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Working Memory Capacity in Hot and Cold Cognition

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Much has been said about the relationship between measures of Working Memory Capacity (WMC) and higher order cognition. Indeed, what exactly accounts for this relationship has been a major topic of inquiry in cognitive psychology for over 20 years (Engle & Oransky, 1999). Attempts to better understand this problem have shed considerable light on the role of WMC in a wide array of research domains. Specifically, research has shown that measures of WMC are related to complex learning (Kyllonen & Stephens, 1990), following directions (Engle, Carullo, & Collins, 1991), reasoning ability (Engle, Tuholski, Laughlin, & Conway, 1999; Kyllonen & Christal, 1990), and vocabulary learning (Daneman & Green, 1986). Additionally, not only has WMC been implicated in higher order cognition – indeed, these correlations point to the utility of such a concept in the first place – but also now WMC is being implicated in other research domains. Working memory measures not only predict reading comprehension scores (Daneman & Carpenter, 1980), performance on standard achievement tests (i.e., SAT: Engle et al., 1999), and reasoning, but also seem to predict early onset Alzheimer's (Rosen, Bergeson, Putnam, Harwell, & Sunderland, 2002), the effects of alcohol consumption (Finn, 2002), and one's ability to deal with life-event stress (Klein & Boals, 2001). Thus, the utility of WMC is not merely limited to performance on high-level cognitive tasks, but is also important in a variety of situations that impact people on a day-to-day basis. Working Memory Capacity is important in situations requiring both rational or cold cognition such as selective attention and reasoning (Engle et al., 1999; Kane & Engle, 2003) and is also important under conditions of emotional or hot cognition, such as stress and depression (Arnett et al., 1999; Klein & Boals, 2001). The present chapter will focus on the WMC's role in these situations in terms of our view that the basis for WMC is the ability to control attention.

WORKING MEMORY CAPACITY, HIGHER ORDER COGNITION, AND ATTENTIONAL CONTROL

We view WMC as primarily reflecting the executive attentional component of a broader working memory (WM) system. Similar to Cowan's conception (1988, 1995), we think of working memory as consisting of memory units active above some threshold, which can be represented via a variety of different codes (phonological, visuospatial, semantic, etc.), and as an executive attention component. The executive attention component primarily deals with maintaining or suppressing activation of long-term memory units and task goals, conflict monitoring and resolution, and the flexible allocation of attentional resources. Thus, individual differences in WMC, and hence by our view executive attention, should be most apparent in situations in which active maintenance is needed, particularly in the face of potent environmental distractors or strong internal interference. That is, interference-rich situations make it more likely to temporarily lose novel task goals or for attention to be captured by environmental distractors and thus put a premium on the need for active maintenance. For example, consider a baggage screener at a busy international airport. The screener's task is to watch a monitor for several hours a day to make sure that unauthorized items are not brought onto the airplanes. Here, the screener must sustain attention on the task while simultaneously dealing with constant environmental distraction from crying babies, irritable passengers, and other events that capture one's attention away from the task. A temporary loss in goal maintenance (checking the monitor) can have detrimental consequences. It is in such situations that we believe WMC is of critical importance.

Furthermore, it is our belief that it is the executive attention component that drives the correlation between WM measures and higher order cognition. To investigate these claims, we have utilized quasi-experimental designs and large-scale correlation-based designs. Research reflecting the quasi-experimental methods is aimed primarily at determining what is the underlying primitive of individual differences in WMC. That is, what is the fundamental underlying cognitive mechanism that leads to covariation of the WMC tasks with tasks of higher order cognition? The correlation-based designs are aimed at determining the association and dissociation of various tasks and the domain-specific and domain-general nature of constructs identified by these methods. For both approaches, complex span measures modeled after the Daneman and Carpenter (1980) reading span task are used as the WMC measures. These tasks are essentially dual tasks in which the participant is required to engage in some process such as reading sentences (Daneman & Carpenter, 1980) or solving simple math operations (Turner & Engle, 1989) while simultaneously remembering stimuli (such as words, digits, or letters). These tasks have been shown to be reliable and

valid. Specifically, previous research shows that measures of WMC have both good test-retest reliability and internal consistency (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle et al., 1999; Klein & Fiss, 1999). Likewise, as noted previously, over the past 20 years, these complex span tasks have shown impressive correlations with a wide variety of higher order cognitive operations, which points to their validity.

Complex Span Measures as Predictors of Higher Order Cognition

In our view, these complex WM span tasks measure a confluence of domain-specific skills and memory processes as well as a domain-general executive attention component. Although individuals will no doubt differ in their ability to utilize domain-specific processes such as verbal/phonological skills, the domain-general executive attention component (central executive) is what is critical for the relationship between WMC measures and high-level cognition. For example, consider the operation span task (O-span; Turner & Engle, 1989). Here, the task is to solve simple math equations while simultaneously remembering unrelated words. Individual differences in math ability, and short-term storage skills, such as rehearsal and chunking, might contribute individual differences in overall task performance. That is, people will differ in both the processing component of the task and the storage component of the task. However, each of these abilities alone does not account for the correlation with higher order cognition. Rather, it is the executive attention component that coordinates the processing and storage components of the task that is important for higher order cognition.

Evidence for such a claim comes from several studies conducted by Engle and colleagues. First, Conway and Engle (1996) demonstrated that once participants are equated on math ability, the correlation between a WM measure (O-span) and reading comprehension (VSAT) does not diminish. Thus, individual differences in the processing component, in this case math skills, do not account for the relationship between WM and higher order cognition (see also Engle, Cantor, & Carullo, 1992). Second, Engle et al., (1999; see also Conway et al., 2002) showed, via structural equation modeling, that a latent variable made up of WM span tasks and a latent variable made up of simple short-term verbal memory span tasks were significantly correlated. However, the correlation between the STM measures and a gF composite was mediated by the WM span measures. Thus, simple storage alone cannot account for the relationship with higher order cognition, but rather it is the residual variance in WM span measures not indexed by storage that is important for higher order cognition. Engle et al. argued that the residual variance is an index of central executive processing and showed that this variance was highly correlated with gF (.49). The argument here is that both WMC and STM measures require simple storage of information and WM measures require additional attentional processes. Once the shared variance between the two constructs is accounted for, what is left over in the WM factor is essentially variance thought to be attributable to the executive attention component.

Individual Differences in WMC and Attentional Control

By our rationale, then, individual differences in the efficacy of the executive attention component is critical for demonstrating correlations between WMC and tasks that measure higher order cognition. However, what evidence do we have that individual differences in WMC are primarily attentional differences? That is, what evidence is there that individual differences on measures of WMC correspond to individual differences in the ability to control attention? To test this claim, we used quasi-experimental, extreme groups designs in which participants were prescreened on a WM measure (typically operation span) and only those participants who scored in the top (high spans) and bottom (low spans) quartiles of the distribution were tested on a variety of classic selective attentional paradigms. If our logic is correct, we should see that high- and low-span individuals do not differ on relatively automatic forms of information processing, but that differences will emerge when controlled attention is necessary (Conway & Engle, 1994; Rosen & Engle, 1997; Tuholski, Engle, & Baylis, 2001).

As an elegant test of the claim that WMC is related to attentional control, Conway, Cowan, and Bunting (2001) tested high- and low-span individuals in the dichotic listening paradigm first popularized by Cherry (1953). Here, high- and low-span individuals were required to monitor a message presented to one ear while ignoring a message presented in the other ear. Moray (1959; see also Wood & Cowan, 1995) demonstrated that for the most part individuals have little difficulty in monitoring one channel at a time. However, Moray also found that when participants were presented with their own name in the irrelevant channel, roughly 33% of the participants reported detecting their own name. Conway et al. reasoned that if WMC is akin to attentional control capabilities, then WMC would be important for resisting particularly salient attentional capture (hearing your own name in the irrelevant channel). Thus, Conway et al. suggested that high-span individuals would be better at resisting the powerful attentional orienting cue of their own first name than would low-span individuals and thus would be less susceptible to the "cocktail party" effect. Indeed, this is what they found: 65% of participants classified as low spans reported hearing their name in the irrelevant ear, whereas only 20% of the high-span individuals reported hearing their name. These results suggest that individuals who differ on a WM span measure differ in their ability to resist a salient attention capturing cue when it conflicts with task goals.

Another striking example of individual differences in WMC being related to attentional control capabilities comes from a comprehensive analysis of the role of WMC in the Stroop task (Kane & Engle, 2003). The Stroop task has long been hailed as the "gold standard" of selective attention paradigms. On the face of it, the Stroop task is quite simple. Typically, participants are required to name the color in which color names are printed. When the color and the word match (e.g., red presented in red ink), the task is quite easy. However, when the color and the word conflict (e.g., blue presented in red ink), both reaction time and error rates increase. It is generally believed that the increase in latency and error reflect an inability to inhibit a prepotent response that conflicts with the task goal (e.g., "Say the color not the word"). Kane and Engle (2003) proposed that individual differences in WMC would arise in the Stroop when the need to maintain the task goal is high and that the differences would be differentially reflected in latency and errors. That is, based on the view that individual differences in WMC are due to differences in active maintenance and conflict monitoring and resolution, Kane and Engle argued for a dual-process view of Stroop performance in which span differences would arise in latency when response competition is highest and in errors when the demand for goal maintenance is greatest.

To test this claim, Kane and Engle (2003) manipulated the proportion of congruent and incongruent trials. In the 0% congruent condition, the color and word never matched and thus the task goal was consistently reinforced. In such trials, span differences mainly arose in RT reflecting a greater inability of low-span individuals to resolve competition between saying the color and not the word. In the 75% congruent condition in which the color and word matched most of the time, there is little response competition and thus little need for conflict resolution. In these trials, high- and low-span individuals did not differ on RT, but rather in error rates. Here, low-span participants tended to make more errors than high-span participants. Kane and Engle argued that these errors were an example of what Duncan (1990) has termed "goal neglect." Specifically, in the 75% congruent condition, subjects can respond correctly on most trials even if they don't work to keep active the goal ("say the color not the word"). However, on the rare occasion that the color and word do not match, then the response tendency to say the word is likely to be stronger and an error is more likely to occur.

Individual Differences in WMC and the Antisaccade Task

The previous results provide compelling evidence that individuals differing in the number of items they recall while engaging in simultaneous online processing predict performance in two classic attentional control paradigms. Further evidence for this claim comes from several studies investigating the role of WM in the antisaccade task (Kane, Bleckley, Conway, & Engle, 2001; see also Roberts, Hager, & Heron, 1994; Larson & Perry, 1999). The antisaccade task, like dichotic listening and Stroop, is an attentional control paradigm that requires individuals to maintain task goals in the face of interference via the inhibition of a prepotent response in order to generate the correct response. The antisaccade task (Hallet, 1978; Hallet & Adams, 1980; see Everling & Fischer, 1998 for a review) requires participants to fixate on a central cue; after a variable amount of time, a flashing cue appears either to the right or left of fixation, and participants have to shift their attention and gaze to the opposite side of the screen as quickly and accurately as possible. Thus, in this task, there is good deal of conflict between the automatic orienting response and the task goal.

Given the reliance on inhibition of prepotent responses inherent within the antisaccade task, it is no surprise that the task has been used, much like Stroop, in a wide array of clinical and developmental research. For example, patients with lesions in the prefrontal cortex are more likely to make reflexive saccades, and even if they do make a correct saccade, they are slower to do so compared to healthy controls (e.g., Guitton, Buchtel, & Douglas, 1985). Additionally, these patients tend to show no decrements in the relatively automatic prosaccade task in which the goal is to simply shift your eyes and attention toward the exogenous cue. These same results also hold for schizophrenic and Parkinson patients, whose conditions are associated with disruptions in prefrontal cortex function (Everling & Fischer, 1998). For example, Fukushima et al. (1988) found that schizophrenic patients made more errors and had longer response latencies in an antisaccade but no differences on the prosaccade task compared to healthy controls.

Antisaccade task performance also tends to change as a function of age with young children and older adults making more reflexive saccades and having longer correct saccade latencies than young adults (e.g., Butler, Zacks, & Henderson, 1999; Fischer, Biscaldi, & Gezeck, 1997; Fukushima, Hatta, & Fukushima, 2000; Nieuwenhuis, Ridderinkhof, De Jong, Kok, & Van Der Molen, 2000). Accuracy and reaction times in the antisaccade task show a steady improvement with age, up to about 16 to 18 years old. Within the adult population, older adults show performance changes on the antisaccade task after their mid-30s, with error rates and reaction times increasing with age as compared to younger controls (Fischer et al., 1997; Butler et al., 1999). A similar decline in performance with age does not appear for the prosaccade task. These results demonstrate that suppression and voluntary control are critical for success on the antisaccade task and that these abilities seem to be reliant on prefrontal cortex (PFC) functioning. Additionally, given the strong link between WM and PFC functioning (see Kane and Engle, 2002 for a review), it seems logical to reason that individual

differences in WM would correlate with performance on the antisaccade task.

Kane et al. (2001) reasoned that WMC would be important in the antisaccade because it relies on the same domain-general executive attention component important in both dichotic listening and the Stroop task. Specifically, Kane et al. suggested that WMC would be important in the antisaccade condition because of the need for active goal maintenance in the face of a powerful attention capturing cue. Roberts and Pennington (1996) advanced a similar view, noting: "the Antisaccade and Stroop tasks have strong prepotent responses but relatively light working memory demands: thus, even momentary lapses or slight deficiencies in working memory will affect the balance in favor of prepotency" (p. 112). That is, although the antisaccade task does not have a high memory load, it does carry a substantial executive load in order to resist prepotency and perform the correct behavior. Kane and colleagues, therefore, hypothesized that low-span individuals would be worse at maintaining the production in active memory ("if flash on the left – look right") than high-span individuals, and thus any lapse in attention (or intention) will result in the prepotent response guiding behavior and hence the occurrence of a fast error. Even if the first saccade is the correct direction, low spans should still be worse at controlling their attention, and thus differences in latency will occur when control is needed to resolve the conflict between the task goal and habit. However, in a prosaccade condition in which the subject is simply required to look at the flashing cue, Kane and colleagues (2001) argued that there should be no differences in WMC because both the task goal ("look at the flashing cue") and the automatic orienting response are the same and attentional control capabilities are not needed.

To test these claims, Kane et al. (2001) required participants to perform blocks of both prosaccade and antisaccade trials. Participants fixated on a central cue, and after a variable amount of time, a cue flashed either to the right or left of fixation. In the prosaccade condition, participants shifted their gaze to the same side of the screen and attempted to identify a briefly presented letter (B, P, or R) as quickly and accurately as possible via a key press. In the antisaccade condition, participants were also required to identify a briefly presented letter, but this time it appeared on the opposite side of the screen. The results supported the predictions. Specifically, there were no WM span differences in either RT or errors on prosaccade trials. In antisaccade trials, in contrast, lows spans were both slower to correctly identify the target letter and were less accurate. Additionally, in a second experiment in which eye movements were also recorded, Kane et al. demonstrated that the span differences in both accuracy and RT continued to hold even over 360 antisaccade trials. These results suggest that high- and low-span individuals do not differ on relatively automatic forms of processing, but rather, differences emerge when attentional control is needed to maintain task goals in the face of potent environmental distractors. The finding that low spans were slower to correctly identify the target letter suggests, similar to Stroop's finding, that low spans are particularly deficient in their attentional control capabilities, especially when there is a conflict between task goals and habitual responses. Indeed, this argument was further bolstered by the fact that in addition to being slower at correctly identifying the target letter, low-span individuals were also slower to perform a correct saccade on antisaccade trials. In terms of the accuracy data, the eye movement results suggested that the reason low-span individuals made more errors at correctly identifying the target letter was due to the fact that they made more reflexive saccades to the flashing cue than did high spans. Thus, as predicted, low-span individuals were particularly deficient in their ability to maintain the task goal ("if flash on the left – look right") in active memory and thus were particularly susceptible to a salient environmental distractor. Additionally, even when the task goal was maintained, low spans were slower to implement control and thus resolve the conflict between the automatic orienting response and the task goal.

Although the above results are quite convincing, there is a possible problem that could limit the conclusions drawn from this study. Namely, it has been shown previously that adding a secondary task to the antisaccade task increases the number of reflexive errors (Roberts et al, 1994; Stuyven, Van der Goten, Vandierendonck, Claeys, & Crevits, 2000). It is therefore possible that low-span individuals made more reflexive errors in the Kane et al. study (2001) because the letter identification task acted as a secondary task that put low spans at a marked disadvantage. To alleviate this possible shortcoming, we (Unsworth, Schrock, & Engle, 2004) had high- and low-span individuals perform a simpler saccade paradigm in which the sole task requirement was an eye movement. When the flashing cue appeared, subjects had 600 ms to move their gaze to a target in the same location as the cue (prosaccade) or to a target on the opposite side of the screen (antisaccade). Unsworth et al. nicely replicated the basic findings of Kane et al. (2001) by demonstrating that high- and low-span individuals were equivalent in both RT and accuracy in the prosaccade condition, but that once again, as shown in Figure 2.1, low-span individuals made more reflexive saccades toward the flashing cue and were slower to make a correct saccade in the opposite direction. It seems that the span differences reported in Kane et al. were not solely a function of the secondary letter identification task.

In a second experiment, we questioned whether high- and low-span individuals would also differ on prosaccade trials if a premium was placed on active maintenance. Previous studies showed that in some situations, a secondary task can disrupt prosaccade trials (Pashler, Carrier, & Hoffman, 1993; Stuyven et al., 2000; but see Roberts et al., 1994). Additionally, several studies found that randomly intermixing prosaccade and antisaccade trials

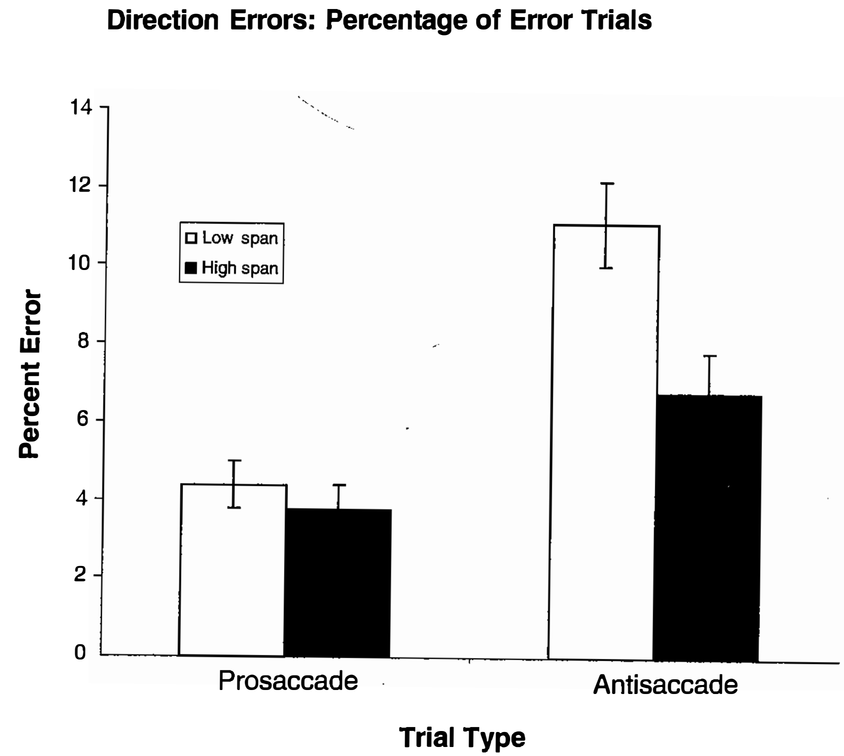

FIGURE 2.1. Mean percentage of direction errors for antisaccade and prosaccade trials for high- and low-span participants in Experiment 1. Error bars represent standard errors of the means.

can lead to disruptions in both antisaccade and prosaccade trials (Hallet & Adams, 1980; Weber, 1995). This suggests that increasing interference, and thus increasing the need for goal maintenance and strategic control, can affect performance on even prosaccade trials. We tested this idea by randomly intermixing prosaccade and antisaccade trials within the same block. In this task, as before, participants moved their eyes either toward or away from a flashing cue. However, unlike the previous studies, each trial began with a fixation symbol that remained on screen for 1,000 ms. The fixation symbol signaled to the participant whether the upcoming trial would be a prosaccade or antisaccade trial. Specifically, if a diamond symbol was presented, then the subject knew that the upcoming trial would be an antisaccade. If, however, the symbol was a circle, then this signaled to the subject that the upcoming trial would be a prosaccade. Strikingly, as can be seen in Figure 2.2, low spans made more eye movement errors and were marginally slower in making correct saccades on both antisaccades and prosaccades trials.

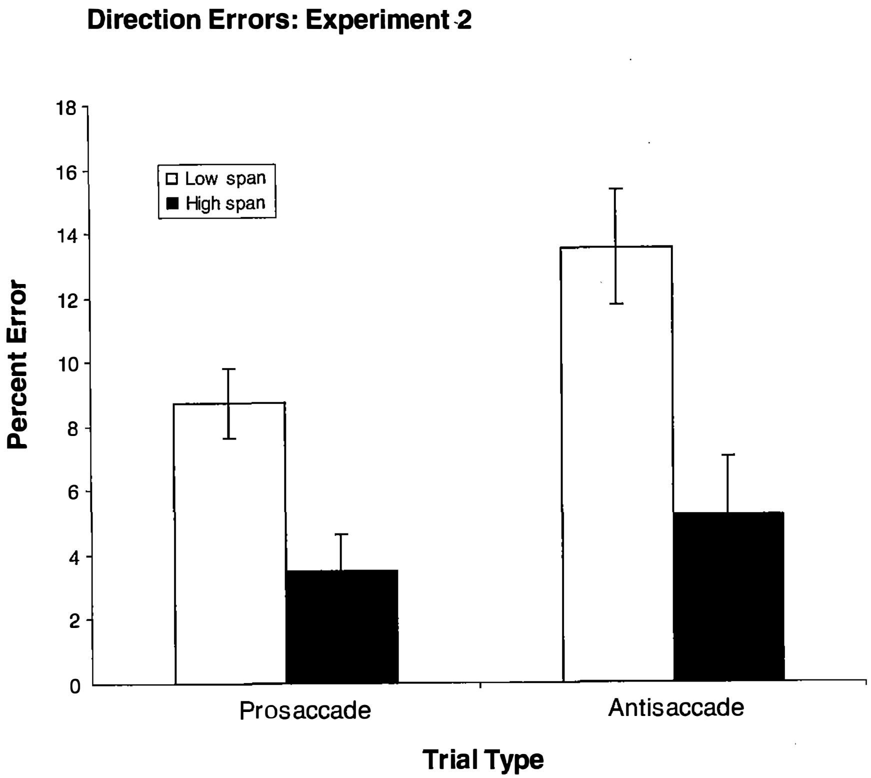

FIGURE 2.2. Mean error percentages for antisaccade and prosaccade trials for high- and low-span participants in Experiment 2. Error bars represent standard errors of the means.

Even in prosaccade trials in which both the automatic orienting response and the task goal coincide, low spans were more likely than high spans to look away from (and not toward) the flashing cue. These results suggest that low spans were unable to actively maintain the task goal long enough to perform the correct response. Thus, it seems that low spans were deficient in either interpreting the cue at the time of presentation (i.e., "What does diamond indicate again?") or even if they did correctly interpret the cue, they were unable to maintain the production in the period between the trial signal and the flashing cue. Either way, the results present a picture in which low spans are more susceptible to losses of goal maintenance (goal neglect) than high-span individuals, and these loses of goal maintenance impede low spans' ability to perform the task.

What can we conclude from the results of the antisaccade studies? It seems quite reasonable to conclude that individual differences in WMC correspond to attentional control abilities that are most apparent when active maintenance is needed in conditions of interference. Individuals

scoring in the upper quartile on a WM span measure are better at inhibiting prepotent responses and maintaining task goals in memory than those scoring in the bottom quartile. Additionally, these results suggest that individual differences in WMC are probably not about the number of things that can be held in memory (e.g., Miller, 1956), but rather about the idea that individual differences in WMC seem to be related to the efficacy of the executive attention component of the broader WM system. The finding that low-span individuals are quite poor on tasks such as the antisaccade also suggests that individual differences in WMC are related to the broader issue of behavioral inhibition, which is important in a variety of real-world applications. It is these issues to which we now turn.

ANTISACCADE AS A MODEL OF BEHAVIORAL INHIBITION

Performance on the antisaccade poses some interesting implications for day-to-day cognitive processing. According to our view, executive attention is necessary in situations in which task goals may be lost to potent environmental distractors (see also Roberts & Pennington, 1996). Within the antisaccade task, executive attention is needed to maintain the task goal ("look away from the flashing cue"), suppress the tendency to look toward the cue, and for the voluntary generation of a correct saccade in the opposite direction. A loss in maintenance will result in a fast reflexive saccade toward the cue, whereas a deficiency in control implementation will result in a correct, but slow, saccade in the opposite direction. These two functions of executive attention are needed in a host of other activities that people engage in on a routine basis. For instance, going back to the baggage screener example, as most of us know, airports are extremely busy environments with a plethora of distracting information. Keeping attention focused on the screen for a continuous amount of time and not letting attention be captured by attractive distractors requires considerable effort. Here the screener must constantly look for potentially dangerous material that passengers may be attempting to bring onboard. Any momentary lapse in attention, and hence a loss of goal maintenance, could result in a potentially serious error in detection.

It is easy to see how these basic concepts can be extrapolated to even broader issues in which a loss in goal maintenance or an inability to implement control can occur. This view is consistent with the work of Wegner (1989, 1994) who suggests that mental control is guided by the need to do one thing (A) while not doing another (B). However, making sure that you are doing A requires that you check and make sure you are not doing B. If B represents a sufficiently powerful construct (e.g., a flashing cue), then suppression will be needed to make sure that A is done and not B. However, like antisaccade and Stroop, any lapse in attention (or intention) will result in B being done instead. Wegner (1994) suggested that two processes are important for successful mental control. One is an automatic process that monitors for thoughts that are counter to the current goal-state and hence are unwanted. When such a thought is discovered, a second attentional process attempts to suppress the thought and maintain the current thought. This view is consistent with ours in that both internal and external distractors can automatically capture attention and therefore interfere with goal maintenance, in which case executive attention is needed to resolve the conflict between the unwanted thought and the current goal state in the form of active suppression.

WMC and Thought Suppression

Klein and Boals (2001) have recently linked Wegner's theory of mental control (1994) with a view of WMC similar to ours. Klein and Boals argued that stressful thoughts are essentially internal distractors that need to be suppressed in order to maintain attention on the task at hand (e.g., Kahneman, 1973). The authors suggested that stress acts as a secondary load that disrupts attentional processing on a primary task, and thus, successful performance requires that stressful thoughts be suppressed. In order to test this hypothesis, participants were tested on a version of the operation span task and on a measure of overall life experience. Life-event stress was operationalized as the sum of events that were rated as negative life experiences. The authors reasoned that life-event stress effects should be most pronounced as a task becomes more demanding. In particular, as set size increases on the operation span (trying to remember seven instead of two words while solving math equations) the high stress levels should disrupt task performance. Indeed, this is precisely what Klein and Boals found. Specifically, the authors found that there was an almost linear increase in the correlation between the number of words recalled in each set size and life-event stress scores, with the largest correlation occurring at the largest set size (r set size $7 = -.57$).

In a second study, the authors extended these findings by demonstrating that not only was an index of stress related to WMC, but also that the type of errors made on the WM span task was correlated with stress. Specifically, Klein and Boals (2001) recorded the number of intrusion errors made by subjects while performing the operation span task. Remember that in this task, subjects are required to verify whether or not math equations are correct while simultaneously remembering words. At the end of one set, subjects are required to recall the words in that set and only in that set. However, sometimes, subjects will recall words that were presented in earlier sets or even recall the words "true" and "false" (verification of the answer on the math equation). These intrusion errors are taken as an inability to deal with proactive interference from the previous trials (e.g., Chiappe, Hasher, & Siegal, 2000). Thus, Klein and Boals reasoned

that if WM resources are needed to deal with proactive interference on the previous trial and to deal with possible intrusive thoughts brought about by heightened stress, then individuals with higher stress levels should also have more intrusive thoughts. Indeed, the correlation between an index of negative life-event stress and intrusion errors was moderate ($r = .33$). Taken together, these two studies suggest that WM span measures are related to the ability to deal with intrusive thoughts brought about by stress. Klein and Boals argued that intrusive thoughts brought about by increased levels of stress compete with WM resources, and this results in deficits in the ability to effectively inhibit these unwanted thoughts.

Brewin and Beaton (2001) also linked the concepts of thought suppression and WMC via the "white bear" paradigm, made popular by Wegner and colleagues (Wegner, Schneider, Carter, & White, 1987). In this study, Brewin and Beaton tested 64 participants on a measure of WMC (operation span), measures of both general fluid and crystallized intelligence, and the "white bear" paradigm. In the "white bear" paradigm, participants are instructed to verbalize their streams of consciousness while suppressing thoughts of a white bear. Each time a participant thinks of a white bear, they are instructed to ring a bell. Thus, like the antisaccade task, successful performance requires participants to maintain the task goal ("don't look at the flashing box," "don't think of a white bear") by suppressing the competing response ("looking at the flashing box," "thinking of a white bear"). The authors found that the number of intrusions was negatively correlated with both the WM measure and the gF measure. Thus, the ability to effectively deal with intrusive thoughts is related to measures of both WM and intelligence. Once again, these results suggest the importance of WMC in suppressing unwanted behaviors.

Recall that by our view, WMC is needed in situations in which attention must be devoted to a primary task while inhibiting possible internal and external distractors. This form of attentional control is typically found in many low-level attentional paradigms as demonstrated previously with both the Stroop and antisaccade. However, the above studies further demonstrate that executive attention is also needed to inhibit unwanted thoughts brought about by stress and task manipulations in order to perform the correct behavioral response, and that individuals who differ in WMC will differ in their ability to suppress unwanted thoughts. We take these results to suggest that the utility of WMC is not merely apparent in low-level tasks and higher order cognition such as reasoning and reading comprehension, but also apparent in tasks and constructs typically found within the social psychological literature.

In further support of this notion, consider a study by Schmader and Johns (2003) in which the role of WMC in stereotype threat was examined. Stereotype threat occurs when individuals perform poorly on a given task if a relevant stereotype is associated with performance on that task.

For example, saying that African Americans score more poorly on intelligence tests than Caucasians would result in poorer scores for the African American participants than would be obtained otherwise, with little to no change in the scores of Caucasians. Schmader and Johns (2003) reasoned that stereotype threat reduces WMC and thus results in poorer performance on a given task. Across three studies, Schmader and Johns found that stereotype threat lead to lower scores on a measure of WMC. Furthermore, in their Experiment 3, the authors found that the effects of stereotype threat on a measure of higher order cognition were mediated WMC. Thus, the authors argued that stereotype threat lead to reduced scores because stereotype information interfered with the individual's attentional control abilities and thus reduced the WMC.

Executive Attention and Prejudice

A recent set of studies by Richeson and colleagues has further demonstrated the importance of executive attention in a dynamic social situation. In particular, one study (Richeson & Shelton, 2003) examined the effects of interracial interaction on executive control. Richeson and Shelton argued that interracial interaction can be an especially taxing exercise for individuals who are prejudiced against the person with whom they are interacting. Additionally, drawing on the work of Baumeister and colleagues (Baumeister, Muraven, & Tice, 2000), Richeson and Shelton suggested that interracial interaction for high prejudiced individuals would deplete executive attentional resources, and therefore, performance on a subsequent task requiring executive attention would be diminished. Richeson and Shelton (2003) first tested fifty White undergraduate participants on a version of the Implicit Association Test (IAT; Greenwald, McGhee, & Schwartz, 1998) to assess participants' implicit attitudes toward Whites and Blacks. Next, participants interacted with either a White or a Black experimenter on an unrelated task. Finally, participants performed a typical Stroop task. Richeson and Shelton reasoned that interacting with a Black experimenter for a person rated high in prejudice would tax executive attention and thus according to Baumeister and colleagues would diminish performance on a subsequent task relying on executive attention. As expected, the results showed that the amount of prejudice, as indexed by the IAT, predicted the amount of interference observed in the Stroop task only when participants interacted with the Black experimenter. Additionally, high prejudiced individuals experienced greater Stroop interference than did low prejudiced individuals after the interracial interaction. Thus, Richeson and Shelton argued that interracial interaction required a degree of executive control in the form of self-regulation and inhibition and that this engagement of executive control led to a subsequent disruption on another task requiring executive control.

Richeson et al. (2003) recently replicated and extended these findings via an fMRI study. Here, White undergraduates again completed the IAT to assess implicit attitudes; they then interacted with a Black confederate and finally performed the Stroop task. Additionally, in a separate session, the same subjects came back and participated in an fMRI session. In this session, participants were required to indicate whether a face appeared to the right or left of fixation. The faces were of either Black or White young adults. Richeson and colleagues reasoned that those individuals higher in implicit prejudice should show greater activation in areas thought to be important for behavioral inhibition (i.e., frontal gyrus; dorso-lateral prefrontal cortext, DLPFC; and anterior cingulate cortex). Additionally, the authors reasoned that the amount of activation in the DLPFC should also be related to the amount of interference observed in the Stroop task. That is, if behavioral inhibition is needed during interracial interaction, then areas associated with this inhibition should be related to areas involved in the inhibition of prepotent responses such as those in Stroop.

Strikingly, this is precisely what Richeson et al. (2003) found. Specifically, in addition to replicating the basic finding that engaging in behavioral inhibition actually hurt performance on the Stroop task for high prejudiced individuals, results suggest that the activation in the frontal gyrus and DLPFC, upon seeing Black faces, was significantly correlated to IAT scores. For White faces, however, no significant correlations were obtained. Thus, the amount of prejudice, as indexed by the IAT, was related to the amount of activation in areas thought to be important for behavioral inhibition. The results further demonstrated that the amount of interference observed in Stroop was significantly related to the amount of activity for Black faces in the frontal gyrus. Finally, the authors regressed the interference scores from the Stroop task on IAT scores and on activation from the frontal gyrus. The regression revealed that frontal gyrus activity was the only significant predictor of Stroop interference, suggesting that the relation between IAT scores and Stroop interference is mediated by activity in the frontal gyrus. Richeson et al. argued that this was due to the fact that interacting with a Black individual required relatively high prejudiced individuals to engage in behavioral inhibition; this need for behavioral inhibition resulted in a increase in activity in the frontal gyrus. This increased behavioral inhibition depleted executive attentional capacity, which diminished subsequent performance on the Stroop task.

These results and conclusions are intriguing. They suggest that the need for an executive attention mechanism is important for inhibition not only in low-level processing tasks, but also in situations in which social schemas and emotional attitudes are activated. According to the view outlined here, the executive attention mechanism responsible for the results of Richeson and colleagues findings is the same mechanism found to differentiate high and low working memory individuals. That is, despite the fact that WMC was not directly measured in these studies, the results do suggest a common link between our experiments and the findings of Richeson and colleagues. Specifically, goal maintenance in the face of interference or distraction and the resolution of the interference (conflict) are needed to generate the correct response. People who are prejudiced against a particular racial group, yet wish to maintain some degree of civility, then must attempt to act in accordance with the civility despite their prejudicial beliefs. Thus, the goal here is to act civil, not letting the prejudicial beliefs slip out. Similar to the antisaccade, in order to maintain the task goal and generate the correct response, you must inhibit the prepotent response, and in a sense, "block" your prejudicial views from becoming apparent. Richeson and colleagues (2003) further suggested that engaging in this form of behavioral inhibition is extremely effortful and can deplete executive attentional resources to the point that a subsequent task requiring these resources is hurt as well (see also Baumeister et al., 2000).

The Effect of Alcohol on WMC

The work relating stress (Klein & Boals, 2001) and prejudice (Richeson & Shelton, 2003) to executive attention suggested that these constructs work much like a cognitive load in the sense that they disrupt ongoing processing. Furthermore, these studies showed that successful performance is diminished when the need for conflict resolution between the task goal and a prepotent response is high. Work on the effects of alcohol on cognition has demonstrated that alcohol works similar to a cognitive load. Work by Finn and colleagues demonstrated a link among WM, behavioral inhibition, and alcohol consumption. Finn, Justus, Mazas, and Steinmetz (1999) had participants perform a Go/No-Go task with a contingency reversal halfway through the task while under the influence of alcohol and while sober. The Go/No-Go task required participants to learn when to hit the space bar (Go) and when not to hit the space bar (No-Go) based on rewards and punishments imposed after each trial. That is, after a response, a screen would appear indicating whether the participant had won or lost money during that trial. Participants performed 20 blocks of trials with a contingency reversal occurring at the eleventh block. At the onset of the 11th block, those stimuli and responses that had previously indicated a Go trial were now considered a No-Go trial and vice versa. Thus, contingency reversal created a response incompatibility in order to increase the need for behavioral inhibition. In addition, each participant completed a backward digit span task to assess WMC.

Finn et al. (1999) hypothesized that alcohol ingestion would lead to a deficiency in the ability to inhibit, and that these deficits in inhibition would be greatest for low WMC individuals. Furthermore, these inabilities should manifest themselves both in false alarms on the Go/No-Go task and in poorer performance after the contingency reversal. In support of these hypotheses, Finn et al. found that low WMC individuals, but not high WMC individuals (based on a median split), showed increased false alarm rates as a result of alcohol ingestion. Additionally, low WMC scores were related to inhibitory deficits after contingency reversal. Thus, low WMC individuals had a more difficult time inhibiting responses after the contingency reversal. These same low WMC individuals also demonstrated diminished performance because of alcohol ingestion. These results suggest that alcohol essentially places a load on WM and results in reduced ability to do the work required to inhibit. This deficiency in goal maintenance biased responding in favor of prepotent behavior and led to the incorrect response. Furthermore, these effects are most pronounced for individuals with low WMC scores. That is, those individuals hypothesized to be poorer at actively maintaining task goals demonstrated greater impulsive behavior brought about by a physiological load. This led Finn et al. to conclude that WM modulates behavioral inhibition and that alcohol consumption reduces the ability to effectively control impulsive behavior.

Taken together, the previous studies demonstrate the importance of WMC in wide array of real-world issues. Not only is WMC related to many real-world cognitive tasks such as reading comprehension (e.g., Daneman & Carpenter, 1980), reasoning (e.g., Kyllonen & Christal, 1990; Engle et al., 1999), and complex learning (Kyllonen & Stephens, 1990), but also these studies demonstrate the utility of executive attention in issues such as stress, prejudice, and alcohol consumption. The work has further demonstrated that executive attention is important in these areas because of a need to maintain task goals in the face of interference via behavioral inhibition. We have argued that our work with the antisaccade paradigm provides a clear and simple parallel between low-level attention tasks and these real-world issues via the need for active maintenance and inhibition. That is, the processes required in the antisaccade task can be extrapolated to other areas as a means of explaining the need for executive attention. When goal maintenance is threatened by heightened internal and external interference, executive attention works to keep task goals appropriately activated in order to deal with this interference. Our view, as well as the view of others (e.g., Roberts & Pennington, 1996), suggests that behavioral inhibition of intrusive thoughts and/or environmental distractors can only occur when the goal to do so is actively maintained.

DIFFERENCES IN WMC AS A CAUSE OR A RESULT IN COGNITIVE FUNCTIONING

So far, we have discussed the role of WMC on a variety of tasks with relatively healthy, young adults. The results of our own studies suggest that individuals differing in WMC also differ on low-level attention paradigms in which goal maintenance and inhibition are important for successful task performance. In particular, both the Stroop and antisaccade task require that participants maintain a task goal (e.g., "say the color not the word," "don't look at the flashing box") in the face of a powerful prepotent response. When task goals are actively maintained, inhibition of the prepotent response occurs and appropriate action is generated. However, if for any reason goal maintenance is lost, then habitual responding will guide behavior and errors or inappropriate responding will occur. Furthermore, we have argued that these executive control capabilities share common variance with tasks of higher order cognition. In several studies, we demonstrated that the same WM span measures that differentiated participants in the attentional tasks are highly predictive of higher order cognition. In particular, we argued that WMC is an important component of general-fluid intelligence. Thus, the results from normal, healthy adults suggest that WMC is a relative primitive in terms of cognitive functioning.

In addition, the results of the preceding section on behavioral inhibition have demonstrated that executive control is diminished under conditions of load brought about by stress, prejudice, and alcohol. We argued in the preceding section that the results of these studies could be interpreted in a framework similar to the antisaccade in that these loads introduced interference into the task in the form of unwanted thoughts that had to be suppressed. The loads imposed by these tasks make it more likely to temporarily lose task goals, and thus any loss in attention will result in the inappropriate behavior and subsequent decrements in performance.

In these cases, reductions in WMC and subsequent diminished cognitive functioning are a result of the load imposed by the relevant phenomena. That is, it is not that low WMC causes stress or alcohol consumption (although cyclic effects may occur in which low WMC may lead to more stress, which then leads to decrements in WMC, etc.), but rather these act as a secondary load that leads to disinhibited behavior and poor performance on tasks that require sustained and focused attention. Furthermore, these effects are similar to those brought about by normal aging and even psychopathology. In this view, tasks and situations that rely on WMC can be affected independently or interactively by both individual differences in WMC and secondary loads, stress, schizophrenia, depression, and alcohol consumption. As shown in Figure 2.3, performance on tasks such as Stroop and antisaccade is dependent on WMC, which in turn is affected by individual differences and also by secondary task loads, normal aging, and psychopathology. Additionally, some of these same factors (e.g., alcohol/prejudice) may work more as a moderator variable whereby the relationship between WMC and higher order cognition is affected only for those participants low in WMC. In this case, low WMC can be seen as a

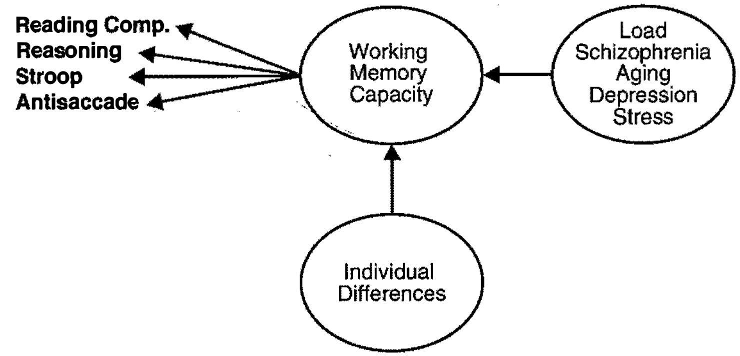

FIGURE 2.3. Schematic demonstrating the role of WMC to task performance as a function of individual differences and/or secondary loads, psychopathology, etc. Reading comp. = reading comprehension.

risk factor.[i] Therefore, performance deficits can occur as a result of abiding differences among individuals or because of other phenomena that tax WMC such psychopathology or a combination thereof.

Aging

Extensive work has linked cognitive decrements in normal aging with deficits in WMC (e.g., see Oberaurer, this volume). It is our view that differences typically observed between older and younger adults are similar to those seen by low- and high-span individuals. That is, low WM span individuals and older adults tend to act similarly on many of the tasks discussed previously. Indeed, as noted earlier, research has shown performance differences on both Stroop (see West & Bowry, this volume) and the antisaccade task (Butler et al., 1999; Nieuwenhuis et al., 2000) between older and younger adults. Although the reasons for performance decrements for older adults and young adults who are low spans may be quite different (e.g., Engle, 1996).

Hasher, Zacks, and colleagues (1988; Stoltzfus, Hasher, & Zacks, 1996) advanced a theory similar to ours to explain cognitive declines in aging. Specifically, they (1988; Stoltzfus et al., 1996) argued that cognitive functioning declines in older adults because of a loss in efficient inhibitory ability. Thus, like our view, inhibition of irrelevant thoughts and distractors is needed to maintain task goals in the face of interference. However, the views differ slightly in regard to the underlying primitive responsible. We assume that difficulty in inhibiting task-irrelevant items is a function of attentional control (e.g., see Engle, Conway, Tuholski, & Shisler, 1995;

[i] We would like to thank Greg Sedek for suggesting this to us.

Engle, 1996), whereas Hasher, Zacks, and colleagues (1988; Stoltzfus et al., 1996) argued that the underlying primitive is individual differences, specifically in the ability to inhibit.

Regardless, difficulty in dealing with interference seems to result in performance decrements on many higher order tasks. Furthermore, for older adults, the declines in WMC are a result of a normal process, and thus subsequent disruption in higher order cognition is ultimately a result of normal aging of the neural circuitry involved in goal maintenance and conflict resolution (see West & Bowry, this volume). That is, in this case, processes involved in normal aging result in declines in WMC, which in turn results in declines in normal cognitive functioning. Thus, WMC acts as a mediator between normal cognitive aging and declines in higher order cognition.

Psychopathology

In addition, cognitive declines in psychopathology (e.g., schizophrenia, depression, Alzheimer's disease, etc.) can often be seen as declines in goal maintenance and conflict resolution, which result in subsequent declines in higher order cognition. In these cases, it is not that WMC causes psychopathology, but rather that psychopathology results in declines in WMC. Then, to the extent to which WMC can be seen as a relative primitive in cognitive functioning, these declines in WMC result in subsequent declines in higher order functioning. The work of Cohen and colleagues (e.g., Cohen, Braver, & O'Reilly, 1996; see also Barch & Braver, this volume) suggested that the control deficits observed in schizophrenia are a result of deficits in active maintenance and inhibition, whereby disruptions in active maintenance result in a failure to inhibit prepotent responses. Indeed, Roberts and Pennington (1996) advanced a similar view of frontal dysfunction noting: "Frontal dysfunction could create two types of inhibitory deficits: a more global inhibitory deficit from tonic disinhibition, which would lower thresholds for prepotent responding generally, and a more specific form of response disinhibition that results from weaker working memory activations" (p. 112). Thus, like the view presented here, deficits as a result of psychopathology can be seen as disrupting the executive attention capabilities of the WM system in which active maintenance is lost and prepotent responses guide behavior.

Likewise, work in the realm of depression has suggested that depressed individuals show more interference than control subjects when attentional control is necessary, but little to no differences when relatively automatic processing is necessary (e.g., Hartlage, Alloy, Vázquez, & Dykman, 1993; Hasher & Zacks, 1979). Similarly, Arnett et al. (1999) demonstrated that depressed individuals performed worse on a measure of WMC (reading span), but there were no differences on a simple short-term memory measure (word span). Arnett et al. suggested that depression reduces the capacity of the executive attention component of the WM system. Additionally, work by Wegner and colleagues (Wenzlaff, Wegner, & Roper, 1988) showed that depressive individuals are worse at suppressing unwanted thoughts than are control subjects, specifically when the unwanted thoughts are negative in nature. Like the effects brought about by stress, depression results in a loss of goal maintenance, which in turn leads to an inability to effectively deal with interference and hence more intrusive thoughts. Thus, the rumination of negative thoughts associated with depression make it more difficult to focus attention on the task at hand, and thus performance decrements are observed.

In our view, individual differences in WMC, as measured by complex span tasks in healthy, normal, young adults provide a fruitful arena in which to investigate the possible mechanisms and consequences of these issues. That is, although it is possible that the underlying mechanisms responsible for individual differences in a "normal" population are not the same as those observed in normal aging and psychopathology, we believe that work within a "normal" population can shed light on these issues via a framework that relies on executive attentional capabilities in terms of active maintenance and inhibition (e.g., Roberts & Pennington, 1996).

CONCLUSION

We have presented a view of working memory capacity in which the executive attention component of the broader WM system is important in a diverse array of real-world phenomena including lower level attention tasks, measures of higher order cognition, as well as stress, prejudice, and alcohol consumption. Furthermore, we argued that the results from the antisaccade paradigm provide a simple framework in thinking about the possible role of WMC in many tasks. That is, we argued that the antisaccade task requires the inhibition of prepotent responses and that the inhibition of these responses can only occur when the intention to do so is actively maintained in WM. Furthermore, individual differences in WMC are most apparent in situations in which active maintenance is needed to generate the correct response in the face of potentially distracting information. We argued that these two functions of executive attention – active maintenance and conflict resolution, and hence WMC – are needed in many real-world situations. Whether or not the views outlined here will ultimately prove to be accurate, we believe that research in the next 20 years will not only provide more evidence about the ultimate link between measures of WM and higher order cognition, but will also provide evidence on the role of WMC in many other research domains.

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