least partly, driven by the shared need for retrieving information from secondary memory. Unsworth and Engle (2006) addressed this issue by examining how recall performance for lists of varying lengths in simple span (e.g., digit span) and complex span (e.g., operation span) tasks predicted variation in fluid intelligence. Engaging in the processing component of complex span tests purportedly requires participants to move the to-be-remembered items to secondary memory, whereas only the longer list lengths (e.g., > 4 items) of simple span tasks require this process once the items have exceeded the capacity of primary memory. However, items from the shorter list lengths (e.g., < 4 items) can be maintained in primary memory if participants are not required to engage in any secondary task. Unsworth and Engle found that individual differences in the number of items people could recall from complex span tests (across all list lengths) and the longer list lengths of simple span tests predicted a significant amount of unique and shared variance in fluid intelligence; however, the number of items recalled from shorter simple span lists were not good predictors of the criterion variable. These data suggest that simple span tests are good predictors of fluid intelligence only if the longer list lengths are isolated, whereas performance on complex span tasks is a good predictor of fluid intelligence regardless of list length. The authors concluded that the dual emphasis on processes underlying both primary and secondary memory in working memory tasks is the driving force behind their strong association with higher-order cognition.

A provocative study published by Mogle, Lovett, Stawski, and Sliwinski (2008) extended this line of inquiry. In their study, a large sample of undergraduates completed three measures of working memory (complex span tests), primary memory (simple span tests), secondary memory (cued recall and recognition of supraspan lists, and story recognition), processing speed, and one fluid intelligence test (Raven’s Advanced Progressive Matrices). Participants completed these tests in one of three testing conditions: via the internet, unsupervised computer testing, or supervised computer testing. They used structural equation modeling techniques to analyze the data, reporting an unexpected trend. Controlling for working memory variability did not diminish the relationship between secondary memory and fluid intelligence; however, controlling for secondary memory variability did diminish the relationship between working memory and fluid intelligence. In fact, the working memory construct no longer accounted for any unique variance in fluid intelligence. The authors interpreted their data as support for the argument that the relationship between working memory and fluid intelligence was driven by individual differences in the ability to retrieve information from secondary memory. Mogle et al. concluded by posing the following proposition, “if the relationship between these tasks and fluid intelligence is not due to any unique features of complex span tasks, it may prove more fruitful to determine which secondary memory processes relate to fluid intelligence…” (p. 1076).

The present study sought replication and extension of the findings of Mogle et al. with the advantage of using a controlled laboratory design. Participants completed a battery of cognitive tests that were used to represent the constructs of working memory, secondary memory, primary memory, fluid intelligence, and processing speed. An important strength of the present study was the way in which we operationalized working memory and secondary memory. We utilized a combination of laboratory-based working memory tests (2 complex span tests and the N-back task) which allowed for a broader assessment of this multi-faceted construct (see Oberauer et al., 2008 for a discussion of this issue), as well as neuropsychological tests to assess secondary memory that have been shown to have strong psychometric properties (Wechsler, 1997a). Our goal was to investigate the robustness of the finding that secondary memory is the driving force behind the predictive power of working memory. To foreshadow our results, we found that working memory, rather than secondary memory, was special in its ability to predict higher-order cognition.

Method

Participants

There were 172 undergraduates (age *M* = 20.55, *SD* = 3.74; 43 males) retained in the final sample. They participated either for extra credit or partial fulfillment of course credit in psychology courses.

Materials

Portions of this data set were reported in Shelton et al. (2009). The previous study focused on the relationship between laboratory and clinical tests of working memory in their prediction of fluid intelligence. Please see this reference for a more complete description of the working memory and fluid intelligence tasks.

Working memory Tests—Participants completed three traditional laboratory working memory tests: the automated operation span (Ospan; Unsworth, Heitz, Shrock, & Engle, 2005), the listening span (Lspan; Cowan et al., 2003) and the N-back task (Shelton, Metzger, & Elliott, 2007). In the Ospan task, participants viewed a series of intermixed letters and math problems. First, they were told to respond to the veracity of the presented math solution which remained on the screen for a set amount of time (participants mean response time during the practice trials plus 2.5 SD's). Next, a letter appeared on the screen for 800 ms and they were told to remember the series of letters until a later point. Their score consisted of the total number of items they recalled in perfectly recalled trials. In the Lspan task participants heard sentences read aloud over headphones and they had to determine the veracity of each sentence. The decision phase was not timed but an experimenter was present to encourage participants to move forward to the next trial. Participants were told to remember the last word in each sentence for later recall. Their score reflected the total number of items correctly recalled from trials that were performed perfectly. The N-back task consisted of a list of items presented individually at a rate of 1 item per second and at the end of each list participants were asked to recall the last item in the list, the one presented 1-back, 2-back, or 3-back in the list. Only performance in the 2-back and 3-back positions was used to index working memory function. Their score was determined by the average number of items correctly recalled in the 2-back and 3-back positions.

Primary Memory—The last word and 1-back positions of the N-back task constituted our index of primary memory[1]. Participant's scores were the average number of items recalled correctly in the last word and 1-back positions.

Processing speed Tests—Digit Symbol Coding (Wechsler, 1997a) involved the participant copying symbols that have been paired with numbers. A key with the symbol/ number pairs was presented for the entire test at the top of the page containing the stimuli. The raw score reflected the number of symbols drawn beneath the presented number in 120 seconds. In the second subtest, Symbol Search (Wechsler, 1997a), the participant visually scanned for 2 target symbols embedded within a search group of 5 symbols. They were instructed to mark "yes" or "no" whether a target symbol was found in the search group. The raw score for Symbol Search was determined by the number of correct responses obtained in 120 seconds minus the number of incorrect responses.

Fluid intelligence Tests—On the Block Design subtest (Wechsler, 1997a), the participant used bicolored blocks to replicate a visually presented design. Scoring was based both on the correct replication of the design and how quickly the individual completed the task. Matrix Reasoning (Wechsler, 1997a) involved asking the participant to complete a picture or pattern by choosing the missing part from potential solutions. The task was untimed and scores reflected the number of correct solutions made. Participants also completed Raven's Advanced Progressive Matrices (Raven et al., 1998). In this task, participants viewed incomplete matrix patterns and were told to choose which option best completed the pattern. Individual scores reflected the total number of items responded to correctly in the task.

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[1] Digit span forward scores were available in this data set and we attempted to use this as an index of PM; however, several statistical analyses revealed that these scores were highly related to our WM measures and could not be statistically separated from these measures. The PM N-back index did separate nicely from the other memory measures without creating problems for the model and represented a theoretically sound index of PM. The zero-order correlation between the last item and 1-back positions used to create this index was .35, $p < .001$.

Secondary memory Tests—The following subtests of the WMS-III (Wechsler, 1997b) were used as indicators of secondary memory and were administered to participants according to the protocol described in the test manual. Raw score data were utilized for all analyses. Three of the four subtests comprising the Immediate Memory Index of the WMS-III were used to index secondary memory. The Faces I subtest was not used in further analyses as exploratory model testing revealed that it loaded poorly on the secondary memory factor. In Logical Memory I, the participant was presented with a short story and asked to immediately repeat back what they remembered. They were instructed to use the same words read by the examiner, if possible, and to start at the beginning of the story. Logical Memory I consisted of 2 stories. The first story was presented once and the second story was presented twice. Learning and recall for story material was assessed after each presentation, but only the first recall scores from the two stories were averaged to constitute scores on this test. Verbal Paired Associates I assessed the ability of the participant to learn unrelated word pairs. They were initially presented with 8 pairs of unrelated words at the rate of 1 pair every 3 seconds. They were then given the first word of each pair and asked to recall the second word. This was repeated for 4 trials always using the same list of word pairs. The total number of correctly recalled word pairs formed the total score. In Family Pictures I, the participant was shown 4 different scenes (for 10 seconds each) involving 4 different family members and were asked to remember as much as they could about each scene. Participants were then asked to name a character from the scenes, provide the character’s location, and describe what the character was doing in the scene. Scores were calculated according to the protocol outlined in the manual (Wechsler, 1997b).

Procedure

Participants completed all of the tests as part of a larger battery in two sessions that lasted two hours each, and occurred approximately one week apart. All of the laboratory tests were administered to participants at individual computer stations. The WAIS-III and WMS-III were administered by trained personnel according to manual protocols (Wechsler 1997a; 1997b). The informed consent process took place at the beginning of the first session and debriefing occurred at the end of the second session.

Results

The goal of the analyses was to examine the relationships among the measures and constructs of processing speed, primary memory, working memory, secondary memory, and fluid intelligence. This goal was approached in several steps. First, the variables were each examined for the presence of outliers. Only four variables, out of the possible 1,914, revealed values greater than 3.5 *SD* above or below the mean of the respective variable. The results did not change when these values were replaced with the mean ± 3.5 *SD*, thus the raw values were used in the following analyses. As presented in Tables 1 and 2, descriptive statistics and correlations were examined. No extreme values were observed in the skewness and kurtosis indices (Kline, 2005), suggesting univariate normality can be assumed. Next, a measurement model was tested to examine the underlying structure of the multiple indicators used to assess the four latent constructs (processing speed, working memory, secondary memory, and fluid intelligence) and the observed measure of primary memory; AMOS 7 was used (Arbuckle, 2006). It was proposed that each of the different indicators would load onto one of the four latent factors, and that each of the latent factors would be distinguishable (i.e., multicollinearity would not exist). Finally, a nested series of models was compared to evaluate the relative contributions of the different measures and constructs (i.e., processing speed, primary memory, working memory, and secondary memory) to the prediction of fluid intelligence (see Mogle et al. 2008, for a similar approach).

Three measures of model fit were calculated: χ^2, comparative fit index (CFI), and root mean square error of approximation (RMSEA). A non-significant χ^2 indicates good model fit; however, χ^2 is sensitive to sample size. A CFI value of .95 or higher, and a RMSEA value of .06 or lower, are indicative of good model fit (Hu & Bentler, 1999).

Model fit for the measurement model was good (see Figure 1) [$\chi^2(46) = 61.0$, $p = .068$, CFI = .958, RMSEA = .044]. Each of the different indicators loaded well on their respective latent constructs. Standardized factor loadings ranged between .40 and .72[2], and all paths from the observed variables to the latent constructs were significant at $p < 0.01$. Additionally, fluid intelligence was significantly correlated with processing speed ($r = .26$), primary memory Nback ($r = .37$), working memory ($r = .71$), and secondary memory ($r = .57$).

In addition to demonstrating that processing speed, primary memory, working memory, and secondary memory were all correlated with fluid intelligence, we were specifically interested in examining how these different constructs relate to the explanation of variance in fluid intelligence (i.e., how much unique variance do each of these three constructs explain in terms of fluid intelligence). Following the technique used by Mogle et al. (2008), a series of four, nested SEMs were compared, to test the changes in the model fits when different paths in the model were set to zero (see Figure 2). In the first model, the paths from working memory and secondary memory to fluid intelligence were constrained to zero, and as shown in Figure 2a, model fit was poor. The secondary memory path was constrained in Model 2 (see Figure 2b), the working memory path was constrained in Model 3 (see Figure 2c), and Model 4 allowed all of the predictors to contribute, such that processing speed, primary memory, working memory, and secondary memory were set to predict fluid intelligence (see Figure 2d). Inspection of Figure 2 revealed that Model 2 and Model 4 had very similar fit statistics. Indeed, constraining the secondary memory path in Model 2 did not result in a significant drop in model fit compared to Model 4 ($\chi^2(1) = 1.7$, $p > .05$). This clearly demonstrates that working memory is contributing special and unique variance in the prediction of fluid intelligence, above and beyond secondary memory. The only model showing a significant path for secondary memory, Model 3, was when working memory did not contribute to the prediction of fluid intelligence. Thus, our results contradict those of Mogle et al. (2008).

General Discussion

The present study addressed an important question: Is working memory special? These data suggest the answer is yes. The results of the SEM analyses revealed that working memory was a unique predictor of fluid intelligence, whereas secondary memory was not a unique predictor of the criterion construct. These results were inconsistent with the findings of Mogle and colleagues (2008) that suggested working memory was not a significant predictor of fluid intelligence once they controlled for individual differences in secondary memory. There are several possibilities for why these differences emerged.

One potential explanation for the discrepant findings stems from differences in the way in which the constructs were operationalized in the two studies. In the present study two of the three secondary memory tasks utilized recall measures, whereas two of the three secondary memory measures used in the Mogle et al. study required recognition rather than recall. It is possible that the driving force behind secondary memory and fluid intelligence in the Mogle

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[2] The standardized factor loading for Symbol Search was above 1, representing a Heywood case, that could have been driven by having only two indicators on the processing speed construct (Kline, 2005). We took two approaches to addressing this issue. First, we constrained this parameter value to 1 and tested the measurement model as well as the nested structural models (see Figures 1 and 2). Second, we removed Symbol Search from the processing speed construct, which left one observed variable representing processing speed (Digit Symbol). No notable differences were observed in the fit of the measurement model or nested structural models relative to when Symbol Search was retained in the model.

study is an overlap between the discrimination process required by the recognition tasks and the need to make a decision between potential solutions in the Raven's test. This is, of course, speculative and runs counter to the argument that recognition tests should be less related to higher-order cognition than recall tests because external cues are available to assist the retrieval process (see Unsworth & Engle, 2007b for a discussion on this topic).

A potentially more important difference between the present study and Mogle et al. is the way in which working memory was assessed. As noted by Mogle et al., one potential limitation of their study is that participants had control over the pacing of the working memory tasks (self-paced) as opposed to using tests where task administration parameters (e.g., item presentation rate, time allowed to respond to processing component) were controlled (experimenter-paced). Friedman and Miyake (2004) demonstrated that experimenter-paced tasks were more correlated with higher-order cognition than self-paced tasks. They argued that the reason for the superior predictive utility of experimenter-paced working memory tasks was that participants have to actively maintain the incoming information rather than taking additional time to implement various strategies, as is afforded by self-paced tests. In the present study two of the three working memory tasks were experimenter-paced (Ospan and N-back), while only the Lspan task was self-paced. Additionally, in the Mogle et al. study the working memory construct was defined by three complex span tasks, whereas in the present study working memory was assessed using two complex span tasks as well as the N-back task. Oberauer et al. (2008) concluded that working memory was a multi-faceted construct and defining it in this way led to superior prediction of reasoning ability (see also Süβ, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). Oberauer et al. further argued that latent constructs of working memory should be more broadly defined using a variety of different tasks. Thus, the heterogeneity of the working memory construct in the present study could have contributed to its superior prediction of fluid intelligence.

Previous research has been mixed regarding the construct validity of the N-back task as a measure of working memory but the key difference in these studies was that a recognition version of the N-back task did not correlate well with complex span tasks (Kane, Conway, Miura, & Colflesh, 2007) while a recall version of the N-back task, like the one used in the present study, was shown to be significantly correlated with complex span tasks (Shelton et al., 2007; Shelton et al., 2009). The inclusion of the N-back task strengthened the present study in several ways. First, this task encouraged participants to quickly shift items in and out of the focus of attention. Research using the N-back task has identified the focus-switching mechanism as a distinct working memory control process (Verhaeghen & Basak, 2005). The focus-switching mechanism that is presumably tapped by the N-back task could contribute to its strong relationship with fluid intelligence. Future research is needed to investigate this possibility. In addition, the results of the present study suggest another advantage of the N-back task is that an estimate of primary memory (or information present in the focus of attention) can be easily extracted from the performance index.

Although the recall version of the N-back task is a valid and useful measure of working memory, complex span tasks are the most widely used measures of working memory in laboratory-based studies and are considered by many to be the gold standard. The covert retrieval model proposed by McCabe (2008) provides an explanation for what is special about complex span tasks. According to this model, these tasks emphasize active maintenance and retrieval processes by allowing the opportunity for strategic activity during the processing stage. Specifically, many participants can complete the processing activity while also rehearsing the to-be-remembered items. McCabe provided empirical support for these predictions by observing better recall of items from complex relative to simple span tasks on a delayed test. Superior memory for items from the complex span tasks was particularly evident for the initial list items presented, supporting the prediction that participants practice retrieving the presented items during each interleaved processing stage. The fact that delayed recall rates were higher for complex span tasks suggests that the processes underlying successful performance on these tests help to facilitate learning of the material (see Roediger & Karpicke, 2006 for a review on the benefit of repeated retrieval attempts for later retention). The way in which active maintenance and repeated retrieval attempts help to reinforce learning in working memory tests could be key for why they are able to predict complex human behavior so well. Indeed, recent research has demonstrated that individual differences in associative learning predicted performance on a fluid intelligence test (Tamez, Myerson, & Hale 2008).

One potential criticism of both the Mogle et al. and the present study is that secondary memory was assessed with immediate memory tests. In previous research using immediate recall tests, separate estimates of primary and secondary memory were both derived from the memory output (Craik, 1968; Unsworth & Engle, 2006). The assumption was that most memory tests requiring immediate retrieval, and that contain enough information to exceed the capacity limit of primary memory, will elicit items that are currently being maintained in both primary and secondary memory. We were able to further evaluate this issue in the present study because participants were re-tested on all of the measures used to assess secondary memory approximately 25–35 minutes after the immediate test (Wechsler, 1997b). The scores from the delayed tests were used to represent secondary memory in a structural model that was otherwise identical to Model 2d. This model provided good fit to the data and revealed a similar pattern as that observed in Model 2d: working memory, but not secondary memory, was a unique predictor of fluid intelligence. Researchers should be cautious in choosing how to assess secondary memory to ensure the purest possible measurement is achieved; however, in the present study the same pattern of results emerged regardless if secondary memory was defined by immediate or delayed tests.

In sum, the present study demonstrated that although working memory, secondary memory, primary memory, and processing speed were all significantly related to fluid intelligence, individual differences in working memory, but not secondary memory, accounted for a significant amount of unique variance in fluid intelligence. There is converging evidence from a recent study that demonstrated working memory accounted for unique variance in fluid intelligence after controlling for individual differences in secondary memory (Unsworth, Brewer, & Spillers, 2009). Both sets of data are in line with the argument that working memory tasks are special because they demand an interaction between active maintenance of items in primary memory and a controlled search of secondary memory (Unsworth & Engle, 2007b). These results are, however, inconsistent with recent findings that suggest secondary memory is the driving force behind the observed working memory-fluid intelligence link. Although secondary memory does not appear to be the primary determinant of fluid intelligence, we do not want to minimize the important contribution of retrieval processes to performance on fluid intelligence tests. Rather, we argue that future research should focus on how working memory tests, in particular, emphasize the specific processes that drive learning. This, in turn, will shed light on why working memory consistently predicts such a diverse set of human behaviors and does so better than competing constructs.

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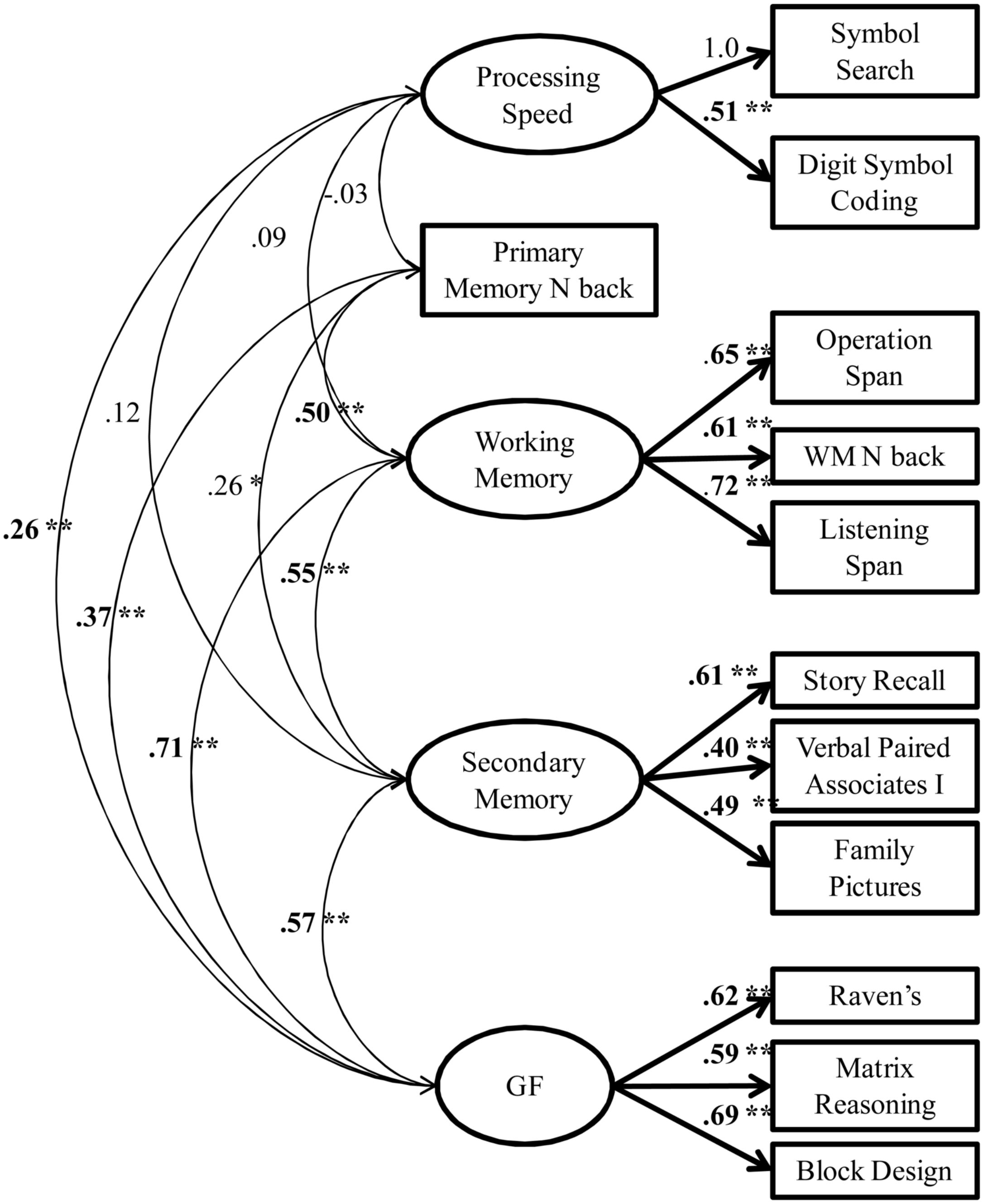

Figure 1.

Measurement model depicting the path estimates for the latent constructs of processing speed, working memory, and secondary memory predicting general fluid intelligence (*g*F). The rectangles indicate observed variables, while the ovals indicate latent constructs. The numbers on the double-headed arrows represent correlation coefficients. * indicated $p < .05$, ** indicated $p < .01$.

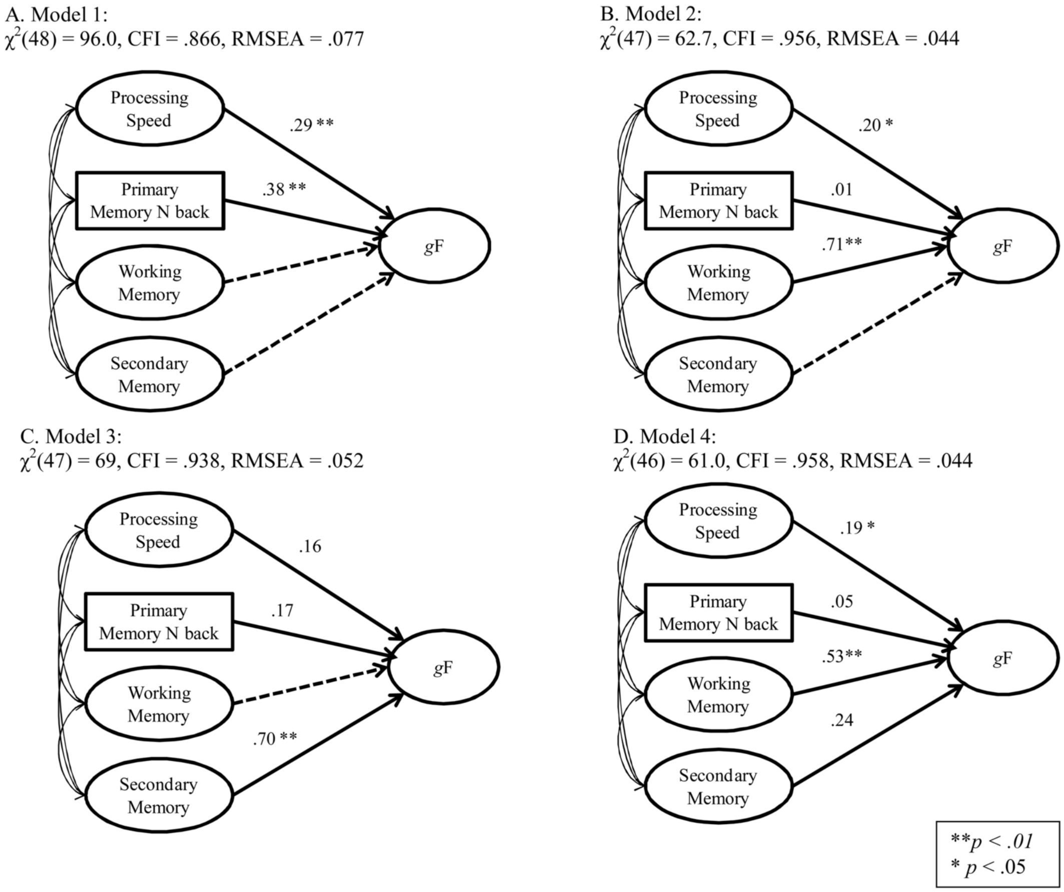

Figure 2.

Model comparison using nested structural equation models to illustrate the importance of working memory (WM) in the prediction of *g*F when other paths in the model were constrained to zero. * indicated $p < .05$, ** indicated $p < .01$.

Table 1

Descriptive Statistics for all Measures

Measure	Mean	*SD*	Range	Skew	Kurtosis
Processing Speed					
Symbol Search	41.09	6.80	39	−0.09	0.57
Digit Symbol Coding	88.25	13.27	75	−0.00	0.62
Primary Memory					
PM N-back	8.73	1.15	6.50	−1.41	3.13
Working Memory					
Operation Span	44.15	15.54	68	−0.03	−0.52
Listening Span	29.77	12.22	67	1.075	1.63
WM N-back	4.15	2.07	9.50	.19	−0.67
Secondary Memory					
Story Recall	13.86	3.24	15.5	−.11	−.64
Verbal Paired Assoc. I	22.97	5.95	28	−1.04	.98
Family Pictures I	51.36	7.44	40	−1.31	2.10
Fluid Intelligence					
Raven’s	25.50	4.04	19	−0.22	0.04
Block Design	45.79	10.94	52	−0.10	−0.67
Matrix Reasoning	19.89	2.92	17	−0.94	1.72

Note: N = 172 for all measures. Raw scores were used for the measures from the WAIS-III (processing speed) and the WMS-III (secondary memory), while weighted summary scores were used for the laboratory measures of working memory. The N-back task was divided into two components, the Primary Memory N-back measure includes the average of the raw scores for lags 0 and 1, while the Working Memory N-back includes the average of the raw scores for lags 2 and 3. Story Recall represents the average of the total number of items recalled from the first two stories in the WMS-III test, Logical Memory I. Verbal Paired Assoc. I represents the total score from the four recall trials of the WMS-III test. Fluid intelligence was represented by a combination of measures from the WAIS-III, in which raw scores were used, and the Raven’s, for which the total score was used.

Table 2

Correlations Among All Measures

Measure	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Symbol Search	*.77*											
2. Digit Symbol Coding	.51**	*.84*										
3. PM N Back	−.03	.11	*.62*									
4. Operation Span	.08	.10	.36**	*.77*								
5. Listening Span	.05	−.04	.30**	.54**	*.74*							
6. WM N Back	.05	.13	.35**	.32**	.41**	*.77*						
7. Story Recall	.02	.00	.15*	.24**	.31**	.30**	*.64*					
8. Verbal Paired Associates I	.05	.11	.17*	.07	.07	.16*	.25**	*.86*				
9. Family Pictures I	.15	.07	.08	.06	.17*	.13	.28**	.22**	*.72*			
10. Raven’s	.06	.09	.22**	.29**	.33**	.38**	.20**	.07	.20**	*.75*		
11. Block Design	.27**	.11	.29**	.29**	.31**	.34**	.15*	.17*	.28**	.41**	*.75*	
12. Matrix Reasoning	.14	.12	.19*	.18**	.26**	.32**	.20**	.18*	.21**	.40**	.40**	*.65*

[**] *Note:* represents $p < 0.01$,

[*] represents $p < 0.05$. Italicized numbers on the diagonal represent Cronbach’s Alpha measure of internal consistency, reported from the raw data, with the exception of the two measures of processing speed. As these were speeded measures, test-retest stability coefficients were used instead. These values are reported from the normed values available in the Technical Manual, across the normative sample (Wechsler, 1997a).