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Interference control, working memory capacity, and cognitive abilities: A latent variable analysis

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ABSTRACT

The present study examined whether various indices of interference control were related to one another and to other cognitive abilities. It was found that the interference control measures were weakly correlated and could form a single factor that was related to overall memory performance on the tasks as well as to measures of working memory capacity and fluid and crystallized intelligence. Furthermore, it was found that both working memory capacity and memory performance mediated the relation between interference control and intelligence and both accounted for variance in intelligence over and above that accounted for by interference control. These results suggest that interference control is an important cognitive construct that is related to other cognitive abilities. These results have implications for a number of areas that rely on the notion of interference control as an explanatory construct.

1. Introduction

The notion that the ability to control one's memory is an important aspect of remembering has long been a topic of interest for memory researchers. For instance, Atkinson and Shiffrin (1971) in a paper pointedly titled "The Control of Short-Term Memory" emphasized that control processes such as rehearsal, coding, decisions, and retrieval strategies were important components of remembering. Furthermore, Atkinson and Shiffrin emphasized that these processes were under the direct control of the individual and thus performance by a given individual was determined in large part based on which control processes were utilized in a given task and the individual's ability to adequately use those control processes. Thus, it can be expected that individuals who are better able to control aspects of their memories will demonstrate better performance on a number of memory tasks and will likely show better performance in a number of situations that rely on an efficient memory system than individuals who are less able to control the aspects of their memories.

1.1. Interference control and cognitive abilities

One function that has received a great deal of attention of late is the ability to control interference of information in working memory (WM). Specifically, recent work has suggested that the ability to deal with interference or conflict from recently presented information that was once relevant, but is now irrelevant, is one key component of WM and one reason why WM tasks tend to predict performance on many higher-order cognitive tasks. In these interference control views it is assumed that relevant and irrelevant representations compete for limited access in WM requiring individuals to either prevent these irrelevant representations from gaining access in the first place or to get rid of them once they have gained access (Braver, Gray, Burgess, 2007; Hasher , Lustig, & Zacks, 2007; Kane, Conway, Hambrick, & Engle, 2007; Unsworth & Engle, 2007). Note in the current paper interference control refers only to interference from competing memory traces and does not index other potential inhibitory constructs such as resistance to prepotent responses. Currently these views differ in the mechanism(s)

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that is responsible for preventing or resolving this interference with some arguing for inhibition or suppression as the key mechanism (Hasher et al., 2007), while others argue for the role of active goal maintenance (Braver et al., 2007; Kane et al., 2007), or for the use of accurate retrieval cues and source monitoring processes to focus the search process (Hedden & Park, 2003; Unsworth & Engle, 2007). Regardless of the specific mechanism(s) that is postulated to deal with interference each of these interference control views suggests that the ability to effectively deal with interference is an important control process that is utilized in a number of memory tasks and may be one important determinant of individual differences in cognitive abilities more broadly.

Additional recent work has specifically focused on interference control as a potentially important control function not only in healthy young adults, but also in healthy older adults (Hasher et al., 2007), healthy children (Dempster 1992, Kail, 2002), individuals with reading disabilities (Chiappe, Hasher, & Siegel, 2000), as well individuals with frontal damage (Janowsky, Shimamura, Kritchevsky, & Squire, 1989) to name a few. In each of these situations it is suggested that the low ability participants demonstrate poorer overall performance in part due to deficits in interference control in which they cannot effectively prevent or resolve conflict between competing traces. Furthermore, recent neuropsychological and neuroimaging work has suggested that several areas seem to be related to interference control including inferior frontal gyrus, lateral prefrontal cortex, and possibly the anterior cingulate (see Jonides & Nee, 2006 for a review). Finally, recent work has suggested that interference control is likely needed in a number of real world situations where task irrelevant information competes for access in WM including stress and anxiety, depression, stereotype threat, as well as potentially socially inappropriate responses (see Unsworth, Heitz, & Engle, 2005 for a review). For instance, Joormann and Gotlib (2008) have recently shown that depressed individuals are poorer at interference control when the irrelevant material is negative in nature. Thus, interference control is an important explanatory construct in a number of research domains.

This work points to a fairly standard view of interference control (e.g., Dempster & Corkill, 1999; Friedman & Miyake, 2004) in which the ability to deal with interfering representations in WM is required on many memory tasks and in many real world situations. Individuals who perform poorly on these memory tasks do so, in part, because they are unable to deal with interference due to deficits in inhibition, active maintenance, or source monitoring. Furthermore, aspects of the frontal lobes are critical for this ability to effectively deal with interference. This standard view suggests that measures of interference control obtained from various memory tasks are all in fact measuring the same thing, and that this common variance is related to other importance cognitive abilities such as intelligence (Dempster & Corkill, 1999).

Recent work has focused on this last point and has attempted to examine the extent to which indices of interference control are related to one another and to other measures of cognitive abilities. For instance, Friedman and Miyake (2004) examined the extent to which multiple measures of interference control were related to one another and were related to other inhibitory constructs (such as resistance to prepotent responses) and to other putative measures of inhibition and executive functions. Friedman and Miyake (2004) found that indices of interference control were moderately related to one another and loaded on the same factor. Furthermore, this interference control factor was related to performance on a measure of working memory capacity (WMC) as well as the White Bear Suppression Inventory (Wegner & Zanakos, 1994), but was generally not related to the other inhibition related tasks and factors. Thus, this work suggests that interference control represents a distinct cognitive construct that is related to other cognitive abilities.

Using another large sample of participants and tasks, Salthouse, Siedlecki, and Krueger (2006) found little evidence that several indices of interference control were related to one another, or any evidence that they were related to other cognitive abilities such as fluid and crystallized intelligence (gF and gC). Given the lack of evidence of a distinct interference control factor in their study, Salthouse et al. suggested that it was still an open question as to whether interference control measures are related to one another at the individual level and whether they are related to other cognitive abilities. Furthermore, some additional studies have suggested a relationship between indices of interference control and WMC and performance on cognitive abilities measures (e.g., Bunting, 2006; Cantor & Engle, 1993; Dempster & Corkill, 1999). Thus, the evidence that different indices of interference control are related to one another and to other cognitive abilities is somewhat mixed and as noted by Salthouse et al. (2006) more work is needed to examine the notion of a distinct interference control factor that is related to other cognitive abilities.

1.2. The present investigation

The purpose of the current paper was to better explore the notion that individuals differ in their interference control abilities and that these abilities are related to other important cognitive abilities. Specifically, similar to Friedman and Miyake (2004) and Salthouse et al. (2006), multiple indicators of interference control and of the various cognitive abilities constructs were used to form latent variables and the relation among the latent variables was examined. The three interference control tasks chosen for investigation were:

1. A version of the Brown-Peterson task with category switches to assess the buildup and release of proactive interference. A great deal of work has been done on this task elucidating the build and release of proactive interference as well as determining various individual, group, and neuropsychological differences.
2. A cued-recall directed forgetting task (Tolan & Tehan, 1999) with category cues to assess directed forgetting and susceptibility to interference. Like the Brown-Peterson task discussed above, this task has been used to examine interference and cuing effects in immediate memory tasks as well as individual and group (aging) differences in these processes (Tehan & Hauff, 2000).
3. A recent probes recognition task (Nelson, Reuter-Lorenz, Sylvester, Jonides, & Smith, 2003) to assess susceptibility to interference and conflict from recent trials. This task has

been used extensively by Jonides and colleagues to examine the neural substrates of interference and conflict in immediate memory as well as age differences in those processes (e.g., Jonides et al., 2000).

These three tasks were chosen because they have trials/conditions that theoretically require a great deal of interference control as well as trials/conditions where interference control is likely not needed. As such it should be possible to compute difference scores that provide an index of specific interference control abilities which should be related to one another and to other cognitive abilities.

In addition to examining the relation between interference control and cognitive abilities, a second question addressed in the current study was the extent to which WMC would mediate the relation between interference control and cognitive abilities. Specifically, although it has been suggested that resistance to interference is an important determinant of performance on WMC measures and a possible reason for the consistent correlation between WMC and other cognitive abilities, it has also been suggested that WMC performance is driven by other control mechanisms (such as active maintenance in the focus of attention) that also account for the correlation between these tasks and higher-order abilities. Thus, it might be expected that WMC tasks account for variance over and above that accounted for by interference control measures. That is, the correlation between WMC tasks and measures of intellectual functioning are likely due, in part, to interference control abilities as well other cognitive control abilities. The shared variance between interference control measures and WMC would reflect the shared need for interference control in both, while the unique variance in WMC measures would reflect the need for additional control processes over and above those required on the interference control measures (e.g., Unsworth, 2009).

Likewise, it is possible that overall memory performance on the interference control tasks would mediate the relation between the interference control indicators and cognitive abilities for much the same reason that WMC would mediate the relationship; namely that performance on these tasks is driven by additional control mechanisms that should be related to cognitive abilities. Specifically, performance on these tasks also likely relies on other strategic memory processes such as organizing information at encoding, engaging in elaborative rehearsal at encoding, selecting cues to engage in a strategic search of memory, and monitoring the outputs of the search process (e.g., Moscovitch, 1992). As such overall memory accuracy on these tasks should account for variance in cognitive abilities over and above that accounted for by the interference control indicators.

Thus, the overall goals of the current study were threefold. 1) Examine the extent to which indices of interference control are related to one another and form a single latent factor. As noted above, the results from previous studies are somewhat mixed in determining whether various indicators of interference control are related to one another and form a distinct factor. 2) Examine the extent to which the interference control factor is related to other cognitive abilities such as WMC and intelligence. Previous theorizing has suggested that interference control abilities are an important determinant of other cognitive abilities, but once again the results are somewhat mixed. 3) Examine the extent to which the interference control factor accounts for the shared variance between measures of WMC and memory more broadly with intellectual functioning or whether WMC and other memory tasks account for variance in intellectual functioning over and above that accounted for by interference control. That is, does interference control account for all of the shared variance between WMC and intelligence or only part of the variance? These issues were examined via confirmatory factor analysis (CFA) and structural equation modeling (SEM).

2. Method

2.1. Participants

A total of 161 participants (61% female) were recruited from the subject-pool at the University of Georgia. Participants were between the ages of 18 and 35 ($M = 19.19$, $SD = 1.71$) and received course credit for their participation. Each participant was tested individually in two laboratory sessions lasting approximately an hour and a half each.

2.2. Materials and procedure

After signing informed consent, all participants completed the Operation span (Ospan) task, the Symmetry span (Symspan) task, the Reading span (Rspan) task, a brief paper pencil verbal analogies test, a version of Thurstone's (1962) Number Series test, and a version of the Brown-Peterson task with category switches in Session 1. In Session 2 all participants completed a version of the recent probes recognition task (Nelson et al., 2003), a cued-recall directed forgetting task (Tolan & Tehan, 1999), a brief paper pencil vocabulary test, and a brief paper pencil general knowledge test. All tasks were administered in the order listed above.

2.3. Tasks

2.3.1. Working Memory Capacity (WMC) Tasks

2.3.1.1. 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). Before beginning the real trials, participants performed three practice sections. The first practice was simple letter span. A letter appeared on the screen and participants were required to recall the letters in the same order as they were presented. In all experimental conditions, letters remained onscreen for 1000 ms. At recall, participants saw a 4 × 3 matrix of letters. Recall consisted of clicking the box next to the appropriate letters (no verbal response was required) in correct order. The recall phase was untimed. After recall, the computer provided feedback about the number of letters correctly recalled in current set. Next, participants performed the math portion of the task alone. Participants first saw a math operation (e.g. $(1^*2)+1=?$). Participants were instructed to solve the operation as quickly as possible and then click the mouse to advance to the next screen. On the next screen a digit (e.g., “3”) was presented and the participant was required to click either a “True” or “False” box depending on their answer. After each operation participants were given accuracy feedback. The math practice served to familiarize participants with the math portion of the task as well as to calculate how long it would take that person to solve the math operations. Thus, the math practice attempted to account for individual differences in the time required to solve math operations without an additional storage requirement. After the math alone section, the program calculated each individual's mean time required to solve the equations. This time (plus 2.5 standard deviations) was then used as a time limit for the math portion of the main session for that individual. Participants completed 15 math operations in this session.

The final practice session had participants perform both the letter recall and math portions together, just as they would do in the real block of trials. Here participants first saw the math operation and after they clicked the mouse button indicating that they had solved it, they saw the letter to be recalled. If a participant took more time to solve the operations than their average time plus 2.5 *SD*, the program automatically moved on and counted that trial as an error. Participants completed three practice trials each of set-size two. After participants completed all of the practice sessions, the program progressed to the real trials. The real trials consisted of three trials of each set-size, with the set-sizes ranging from 3 to 7. This made for a total of 75 letters and 75 math problems. Note that the order of set-sizes was random for each participant. See Unsworth et al. (2005) for more task details. The score was the proportion of correct items recalled in the correct position.

2.3.1.2. Symspan. In this task participants were required to recall sequences of red squares within a matrix while performing a symmetry-judgment task. In the storage alone practice session, participants saw sequences of red squares appearing in the matrix and at recall were required to click the correct locations in the matrix in the correct order. In the symmetry-judgment task alone session participants were shown an 8×8 matrix with some squares filled in black. Participants decided whether the design was symmetrical about its vertical axis. The pattern was symmetrical approximately half of the time. Participants performed 15 trials of the symmetry-judgment task alone. The same timing parameters used in the Ospan and Rspan were used. The final practice session combined the matrix recall with the symmetry-judgment task. Here participants decided whether the current matrix was symmetrical and then were immediately presented with a 4×4 matrix with one of the cells filled in red for 650 ms. At recall, participants recalled the sequence of red-square locations in the preceding displays, in the order they appeared by clicking on the cells of an empty matrix. There were three trials of each set-size with list length ranging from 2 to 5. The same scoring procedure as Ospan and Rspan was used.

2.3.1.3. Rspan. Participants were required to read sentences while trying to remember the same set of unrelated letters as Ospan. As with the Ospan, participants completed three practice sessions. The letter practice was identical to the Ospan task. In the processing-alone session, participants were required to read a sentence and determine whether the sentence made sense (e.g. “The prosecutor's dish was lost because it was not based on fact. ?”). Participants were given 15 sentences, roughly half of which made sense. As with the Ospan, the time to read the sentence and determine whether it made sense was recorded and used as an overall time limit on the real trials. The final practice session combined the letter span task with the sentence task just like the real trials. In the real trials, participants were required to read the sentence and to indicate whether it made sense or not. 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. There were 10–15 words in each sentence. After participants gave their response they were presented with a letter for 1000 ms. 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 set-size with list length ranging from 3 to 7. The same scoring procedure as Ospan was used.

2.3.2. General fluid intelligence (gF) tasks

2.3.2.1. 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 min 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 proportion of items solved correctly.

2.3.2.2. 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 min to complete 15 test items. A participant's score was the proportion of items solved correctly.

2.3.3. General crystallized intelligence tasks

2.3.3.1. Vocabulary. In the first half of this task participants were given 20 vocabulary words and were required to select the best synonym (out of five possible choices) that best matched the target vocabulary word (Hambrick, Salthouse, & Meinz, 1999). Participants were given 2 min to complete the 10 items. In the second half of this task participants were given 10 vocabulary words and were required to select the best antonym (out of five possible choices) that best matched the target vocabulary word (Hambrick et al., 1999). Participants were given 2 min to complete the 10 items. A participant's score was the proportion of items solved correctly across both halves.

2.3.3.2. General knowledge. In this task participants were given 24 general information questions and were required to select the best answer (out of four possible choices) to the question (Hambrick et al., 1999). Topics included American politics, sports, music, literature, history, art, and economics.

Participants were given 5 min to complete the 24 items. A participant's score was the proportion of items solved correctly.

2.3.4. Interference control tasks

2.3.4.1. Brown-Peterson. In this task participants were given 12 lists of five words each broken down into three blocks (four lists per block). All words in each block came from the same semantic category (e.g., fruits, animals, and professions). The first four lists allowed for proactive interference (PI) to accrue and the first list in the next block allowed for a "release from PI." Each word was presented onscreen for 1 s each. Following the last word in a list participants were required to count backwards by three's as quickly and accurately as possible from a three digit number presented onscreen. Participants wrote their answers down until instructed to stop after 18 s. At the conclusion of the distracting task, participants had 15 s to recall as many words as possible from the current list in any order they wished. Prior to the real lists participants completed two practice lists with letters to familiarize them with the task. Two measures were calculated for this task. 1) Proportion correct on the first trial for each block provided an index of memory abilities in the absence of strong proactive interference, and 2) proportional proactive interference effect associated with each individual within a category block (e.g., Kane & Engle, 2000). This was calculated by subtracting performance on Trial 4 from Trial 1 and then dividing by Trial 1 for each individual.

2.3.4.2. Cued-recall directed forgetting. In this task participants were presented with a block of four serially presented words and were required to recall the word from the most recently presented list that matched a specific cue (Tolan & Tehan, 1999). Each word was presented on screen for 1 s. Immediately after the presentation of the last word, and before the cue, participants performed a distracting task for 8 s. In the distracting task participants saw a three digit number and were required to arrange the digits in descending order. Each three digit number was onscreen for 2 s. In 8 of the trials participants saw only one block (one-block trials) of words before performing the distracting task and then being cued to recall one of the words. Immediately following the distracting task participants were presented with a semantic category cue (e.g., Animal) and were instructed to recall the one word from the most recent list that matched the cue (e.g., Dog). Participants had 5 s for recall.

In 8 of the trials participants saw two blocks (two-block trials) of words before performing the distracting task and then being cued via a category name (e.g., Animals) to recall one of the words. In the two-block trials after the first block of words was presented participants were signaled via an exclamation point (!) that another block of words was about to appear and were instructed to only remember words from the most recent list (i.e., directed forgetting). In these trials the cue only matched one of the words from the most recent list that was presented. That is, only in the second list was an animal word (e.g., Dog) presented that would match the category cue (e.g., Animals). In another 8 trials participants were presented with two blocks of words like the two-block trials, however here, the cue matched a word from both the most recent list and a word from the immediately preceding list (e.g., lure trials). That is, an animal word appeared in both lists (e.g., Horse in list 1 and Dog in list 2) and participants were instructed to recall the word that matched the category cue (e.g., Animals) only from the most recent list. All three trial types were presented in a fixed random order. Proportion correct on the block 1 trials was taken as the memory measure in the absence of interference and the number of lure errors was taken as the index of interference.

2.3.4.3. Recent probes recognition. In this task participants were presented with four letters onscreen simultaneously, followed by a short retention interval (1.5, 3, or 6 s), and then a single probe letter appeared onscreen (Nelson et al., 2003). Upon presentation of the probe letter, participants were required to indicate whether the letter appeared in the target set. Participants pressed the "f" key for positive responses and pressed the "j" key for negative responses. On 50% of the trials the probe was a member of the target set and required a positive response. The other 50% of trials were broken down into four different types of negative trials each comprising 12.5% of trials. On non-recent negative trials the probe letter was not a member of the target set nor had it appeared in the target in the preceding two trials. In familiar negative trials the probe was not a member of the current target set but was a member of the immediately preceding target set. In high familiar negative trials the probe was not a member of the current target set, but was a member of the two preceding target sets. Finally, in response conflict negative trials the probe was not a member of the current target set, but was a member of the previous target set and was a positive probe on the previous trial. Thus, in these trials the probe was not only seen recently, as with the two types of familiar trials, but it also required a positive response on the previous trial. See Nelson et al. (2003) for more task details. Proportion of items correctly recalled across positive and non-recent negative trials was taken as the memory measure in the absence of interference. Two interference scores were also calculated. 1) Familiarity based interference was scored as the difference between non-recent negative trials and familiar negative trials. 2) Response based interference was scored as the difference between non-recent negative trials and the response conflict negative trials.

3. Results

Descriptive statistics and correlations for all of the measures are shown in Table 1. Consistent with previous research (e.g., Friedman & Miyake, 2004; Salthouse et al., 2006) reliabilities for the interference measures were generally poor (i.e., Brown-Peterson interference = .42; Lure errors in cued-recall = .64; Familiarity based interference = .40; Response based interference = .41). Because reliability places an upper limit on the observed correlations, the correlations for the interference measures with each other and with the other measures were generally low (see General discussion for further discussion of this limitation). Furthermore, it should be noted that all of the indicators of interference were significantly different from zero suggesting

Table 1
Descriptive statistics and correlations for all measures.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. BPI	–													
2. Lures	.28	–												
3. Fam	.07	.07	–											
4. Resp	.24	.10	.30	–										
5. BPT1	−.07	−.18	−.12	−.09	–									
6. CRBlk1	−.23	−.28	−.06	−.16	.21	–								
7. RPPoNeg	−.05	−.22	−.01	−.07	.13	.28	–							
8. Ospan	−.13	−.27	−.14	−.19	.42	.25	.23	–						
9. Symspan	−.16	−.20	−.01	−.07	.16	.24	.16	.26	–					
10. Rspan	–.30	−.16	−.02	−.16	.41	.29	.25	.51	.33	–				
11. NS	−.16	−.22	−.02	−.08	.21	.20	.06	.21	.23	.21	–			
12. Ang	−.04	−.12	−.16	−.14	.19	.23	.13	.20	.11	.28	.23	–		
13. GenK	−.08	−.03	−.16	−.20	.03	.13	.05	.08	.02	.20	.17	.40	–	
14. Vocab	.02	.08	−.13	−.12	.20	.08	.08	.16	.02	.19	.13	.31	.38	–
Mean	.20	.83	.03	.06	.90	.89	.92	.81	.70	.79	.64	.64	.61	.44
SD	.17	1.07	.05	.05	.10	.13	.04	.12	.17	.15	.16	.16	.15	.17
Rel	.42	.64	.40	.41	.62	.70	.75	.80	.72	.69	.67	.63	.68	.63
Skew	.51	1.46	1.04	1.24	−.97	−1.36	−1.60	−.86	−1.23	−.66	.17	−.32	−.39	.65
Kurtosis	.20	2.26	1.86	2.04	.23	1.56	2.78	.56	2.25	.25	−.93	−.05	−.21	.26

Note. Correlations $>.16$ are significant at the $p<.05$ level; correlations $>.20$ are significant at the $p<.01$ level. BPI = interference index from Brown-Peterson task; Lures = number of lure errors in the cued-recall task; Fam = Familiarity based interference index from the recent probes task; Resp = response based interference index from the recent probes task; BPT1 = trial 1 accuracy in the Brown-Peterson task; CRBlk1 = accuracy on 1 block trials in the cued-recall task; RPPoNeg = accuracy on positive and non-recent negative trials in the recent probe recognition task; Ospan = operation span; Symspan = symmetry span; Rspan = reading span; NS = number series; Ang = verbal analogies; GenK = general knowledge test; Vocab = vocabulary test; Rel = estimate of reliability. Reliability for all measures except BPI, Fam, and Resp were based on Cronbach's alpha. Reliability for BPI, Fam, and Resp was based on the reliability of the two measures contributing to the difference score (see Cohen & Cohen, 1983).

the presence of interference in each (all $ts>6.7$, $ps<.01$). For instance, as shown in Table 1, there was substantial proactive interference in the Brown-Peterson task ($M=.20$), each participant had close to one lure error on the cued-recall task (M = .83), and there was both familiarity and response based interference in the recent probes recognition task (Familiarity $M=.03$, Response $M=.06$). Thus, it was clear that interference was present in each of the tasks and as shown in Table 1, there were individual differences in the amount of interference.

Next, the extent to which the four indicators of interference (Brown-Peterson PI, lures in cued-recall, familiarity based interference, and response based interference) were related to one another and to WMC, gF, and gC was examined via confirmatory factor analysis (CFA). Specifically, in the first CFA an interference control factor (INT) was formed by allowing the four indicators of interference to load on it. Separate WMC, gF, and gC factors were also formed by allowing their respective markers to load on only those factors. All four latent variables (INT, WMC, gF, and gC) were allowed to correlate. Shown in Fig. 1 is the resulting model. Note because of the low reliabilities associated with the interference control measures, which can result in imprecise parameter estimates (i.e., large standard errors for factor loadings, latent correlations, and path coefficients), standard errors associated with the latent correlations are provided in Fig. 1 (see also Friedman & Miyake, 2004). Standard errors associated with loadings for each indicator were all less than .12. Fit statistics for all models are shown in Table 2.

As can be seen all of the measures loaded significantly on their intended constructs and all of latent variables were significantly correlated. Of interest, the interference control factor (INT) was moderately related to the WMC factor as expected. The INT factor was also moderately related to gF, but demonstrated a weaker relation with gC, $t(158)=-5.38$. Finally, as suggested by previous theorizing (Unsworth & Engle, 2007), WMC and gF were moderately related, but WMC and gC demonstrated a weaker relation, $t(158)=9.53$, even though gF and gC were highly related. This pattern of results suggests that the factors demonstrated both convergent and discriminant validity. These results are consistent with Friedman and Miyake (2004) who demonstrated the presence of a similar INT factor. However, unlike Friedman and Miyake (2004) the current results suggest that the INT factor was related to both WMC and gF.[1] An alternative model was also tested to see if the WMC and INT factor could be combined into a single factor. In this model all of the INT and WMC measures loaded onto a single factor and this factor was allowed to correlate with the gF and gC factors. Although the overall fit of the model was acceptable (see Table 2), the fit of this model was significantly worse than the previous CFA in which INT and WMC were separate factors, $\Delta\chi^2(3)=8.84$, $p<.05$. Therefore the previous CFA in which INT and WMC were separate, yet correlated factors was retained.

Next, in order to examine the possible mediating effects of WMC on the INT to intelligence correlations a structural equation model (SEM) was specified in which INT predicted

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[1] An exploratory factor analysis suggested a similar factor structure with separate WMC and intelligence factors. However, the INT factor was divided into a recall factor consisting of PI in the Brown-Peterson task and lure errors in the cued-recall task and a recognition factor consisting of the two recent probe recognition interference measures. This splitting of the INT factor into two separate factors likely reflects task specific method variance given that the two recognition interference measures were derived from the same task. Adding memory performance on the non-interference trials of the memory tasks suggested a similar factor structure with separate INT and Mem factors, but several of the Mem tasks loaded on the WMC factor suggesting that they represented a single factor.

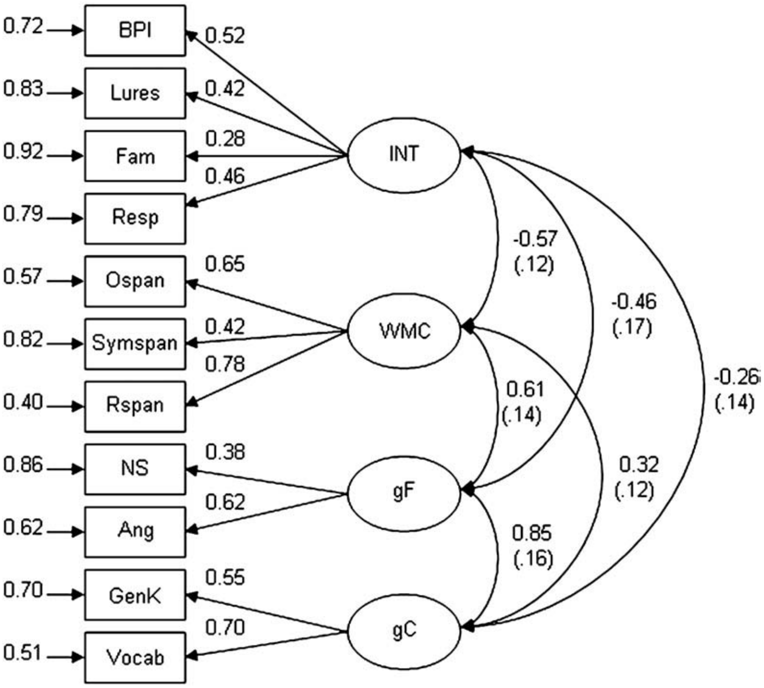

Fig. 1. Model for the interference indicators (INT), working memory capacity (WMC), general fluid intelligence (gF), and general crystallized intelligence (gC). Paths connecting latent variables (circles) to each other represent the correlations between the constructs, the numbers from the latent variables 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. BPI = PI effect in Brown-Peterson; Lures = lure errors in cued-recall; fam = accuracy difference between familiar and non-recent negative trials; resp = accuracy difference between response conflict and non-recent negative trials; Ospan = operation span; Symspan = symmetry span; Rspan = reading span; NS = number series; Ang = verbal analogies; GenK = general knowledge test; Vocab = vocabulary test. All loadings and paths are significant at the $p<.05$ level. Numbers in parentheses are standard errors.

WMC, gF, and gC and WMC predicted both gF and gC. As suggested previously, it is possible that the shared variance between WMC and intelligence is completely accounted for by INT, in which case WMC should not have a unique relation with intelligence (specifically gF). It is also possible that WMC has a unique relation with intelligence. Shown in Fig. 2 is the resulting model. Note, given the strong relation between gF and gC that is likely independent of WMC, the error variances for gF and gC were allowed to correlate.

As can be seen, INT accounted for variance in WMC and WMC accounted for unique variance in gF. However, the direct effects of INT to gF and gC were not significant. Thus, WMC mediated the effect between INT and gF. In order to determine if WMC accounted for additional variance in gF over and above that shared with INT, a two-step regression in which INT and WMC predicted gF was carried out on the latent correlations. Specifically, INT was entered in the first step and WMC was entered in the second step. In the first step INT accounted for 21% of the variance in gF, $F(1,159)=42.67$, $p<.01$. Entering WMC in the second step accounted for an additional 18% of the variance in gF, $\Delta F(1,158)=46.47$, $p<.01$. Thus, WMC not only mediated the relation between INT and gF, but WMC also accounted for variance over and above that accounted for by the shared relation with INT. This suggests that the relation between WMC and intelligence is only partially due to shared variance with INT. Some other

Table 2
Fit indices for all models.

Model	χ^2	*df*	*p*	χ^2/df	RMSEA	NNFI	CFI	SRMR
INT-WMC CFA	57.47	38	.02	1.51	.06	.92	.95	.06
INT-WMC Alt CFA	66.31	41	.00	1.62	.06	.88	.91	.07
INT-WMC SEM	57.47	38	.02	1.51	.06	.92	.95	.06
INT-Mem CFA	84.52	67	.05	1.26	.04	.95	.96	.06
INT-Mem Alt CFA	94.41	71	.03	1.33	.05	.94	.95	.06
INT-Mem SEM	50.81	38	.08	1.34	.05	.93	.95	.06
MemC One Factor	9.60	9	.38	1.07	.02	1.00	1.00	.04
MemC Two Factor	9.63	8	.29	1.20	.04	.99	.99	.04
MemC CFA	28.64	32	.64	.90	.00	1.00	1.00	.05

Note. RMSEA = root mean square error of approximation; NNFI = nonormed fit index; CFI = comparative fit index; SRMR = standardized root mean square residual.

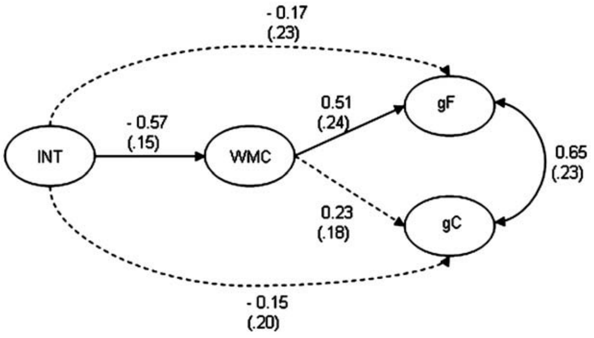

Fig. 2. Structural equation model examining the mediating effects of working memory capacity (WMC) on the relation between interference control (INT), and general fluid (gF) and general crystallized (gC) intelligence. Single-headed arrows connecting latent variables (circles) to each other represent standardized path coefficients indicating the unique contribution of the latent variable. The double headed arrow connecting gF and gC represents the correlation between the residual variances for those two factors. Solid paths are significant at the $p<.05$ level, whereas dashed paths are not significant. Numbers in parentheses are standard errors.

process or processes must also be required in order to account for the substantial relation between WMC and intelligence.[2]

Similar models were used to examine what would happen once memory performance on the non-interference trials in the memory tasks used to compute the INT measures were added to the model. Specifically, memory performance on the Brown-Peterson task, the cued-recall tasks, and the recent probe task formed a single latent factor, and that latent factor was added to the previous CFA which consisted of latent factors for INT, WMC, gF, and gC. Shown in Fig. 3 is the resulting model. All of the loadings and correlations were significant. Note because of the low reliabilities associated with the interference control measures, standard errors are provided. Standard errors associated with each indicator loading were all less than .12.

Of note is that overall memory performance (Mem) was substantially related to the INT, WMC, and gF factors, but demonstrated a weaker relation with gC, all $ts>10.51$. This is consistent with the notion that memory accuracy in these tasks is similar to accuracy scores in the WMC tasks, and that part of the variance in overall memory accuracy is accounted for by individual differences in INT. Similar to the WMC CFA, an alternative model was tested to see if the Mem and INT factors could be combined into a single factor. In this model all of the INT and Mem measures loaded onto a single factor and this factor was allowed to correlate with the WMC, gF and gC factors. Although the overall fit of the model was acceptable (see Table 2), the fit of this model was significantly worse than the previous CFA in which INT and Mem were separate factors, $\Delta\chi^2(4)=9.89$, $p<.05$. Therefore the previous CFA in which INT and Mem were separate, yet correlated factors was retained.

As with the WMC models, in order to examine whether Mem would mediate the relation between INT and the other latent factors, SEM was used. Shown in Fig. 4, INT accounted for variance in Mem and Mem accounted for unique variance in WMC, gF and gC. However, INT did not account for any unique variance in gF or gC. Again, although INT was significantly related to the other constructs, this variance was completely accounted for by Mem. In order to determine if Mem accounted for additional variance in gF over and above that shared with INT, a two-step regression in which INT and Mem predicted gF was carried out on the latent correlations. Specifically, INT was entered in the first step and Mem was entered in the second step. In the first step INT accounted for 24% of the variance in gF, $F(1,159)=50.24$, $p<.01$. Entering Mem in the second step accounted for an additional 34% of the variance in gF, $\Delta F(1,158)=127.77$, $p<.01$. Thus, Mem not only mediated the relation between INT and gF, but Mem also accounted for variance over and above that accounted for by the shared relation with INT. Thus, this suggests that the relation between overall memory accuracy in these tasks and other cognitive abilities is due in part to INT abilities, but also due to other unique sources of variance.

Finally, given the relatively high correlation between the Mem and WMC factors and the fact that both seemed to account for the relation between INT and intelligence, the last models examined the extent to which the WMC and Mem measures could be represented by a single factor (MemC) and how this factor would relate to the two intelligence factors. First two separate models were specified for the WMC and Mem measures. In the first model all measures were specified to load on a single factor. In the second model the WMC measures loaded onto a WMC factor and the Mem measures loaded onto a Mem factor and these two factors were allowed to correlate. As shown in Table 2, the fit of both models was acceptable. Importantly, however, the two-factor model did not demonstrate a significant improvement in model fit, $\Delta\chi^2(1)=0.03$, $p>.86$, and thus, the simpler one factor model was retained. Next, both gF and gC latent variables were added to the one factor model to determine how MemC would relate to these two components of intelligence. Shown in Fig. 5 is the resulting model.

As can be seen all of the measures loaded significantly on their intended constructs and all of latent variables were significantly correlated. Consistent with the other models, gF correlated moderately with both MemC and gC, but these two factors demonstrated a much weaker correlation, $t(158)=13.08$. This suggests that all of these MemC tasks can be seen as measures of the same underlying latent variable and this latent variable is highly related to gF, but related less so with gC. Furthermore, these analyses suggest that there at least two distinct sources of variance account for gF; variance associated with memory control measures, and variance associated with crystallized measures.

Note, given the high correlation between gF and gC alternate models that combined these two factors into a single g factor were also examined. In all cases the primary results were the same as those reported with separate gF and gC factors. Specifically, WMC, Mem, and INT were all related

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[2] Note, given the correlational nature of the study, one should be cautious is assuming causality in the models that are specified. Specifically, the mediation models presented are not meant to suggest that interference control causes working memory capacity which in turn causes fluid intelligence. Rather, the models simply suggest that the variance shared between interference control and fluid intelligence is due to shared variance with working memory capacity and interference control does not account for any unique variance in fluid intelligence once working memory capacity is taken into account. Thus, the models are not necessarily empirical tests of causality; rather they are simply representations of the current theoretical perspective.

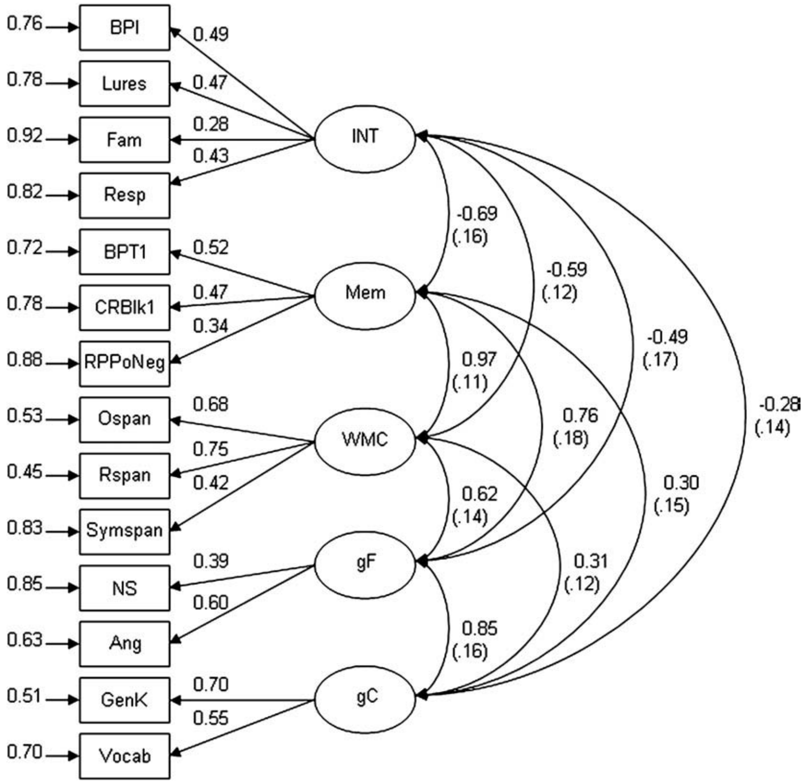

Fig. 3. Model for the interference indicators (INT), overall memory performance (Mem), working memory capacity (WMC), general fluid intelligence (gF), and general crystallized intelligence (gC). Paths connecting latent variables (circles) to each other represent the correlations between the constructs, 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. BPI = PI effect in Brown-Peterson; Lures = lure errors in cued-recall; fam = accuracy difference between familiar and non-recent negative trials; resp = accuracy difference between response conflict and non-recent negative trials; BPT1 = accuracy on Trial 1 in the Brown-Peterson task; CRBlk1 = accuracy on one block trials in the cued-recall task; RPPoNeg = accuracy on positive and non-recent negative trials in the recent probe recognition task; Ospan = operation span; Symspan = symmetry span; Rspan = reading span; NS = number series; Ang = verbal analogies; GenK = general knowledge test; Vocab = vocabulary test All loadings and paths are significant at the $p<.05$ level. Numbers in parentheses are standard errors.

to g, but WMC and Mem mediated the relation between INT and g. For instance, examining the same INT-WMC CFA as reported previously, but with a single g factor, suggested that both WMC (.47) and INT (−.37) were significantly related to g. Furthermore, examining the same SEM (INT-WMC SEM) as reported previously, but with a single g factor, suggested that INT was significantly related to WMC (−.56), WMC was significantly related to g (.40), but INT was no longer related to g (−.14) once WMC was taken into account. Thus, the results are qualitatively the same when examining either separate gF and gC factors or a single g factor. Importantly, as noted previously, there is reason to have separate gF and gC factors given that WMC, INT, and Mem all correlated more strongly with gF than gC, suggesting some divergence between the two constructs.

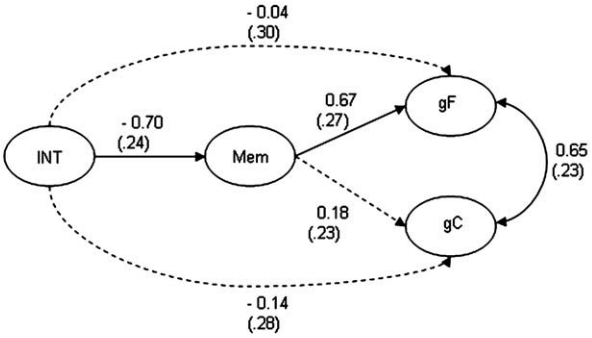

Fig. 4. Structural equation model examining the mediating effects of overall memory (Mem) on the relation between interference control (INT), general fluid (gF) and general crystallized (gC) intelligence. Single-headed arrows connecting latent variables (circles) to each other represent standardized path coefficients indicating the unique contribution of the latent variable. The double headed arrow connecting gF and gC represents the correlation between the residual variances for those two factors. Solid paths are significant at the $p<.05$ level, whereas dashed paths are not significant. Numbers in parentheses are standard errors.

4. General discussion

The goal of the current study was to examine whether different measures of interference control were related to one another and related to other cognitive abilities. It was found that the interference control measures were weakly related to one another and formed a single latent variable (INT) consistent with previous research (Friedman & Miyake, 2004). Furthermore, it was found that this latent variable was related to other latent variables including overall performance on the memory tasks (Mem), WMC, gF, and to a lesser extent gC. Consistent with much

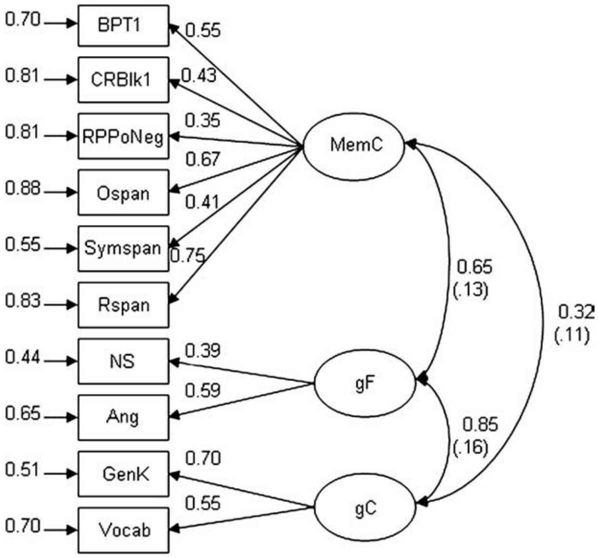

Fig. 5. Model for overall memory factor (MemC) combining Mem and WMC factors, general fluid intelligence (gF), and general crystallized intelligence (gC). Paths connecting latent variables (circles) to each other represent the correlations between the constructs, the numbers from the latent variables 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. BPT1 = accuracy on Trial 1 in the Brown-Peterson task; CRBlk1 = accuracy on one block trials in the cued-recall task; RPPoNeg = accuracy on positive and non-recent negative trials in the recent probe recognition task; Ospan = operation span; Symspan = symmetry span; Rspan = reading span; NS = number series; Ang = verbal analogies; GenK = general knowledge test; Vocab = vocabulary test All loadings and paths are significant at the $p<.05$ level.

previous theorizing, it was found that interference control cuts across multiple tasks and this shared variance was related to a number of other important cognitive constructs likely due to the shared need for general control processes in all. However, it was also found that the variance shared between INT and the two intelligence constructs was completely accounted for by both WMC and Mem suggesting that these constructs included the same variance as INT plus additional unique variance that was shared with intelligence. This latter finding is consistent with Salthouse et al. (2006) claim that interference control abilities are closely related to basic episodic memory abilities. Finally, it was found that WMC and Mem measures largely measured the same underlying construct and this construct was highly related to gF but was related less so with gC. These finding are consistent with recent work by Salthouse, Pink, and Tucker-Drob (2008; see also Tucker-Drob & Salthouse, 2009) suggesting that WMC, gF, Mem, and INT likely reflect the same dimension of cognitive abilities in that all require broad cognitive control abilities (see also Engle & Kane, 2004; Unsworth & Engle, 2007). Thus, the current findings suggest that there is a substantial amount of shared variance between these constructs which likely reflects the need for general control processes in each.

4.1. Interference control, WMC, and intelligence

Overall, the current results support the notion that interference control is an important cognitive construct that is likely required in many memory tasks and this ability is related to other cognitive abilities as suggested by previous research. At the same time the results suggest that interference control is only part of the story in accounting for variance in constructs such as gF. In particular, the finding that both WMC and Mem accounted for variance over and above that accounted for by INT, suggests that these measures likely tap additional processes which are related to aspects of intelligence. This is inconsistent with a strong version of the interference control view that would suggest that the shared variance between WMC and intelligence should be completely accounted for by the interference control measures. However, it is clear that in the current study such a model simply would not work. Specifically, WMC was more strongly related to gF ($r=.61$) than interference was ($r=-.46$), $t(158)=-9.60$. Thus, any model suggesting that interference control should mediate the relation between WMC and gF simply would not work. Rather the results suggest that WMC accounts for the relation between interference control and intelligence. Furthermore, it is possible that this relation is due to a third unspecified variable. Similarly, the results suggested that overall memory performance was likely determined in part by interference control abilities, but also by other important memory control processes. These other control processes include elaboration at encoding, generating internal cues at retrieval, and monitoring the products of retrieval which are needed in situations in which interference may not be playing a prominent role (e.g., Moscovitch, 1992). Thus, although interference control is an important cognitive function that is related to other cognitive abilities, this is likely due in large part to the shared variance amongst all of these constructs. Furthermore, this works highlights the multifaceted nature of WMC and other memory tasks and suggests that more work is needed to better understand the multiple component processes inherent in these tasks.

On a related note, a similar conclusion can be made regarding fluid intelligence. Specifically, as shown throughout gF and gC were highly related to one another, gF was highly related to the different memory factors (WMC, Mem, and MemC), but gC and the different memory factors demonstrated much weaker relations. This suggests that most of the variance in gF can be accounted for by either gC or performance on the memory tasks, with less variance being shared between gC and the memory tasks. As such, this suggests that gF is multiply determined with some variation being due to differences in flexible memory control processes and some variation being due to differences in knowledge base (as well as other potential sources of variance not measured in the current study).

The results of the current study add to the growing body of work examining how certain control functions are related to one another and to other cognitive abilities (e.g., Friedman et al., 2006) and have important implications for areas that have relied on the idea of interference control as an explanatory construct. Indeed, each of the tasks used in the current study have been used to examine interference control via studies in aging (e.g., Dobbs, Aubrey, & Rule, 1989; Jonides et al., 2000; Tehan & Hauff, 2000), neuropsychology (e.g., Thompson-Schill et al., 2002), as well as neuroimaging (e.g., Nelson et al., 2003). For instance, Nee, Jonides, and Berman (2007) recently demonstrated similar activation in a version of the recent probes task and a directed forgetting task, suggesting that the ability to deal with proactive interference in both relied on overlapping frontal regions. Specifically, Nee et al. (2007) found that both the ventrolateral prefrontal cortex (VLPFC) and the anterior prefrontal cortex (APFC) were involved in interference control in both tasks. Nee et al. suggested that the common activation in VLPFC across the tasks reflected episodic search processes needed to extract relevant representations from the medial temporal lobes, whereas the common activation in the APFC reflected conflict monitoring requirements. In terms of the present study, this work suggests that the common variance extracted from each of the interference control tasks reflects the ability to extract task relevant representations and monitor for possible conflict between interfering traces. Individuals who are poor at interference control not only activate more task irrelevant representations than individuals good at interference control, but they are also poorer at monitoring for potential conflict amongst active representations which may be needed in many tasks and situations.

5. Limitations and future directions

One limitation of the current study is that only undergraduate students from a fairly narrow age range (i.e., approximately 19 years old) were used. Thus, it is possible that the current results may not generalize to other age groups such as children (Kail, 2002) or older adults (Salthouse et al., 2006) or to a more diverse sample within an age group (i.e., differences in educational levels). Using a broader age range and a broader range of intellectual abilities and/or educational levels may lead to different results, whereby interference control abilities (or lack thereof) are more important at the lower end of the ability spectrum, leading to larger correlations with measures of intelligence. Furthermore, having a more diverse sample could increase the amount of overall variability in a study and thereby increase the zero-order correlations and factor loadings leading to more precise results. In addition, although the sample size for the current study can be considered a medium size, larger samples will also lead to more precise (i.e., smaller standard errors) parameter estimates. However, it should be noted that the current study used a similar undergraduate population as Friedman and Miyake (2004) and found very similar results as their study. Thus, using a similar sample of participants the current study replicated and extended the interference control findings of Friedman and Miyake (2004) and it is an open question as to whether similar results will be found with a more intellectually diverse sample. Future work is needed to examine how inference control measures are related to one another and to other cognitive abilities such as WMC and intelligence in a broader sample of participants.

An additional, and potentially more problematic, limitation of the current study was the fact that nearly all of the interference control measures had poor reliabilities. This problem of low reliabilities for interference control measures has been discussed extensively by a number of researchers (e.g., Friedman & Miyake, 2004; Salthouse et al., 2006). Because reliability places an upper limit on correlations, the zero-order correlations among the measures will be low. Indeed, as shown below in Table 3, when the correlations among the interference control measures are corrected for unreliability, the correlations are generally much stronger (ranging from .14 to .75). Because the zero-order correlations were weak, there is little shared variance among the measures leading to low communalities for the latent factors. As noted by Friedman and Miyake (2004) the result is that the parameter estimates in the subsequent models will be less precise than when stronger inter-correlations are examined. As shown in Figs. 1–5 the standard errors associated with several of the latent correlations and path coefficients were somewhat large. Thus, there is certainly some imprecision within the current models. Although it should be noted that the standard errors for the INT latent variable were very similar to the standard errors for the other latent variables whose indicators had larger estimates of reliability. Thus, the INT latent variable has a similar amount of imprecision as the other latent variables.

Table 3
Correlations for the interference control measures corrected for unreliability.

Variable	1	2	3	4
1. BPI	–			
2. Lures	.54	–		
3. Fam	.17	.14	–	
4. Resp	.59	.20	.75	–

Note. Correlations>.16 are significant at the $p<.05$ level; correlations>.20 are significant at the $p<.01$ level. BPI = interference index from Brown-Peterson task; Lures = number of lure errors in the cued-recall task; Fam = Familiarity based interference index from the recent probes task; Resp = response based interference index from the recent probes task.

Despites these low reliabilities there are a number of pieces of evidence in favor of the models presented.

1) It is well known that CFA and SEM partially correct for measurement error in the indicators and thus, path coefficients and latent correlations are disattenuated and the standard errors are adjusted accordingly (e.g., DeShon, 1998). Although as noted by DeShon (1998) SEM only corrects some forms of measurement error and does not generally account for other sources. Thus, more evidence is needed to determine the reliability (test–retest and alternate forms) of these constructs.
2) In order to assess test–retest and alternate forms reliability of the INT latent variable I reanalyzed data from Friedman and Miyake (2004) that relied on very similar indicators of INT (based on difference scores; see their Fig. 2) and included a measure of WMC (i.e., reading span). As noted by Friedman and Miyake (2004) their INT indicators had low levels of reliability similar to the current study, yet each of these indicators loaded significantly on an INT latent variable. Importantly, the loadings of Friedman and Miyake's indicators were very similar to the loadings found in the current study (i.e., average loading for Friedman and Miyake = .38; average loading in the current study = .42). Additionally, the latent INT factor from Friedman and Miyake (2004) was significantly related to a measure of WMC ($r = -.47$) similar to what was found in the current study. Thus, although the estimates of reliability were weak in the current study, a very similar factor structure and relation between measures was found across different samples of participants and slightly different indicators. This provides important evidence for the ability to replicate the current results.

3) Another, if less desirable, means of assessing reliability is to examine the multiple R^2 of measure with all other measures in the study as predictors (e.g., Bollen, 1989; Salthouse et al., 2008). The average multiple R^2 for the INT indicators was .30, which is very similar to the average multiple R^2 for the indicators from the other constructs (i.e., WMC = .42; Mem = .27; gF = .27; gC = .46). Additionally, note that the overall multiple R^2 for the current indicators was similar to those found in other work which has utilized similar indicators (e.g., Engle et al., 1999; Salthouse et al., 2008). Thus, although the overall amount of systematic variance is low in the INT indicators, it is a similar amount of systematic variance as the other (more reliable) indicators from the other constructs.
4) Despite the low amount of systematic variance in the INT indicators all of the indicators loaded significantly on the INT latent variable, and the INT latent variable was related in a theoretically meaningful manner with the other latent variables. That is, the INT latent factor was related to the other latent variables as predicted and consistent with prior work (e.g., Friedman & Miyake, 2004). Furthermore, the endorsed models fit significantly better than alternative models in which it was assumed that there was not a separate INT latent variable. That is, models that assumed the INT indicators formed a separate latent variable fit significantly better than models that assumed the INT indicators were just measures of Mem or WMC. Thus, despite low reliabilities and low zero-order correlations, the current results demonstrated that a separate INT factor was present in the data and this factor was related to a number of other important cognitive abilities.

Before concluding it would be remiss not to address the fact that the current results are somewhat at odds with the results from Salthouse et al. (2006). Specifically, Salthouse et al. found little evidence for a common interference control factor based on 6 different tasks that measured aspects of memory control including directed forgetting, proactive interference, and episodic and semantic retrieval inhibition. The zero-order correlations between these tasks were generally weak and non-significant. Additionally, and consistent with the results of the current study, Salthouse et al. found that most of the indicators of interference control had fairly weak reliabilities. Given these issues, Salthouse et al. argued that a single interference control factor could not be successfully extracted from these tasks. One possible reason for the differences in results obtained in the current study and those obtained in Salthouse et al. is the tasks used to measure interference control. In the current paper, all of the tasks used specifically manipulated and measured some aspect of proactive interference. In the Salthouse et al. paper several different memory control measures were used some of which were an index of proactive interference and some of which were an index of other memory control measures such as retrieval-induced forgetting. Given that previous work has suggested that retrieval-induced forgetting measures may not provide the same information as other interference control measures (e.g., Williams & Zacks, 2001) it is possible that lack of correlation between the measures simply reflected the fact that the tasks draw on very different processes. For instance, Bäuml et al. (2005) have suggested that retrieval inhibition in retrieval-induced forgetting paradigms leads to a recovery failure in which items are sampled, but are degraded to the point that they cannot be recovered. Wixted and Rohrer (1993), on the other hand, have suggested that proactive interference in Brown-Peterson type tasks results in a sampling failure rather than a recovery failure. This suggests two different mechanisms might underlie forgetting in the two paradigms. Although, both retrieval-induced forgetting and proactive interference paradigms may both require some form of “memory control” (e.g., Anderson, 2003) it is possible that they rely on different manifestations of control. Thus, the findings obtained in the current paper are likely due to the fact that a fairly narrow interference control factor was specified based on tasks that all required fairly similar processes. This suggests the possibility that “memory control” is not a single underlying construct but rather represents several distinct constructs, only one of which is interference control. The current study combined with the work of Salthouse et al. (2006) suggests that it is important to examine the extent to which putative memory control processes are related to one another and the extent with which these processes are related other cognitive ability constructs.

Finally, although the current results have implications for interference control relations, several important issues remain. In particular it is still unclear what the underlying mechanism is that gives rise to differences in interference control. As noted previously some researchers have appealed to the notion of inhibition (Hasher et al., 2007), while others have appealed to active goal maintenance (Kane, et al., 2007), and still others have suggested context retrieval/source monitoring processes are important (Unsworth & Engle, 2007). Clearly more work is needed to elucidate the mechanism that underlies interference control. An additional issue raised by the current study is what exactly the underlying mechanism(s) is that accounts for the unique variance between WMC and Mem with intelligence. As suggested above this additional variance might reflect additional control processes that are needed in these tasks and are subsequently related to other cognitive abilities, but as yet there is little work examining these other potential control functions and how they are related to intelligence. At the very least, the current findings suggest a promising avenue of research into memory control functions and their relation to cognitive abilities.

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References

Anderson, M. C. (2003). Rethinking interference theory: Executive control and the mechanisms of forgetting. *Journal of Memory and Language*, *49*, 415−445.

Atkinson, R. C., & Shiffrin, R. M. (1971). The control of short-term memory. *Scientific American*, *225*, 82−90.

Bäuml, K. H., Zellner, M., & Vilimek, R. (2005). When remembering causes forgetting: Retrieval-induced forgetting as recovery failure. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *31*, 1221−1234.

Berger, F. R., Gupta, W. B., Berger, R. M., & Skinner, J. (1990). Air Force Officer Qualifying Test (AFOQT) form P: Test Manual (AFHRL-TR-89-56). Brooks

Air ForceBase, TX: Manpower and Personnel Division, Air Force Human Resources Labatory.

Bollen, K. A. (1989). *Structural equations with latent variables.* New York: John Wiley & Sons.

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* NY: Oxford.

Bunting, M. F. (2006). Proactive interference and item similarity in working memory. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *32*, 183−196.

Cantor, J., & Engle, R. W. (1993). Working memory capacity as long-term memory activation: An individual differences approach. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *19*, 1101−1114.

Chiappe, P., Hasher, L., & Siegel, L. S. (2000). Working memory, inhibitory control, and reading disability. *Memory & Cognition*, *28*, 8−17.

Cohen, J., & Cohen, P. (1983). *Applied multiple regression/correlation analysis for the behavioral sciences.* Hillsdale, NJ: Lawrence Erlbaum.

Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, *12*, 45−75.

Dempster, F. N., & Corkill, A. J. (1999). Individual differences in susceptibility to interference and general cognitive ability. *Acta Psychologica*, *101*, 395−416.

DeShon, R. P. (1998). A cautionary note on measurement error corrections in structural equation models. *Psychological Methods*, *3*, 412−423.

Dobbs, A. R., Aubrey, J. B., & Rule, B. G. (1989). Age-associated release from proactive interference: A review. *Canadian Psychology*, *30*, 588−595.

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. Ross (Ed.), *The psychology of learning and motivation*, *Vol. 44*. (pp. 145−199)NY: Elsevier.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, *128*, 309−331.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*, *133*, 101−135.

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science*, *17*, 172−179.

Hambrick, D. Z., Salthouse, T. A., & Meinz, E. J. (1999). Predictors of crossword puzzle proficiency and moderators of age-cognition relations. *Journal of Experimental Psychology: General*, *128*, 131−164.

Hasher, L., Lustig, C., & Zacks, R. T. (2007). Inhibitory mechanisms and the control of attention. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* NY: Oxford.

Hedden, T., & Park, D. (2003). Contributions of source and inhibitory mechanisms to age-related retroactive interference in verbal working memory. *Journal of Experimental Psychology: General*, *132*, 93−112.

Janowsky, J. S., Shimamura, A. P., Kritchevsky, M., & Squire, L. R. (1989). Cognitive impairment following frontal lobe damage and its relevance to human amnesia. *Behavioral Neuroscience*, *103*, 548−560.

Jonides, J., & Nee, D. E. (2006). Brain mechanisms of proactive interference in working memory. *Neuroscience*, *139*, 181−193.

Jonides, J., Marshuetz, C., Smith, E. E., Reuter-Lorenz, P. A., & Koeppe, R. A. (2000). Age differences in behavior and pet activation reveal differences in interference resolution in verbal working memory. *Journal of Cognitive Neuroscience*, *12*, 188−196.

Joormann, J., & Gotlib, I. H. (2008). Updating the contents of working memory in depression: Interference from irrelevant negative material. *Journal of Abnormal Psychology*, *117*, 182−192.

Kail, R. (2002). Developmental change in proactive interference. *Child Development*, *73*(73), 1703−1714.

Kane, M. J., & Engle, R. W. (2000). Working memory capacity, proactive interference, and divided attention: Limits on long-term retrieval. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *26*, 333−358.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working-memory capacity: A latent-variable approach to verbal and visuo-spatial memory span and reasoning. *Journal of Experimental Psychology: General*, *133*, 189−217.

Kane, M. J., Conway, A. R. A., Hambrick, D. Z., & Engle, R. W. (2007). Variation in working memory capacity as variation in executive attention and control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* NY: Oxford.

Moscovitch, M. (1992). Memory and working with memory: A component process model based on modules and central systems. *Journal of Cognitive Neuroscience*, *4*, 257−267.

Nee, D. E., Jonides, J., & Berman, M. G. (2007). Neural mechanisms of proactive interference-resolution. *NeuroImage*, *38*, 740−751.

Nelson, J. K., Reuter-Lorenz, P. A., Sylvester, C. C., Jonides, J., & Smith, E. E. (2003). Dissociable neural mechanisms underlying response-based and familiarity-based response conflict in working memory. *Proceedings of the National Academy of Sciences*, *100*, 11171−11175.

Salthouse, T. A., Siedlecki, K. L., & Krueger, L. E. (2006). An individual differences analysis of memory control. *Journal of Memory and Language*, *55*, 102−125.

Salthouse, T. A., Pink, J. E., & Tucker-Drob, E. M. (2008). Contextual analysis of fluid intelligence. *Intelligence*, *36*, 464−486.

Tehan, G., & Hauff, H. M. (2000). Proactive interference effects on aging: Is inhibition a factor? *Australian Psychologist*, *35*, 249−254.

Thompson-Schill, S. L., Jonides, J., Marshuetz, C., Smith, E. E., D'Esposito, M., Kan, I. P., Knight, R. T., & Swick, D. (2002). Effects of frontal lobe damage on interference effects in working memory. *Cognitive, Affective, & Behavioral Neuroscience*, *2*, 109−120.

Thurstone, T. G. (1962). *Primary mental abilities.* Chicago: Science Research Associates.

Tolan, G. A., & Tehan, G. (1999). Determinants of short-term forgetting: Decay, retroactive interference, or proactive interference? *International Journal of Psychology*, *34*, 285−292.

Tucker-Drob, E. M., & Salthouse, T. A. (2009). Confirmatory factor analysis and multidimensional scaling for construct validation of cognitive abilities. *International Journal of Behavioral Development*, *33*, 277−285.

Unsworth, N. (2009). Individual differences in self-initiated processing at encoding and retrieval: A latent variable analysis. *Quarterly Journal of Experimental Psychology*, *62*, 257−266.

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*, *114*, 104−132.

Unsworth, N., Heitz, R. P., & Engle, R. W. (2005). Working memory capacity in hot and cold cognition. In R. W. Engle, G. Sedek, U. Hecker, & D. N. McIntosh (Eds.), *Cognitive limitations in aging and psychopathology: Attention, working memory, and executive functions* (pp. 19−43). New York: Oxford University Press.

Wegner, D. M., & Zanakos, S. (1994). Chronic thought suppression. *Journal of Personality*, *62*, 615−640.

Williams, C. C., & Zacks, R. T. (2001). Is retrieval induced forgetting an inhibitory process? *American Journal of Psychology*, *114*, 329−354.

Wixted, J. T., & Rohrer, D. (1993). Proactive interference and the dynamics of free recall. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *19*, 1024−1039.