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Sources of individual differences in working memory: Contributions of strategy to capacity

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Some research on attentional control in working memory has emphasized theoretical capacity differences. However, strategic behavior, which has been relatively unexplored, can also influence attentional control and its relationship to cognitive performance. In two experiments, we examined the relationship between attentional control (measured with operation span) and interference in a part-list cuing paradigm. Paradoxically, the results indicated that superior attentional control was related to increased interference. This relationship reflected the participants' use of more complex encoding strategies, rather than superior interference control at retrieval, and was eliminated following brief encoding strategy training. The results suggest that complex span measures sometimes predict individual differences in task strategies related to interference control and that these strategies may be amenable to training. The implications for working memory research and the roles of strategies in basic memory and attention paradigms are briefly discussed.

Working memory (WM) is related to intelligence, cognitive control, and the function of the prefrontal cortex (Friedman & Miyake, 2004a; Kane & Engle, 2002) and may influence a wide range of behavior, including cognitive development, self-regulation, personality, and psychopathology (Barrett, Tugade, & Engle, 2004). Research indicates that a number of aspects of WM are flexible and deeply influenced by skills and knowledge (Ericsson & Kintsch, 1995). However, key individual differences in WM are also argued to result from abiding, domain-general capacities that maintain or suppress mental and behavioral activity (Dempster & Corkill, 1999; Barrett et al., 2004; Friedman & Miyake, 2004b; Hasher & Zacks, 1988; Rougier, Noelle, Braver, Cohen, & O'Reilly, 2005). Theoretically, one such capacity linking WM to higher order cognition is the capacity to control attention according to one's goals in the face of competing external and internal interference (Unsworth, Schrock, & Engle, 2004). For this reason, the nature of attentional control is commonly investigated in interference paradigms involving memory or attention tasks.

Research has identified separate components of inhibitory control associated with individual differences in attentional control, including resistance to proactive interference in long-term memory tasks (Friedman & Miyake, 2004b). However, across a number of laboratory tasks, individual differences in task strategies have been identified (Barrett et al., 2004; McNamara & Scott, 2001; Schunn, Lovett, & Reder, 2001; Turley-Ames & Whitfield, 2003). More critically, most studies have been designed in such a way that greater capacities, better strategies, or a combination of both could improve task performance.

We hypothesize that individual differences in attentional control are not solely differences in the capacity to control attention but can stem from better strategic allocation of executive resources. Even in basic attention and memory tasks, attention to different representations of task goals and different rules for attaining those goals can affect task performance (Kieras & Meyer, 2000). For example, differences in attentional control related to memory interference may sometimes result from different processes used at encoding (e.g., elaboration vs. rote rehearsal). McNamara and Scott (2001) and Turley-Ames and Whitfield (2003) found that high attentional control participants spontaneously encoded words with more elaborative strategies, whereas low-control participants were more likely to use rote rehearsal. Different encoding processes and different retrieval processes may also account for the positive relationship reported between resistance to proactive interference (PI) and attentional control (Friedman & Miyake, 2004a; Kane & Engle, 2000). Given that PI is a function of encoding similarity (cf. Hunt, 1976), such results may reflect a differential use of distinctive encoding that limits PI at retrieval. Therefore, we sought to examine the processes by which individual differences in attentional control translate into performance differences in a paradoxical interference task.

Part-List Cuing Interference

First reported by Slamecka (1968), part-list cuing is an interference effect in which memory cues (e.g., half of a set of studied items) presented at recall significantly impair the recall of noncued items (for a review, see Nickerson, 1984). Although the interference mechanism of part-

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list cuing is debated, it has generally been interpreted in terms of retrieval competition. Originally, it was argued that the presentation of cues increases their strength or activation, so that cues are repeatedly resampled, blocking retrieval of the noncued items (Rundus, 1973). A second theory, the strategy disruption account, proposed that part-list cuing occurs because the presentation of random cues competes with participants' use of retrieval plans that match their subjective organization of the list (D. R. Basden & B. H. Basden, 1995). Alternatively, Bäuml and colleagues (Bäuml & Aslan, 2004) have recently proposed that part-list cuing is a case of retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994), whereby participants covertly retrieve the cues during the test and create inhibition of noncue target items in memory.

According to each of these accounts, if interference control is achieved primarily via attentional control at retrieval, participants with superior control should be better able to inhibit or control task-irrelevant stimuli and ideas, showing less interference than do participants with lower control. Specifically, within the Rundus model, successful recall in the presence of part-list cuing interference requires suppression or inhibition of the retrieval cues. Within the strategy disruption account, successful recall of noncued items depends on overcoming competing cues and maintaining in an active state one's own retrieval plan. Finally, within the retrieval inhibition account, successful recall would require controlling or inhibiting cues in order to overcome the inhibition of noncue targets.

In contrast, if high attentional control individuals also achieve their typically superior interference performance through the use of better encoding strategies, they may suffer more interference in part-list cuing. Part-list cues are particularly disruptive when participants establish interitem associations among studied items (B. H. Basden, D. R. Basden, & Stephens, 2002). Similarly, retrieval-induced forgetting occurs only for items that are strong competitors of to-be-retrieved items (Anderson et al., 1994). If strong links are established at encoding, retrieval of cues should induce greater inhibition of noncued items. For these reasons, we predicted that high attentional control participants would show more part-list cuing interference than would low attentional control participants. This hypothesis was tested in Experiment 1, in which we examined the relationship between attentional control and part-list cuing interference. In Experiment 2, we replicated Experiment 1 and also examined the effect of controlling encoding strategy.

EXPERIMENT 1

Method

Participants. Forty undergraduate students from introductory psychology courses at Florida State University participated in partial fulfillment of course requirements and were tested individually.

Procedure and Materials. The experiment began with the part-list cuing procedure. A within-participants design was used to examine cuing interference (cued or noncued). The participants studied six lists (half of them cued) of 16 words each, taken from the Toronto word pool (Friendly, Franklin, Hoffman, & Rubin, 1982). The order of the six different lists (list order) and the order in which the lists were cued (e.g., first list cued vs. second list uncued) were counterbalanced across participants.

The participants were instructed to learn all the words and to expect that sometimes they would receive cue words from the list at the time of recall to remind them of the remaining words. At study, words were presented at a 2.5-sec rate, in the center of a computer screen, in 24-point font. At test, for cued trials, eight words from the list were presented in a random order on the screen, and the participants were instructed to avoid writing cue words on their recall answer sheets. For uncued trials, no words were presented. Recall immediately followed each list for 1 min, followed by a 20-sec interval before presentation of the next list.

Following all six lists, attentional control was measured using operation span, developed by Turner and Engle (1989). The span score was the number of words recalled from trials in which all the words were recalled in the correct order with a minimum of 85% math accuracy.

Results and Discussion

An alpha level of .05 was used for all the statistical tests. The dependent variable was proportion of noncued words recalled (Reysen & Nairne, 2002). A one-factor repeated measures ANOVA revealed a large part-list cuing effect [$F(1,39) = 28.74, MS_e = 0.006; \eta_p^2 = .42$], such that cuing impaired recall ($M = .33, SD = .11$) in comparison with noncued recall ($M = .43, SD = .11$). We constructed a regression equation to analyze the relationship of WM span and part-list cuing interference as measured by the difference in recall on cued and uncued trials. There was no linear relationship ($F < 1$), but there was an unexpected curvilinear relationship [$F(1,37) = 4.14, p = .024; r^2 = .184$]. Specifically, interference increased with WM span to a point but decreased with the highest span scores (Figure 1). This curvilinearity appears be the result of a metacognitive strategy by high-span participants, several of whom reported that they "tried not to look" at the cues or tried to "remember the words before" looking at cues. To anticipate, in Experiment 2, we forced all the participants to process the cues and found the predicted linear relationship between WM span and part-list cuing interference.

We also followed a common approach for WM span studies and examined these data with a planned analysis via a two-factor ANOVA of the extreme span groups (span: bottom vs. top quartile) by cuing (cue vs. noncued) relationship (see Figure 2). The model revealed a large and reliable interaction [$F(1,18) = 5.56, MS_e = 0.006; \eta_p^2 = .24$]. As is predicted by the strategic attentional control hypothesis, low-span participants were not significantly affected by cues ($M = .35, SD = .07$), relative to noncued conditions ($M = .36, SD = .10$) ($F < 1$). In contrast, high-span participants exhibited a large interference effect [$F(1,9) = 12.52, MS_e = 0.007; \eta_p^2 = .58$], so that cuing impaired recall ($M = .37, SD = .16$), relative to noncued recall ($M = .50, SD = .12$).

These results suggest a departure from the typical relationship of WM span and interference. The participants with high spans exhibited a very large interference effect, whereas the low-span participants did not show any interference. The high-span participants may have produced greater interference as a by-product of more elaborative

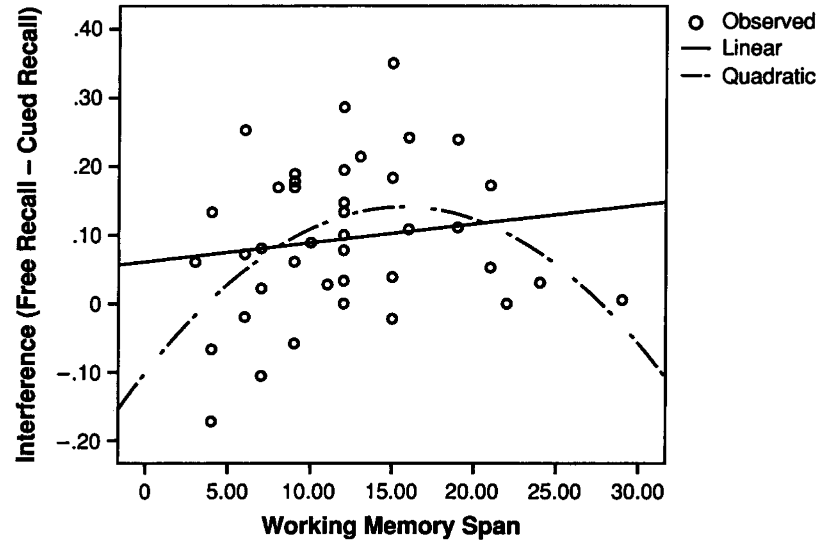

Figure 1. Experiment 1: Regression (linear and quadratic) with working memory span predicting part-list cuing interference (free recall – cued recall). Data points represent interference scores for single or multiple participants.

encoding strategies. Also consistent with the task strategy hypothesis, although unexpected, a curvilinear relationship was detected, suggesting that the participants with intermediate spans demonstrated the most interference. We hypothesized that this resulted from a metacognitive strategy by some high-span participants who avoided viewing the cues. This hypothesis and the role of encoding strategies were directly tested in Experiment 2.

EXPERIMENT 2

In Experiment 2, we sought to refine and extend Experiment 1. One aim of the experiment was to constrain attention to the cues before recall, in order to test for a linear relationship between span scores and part-list cuing interference. In addition, in the second part of the experiment (2B), we sought to examine the causal relationships between interference, span, and encoding strategy. If encoding strategies are a cause of the span and interference relationship, it should be possible to affect the relationship by manipulating encoding.

Method

Participants. Sixty-four undergraduate students from introductory psychology courses at Florida State University participated in partial fulfillment of course requirements and were tested individually.

Procedure and Materials. In *Experiment 2A*, the procedure was similar to that in Experiment 1. The participants first studied four systematically counterbalanced lists of words. However, we also ensured that the participants attended to the part-list cues at test. Specifically, the participants were asked to identify in writing whether each cue occurred at the beginning, middle, or end of the list (writing only B, M, or E), making a guess if the answer did not immediately come to mind. Thus, part-list cuing interference could not be avoided by ignoring the cues. The participants were further instructed to never write down cue words on the recall sheet. During control lists, a 30-sec math filler task was used to approximate the delay between study and test caused by the cue position judgments. The operation span test followed the first part-list cuing phase.

In *Experiment 2B*, after the span task, another four-list, part-list cuing experiment was conducted, following the same guidelines as those set in Experiment 2A. However, before beginning, all the participants were instructed to link the to-be-remembered words in a story in which each word was related to the next (Bower & Clark, 1969). The participants were given a three-word example, followed by a three-word practice trial. To ensure compliance, the participants were asked to speak aloud during the encoding of each list.

Results and Discussion

Experiment 2A. A one-factor repeated measures ANOVA revealed a moderate-sized, reliable part-list cuing effect [$F(1,63) = 9.46$, $MS_e = 0.013$; $\eta_p^2 = .13$], such that cuing ($M = .31$, $SD = .15$) impaired recall in comparison with noncued recall ($M = .37$, $SD = .14$). We also tested

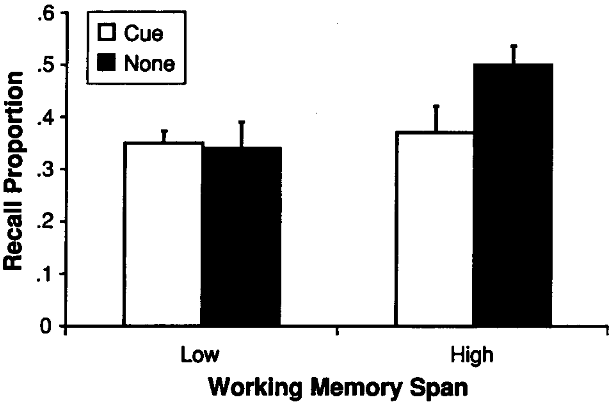

Figure 2. Experiment 1: Working memory span (top and bottom quartiles) by part-list cuing (cue vs. none) recall proportions. Error bars represent standard errors.

a regression equation in which span was used to predict interference. A positive linear relationship[1] was evident [$F(1,62) = 13.8$; $r^2 = .174$], indicating that interference increased with span (Figure 3).

Planned analyses again split the participants into bottom and top span quartiles (Figure 4). Replicating Experiment 1, a large span (high or low) × cuing (cued or noncued) interaction was detected [$F(1,30) = 11.15$, $MS_e = 0.009$; $\eta_p^2 = .27$]. Low-span participants were not affected by cues ($M = .31$, $SD = .11$), relative to the uncued condition ($M = .31$, $SD = .10$) ($F < 1$). In contrast, high-span participants demonstrated a large interference effect [$F(1,15) = 27.35$, $MS_e = 0.007$, $\eta_p^2 = .65$], in which cuing impaired recall ($M = .28$, $SD = .13$), relative to noncued recall ($M = .45$, $SD = .16$).

Experiment 2B. A one-factor repeated measures ANOVA on recall following the story mnemonic training revealed a part-list cuing effect [$F(1,63) = 8.78$, $MS_e = 0.016$, $\eta_p^2 = .12$], where cuing impaired recall ($M = .42$, $SD = .18$), relative to noncued recall ($M = .49$, $SD = .16$). The results from a regression equation testing the WM span and interference relationship showed that the relationship was no longer reliable ($F < 1$; see Figure 5). After story mnemonic encoding instructions, there was no relationship between part-list cuing interference and span. Additional planned analyses of data from the participants in the top and bottom span quartiles, in contrast to the results in Experiments 1 and 2A, also failed to detect a relationship even for the extreme quartile groups ($F < 1$); however, a cuing effect [$F(1,30) = 6.44$, $MS_e = 0.019$; $\eta_p^2 = .18$; see Figure 6] indicated that cues uniformly impaired recall ($M = .39$, $SD = .19$), relative to noncued recall ($M = .50$, $SD = .16$).

The results of Experiment 2A suggest that when the participants were forced to attend to cues, span predicted increased interference. However, when the participants were required to use a story mnemonic, the relationship between span and interference disappeared (Experiment 2B). The results indicate that encoding strategies play a causal role and that low WM span participants have the capacity to adopt encoding strategies that eliminate differences in interference.

GENERAL DISCUSSION

The results suggest a paradoxical relationship between attentional control and interference in part-list cuing. In contrast to other paradigms and retrieval-based interpretations of memory interference, superior attentional control was associated with increased interference. When encoding strategies were controlled, this relationship disappeared, supporting the interpretation that encoding strategies play a causal role in the relationship of attentional control and part-list cuing interference. Therefore, in this case, attentional control appears to be related to the likelihood of engaging in strategic processing at encoding. Furthermore, low-control participants demonstrated the capacity to engage in complex encoding strategies that eliminated individual differences in interference control.

Our results are consistent with the hypothesis that individual differences in attention and interference control can be caused by differences in acquired cognitive mechanisms, including strategies, skills, and knowledge (Daneman & Carpenter, 1980; Ericsson & Kintsch, 1995; McNamara & McDaniel, 2004; McNamara & Scott, 2001). Specifically, these results indicate that individual differences in interference control on a memory test may cascade from different strategies used during encoding. In this case, controlling encoding strategy eliminated individual differences in interference; however, controlling strategies in a complex

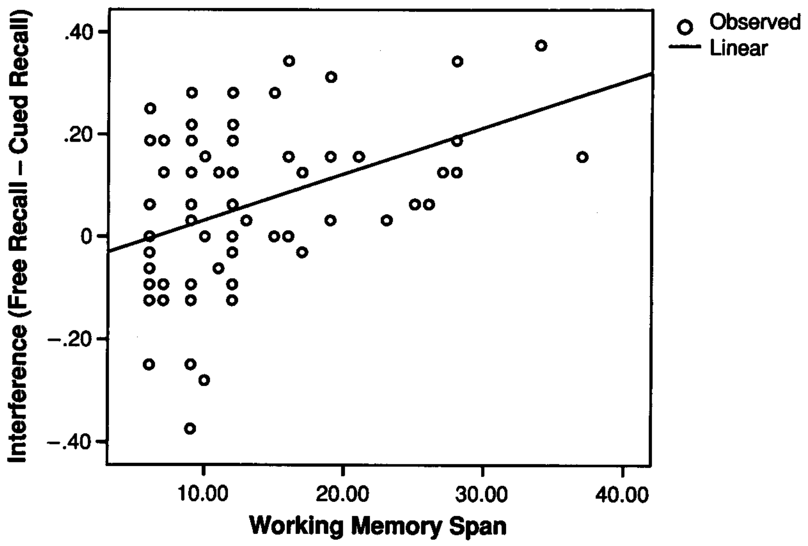

Figure 3. Experiment 2A: Linear regression with working memory span predicting part-list cuing interference (free recall − cued recall). Data points represent interference scores for single or multiple participants.

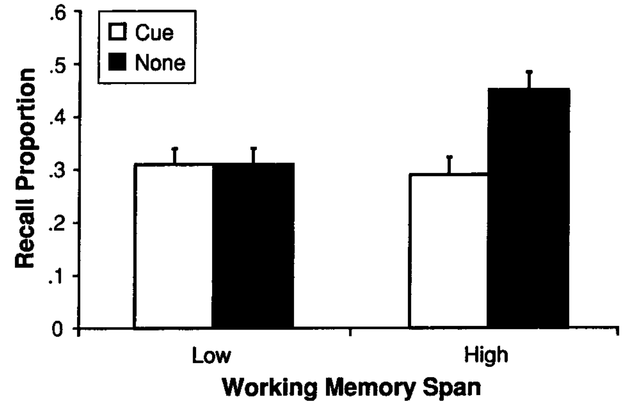

Figure 4. Experiment 2A: Working memory span (top and bottom quartiles) by part-list cuing (cue vs. none) recall proportions. Error bars represent standard errors.

span task itself has improved predictive relationships between complex span and reading skill (Friedman & Miyake, 2004a; Turley-Ames & Whitfield, 2003).

Of note, in the present data, there was a reliable positive relationship between attentional control and free recall on uncued trials. In Experiment 1, the correlation was *r*(38) = .47; in Experiment 2A, *r*(62) = .42; and in Experiment 2B, *r*(62) = .34 (95% CI = .1–.6). This suggests that higher attentional control participants' overall recall advantage remained even when all the participants used the same encoding strategy. These results indicate that there may be important individual differences in implementing the story mnemonic, perhaps in the ability to integrate words within the story (see Bryan, Luszcz, & Pointer, 1999, for a similar interpretation with aging populations). These individual differences could reflect acquired mechanisms, including different levels of skill at elaborative encoding or constructing a theme linking unrelated words, or they may reflect acquired differences in knowledge content or vocabulary (Ericsson & Kintsch, 1995). As well, other retrieval capacity influences, such as verbal fluency (Rosen & Engle, 1997), may influence these relationships.

Parallel to our results, high spans showed *greater* loss of accessibility for studied words in a directed-forgetting paradigm (Delaney & Sahakyan, in press). However, unlike our results, controlling the participants' encoding strategies did not ameliorate individual differences. One theory of how people deliberately forget a studied list is that they shift attention to something outside the experimental context, producing a mental context change (Sahakyan & Kelley, 2002). However, Delaney and Sahakyan found that even when participants were guided in thinking of a different mental context, high spans, but not low spans, showed reduced memory for the list. Greater attentional control may be important for robust activation of a mental context (Delaney & Sahakyan, in press), or low-control participants may be less likely to initially encode extralist context and, so, suffer little from a change of mental context.

Turning to aging research, older adults tend to show reduced scores on measures of attentional control (cf. Rhodes & Kelley, 2005), so one might expect that they would show less part-list cuing interference. Although some evidence supports this hypothesis (Foos & Clark, 2000), other evidence is mixed (Marsh, Dolan, Balota, & Roediger, 2004). Interestingly, older adults may be as likely to use elaborative encoding as are younger adults (Bryan et al., 1999), which would mitigate against age differences. However, our results also point to the importance of requiring participants to process the cues, because we saw some evidence that high-span participants quickly

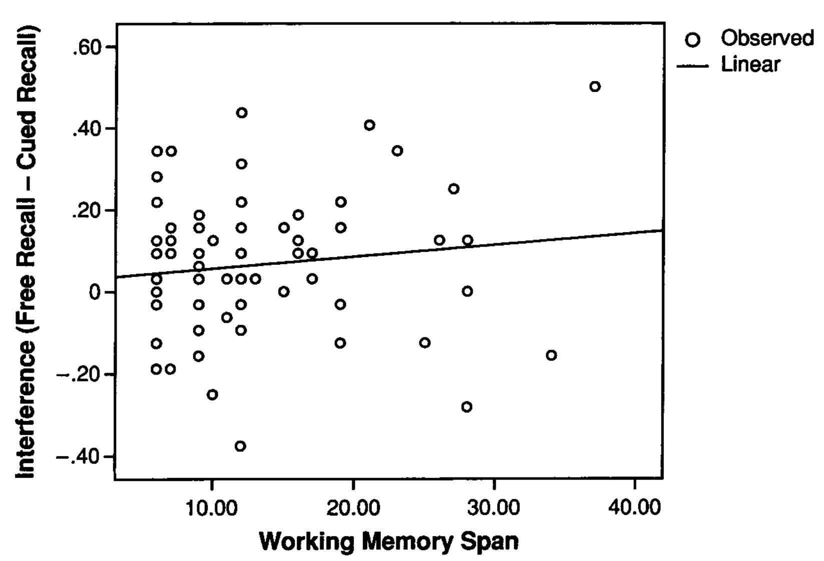

Figure 5. Experiment 2B: Linear regression with working memory span predicting part-list cuing interference (free recall – cued recall). Data points represent interference scores for single or multiple participants.

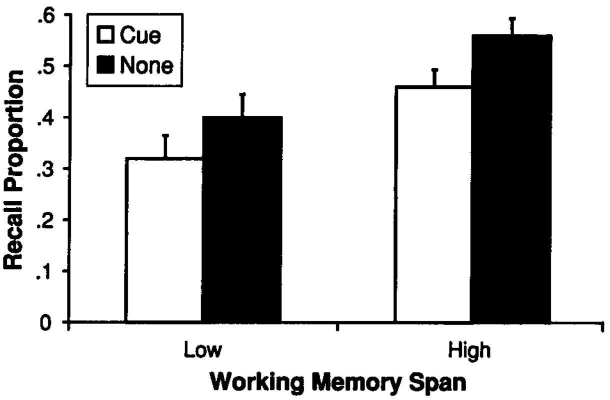

Figure 6. Experiment 2B: Working memory span (top and bottom quartiles) by part-list cuing (cue vs. none) recall proportions. Error bars represent standard errors.

understood the disruptive effects of part-list cues and attempted to avoid looking at cues.

Our results are theoretically consistent with several aspects of the controlled attention framework (Kane & Engle, 2002). In this framework, the critical function linking attentional control to higher order cognition is the ability to maintain goal-relevant information in the face of interference. However, our results suggest that in addition to theoretical capacity differences, attentional control measures (complex span) will sometimes predict individual differences in task strategies. Indeed, even in very elementary cognitive and perceptual tasks, there are so-called optional elements, which create large variations in task performance due to variations in strategies (Kieras & Meyer, 2000; Meyer & Kieras, 1997). Performance differences related to attentional control may, in part, reflect differences in how people represent and configure a strategy for a task, as well as their implementation of that strategy (McNamara & Scott, 2001). Work is currently being done in our laboratory to investigate these hypotheses.

In summary, our results suggest that task performance related to attentional control can be multiply determined and that strategic attentional control will sometimes causally influence interference and may be amenable to training. We speculate that in other basic attention and memory paradigms, variations in goal or task representations may differentially guide processing and may contribute to individual differences in attentional-control-related performance. Generally, studying individual differences in WM can be a valuable tool for revealing relationships between attentional control and task performance. An important next step is to identify precise mechanisms, including variations in task strategies, that are associated with these individual differences.

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NOTE

1. The curvilinear relationship did not provide a significant improvement ($F < 1$) over the linear function ($r^2 = .18$). The result suggests that the addition of the cue position identification task eliminated high-span participants' ability to ignore cues at recall.

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