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Working Memory Capacity and Inhibition: Cognitive and Social Consequences

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The construct of inhibition plays a prominent role within cognitive psychology (Dagenbach & Carr, 1994; Dempster & Brainerd, 1995) despite ongoing controversy surrounding its utility as a concept (MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). For researchers who agree on the existence of inhibition, there are additional debates as to whether inhibition is the cause (Hasher & Zacks, 1988; May, Hasher, & Kane, 1999) or a consequence (Kane, Bleckley, Conway, & Engle, 2001) of individual differences in working memory capacity (WMC). This chapter provides a brief introduction to our executive-attention theory of WMC and how exactly WMC relates to inhibition, and then we review research from the cognitive and social domains that connects WMC and inhibition.

Individual Differences in Working Memory Capacity and Executive Attention

Individual differences in WMC are related to a number of important abilities and behaviors, including fluid intelligence, reading comprehension, and acquisition of various skills (for recent reviews, see Conway et al., 2005; Engle & Kane, 2004; Heitz, Unsworth, & Engle, 2004; Kane, Conway, Hambrick, & Engle, 2007; Unsworth, Heitz, & Engle, 2005). These relations have been discovered mainly in the context of relating criterion measures to individual differences in performance on complex span tasks such as operation span (OSPAN; Turner & Engle, 1989), reading span (Daneman & Carpenter, 1980), and counting span (Case, Kurland, & Goldberg, 1982). These complex span tasks were developed originally as a way to measure the multifaceted nature of cognition based on the Baddeley and Hitch (1974) model of working memory. Complex span tasks such as OSPAN combine the elements of a serial recall task (e.g., list of words) interleaved with a simple decision task (e.g., solving basic mathematic operations). For example, participants taking OSPAN would see a series of items such as the following: IS (2 × 1) + 3 = 6 ? DOG. After two to seven items are presented, the participant would then be signaled to recall the words in serial order. Thus, complex span tasks have also been labeled "processing-and-storage tasks," in contrast to "storage-only tasks" such as digit span, which are commonly included in psychological test batteries.

From this perspective, individual differences in WMC, as measured by the various complex span tasks, represent the ability to maintain item and order information while dividing attention with the processing component of the task. Across trials, the opportunity for interference arises, and WMC is important for selecting only the currently relevant memory representations. Our framework for explaining the relations between measures of WMC and higher order cognition is that *executive attention*, or the ability to control attention in a goal-directed manner, is critical for accurate and efficient cognition. More specifically, WMC is most important when goal-related information must be actively maintained to guide response selection, especially if viable but contextually inappropriate response alternatives are also available (Engle & Kane, 2004). The label *executive attention* was explicitly chosen to emphasize our contention that individual differences in WMC represent mainly the domain-free, limited-capacity functioning of the central executive in the Baddeley and Hitch (1974) working memory model (Kane, Poole, Tuholski, & Engle, 2006).

Although we use the term *working memory capacity*, we view individual differences in WMC as representing an ability to control attention, which leads to differences in the number of items one can store in memory. Therefore, another way to view individual differences in WMC is to think of them as differences in the ability to allocate attention resources. Norman and Bobrow (1975) outlined two kinds of capacity limitations on information processing: (a) data limitations and (b) resource limitations. Critically, performance in a given situation is determined by a combination of the two types of process, but data limitations (e.g., stimulus degradation) occur independent of the amount of attention resources an individual allocates to the task. We argue that individual differences in WMC are akin to resource limitations on processing, and people high in WMC can more flexibly allocate attention resources to achieve some goal (for a related view on the flexibility of attention allocation, see Cowan, 2004).

To study the importance of individual differences in WMC, our research has taken two main forms (Engle & Kane, 2004). Our macroanalytic research with young adults has used the full range of individual differences in several abilities, including WMC, short-term memory, processing speed, and fluid and crystallized intelligence, and has attempted to account for the nature of the relations between these constructs at the latent level using confirmatory factor analysis and structural equation modeling (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004). Our microanalytic research, which is the focus of this chapter, has measured young adults on complex span tasks such as OSPAN and has had individuals who score in the upper and lower quartiles (called *high-span* and *low-span participants*, respectively) perform various cognitive psychology experiments, primarily in the memory and attention domains.

A Resource Account of Inhibition

Several researchers (Friedman & Miyake, 2004; Kipp Harnishfeger, 1995; MacLeod et al., 2003; Nigg, 2000) have recently acknowledged the prevalence of inhibition as an explanatory mechanism in different psychological domains. However, as those authors also noted, the exact meaning of inhibition hypothesized in various studies is often poorly defined. Our view is that inhibition is a controlled and resource-demanding process that influences performance in situations where task success is aided by inhibiting not only task-specific information but also irrelevant thoughts and distracting events (Conway & Engle, 1994; Engle, 1996). Therefore, our use of *inhibition* is equivalent to the active, goal-directed process that Bjork (1989) referred to as *suppression*; our focus is on inhibition as suppression and not inhibition as *blocking*, which Bjork described as "a by-product of the activation of other items in memory . . . [that] may not be adaptive" (Bjork, 1989, p. 325).

Engle, Conway, Tuholski, and Shisler (1995) presented an account of inhibition as an effortful, resource-dependent process that would be impaired if one did not have sufficient attention resources. Engle et al. (1995) tested the inhibition-resource hypothesis by administering a negative priming task under varying conditions of concurrent memory load. Specifically, participants saw a pair of letters on each trial and were instructed to name the red letter while ignoring the green letter. Trials were divided into primes and probes, with one third of the probe trials representing the interference condition, because the probe target had just been presented as the distractor on the prime trial. The other two thirds of the probe trials were control trials, with completely different red and green letters on both the prime and probe trial pair. The critical manipulation involved the presentation of a word to be remembered for later recall after certain probe trials. No word was presented after the probe trial for the initial prime–probe pair in a set of five trials (Load 0); however, a different word for recall was presented after each of the subsequent probe trials in the set (Loads 1, 2, 3, and 4). After completing five trials, participants were instructed to recall the four words in serial order. The negative priming effect (the difference between control and inhibition trials) was compared for each memory load (0–4) and also to a separate experiment in which participants completed the negative priming task without the concurrent memory task.

If inhibition is a resource-dependent process, then the negative-priming effect reflecting inhibition should vary with the increasing attention resources being devoted to the concurrent memory task. That is, as the resources demanded by the memory task increase with the number of items held in memory, there should be fewer resources available to devote to the letter identification task and to suppression of the distractor, as reflected in a decrease in the amount of slowing seen on interference trials compared with control trials. Participants in the control experiment showed the typical negative-priming effect; however, as predicted, this relation changed with increasing load for participants who also performed the memory task. Although interference trials were slower than control trials for the Load 0 condition, the Load 3 and 4 conditions showed that interference trials were actually faster than control trials. The so-called interference trials showed a positive-priming effect, which is what would be expected if the representation of the distractor from the previous trial was not adequately suppressed. The modification of the negative-priming effect by adding a memory load demonstrates that inhibitory processes are indeed resource dependent.

Conway, Tuholski, Shisler, and Engle (1999) proposed that individual differences in WMC also affect inhibitory efficiency by comparing high- and low-span participants on a version of the negative-priming task used in Engle et al. (1995). Replicating their earlier work, negative priming was seen only on trials with a memory load of 0, supporting the argument that inhibition is a resource-dependent process. The critical finding involving WMC was that although high-span participants showed a significant negative-priming effect at Load 0, low-span participants did not produce a reliable negative-priming effect in any memory load condition. These results suggest that even in the easiest version of the task, low-span participants did not suppress the distractor item. Going back to the earlier discussion of the factors involved in determining the resources available for inhibitory processes, these results show that individual differences in WMC influence the effectiveness of inhibition.

Working Memory Capacity and Cognitive Inhibition

As mentioned earlier in this chapter, there are differing views regarding the primary cause of individual differences in WMC. As will become clear, we are confident that WMC is in fact related to inhibition. However, our position is that individual differences in WMC represent a differential ability to control attention, which causes (among other things) individual differences in inhibitory ability. Admittedly, this account makes many predictions similar to those of an alternative view that individual differences in inhibitory processes lead to differences in WMC (Hasher & Zacks, 1988). Although presented originally as a theory to explain the cognitive deficits often seen in older adults, this view can often account for the differences in performance seen within individuals of the same age group, resulting in what has been described as the "chicken–egg" dilemma (Kane et al., 2001; May et al., 1999). However, research conducted in our lab from the time of our last review of WMC and inhibition (Engle, 1996) has provided additional evidence that WMC is the causal factor, and not the consequence, of inhibition.

Especially relevant to our discussion of competing theories of WMC, Hasher, Zacks, and May (1999) put forth a taxonomy of inhibition that distinguishes among the access, deletion, and restraint functions in their discussion of inhibitory failures in older adults. Borrowing from a similar point made by Friedman and Miyake (2004), these separate inhibitory functions can be considered in terms of the three different stages of information processing at which each occurs: (a) Access occurs at the perceptual stage, (b) deletion happens at an intermediate stage after representations enter the focus of attention (Cowan, 1995), and (c) restraint arises at the output level of processing. These separate types of inhibition provide the framework for reviewing our research in the cognitive domain relating WMC to inhibition.

Access

Hasher et al. (1999) defined the *access* function of inhibition as "preventing any activated but goal-irrelevant information (triggered automatically by familiar stimuli in the physical or mental environment) from entering working memory" (p. 654). The physical stimuli correspond to external information, whereas the mental stimuli are analogous to internal thoughts. The research described in this section focuses mainly on the "physical" environment, whereas the research described later in the WMC and Social Inhibition section centers more on the "mental" environment.

Dichotic Listening. Although primarily used as a means to study early-versus late-filter attention theories, dichotic listening also provides a powerful demonstration that WMC is related to one's ability to select what enters memory. Conway, Cowan, and Bunting (2001) used dichotic listening to study the relation between WMC and the ability to inhibit a highly salient distractor—namely, one's own name, as in the cocktail party phenomenon (Moray, 1959). High- and low-span participants were presented with different auditory streams in two channels and told to shadow one input while ignoring the other. As in the original study, the shadowing task was used as a guise to examine whether individuals reported hearing their name, which had been presented in the irrelevant auditory channel.

The authors argued that two opposing hypotheses regarding WMC were possible: (a) High-span participants could have been able to both successfully shadow the relevant channel while also monitoring the irrelevant channel, resulting in more reports of hearing their own name, or (b) high-span participants could have been better at focusing on the relevant channel and actively suppressing the irrelevant channel, resulting in fewer reports of hearing their own name. The latter prediction is exactly what they found; low-span participants were much more likely to report hearing their names than high-span participants (65% vs. 20%, respectively), and they made more shadowing errors than high-span participants at the time their name was presented. The results suggest two very important conclusions: (a) Individual differences in WMC represent differences in ability versus the amount of stored information as a property of an individual, and (b) WMC is determined by an ability to control attention in the service of achieving task goals.

Flanker Task. Another experimental situation where distractor information can interfere with the task goal is the flanker task (Eriksen & Eriksen, 1974). This paradigm demonstrates the importance of being able to selectively focus on a specific aspect of a stimulus, even when it is surrounded by distractors competing for attention. In one version of the task, participants are instructed to respond to a central target letter flanked either by the same letters (e.g., *HHHHH;* compatible) or letters mapped to the competing response (e.g., *HHSHH;* incompatible). Performance on incompatible trials is slower and more error prone when compared with compatible trials because the influence of the distractors interferes with processing of the target letter. Gratton, Coles, Sirevaag, Eriksen, and Donchin (1988) analyzed the response time (RT) distributions for compatible and incompatible flanker trials and measured accuracy as a function of RT. They found that incompatible-trial performance was at chance on the fastest trials, but performance on slightly slower trials was actually less than chance, consistent with the idea that the distractors were not being filtered and in fact were biasing participants toward the competing, incorrect response. In contrast, the slowest incompatible trials were performed without error, suggesting that the flankers were no longer affecting responses.

Heitz and Engle (in press) extended the Gratton et al. (1988) findings by testing high- and low-span participants on the flanker task on the basis of the notion that high-span participants are faster at constraining their attention to the target and less likely to be affected by the distracting information on incompatible trials. High- and low-span participants did not differ in accuracy during either the fastest or slowest incompatible trials. Replicating Gratton et al., on the fastest trials, all participants were performing at chance, suggesting that they were merely guessing; on the slowest trials, all participants were near ceiling. However, high-span participants were significantly more accurate on trials in the middle of the RT distribution, indicating that they were faster in their ability to selectively attend to the target letter and remove the influence of the distractors.

Redick and Engle (2006) also examined individual differences in WMC on a version of the flanker test embedded within the attention network test (Fan, McCandliss, Sommer, Raz, & Posner, 2002). Instead of using letters, the attention network test displays left- and right-pointing arrows as the targets and distractors. Despite the differences in the overall task structure, we corroborated the findings of Heitz and Engle (in press) showing that the presence of incompatible flankers was more detrimental for low-span compared with high-span participants. Overall, these results suggest that individuals high in WMC are more effective at preventing interfering information from affecting further cognition.

Deletion

As part of the memory retrieval process, one must identify and select the appropriate item from among other activated representations within memory. This search through memory is aided if one can inhibit "the activation of any marginally relevant or irrelevant information, along with the activation of any information that becomes irrelevant" (Hasher et al., 1999, p. 654). The *deletion* function is similar both to what Nigg (2000) called *cognitive inhibition* and to the effortful suppression form of retrieval inhibition that Bjork (1989) distinguished from blocking. As stated earlier, the key distinction between *suppression* and *blocking* is that suppression is actively used to achieve some goal, whereas blocking is more of a consequence of retrieving a nontarget item that subsequently impairs access to the target. In addition to the proactive interference (PI) studies that follow, the interested reader is referred to Engle (1996) for a discussion of previous research with WMC and inhibition during memory retrieval.

Paired-Associates Task. Rosen and Engle (1998) examined the role of WMC in a modified paired-associates task. High- and low-span participants were presented with lists of cue–target pairs to learn and then tested for target recall after each list presentation for a total of three separate lists. Although all participants received semantically related cues on each list, the exact list composition was determined by two between-subjects conditions. Participants in the control condition received cues from a new category for each list, and target words were never repeated. In contrast, participants in the interference condition received the same 12 cues for each list and received the same target words on the first and third lists. Thus, we labeled the design for the control condition *EF–CD–AB* and the interference condition *AB–AC–AB* to represent that List 3 items were the same for both conditions. Comparing the span groups in the interference condition allowed us to make the following predictions: (a) If high-span participants are better at suppressing, then List 2 performance should be worse for low-span participants because the List 1 cue–target associations should interfere, and (b) low-span participants should actually be faster than high-span participants on List 3 relearning because they did not inhibit these associations as effectively as high-span participants did.

The results showed that low-span participants were more likely to intrude List 1 targets at recall of List 2 items, and they also took more trials to correctly recall all 12 target items. This finding is consistent with the idea that low-span persons have more difficulty suppressing previously learned information, but one could also argue that low-span persons are slower at learning associations, and thus their deficit is not inhibitory in nature. To test the second prediction, RT on List 3 relearning was compared for both span groups across experimental conditions. On List 3, high-span participants in the interference condition, despite having previously encountered the same cue–target relationships in List 1, were slower to recall the target compared with high-span participants in the control condition. Low-span participants showed the opposite pattern in that they were faster in the interference condition than the control condition at List 3, presumably because they had not suppressed the List 1 associations when learning the List 2 items. Even stronger evidence for the relation between WMC and suppression is taken from the within-subject comparison of participants in the interference condition: High-span participants were slower to recall the target on List 3 compared with List 1 by a much greater degree than low-span participants (157 milliseconds vs. 53 milliseconds, respectively). The demonstration of a cost of suppression for high-span participants, who normally outperform low-span participants in a variety of complex situations, provides strong evidence for the relation between WMC and inhibition.

Brown–Peterson Task. An obvious choice to examine differences in the way high- and low-span persons inhibit irrelevant items during retrieval is to measure their susceptibility to PI in the classic Brown–Peterson task (Brown, 1958; Peterson & Peterson, 1959). Kane and Engle (2000) studied the effects of load in a design similar to a version of the PI buildup task used by Craik and Birtwistle (1971). Across two experiments, high- and low-span groups received three lists of words from the same semantic category (e.g., animals) and were then presented with a fourth list of words from a different semantic category (e.g., occupations). To study the effects of divided attention, participants also concurrently performed variations of a sequential finger-tapping task corresponding to control (no tapping), simple (compatibly mapped tapping), and complex (incompatibly mapped tapping) conditions.

The experimental design allowed the examination of the combined effects of interference, WMC, and divided attention on retrieval. Lists 2 and 3 correspond to buildup of PI, where interference is highest because of the previous lists from the same category. In contrast, List 4 represents release from PI, and interference is lower because the to-be-recalled words are from a different category. Whereas high-span participants should show less PI buildup than low-span participants because of their superior ability to devote attention to suppressing previous-list items, the span groups should achieve similar levels of PI release given that the number of activated items competing for retrieval should be low. In addition, if individual differences in WMC reflect differential ability to allocate attention, then adding an attention-demanding task such as complex tapping should actually impair high-span participants' inhibitory processes. The logic is that high-span persons are allocating attention resources across several processes in the memory and tapping tasks requiring controlled attention, whereas low-span persons are unlikely to change the allocation of resources they are devoting to performing either type of task.

Although both groups showed effects of PI buildup, only high-span participants were affected by the tapping condition. High-span participants were less affected by PI buildup than low-span participants in the control and simple conditions, supporting the view that WMC is related to inhibitory processes during retrieval in high-interference situations. However, high- and low-span participants showed similar PI buildup in the complex tapping condition; as high-span individuals devoted more attention to the difficult secondary task, their ability to sufficiently allocate resources to suppression in the memory task decreased, and their performance fell to the level of the low-span individuals. As predicted, both span groups showed similar levels of PI release across the tapping conditions, demonstrating that WMC is specifically important when dealing with interfering representations. The load manipulation provides further support for our view that individual differences in WMC drive inhibitory abilities. High-span participants' inhibitory efficiency is determined by their ability to allocate attention to various controlled processes, including suppression. Low-span participants are unaffected by secondary tasks (see also Rosen & Engle, 1997) because they lack flexibility in allocating their attention, and thus any processes requiring attention may be impaired. If WMC was determined by inhibitory ability, it is unclear how dividing attention would affect only high-span participants.

Restraint

The final function of inhibition described by Hasher et al. (1999) is the *restraint* function, which aids cognition by "preventing prepotent candidates for response from immediately seizing control . . . so that other, less probable response candidates can be considered" (p. 654). This type of inhibition can be thought of as a kind of last resort for the system, thwarting an automatic, momentarily inappropriate response in favor of an alternative option. Engle and Kane (2004) argued that one of the main determinants of cognitive control is the ability to resolve response competition, especially when an alternative choice is a habitual response in conflict with the current task goals. The following studies are also important in supporting the executive-attention view of WMC, as the surface properties of these low-level attention tasks have little in common with complex span tasks such as OSPAN.

Stroop Task. Kane and Engle (2003) conducted a series of experiments using the well-known Stroop (1935) task. In the color–word Stroop task, individuals are instructed to name the color of the ink (or font) of the word that is presented. The *Stroop interference effect* refers to the common finding that individuals are slower and make more incorrect responses on trials in which the word and color conflict (e.g., the word *green* written in red; incongruent) compared with trials in which the word and color information correspond (e.g., the word *red* written in red; congruent) or the word and color are unrelated to each other (e.g., *book* written in red; neutral). Similar to Friedman and Miyake (2004), we view the color–word Stroop task as predominantly reflecting response inhibition and not perceptual filtering, because reading the word is such a strong competing response for literate individuals. The Stroop task provides a good way to test specific hypotheses regarding the importance of WMC to maintain goal information and resolve response conflict (Engle & Kane, 2004).

For example, Logan and Zbrodoff (1979) demonstrated that the number of incongruent trials relative to all other trials affects the magnitude of the Stroop effect. They found that as the proportion of incongruent trials increases, the magnitude of the Stroop effect decreases. A Stroop task with all incongruent trials reduces the burden on the participant to actively maintain the task goal of saying the color and not reading the word, and therefore each incongruent trial serves as a reminder of the goal to name the ink color. In contrast, a Stroop task with relatively few incongruent trials produces a larger Stroop effect, especially for individuals who have not actively maintained the color-naming goal and instead rely on the prepotent response of reading the word (a strategy that works well for the majority of congruent trials). Across several experiments in Kane and Engle (2003; see also Long & Prat, 2002), low-span participants showed a greater Stroop interference effect in terms of RT and/or error rate in blocks with infrequent incongruent trials. Interestingly, low-span participants also showed a larger facilitation effect than high-span participants, indicating that they were actually faster to respond to congruent compared with neutral trials. In this case, a larger facilitation effect provides additional evidence that low-span participants are responding by word reading on most trials, showing that because they were not maintaining the task goal, they were also less likely to suppress the prepotent response.

Antisaccade Task. The antisaccade task (Hallett, 1978) is particularly well suited for studying goal-oriented responding in the presence of an incorrect prepotent response. In most versions of this task, participants move their eyes from a central fixation point when a peripheral stimulus is presented either to the left or right of fixation. The direction of the eye movement depends on the instructions for that trial; correct prosaccade trials are made by moving toward the stimulus, whereas successful antisaccade trials are performed by moving the gaze in the direction opposite of the stimulus. As Roberts, Hager, and Heron (1994) noted, moving one's eyes toward a presented stimulus is an automatic, highly prepotent reaction, and thus preventing such a response in favor of moving in the opposite direction is difficult. Roberts et al. pointed out another advantage of this task in that most normal individuals likely do not differ on the ability or speed at which they can move their eyes; other tasks have the potential problem that individuals have differentially learned the stimulus–response mapping to be used in the experiment (for further discussion of this issue, see Wilhelm & Oberauer, 2006).

Kane et al. (2001) administered the prosaccade and antisaccade conditions to high- and low-span participants. Participants fixated centrally before a peripheral cue flashed on the left or right side of the screen. After this cue, a letter briefly appeared before being masked, and participants were asked to identify the letter. In the prosaccade condition, the letter appeared in the same position as the cue that had just previously disappeared, and in the antisaccade condition, the letter appeared on the opposite side of the screen. Because correct responses in the prosaccade condition were based primarily on making reflexive saccades, high- and low-span participants were not predicted to differ. However, because the ability to control attention via maintenance of the task goals and suppression of inappropriate, habitual responses is important for success in the antisaccade condition, low-span participants were predicted to make more errors and take longer to respond on antisaccade trials. The results confirmed the importance of WMC in dealing with prepotent responses: The span groups did not differ in errors or RT on prosaccade trials, but low-span participants were slower to respond and made more errors on antisaccade trials than high-span participants.

One problem that could limit the interpretation of these results is the nature of the letter identification task. Specifically, previous research (Roberts et al., 1994) has shown that secondary tasks performed concurrently with antisaccade tasks impair performance. It is possible that the letter identification task was more difficult for low-span participants, and thus the differences in the dependent measures in Kane et al. (2001) were due not to the control of eye movements but instead to the letter identification process. Unsworth, Schrock, and Engle (2004) alleviated this concern by replicating Kane et al., with the exception that there was no letter identification. Instead, high- and low-span participants moved their eyes toward (prosaccade) or away from (antisaccade) a flashing cue, and response latency was measured by analyzing eye movement data. Corroborating the findings of Kane et al., high- and low-span participants did not differ in the time to move their gaze in the prosaccade condition, but low-span participants were slower on antisaccade trials. In addition, low-span participants made more errors only on antisaccade trials.

The final experiment in Unsworth et al. (2004) provided strong evidence for solving the chicken–egg dilemma—namely, trying to differentiate between executive-attention and inhibition theories of WMC. They noted the following distinction between the processes necessary for prosaccade and antisaccade trials:

> Prosaccade trials simply require looking toward the flashing cue, and this response is thought to rely on exogenous, automatic attentional capture and should not require the recruitment of executive control. Antisaccade trials, however, require not only the inhibition of a prepotent response (i.e., *don't look at the flashing box*) but also require the planning and execution of a voluntary saccade in the opposite direction. (p. 1303)

The implication is that although suppression of the prepotent response is important for accurate performance on antisaccade trials, the ability to plan and execute a controlled eye movement also determines trial success. Therefore, if high- and low-span participants differ only in the ability to inhibit, they should not differ in the voluntary saccade aspect of the trial. However, if the critical determinant of WMC is actually controlled attention, then individual differences in WMC should be important for both response inhibition and saccade generation on antisaccade trials.

In Experiment 3, Unsworth et al. (2004) presented high- and low-span participants with the previous exogenous versions of the prosaccade and antisaccade tasks, in which a flashing box at the periphery determined the direction in which the participant was to make a saccade. However, participants also performed endogenous prosaccade and antisaccade trials in which the cue informing participants which way to move their eyes was a centrally presented left- or right-pointing arrow. By making the cue endogenous, the prosaccade condition now required a planned saccade based on interpreting the cue rather than reliance on a reflexive saccade to a flashing peripheral cue. Thus, the important comparison for distinguishing the executive-attention and inhibition theories of WMC is the exogenous and endogenous prosaccade conditions. The results showed that low-span participants were now slower than high-span participants on the endogenous prosaccade trials, suggesting that controlled processes in addition to suppression of the prepotent response were partly responsible for the differences between the span groups on antisaccade trials. This result is difficult to explain using a theory of WMC based solely on inhibitory functions, because inhibition does not seem important for making an eye movement based on the direction of a central arrow.

Working Memory Capacity and Social Inhibition

We now shift our focus to applications of the executive-attention theory of WMC to social phenomena related to the ability to suppress irrelevant thoughts. Thought suppression is an important component of an influential theory of mental control (Wegner, 1994) that has been extended to several neuropsychological conditions. Recently, WMC has been hypothesized as an important factor related to mental control in social cognition (Feldman Barrett, Tugade, & Engle, 2004). The studies discussed next have one common theme: examining the role of individual differences in WMC related to the suppression of irrelevant thoughts in many different domains.

Posttraumatic Stress Disorder

Posttraumatic stress disorder (PTSD) has received increased media attention in the United States following the events of September 11, 2001, and the ongoing military campaigns in Iraq and Afghanistan. The syndrome is characterized by frequent thoughts of traumatic experiences in the form of flashbacks that can severely debilitate an individual's ability to achieve a normal life (Brewin, 2001). Brewin and colleagues (Brewin & Beaton, 2002; Brewin & Smart, 2005) proposed that this condition could temporarily reduce WMC, which would impair an affected individual's ability to suppress disturbing thoughts. Brewin and Beaton (2002) used the white bear paradigm (Wegner, Schneider, Carter, & White, 1987) to study intrusions. The procedure for this task was to compare a condition in which students were told to *not* think of a white bear (suppression) with a condition in which they were told to think of a white bear (expression). Any instances of white bear thoughts were obtained by verbal report and/or by a bell the participants were instructed to ring if they thought of a white bear. OSPAN was significantly correlated with the number of white bear occurrences only in the suppression condition ($r = -.51$).

Brewin and Smart (2005) extended these findings by modifying the white bear task so that the material to suppress was personally relevant. Instead of thinking about white bears, students identified their most frequent intrusive thought before the experiment and then were instructed to either suppress or express that thought internally. In spite of the difficulties in verifying that participants were actually following the task instructions, Brewin and Smart found that OSPAN was again significantly correlated to the number of reported intrusive thought failures in the suppression condition ($r = -.23$). Both of these studies were conducted with nonpatient students; the following section deals with the relation between WMC and intrusive-thought suppression in clinical patients.

Depression

Another clinical condition believed to be related in part to impaired thought suppression is depression (Arnett et al., 1999). Depressed patients may focus on negative thoughts to a greater degree than healthy individuals, and similar to those with PTSD, people with depression may resemble low-span individuals by having a reduced ability to allocate attention resources to processes such as inhibition. Arnett et al. (1999) argued that depression may act as a cognitive load that affects performance on tasks requiring WMC. More explicitly, having to allocate attention resources to suppress frequently occurring negative thoughts is similar to devoting resources to a secondary task in the studies discussed earlier (Conway et al., 1999; Kane & Engle, 2000; see also Rosen & Engle, 1997). Arnett et al. studied the relation between WMC and depression in multiple sclerosis (MS) patients and found that compared with a nondepressed MS group and a nondepressed non-MS group, MS patients with depression showed worse performance on reading span. The authors argued for clinical evaluations of MS patients to rule out depression as the cause of the impaired central executive functioning observed in MS patients.

Life Stress

Similar to frequent traumatic flashbacks in PTSD and constant negative thoughts in depression, individuals dealing with a high amount of life stress may have performance decrements on tasks that tap WMC (Klein & Boals, 2001). Individuals who are devoting resources to attempting to suppress unwanted, task-irrelevant thoughts have less attention to devote to task performance. Klein and Boals (2001) argued that unlike other task-irrelevant thoughts, "unwanted thoughts about adverse life events continue to require effort to inhibit" (p. 566). In two experiments, they found a significant correlation between the self-reported number of negative life stress events recently encountered and OSPAN performance (rs $= -.46$ and $-.36$); that is, lower WMC was associated with more adverse stress. However, positive life stress was not correlated with OSPAN. In a third study, participants identified two major life events and then were given a scale measuring the amount of intrusive (e.g., "I thought about it when I didn't mean to") and avoidant (e.g., "I tried to remove it from memory") thinking they engaged in related to each event. Klein and Boals found that individuals with lower OSPAN scores engaged in more intrusive–avoidant thinking ($r = -.22$). Similar to Wegner's (1994) theory of thought suppression, although thoughts about positive events are task irrelevant, they are not unwanted thoughts like negative stress-related concerns are, and thus they can easily be discounted. Thoughts about negative life events are more difficult to suppress and consume attention resources that could otherwise be devoted to the primary task (in this case, OSPAN).

Stereotype Threat

WMC has recently been explored as a mediating factor in susceptibility to stereotype threat. Following the work of Steele and Aronson (1995), *stereotype threat* refers to the impaired test performance that individuals show after a stereotype about their in-group has been made salient (Schmader & Johns, 2003). Examples of how stereotypes have been activated experimentally include framing the test as an intelligence measure, having participants identify their race and ethnicity, or informing participants that their scores would be compared with those of another racial or ethnic group. The interpretation of test decrements associated with stereotype threat is that test takers have to contend with the added pressure and concern of confirming the negative stereotype with their performance. Similar to the previous research on life stress, the negative stereotype information works as a type of stressor.

Schmader and Johns (2003) hypothesized that stereotype threat reduces WMC because test takers must devote resources to suppressing these extratask thoughts and anxiety. In their first experiment, women and men were assigned to either a stereotype-threat or a control group. All participants performed the OSPAN task, but those in the stereotype-threat group were first informed about previous research showing that women score lower on tests of "quantitative capacity" compared with men. They found that women and men in the control group and men in the stereotype-threat group had equivalent OSPAN scores, but the women in the stereotype-threat group scored significantly lower, representing reduced WMC. In Experiment 2, the participants were instead Latino and non-Hispanic White, and the stereotype-threat instructions were that the OSPAN task was a test highly correlated with intelligence and that their scores would be used to establish ethnic norms. A similar result to Experiment 1 was obtained; Latino participants in the stereotype-threat group had much lower OSPAN scores than the other groups, which were all equivalent to each other. Stereotype threat is yet another form of task-irrelevant, intrusive thought that competes with the attention resources one has to allocate to task performance. The situational reductions in WMC reviewed in this section need to be studied further, given the importance of WMC in higher order cognition and performance on various ability tests used as selection criteria in educational and occupational settings.

Conclusion

In this chapter, we have presented evidence showing that WMC is related to inhibition in many different areas of psychology. We have argued that WMC reflects the ability to control attention and that this is an important construct for higher order cognition, including inhibitory processes. On the basis of our research with divided-attention tasks (Conway et al., 1999; Kane & Engle, 2000; Rosen & Engle, 1997) and the endogenous prosaccade condition of the antisaccade task (Unsworth et al., 2004), we maintain that WMC determines inhibitory ability and not vice versa (cf. May et al., 1999). However, the possibility remains that individual differences among young adults and group differences between young and old adults do not have the same causal mechanism and that older adults may have an additional general inhibitory deficit that impairs their cognition.

By using the terminology of Hasher et al. (1999), we have attempted to be explicit regarding the function of inhibition implied by using the term as an explanatory agent. However, future research with WMC should focus on whether the interference seen in tasks such as the flanker (Heitz & Engle, in press) and Stroop (Kane & Engle, 2003) tasks occurs only at the input and output levels of processing, respectively, as has been presented in this chapter. For example, with the flanker task, it is possible that high- and low-span participants differ in the ability both to suppress distractors during encoding and to stop an incorrectly activated response if the perceptual filtering fails.

Determining more precisely the processing stage at which interference occurs may be aided by studies from the cognitive neuroscience domain. Although we have previously asserted that WMC is related to prefrontal cortex functioning (Kane & Engle, 2002), research published since that review has provided direct evidence of prefrontal cortex involvement.[1] For example, similar to our microanalytic design, a few studies have measured WMC before completing the experiment of interest to examine the role of the prefrontal cortex in both individual differences in WMC and situations involving interference control (Burgess, Gray, Conway, & Braver, 2005; Heitz, Corballis, Parks, & Engle, 2005; Mecklinger, Weber, Gunter, & Engle, 2003). Additional work (Kondo, Osaka, & Osaka, 2004; Osaka et al., 2003) has separated high- and low-span participants on the basis of one complex span task and then measured activation levels during performance of a variant of another complex span task. These results suggest that high- and low-span individuals show a different pattern of frontal activation via an interaction between the dorsolateral prefrontal cortex and anterior cingulate cortex areas. As neuroimaging methodologies improve, cognitive neuroscience should provide additional evidence elucidating the shared relation between WMC and higher order cognition.

In addition, more research should address the alternative explanations (MacLeod et al., 2003) of the many inhibitory effects described here (for an account of WMC focusing on interference caused by inefficient use of retrieval cues, see Unsworth and Engle, in press). Although we have asserted that individual differences in WMC do not represent exclusively inhibitory processes, perhaps an explanation based solely on differences in allocating attention could account for some of the results we presented. Nonetheless, establishing the exact relation between WMC and inhibition is becoming an increasingly important goal for researchers in many areas of psychology.

References

Arnett, P. A., Higginson, C. I., Voss, W. D., Bender, W. I., Wurst, J. M., & Tippin, J. M. (1999). Depression in multiple sclerosis: Relationship to working memory capacity. *Neuropsychology, 13,* 546–556.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. A. Bower (Vol. Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–89). New York: Academic Press.

Bjork, R. A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In H. L. Roediger III & F. I. M. Craik (Eds.), *Varieties of memory and consciousness* (pp. 309–330). Hillsdale, NJ: Erlbaum.

Brewin, C. R. (2001). A cognitive neuroscience account of posttraumatic stress disorder and its treatment. *Behaviour Research and Therapy, 39,* 373–393.

Brewin, C. R., & Beaton, A. (2002). Thought suppression, intelligence, and working memory capacity. *Behaviour Research and Therapy, 40,* 923–930.

Brewin, C. R., & Smart, L. (2005). Working memory capacity and suppression of intrusive thoughts. *Journal of Behavior Therapy and Experimental Psychiatry, 36,* 61–68.

Brown, J. A. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology, 10,* 12–21.

[1]Bunge, Klingberg, Jacobsen, and Gabrieli (2000) and Smith et al. (2001) administered modified versions of complex span tasks to participants in functional magnetic resonance imaging and positron-emission tomography, respectively, but the differences between typical complex span tasks and the tasks they used, mainly the recall period, make it difficult to make firm comparisons between the existing behavioral literature and their work.

Bunge, S. A., Klingberg, T., Jacobsen, R. B., & Gabrieli, J. D. E. (2000). A resource model of the neural basis of executive working memory. *Proceedings of the National Academy of Sciences, USA, 97,* 3573–3578.

Burgess, G. C., Gray, J. G., Conway, A. R. A., & Braver, T. S. (2005, April). *Relationships among fluid intelligence, working memory span, and brain activity during high-interference trials.* Poster presented at the Annual Meeting of the Cognitive Neuroscience Society, New York.

Case, R., Kurland, D. M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology, 33,* 386–404.

Conway, A. R. A., Cowan, N., & Bunting, M. F. (2001). The cocktail party phenomenon revisited: The importance of working memory capacity. *Psychonomic Bulletin & Review, 8,* 331–335.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30,* 163–183.

Conway, A. R. A., & Engle, R. W. (1994). Working memory and retrieval: A resource-dependent inhibition model. *Journal of Experimental Psychology: General, 123,* 354–373.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12,* 769–786.

Conway, A. R. A., Tuholski, S. W., Shisler, R. J., & Engle, R. W. (1999). The effect of memory load on negative priming: An individual differences investigation. *Memory & Cognition, 27,* 1042–1050.

Cowan, N. (1995). *Attention and memory: An integrated framework.* Oxford, England: Oxford University Press.

Cowan, N. (2004). Understanding intelligence: A summary and an adjustable-attention hypothesis. In O. Wilhelm & R. W. Engle (Eds.), *Handbook of understanding and measuring intelligence* (pp. 469–488). Thousand Oaks, CA: Sage.

Craik, F. I. M., & Birtwistle, J. (1971). Proactive inhibition in free recall. *Journal of Experimental Psychology, 91,* 120–123.

Dagenbach, D., & Carr, T. H. (1994). *Inhibitory processes in attention, memory, and language.* San Diego, CA: Academic Press.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19,* 450–466.

Dempster, F. N., & Brainerd, C. J. (1995). *Interference and inhibition in cognition.* San Diego, CA: Academic Press.

Engle, R. W. (1996). Working memory and retrieval: An inhibition-resource approach. In J. T. E. Richardson, R. W. Engle, L. Hasher, R. H. Logie, E. R. Stoltzfus, & R. T. Zacks (Eds.), *Working memory and human cognition* (pp. 89–119). London: Oxford University Press.

Engle, R. W., Conway, A. R. A., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science, 6,* 122–125.

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

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics, 16,* 143–149.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14,* 340–347.

Feldman Barrett, L., Tugade, M. M., & Engle, R. W. (2004). Individual differences in working memory capacity and dual-process theories of mind. *Psychological Bulletin, 130,* 553–573.

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.

Gratton, G., Coles, M. G. H., Sirevaag, E. J., Eriksen, C. W., & Donchin, E. (1988). Pre- and post-stimulus activation of response channels: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 331–344.

Hallett, P. E. (1978). Primary and secondary saccades to goals defined by instructions. *Vision Research, 18,* 1279–1296.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Vol. Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193–225). New York: Academic Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Vol. Eds.), *Attention and performance: XVII. Cognitive regulation of performance: Interaction of theory and application* (pp. 653–675). Cambridge, MA: MIT Press.

Heitz, R. P., Corballis, P. M., Parks, N. A., & Engle, R. W. (2005, April). *Working memory capacity and attentional control: An electrophysiological analysis.* Poster session presented at the annual meeting of the Cognitive Neuroscience Society, New York.

Heitz, R. P., & Engle, R. W. (in press). Focusing the spotlight: Individual differences in visual attention control. *Journal of Experimental Psychology: General.*

Heitz, R. P., Unsworth, N., & Engle, R. W. (2004). Working memory capacity, attention control, and fluid intelligence. In O. Wilhelm & R. W. Engle (Eds.), *Handbook of understanding and measuring intelligence* (pp. 61–77). Thousand Oaks, CA: Sage.

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General, 130,* 169–183.

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* (pp. 21–48). New York: Oxford University Press.

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 336–358.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review, 9,* 637–671.

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General, 132,* 47–70.

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 visuospatial memory span and reasoning. *Journal of Experimental Psychology: General, 133,* 189–217.

Kane, M. J., Poole, B. J., Tuholski, S. W., & Engle, R. W. (2006). Working memory capacity and the top-down control of visual search: Exploring the boundaries of "executive attention." *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 749–777.

Kipp Harnishfeger, K. (1995). The development of cognitive inhibition: Theories, definitions, and research evidence. In F. N. Dempster & C. J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 175–204). San Diego, CA: Academic Press.

Klein, K., & Boals, A. (2001). The relationship of life event stress and working memory capacity. *Applied Cognitive Psychology, 15,* 565–579.

Kondo, H., Osaka, N., & Osaka, M. (2004). Cooperation of the anterior cingulate cortex and dorsolateral prefrontal cortex for attention shifting. *NeuroImage, 23,* 670–679.

Logan, G. D., & Zbrodoff, N. J. (1979). When it helps to be misled: Facilitative effects of increasing the frequency of conflicting stimuli in a Stroop-like task. *Memory & Cognition, 7,* 166–174.

Long, D. L., & Prat, C. S. (2002). Working memory and Stroop interference: An individual differences investigation. *Memory & Cognition, 30,* 294–301.

MacLeod, C. M., Dodd, M. D., Sheard, E. D., Wilson, D. E., & Bibi, U. (2003). In opposition to inhibition. In B. Ross (Ed.), *The psychology of learning and motivation* (Vol. 43, pp. 163–214). New York: Elsevier.

May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory & Cognition, 27,* 759–767.

Mecklinger, A., Weber, K., Gunter, T. C., & Engle, R. W. (2003). Dissociable brain mechanisms for inhibitory control: Effects of interference content and working memory capacity. *Cognitive Brain Research, 18,* 26–38.

Moray, N. (1959). Attention in dichotic listening: Affective cues and the influence of instructions. *Quarterly Journal of Experimental Psychology, 11,* 56–60.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126,* 220–246.

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology, 7,* 44–64.

Osaka, M., Osaka, N., Kondo, H., Morishita, M., Fukuyama, H., Aso, T., & Shibasaki, H. (2003). The neural basis of individual differences in working memory capacity: An fMRI study. *NeuroImage, 18,* 789–797.

Peterson, L. R., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58,* 193–198.

Redick, T. S., & Engle, R. W. (2006). Working memory capacity and attention network test performance. *Applied Cognitive Psychology, 20,* 713–721.

Roberts, R. J., Hager, L. D., & Heron, C. (1994). Prefrontal cognitive processes: Working memory and inhibition in the antisaccade task. *Journal of Experimental Psychology: General, 123,* 374–393.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General, 126,* 211–227.

Rosen, V. M., & Engle, R. W. (1998). Working memory capacity and suppression. *Journal of Memory and Language, 39,* 418–436.

Schmader, T., & Johns, M. (2003). Converging evidence that stereotype threat reduces working memory capacity. *Journal of Personality and Social Psychology, 85,* 440–452.

Smith, E. E., Geva, A., Jonides, J., Miller, A., Reuter-Lorenz, P., & Koeppe, R. A. (2001). The neural basis of task-switching in working memory: Effects of performance and aging. *Proceedings of the National Academy of Sciences, USA, 98,* 2095–2100.

Steele, C. M., & Aronson, J. (1995). Stereotype threat and the intellectual test performance of African Americans. *Journal of Personality and Social Psychology, 69,* 797–811.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28,* 127–154.

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

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* (pp. 19–43). New York: Oxford University Press.

Unsworth, N., Schrock, J. C., & Engle, R. W. (2004). Working memory capacity and the antisaccade task: Individual differences in voluntary saccade control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 1302–1321.

Wegner, D. M. (1994). Ironic processes of mental control. *Psychological Review, 101,* 34–52.

Wegner, D. M., Schneider, D. J., Carter, S. R., III, & White, T. L. (1987). Paradoxical effects of thought suppression. *Journal of Personality and Social Psychology, 53,* 5–13.

Wilhelm, O., & Oberauer, K. (2006). Why are reasoning ability and working memory capacity related to mental speed? An investigation of stimulus–response compatibility in choice reaction time tasks. *European Journal of Cognitive Psychology, 18,* 18–50.

Abstract Cognitive enhancement takes many and diverse forms. Various methods of cognitive enhancement have implications for the near future. At the same time, these technologies raise a range of ethical issues.Â and â€¢ They may eventually come to have important consequences for society and. even, in the longer run, for the future of humankind.Â The working memory effects might thus be part of a more general enhancement of executive function. Modanil was originally developed as a treatment for narcolepsy, and can be used to reduce performance decrements due to sleep loss with apparently small side effects and little risk of dependency (Teitelman 2001; Myrick et al. The Internet has become a primary form of external or transactive memory, where information is stored collectively outside ourselves.Â You are going to email the following Google Effects on Memory: Cognitive Consequences of Having Information at Our Fingertips. Message Subject (Your Name) has forwarded a page to you from Science. Message Body (Your Name) thought you would like to see this page from the Science web site. Cognitive inhibition refers to the mind's ability to tune out stimuli that are irrelevant to the task/process at hand or to the mind's current state. Cognitive inhibition can be done either in whole or in part, intentionally or otherwise. Cognitive inhibition in particular can be observed in many instances throughout specific areas of cognitive science. The early models of what would become the study and concept of cognitive inhibition were developed by Sigmund Freud. Inhibition was believed to play