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Examining the relations among working memory capacity, attention control, and fluid intelligence from a dual-component framework

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Abstract

The current study examined the relations between working memory capacity, attention control, and general fluid intelligence. Participants performed multiple measures of each construct and confirmatory factor analysis and structural equation modeling was used to analyze the data. The results suggested that attention control is an important component of the working memory and general fluid intelligence relation. Additionally, attention control accounted for unique variance in general fluid intelligence above and beyond working memory capacity. Consistent with the dual-component model of working memory, substantial independent variance was left over after accounting for attention control's role in this relation. Therefore, other important mediating variables need to be accounted for to fully appreciate working memory's ability to predict general fluid intelligence (e.g., retrieval from secondary memory).

Key words: working memory; attention control; fluid intelligence

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Measures of working memory capacity such as reading span, operation span, symmetry span, and counting span, to name a few, have frequently been shown to predict performance on measures of intelligence and specifically on measures of fluid intelligence (e.g., Ackerman, Beier, & Boyle, 2005; Conway et al., 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004; Kyllonen & Christal, 1990). However, the reason for the relation between working memory capacity (WMC) and fluid intelligence (gF) is still not fully understood. Several theories have been proposed to account for this substantial relation, with some theories arguing for the importance of attention control (Engle & Kane, 2004), some theories arguing for the importance of the scope of attention (Cowan et al., 2005), some theories arguing for the importance of relational binding (Oberauer et al., 2007), some theories arguing for the importance of secondary memory processes (Mogle et al., 2008), and others arguing for a combination of attention control and controlled retrieval from memory (Unsworth & Engle, 2007). The aim of the current study was to examine whether attention control accounts for the relation between WMC and gF, or whether multiple sources of variance account for the relation.

Working memory capacity, attention control, and fluid intelligence

A number of studies by Engle, Kane, Conway, and colleagues (Engle & Kane, 2004; Kane, Conway, Hambrick, & Engle, 2007) have suggested that individual differences in WMC really reflect differences in executive attention. That is, individual differences in WMC reflect underlying differences in the ability to control attention in order to maintain task or goal relevant information in a highly accessible or active state in situations where there is substantial internal and external distraction and interference. In particular, this view suggests that individuals high in WMC are better at controlling aspects of their attention to actively maintain goal relevant information in order to successfully perform a task than individuals low in WMC. Furthermore, these differences are especially pronounced under conditions of high interference or distraction in which attentional capture away from task or goal irrelevant information is likely. Thus, high WMC individuals are better at preventing interference or distraction than low WMC individuals and this attention control ability is needed in a host of activities regardless of specific stimulus or processing domains.

As a case in point, take the antisaccade task. In this task participants are told to fixate at center and after a variable amount of time one of two boxes at either side of the screen is going flash. In the prosaccade version of this task, participants are instructed to simply look at the flashing box. In the antisaccade version, however, participants are instructed to not look at the flashing box, and instead to look at the box on the opposite side of the screen. According to the executive attention view of WMC, this task requires a great deal of attention control in order to maintain the task goal (e.g., “look away from the flash”) in the presence of a potent distractor that will likely capture attention. Thus, any lapse of attention in this task will likely lead to a loss of the task goal and will result in attention being automatically captured by the cue leading to an error. In terms of individual differences in WMC, this means that high and low WMC individuals should not differ on relatively automatic prosaccades, but that low WMC individuals should make more errors on the attention demanding antisaccades. Results consistent with this prediction have been found in several studies (e.g., Kane, Bleckley, Conway, & Engle, 2001; Unsworth, Schrock, & Engle, 2004). In these studies low WMC individuals consistently performed worse on the antisaccade task compared to high WMC individuals. These results provide strong support for the executive attention view of WMC by suggesting that high and low WMC individuals differ in basic attention control abilities.

Additional work examining WMC differences in a number of attention control paradigms has corroborated the executive attention account of WMC. For instance, recent work has demonstrated WMC differences in dichotic listening (Conway, Cowan, & Bunting, 2001; Colflesh & Conway, 2007), Stroop interference (Kane & Engle, 2003; Long & Prat, 2002), flanker interference (Heitz & Engle, 2007; Redick & Engle, 2006), as well as differences in flexible visual attention allocation (Bleckley, Durso, Crutchfield, Engle, & Khanna, 2003). In each case, high WMC individuals were better at controlling aspects of their attention than low WMC individuals. Recently, Poole and Kane (2009; see also Kane et al., 2006) have suggested that these tasks can be usefully grouped into functional categories in which attention control is needed to *restrain* attention and prevent attentional capture from prepotent responses as in the antisaccade and Stroop tasks. In this view, attention control is also needed to *constrain* attention to specific objects or locations amongst other interfering distractor objects as in flanker tasks. Furthermore, attention control is also needed to *sustain* attention on task over lengthy periods in order to prevent lapses of attention to internal and external distractors (see for example Kane, Brown, et al., 2007; McVay & Kane, 2009). According to Poole and Kane (2009), a common attention control mechanism is needed for these three aspects of attention (i.e., restrain, constrain, and sustain) and the common variance across these three aspects (or functions) of attention should be related to individual differences in WMC.

In terms of the relation between WMC and gF, a strong version of this executive attention theory would suggest that the shared variance between WMC and gF should be fully accounted for by attention control. That is, individual differences in attention control should mediate the relation between WMC and gF. According to a strong version of the executive attention view, the reason for the substantial relation between WMC and gF is because of basic differences in the ability to control attention. Once variance in attention control is accounted for, there should no longer be any shared variance between WMC and gF. However, it should be noted that Kane et al., (2006) have suggested that attention control (or executive attention) may not fully mediate the relation between WMC and gF, given that other processes in addition to attention control may be important for the relation between WMC and gF.

In regards to this latter point, we (Unsworth & Engle, 2007; Unsworth, Brewer, & Spillers, in press) have recently suggested a dual-component framework for interpreting individual differences in WMC. In this view, individual differences in WMC partially reflect differences in attention control abilities as noted above. In addition, individual differences in WMC also reflect differences in controlled retrieval abilities in which information that could not be maintained in the focus of attention (due to distraction and/or capacity constraints) has to be retrieved back into the focus via a cue-dependent search process (e.g., Shiffrin, 1970). Thus, high and low WMC individuals should differ not only on basic low level attention tasks that require attention to be restrained, constrained, or sustained, but also on more basic memory tasks where a controlled/strategic search of memory is needed to recover information that could not be maintained. Similar to the fact that attention control abilities can be functionally broken down, we have also suggested that controlled/strategic retrieval consists of multiple functional components which high and low WMC individuals should differ on (Unsworth, 2008; Unsworth, in press). For instance, in line with search models in general (e.g., Raaijmakers & Shiffrin, 1980) we have suggested that a number of control processes operate at retrieval including setting up an appropriate retrieval plan, selecting cues/probes to engage in a strategic search, monitoring the outputs of the search process for accuracy, editing the products of the search based on correct and error responses, and deciding to continue or terminate search and WMC should be important for each of these memory processes to the extent that willful controlled search is needed for accurate task performance.

In terms of the relation between WMC and gF, this dual-component framework suggests that part of the relation between WMC and gF is due to attention control abilities. Importantly, this view suggests that attention control should not fully mediate the relation between WMC and gF, given that additional processes (e.g., controlled retrieval) should also be important for the relation between WMC and gF. Thus, this view suggests that the shared variance between WMC and gF is due to at least two distinct sources of variance (attention control and controlled retrieval; Unsworth, Brewer, & Spillers, in press) and suggests that it is possible that other distinct sources are important as well (e.g., scope of attention, binding operations, etc.).

The present study

The aim of the present study was to examine the relations between WMC, attention control, and gF. In particular, we examined whether attention control was related to WMC and gF and whether attention control would fully account for the shared variance between WMC and gF. As noted above, according to a strong version of the executive attention view, attention control should fully mediate the relation between WMC and gF (although see Kane et al., 2006), to the extent that the predictive power of WMC is localized to attention control abilities. However, the dual-component framework (Unsworth & Engle, 2007; Unsworth, Brewer, & Spillers, in press) suggests that part of the relation between WMC and gF should be accounted for by attention control, but that WMC should also predict unique variance in gF after controlling for attention control. As noted above, this prediction reflects the fact that attention control is only part of the reason for individual differences in WMC; other sources of differences such as controlled retrieval are also important and must be taken into account to fully understand the WMC-gF relation.

As noted by Cowan et al., (2006), although the strong version of the executive attention theory suggests that attention control should mediate the relation between WMC and gF, relatively few studies have actually examined correlations among WMC, attention control, and gF. For instance, Cowan et al., (2006) found that a measure of the scope of attention (i.e., size of the focus of attention) and a measure of attention control both were correlated with intelligence, and both accounted for unique variance in intelligence. Furthermore, Schweizer, Moosbrugger, and Goldhammer (2005) found that latent variables derived from multiple attention control measures were related to gF, and that a single higher-order attention control factor accounted for 32% of the variance in gF. Similarly, examining latent attention control and WMC variables in the same study, Schweizer and Moosbrugger (2004) found that both attention control and WMC predicted gF as measured by the Raven Advanced Progressive Matrices (Raven, Raven, & Court, 1998). These results suggest that attention control is related to intellectual functioning and accounts for some unique variance in gF even when WMC is taken into account. That is, both WMC and attention control seem to be related to gF and both account for unique variance. These results are consistent with the dual-component model of WMC in that attention control does not fully mediate the relation between WMC and gF as a strong version of the executive attention account would suggest.

The goal of the present study was to build on these results and examine the extent to which attention control fully mediates the relation between WMC and gF, or whether both attention control and WMC account for some unique variance in gF. Although the Schweizer and Moosbrugger (2004) study provides initial evidence for this view, the current study builds on their work in two important ways. First, Schweizer and Moosbrugger (2004) found that both attention control and WMC accounted for unique variance in gF only when examining the Raven task as the criterion variable. Examining another measure of intelligence (the ZVT), Schweizer and Moosbrugger (2004) found that only attention control accounted for unique variance. Thus, it is unclear whether the unique variance accounted for by WMC was due to an idiosyncratic relationship with the Raven task or whether these results would generalize to a broader gF factor. Therefore, in the current study participants not only performed a version of the Advanced Progressive Matrices, but also performed a version of number series (Thurstone, 1962), and an inductive verbal analogies test, in order to have a fairly broad gF factor composed of spatial, numerical, and verbal reasoning tasks.

Second, the tasks used by Schweizer and Moosbrugger (2004) to represent WMC and attention control are a bit different than the tasks used to examine the executive attention and dual-component accounts of WMC (e.g., Engle & Kane, 2004; Unsworth & Engle, 2007). Specifically, Schweizer and Moosbrugger (2004) used versions of the exchange test and the swaps test as their working memory measures, whereas previous work examining the executive attention and dual-component frameworks has almost exclusively relied on complex span tasks (reading span, operations span, etc.) to measure WMC. Although it is likely that these tasks are fundamentally related, it is an open question as to whether the relations found by Schweizer and Moosbrugger (2004) will be found with the complex span tasks. Therefore, in the current study participants performed the reading span and operation span tasks, and these tasks were used as our measures of WMC.

Additionally, Schweizer and Moosbrugger (2004) relied on primarily sustained attention tasks to measure attention control in their study, but as noted above, Poole and Kane (2009) have suggested that attention control is needed not only to sustain attention, but also to restrain and constrain attention. Therefore, in the current study we had participants not only perform a sustained attention task (the psychomotor vigilance task; Dinges & Powell, 1985), but participants also performed a task that required attentional restraint (the antisaccade task), and a task that required attentional constraint (the flanker task). In using these tasks we hoped to derive a broad attention factor that would capture the three important components of attention control as suggested by Poole and Kane (2009). Using these tasks we examined the relations among WMC, attention control, and gF, and the extent to which WMC and attention control would account for unique variance in gF.

Method

Participants

A total of 155 participants (60% female) were recruited from the subject-pool at the University of Georgia. Participants were between the ages of 18 and 35 (*M* = 18.79, *SD* = 1.21) and received course credit for their participation. Each participant was tested individually in a laboratory session lasting approximately two hours.

Materials and procedure

After signing informed consent, all participants completed operation span, reading span, antisaccade, psychomotor vigilance, flankers, Raven, verbal analogies, and number series. All tasks were administered in the order listed above.

Tasks

Working memory capacity tasks

Operation Span (Ospan). Participants solved a series of math operations while trying to remember a set of unrelated letters (F, H, J, K, L, N, P, Q, R, S, T, Y). Participants were required to solve a math operation and after solving the operation they were presented with a letter for 1 s. Immediately after the letter was presented the next operation was presented. Three trials of each list-length (3-7) were presented for a total possible of 75. The order of list-length varied randomly. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters (see Unsworth, Heitz, Schrock, & Engle, 2005 for more details). Participants received three sets (of list-length two) of practice. For all of the span measures, items were scored if the item was correct and in the correct position. The score was the proportion of correct items in the correct position.

Reading span (Rspan). Participants were required to read sentences while trying to remember the same set of unrelated letters as Ospan. For this task, participants read a sentence and determined whether the sentence made sense or not (e.g. "The prosecutor's dish was lost because it was not based on fact. ?"). Half of the sentences made sense while the other half did not. Nonsense sentences were made by simply changing one word (e.g. "dish" from "case") from an otherwise normal sentence. Participants were required to read the sentence and to indicate whether it made sense or not. After participants gave their response they were presented with a letter for 1 s. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters. There were three trials of each list-length with list-length ranging from 3–7 for a total possible of 75. The same scoring procedure as Ospan was used.

Attention control tasks

Antisaccade. In this task (Kane, Bleckley, Conway, & Engle, 2001) participants were instructed to stare at a fixation point which was onscreen for a variable amount of time (200-2200 ms). A flashing white "=" was then flashed either to the left or right of fixation (11.33°

of visual angle) for 100 ms. This was followed by the target stimulus (a B, P, or R) onscreen for 100 ms. This was followed by masking stimuli (an H for 50 ms and an 8 which remained onscreen until a response was given). The participants' task was to identify the target letter by pressing a key for B, P, or R (the keys 1, 2, or 3) as quickly and accurately as possible. In the prosaccade condition the flashing cue (=) and the target appeared in the same location. In the antisaccade condition the target appeared in the opposite location as the flashing cue. Participants received, in order, 10 practice trials to learn the response mapping, 15 trials of the prosaccade condition, and 60 trials of the antisaccade condition. The dependent variable was proportion correct on the antisaccade trials.

Arrow flankers. Participants were presented with a fixation point for 400 ms. This was followed by an arrow directly above the fixation point for 1700 ms. The participants' task was to indicate the direction the arrow was pointing (pressing the F for left pointing arrows and pressing J for right pointing arrows) as quickly and accurately as possible. On 50 neutral trials the arrow was flanked by two horizontal lines on each side. On 50 congruent trials the arrow was flanked by two arrows pointing in the same direction as the target arrow on each side. Finally, on 50 incongruent trials the target arrow was flanked by two arrows pointing in the opposite direction as the target arrow on each side. All trial types were randomly intermixed. The dependent variable was the reaction time difference between incongruent and congruent trials.

Psychomotor Vigilance Task (PVT). The psychomotor vigilance task (Dinges & Powell, 1985) was used as the primary measure of sustained attention. Participants were presented with a row of zeros (i.e., 00.000) on screen indicating seconds and milliseconds. After a variable amount of time the zeros began to count up in 1 ms intervals from 0 ms. The participants' task was to press the spacebar as quickly as possible once the numbers started counting up. After pressing the spacebar the RT was left on screen for 1 s to provide feedback to the participants. Interstimulus intervals were randomly distributed and ranged from 1 to 10s. The entire task lasted for 10 minutes for each individual (roughly 75 total trials). The dependent variable was the average reaction time for the slowest 20% of trials (Dinges & Powell, 1985).

Fluid intelligence (gF) tasks

Raven Advanced Progressive Matrices. The Raven is a measure of abstract reasoning (Raven, Raven, & Court, 1998). The test consists of 36 items presented in ascending order of difficulty (i.e. easiest – hardest). Each item consists of a display of 3 x 3 matrices of geometric patterns with the bottom right pattern missing. The task for the participant is to select among eight alternatives, the one that correctly completes the overall series of patterns. Participants had 10 minutes to complete the 18 odd-numbered items. A participant's score was the total number of correct solutions. Participants received two practice problems.

Number Series. In this task participants saw a series of numbers and were required to determine what the next number in the series should be (Thurstone, 1962). That is, the series follows some unstated rule which participants are required to figure out in order to determine which the next number in the series should be. Participants selected their answer out of five possible numbers that were presented. Following five practice items, participants had 4.5 minutes to complete 15 test items. A participant's score was the total number of items solved correctly.

Verbal analogies. In this task participants read an incomplete analogy and were required to select the one word out of five possible words that best completed the analogy. After one practice item, participants had 5 minutes to complete 18 test items. These items were originally selected from the Air Force Officer Qualifying Test (AFOQT; Berger, Gupta, Berger, & Skinner, 1990), and we used the same subset of items used in Kane et al. (2004). A participant's score was the total number of items solved correctly.

Results

Descriptive statistics

As can be seen in Table 1, the measures had generally acceptable values of internal consistency and most of the measures were approximately normally distributed with values of skewness and kurtosis under the generally accepted values (i.e., skewness < 2 and kurtosis < 4; see Kline, 1998). Correlations, shown in Table 2, were weak to moderate in magnitude. It should be noted that despite the weak nature of these correlations, they are similar in magnitude to similar correlations that have been found for WMC and attention control variables in previous studies (e.g., Friedman & Miyake, 2004; Unsworth et al., in press). It is likely that the weak magnitude of the correlations was due in part to the fact that the current sample of participants tended to be high ability participants (Detterman & Daniel, 1989; Spearman, 1927).

Next, we used confirmatory factor analysis to test several measurement models of the three constructs of interest. Model 1 tested a single factor model in which all of the tasks loaded onto a single factor. The fit of the model was acceptable, χ^2 (20) = 36.99, $p < .05$, RMSEA = .07, SRMR = .07, NNFI = .88, CFI = .91, AIC = 68.99. Model 2 tested a two-factor model in which the WMC and attention control tasks loaded onto a single factor and the gF tasks loaded onto another factor. These two factors were allowed to correlate. The fit

Table 1:
Descriptive statistics and reliability estimates for all measures

Measure	M	SD	Skew	Kurtosis	Reliability
Ospan	64.01	7.25	-.72	-.03	.79
Rspan	60.55	9.19	-.62	-.16	.81
Anti	.54	.12	.31	-.64	.69
Flanker	103.21	45.99	2.02	10.40	--
PVT	519.65	130.47	1.76	4.65	.97
Raven	10.21	2.66	-.42	.45	.66
NS	9.65	2.54	.11	-.85	.71
Analogy	7.32	2.45	-.27	-.46	.68

Note. Ospan = operation span; Rspan = reading span; Anti = antisaccade; Flanker = arrow flankers; PVT = psychomotor vigilance task; Raven = Raven Advanced Progressive Matrices; NS = number series; Analogy = verbal analogies; -- = reliability could not be calculated.

Table 2:
Correlations for all measures.

Variable	1	2	3	4	5	6	7	8
1. Ospan	--							
2. Rspan	.57	--						
3. Anti	.05	.12	--					
4. Flanker	-.18	-.13	-.25	--				
5. PVT	-.13	-.25	-.17	.17	--			
6. Raven	.20	.26	.15	-.20	-.12	--		
7. NS	.17	.20	.16	-.12	-.23	.20	--	
8. Analogy	.18	.35	.08	-.13	-.10	.23	.18	--

Note. Ospan = operation span; Rspan = reading span; Anti = antisaccade; Flanker = arrow flankers; PVT = psychomotor vigilance task; Raven = Raven Advanced Progressive Matrices; NS = number series; Analogy = verbal analogies.

of the model was acceptable, χ^2 (19) = 31.95, $p < .05$, RMSEA = .07, SRMR = .07, NNFI = .90, CFI = .93, AIC = 65.95. Model 3 tested a three factor model, one for WMC, one for attention control, and one for gF. The WMC factor was composed of the operation and reading span tasks, while the attention control factor was composed of the antisaccade task, the flanker task, and the psychomotor vigilance tasks. Finally, the gF factor was composed of the Raven, number series, and verbal analogies. All three factors were allowed to correlate. The fit of this model was good, χ^2 (17) = 13.95, $p > .67$, RMSEA = .00, SRMR = .04, NNFI = 1.0, CFI = 1.0, AIC = 51.95. Importantly, the fit of this model was significantly better than either Model 1 or Model 2, both $\Delta\ \chi^2$'s > 18, p's < .01. This suggests that WMC, attention control, and gF can be considered as three separate, yet related constructs. The resulting model is shown in Figure 1. As can be seen, each of the measures loaded significantly on their construct of interest and each of the latent variables were correlated with one another.

In order to examine the question of primary interest we used structural equation modeling. Specifically, as noted previously, a strong version of the attention control view of WMC would suggest that attention control should fully mediate the relation between WMC and gF (although see Kane et al., 2006). In contrast, the dual-component framework suggests that attention control should account for a substantial amount of the shared variance between WMC and gF, but that WMC should still predict gF even when controlling for attention control given that other processes (such as secondary memory search) are also important. Therefore, we specified a structural equation model in which both WMC and attention control predicted gF and WMC and attention control were allowed to correlate. If the attention control view is correct, then attention control should have a direct effect on gF, but WMC should not. Rather, the relation between WMC and gF should be mediated through attention control. On the other hand, if WMC has a direct effect on gF, then its path to gF should be significant even with the path from attention control to gF freed, and fixing the path from WMC to gF should result in poorer model fit.

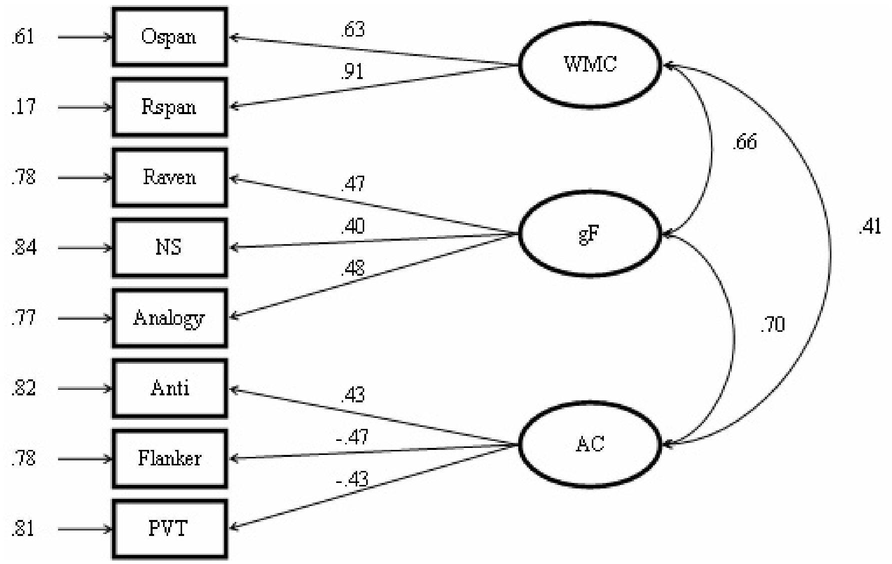

Figure 1:
Measurement model for working memory capacity (WMC), general fluid intelligence (gF), and attention control (AC). Paths connecting latent variables (circles) to each other represent the correlations between the constructs, the numbers from the latent variables to the manifest variables (squares) represent the loadings of each task onto the latent variable, and numbers appearing next to each manifest variable represent error variance associated with each task. Ospan = operation span; Rspan = reading span; Raven = Raven Advanced Progressive Matrices; NS = number series: Analogy = verbal analogies; anti = antisaccade; flanker = arrow flanker; PVT = psychomotor vigilance task. All paths and loadings were significant at the *p* < .05 level

Shown in Figure 2 is the resulting model. As can be seen, both WMC and attention control had direct effects on gF with both paths being significant. Furthermore, the fit of the model was good (and technically the same as the measurement model given the same covariance structure), χ^2 (17) = 13.95, $p > .67$, RMSEA = .00, SRMR = .04, NNFI = 1.0, CFI = 1.0, AIC = 51.95. Importantly, fixing either the path from WMC to gF, or the path from attention control to gF to zero resulted in a significantly poorer fit, both $\Delta\ \chi^2$'s > 4.5, *p*'s < .05. Thus, although attention control significantly predicted gF as attention control views of WMC would suggest, attention control did not fully mediate the relation between WMC and gF. Rather, WMC also had a direct effect on gF even when taking into account attention control.

As argued previously, the dual-component framework of WMC suggests that the shared variance between WMC and gF after controlling for attention control likely reflects secondary memory retrieval processes (as well as other possible processes) that are needed in gF tasks independently of attention control. As a further test of this notion, we specified another structural equation model in which the attention control latent variable was composed of the

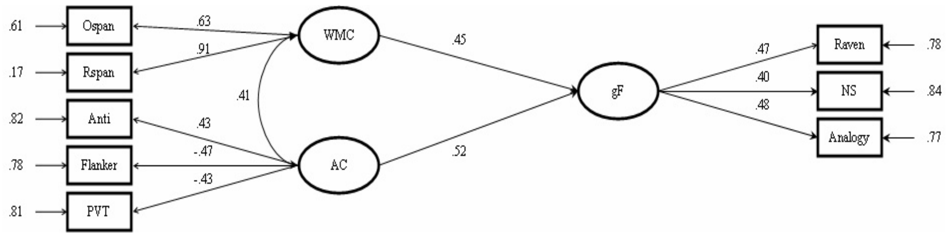

Figure 2:

Structural equation model for working memory capacity (WMC) and attention control (AC) predicting fluid intelligence (gF). All paths and loadings were significant at the $p < .05$ level

variance common to the three attention control tasks and the two complex spans (the logic being that all WMC and attention control tasks are influenced by attention control processes). The WMC latent variable was composed of the common variance shared between the complex spans independent of the shared variance with the attention control tasks. The correlation between these two factors was constrained to zero and both were allowed to predict gF. Thus, this model tests the notion that WMC measures are composed of at least two separate sources of variance, both of which are related to gF (see also Unsworth, Brewer, & Spillers, in press).

The fit of this model was good, χ^2 (16) = 13.81, $p > .61$, RMSEA = .00, SRMR = .04, NNFI = 1.0, CFI = 1.0, AIC = 53.81. As shown in Figure 3, the WMC measures significantly cross-loaded on both the attention control and WMC factors as expected. Furthermore, both the common attention control factor and the independent WMC factor significantly predicted gF. Given that the correlation of these two factors was set to zero, this means that both the common attention control factor and the independent WMC factor accounted for unique variance in gF. In fact, collectively these two factors accounted for 65% of the variance in gF. The common attention control factor accounted for 49% of the variance and the independent WMC factor accounted for 16% of the variance. Thus, at least two sources of variance are important in accounting for the shared variance between WMC and gF.

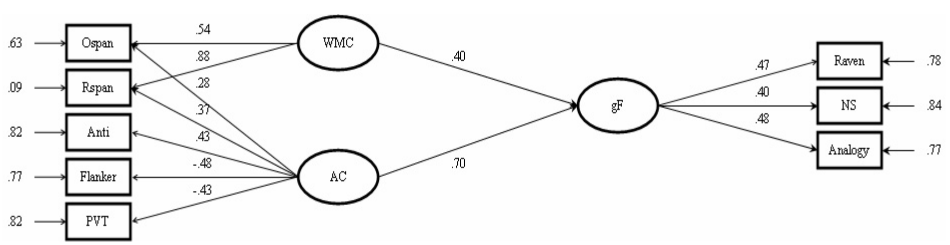

Figure 3:

Structural equation model for the common variance shared across the working memory capacity and attention control tasks (AC) and the independent variance common to only the working memory capacity tasks (WMC) predicting fluid intelligence (gF). All paths and loadings were significant at the $p < .05$ level

Discussion

The current study examined the relations among WMC, attention control, and gF from a latent variable perspective. Participants performed multiple measures of WMC, multiple measures of attention control (i.e., measures of restrained, constrained, and sustained attention), and multiple measures of gF. Consistent with attention control views of WMC (Engle & Kane, 2004) it was found that WMC, attention control, and gF were all moderately related to one another. Using structural equation modeling it was found that both attention control and WMC significantly predicted gF. Fixing either of these paths to zero resulted in poorer model fit. These results are consistent with prior work suggesting that attention control is related to intelligence (Schweizer, Moosbrugger, & Goldhammer, 2005) and that both attention control and WMC account for unique variance in intelligence (Schweizer & Moosbrugger, 2004). Thus, consistent with attention control views of WMC, attention control was a significant predictor of gF. However, inconsistent with strong versions of the attention control view, attention control did not fully mediate the relation between WMC and gF.

A subsequent structural equation model in which one factor was composed of the variance common to all the attention control and WMC tasks, and another factor was composed of only the WMC tasks was also tested. This model suggested that much of the variance shared between WMC and gF was accounted for by common attention control processes that are needed in WMC, attention control, and gF tasks. This model also suggested that the independent WMC factor predicted variance in gF independent of that accounted for by the common factor (i.e., attention control). Thus, processes other than just attention control are important for the shared variance between WMC and gF.

These results are consistent with a dual-component framework of WMC (Unsworth & Engle, 2007), suggesting that at least two sources of variance (attention control and secondary memory) account for much of the shared variance between WMC and gF. That is, this framework suggests that attention control is an important component of WMC and a major reason for its predictive power, but at the same time the framework suggests that it is not the sole reason for the relation between WMC and gF. Rather, in this framework other processes such as controlled retrieval from secondary memory are also important. Thus, this view suggests that attention control should not fully account for the relationship between WMC and gF, rather there should be some shared variance between WMC and gF that is independent of the shared variance with attention control. The results of the current study are clearly consistent with this framework and suggest that at least two sources of variance are important in accounting for the shared relation between WMC and gF (e.g., Unsworth, Brewer, & Spillers, in press). Other possible sources of variance include size or scope of the focus of attention (Cowan et al., 2006), binding operations (Oberauer, Süß, Wilhelm, & Sander, 2007), as well as updating and attention switching operations (Oberauer, 2002; Unsworth & Engle, 2008).

Overall, these results point to the multifaceted nature of WMC and suggest that the predictive power of WMC is multiply determined. Consistent with prior theorizing (Engle & Kane, 2004), a great deal of the predictive power of WMC is due to variance shared with attention control measures such as antisaccade, Stroop, flanker, and psychomotor vigilance. At the same time, this is not the whole story. Other sources of variance such as retrieval from secondary memory, size of the focus of attention, binding operations, and updating are also critical to understanding the WMC-gF relation. To fully understand the WMC-gF relation we need to examine multiple sources of variance, rather than just looking for a unitary source.

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