CHAPTER 16

What Is Working Memory Capacity?

Randall W. Engle

Robert Crowder's 1983 article "The Demise of Short-Term Memory" influenced me on the questions that led to the research and ideas I discuss in this chapter. In that article, Crowder questioned the need for a separate short-term memory (STM) and pointed out that research has not established that STM is necessary for successful cognitive functioning. Furthermore, I make the case that working memory (WM) should be considered a system consisting of temporarily activated long-term memories and controlled attention, which is important in maintaining activation. The maintaining of the activation of a representation is generally unnecessary but becomes particularly important in the face of proactive interference. Both of these issues are discussed at length by Crowder in his 1983 article. Crowder also discussed the role of individual differences in drawing conclusions about the existence of a short-term store; that approach is pivotal to the conclusions I draw here.

Research following Baddeley and Hitch (1974) and Daneman and Carpenter (1980) shows that the broader concept of WM is important to higher order cognition. Furthermore, complex WM tasks "work" in the sense that they predict performance on a variety of cognitive tasks. However, the nature of individual differences in WM is still unclear.

The research I describe in this chapter is directed at two general questions. The first is "What is WM capacity?" That is, what mechanisms account for the covariation between a variety of WM tasks, on the one hand, and tasks of higher level cognition, such as reading comprehension and reasoning, on the other hand? The second question is "What do the results of studies on individual differences in WM capacity tell us about the nature of WM in general?" The conclusions that I draw are based largely on individual differences studies, but studies using dual-task methods were also helpful to me. For example, a relatively safe generalization is that individuals with high WM capacity who are performing a task while concurrently performing

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an attention-demanding secondary task perform similarly to individuals with low WM capacity (Kane & Engle, 2000; Rosen & Engle, 1997). The evidence for my conclusions comes from a variety of memory and attention paradigms, which increase the generality of the results and give convergent validity to the ideas. My interest in these questions was initially directed at relatively molecular issues about the importance of temporarily active memory. However, pursuit of answers to the two questions described above led me to questions of intelligence and attention and the brain structures underlying those constructs.

Measures of Working Memory Capacity

Although numerous tasks have been used over the years to measure WM capacity, I describe only the three tasks that I use most often: reading span, operation span, and counting span. These tasks all work in the sense that performance on them reliably predicts performance on a range of ecologically relevant cognitive tasks, suggesting that they reflect something about WM that is fundamentally important to cognition. Furthermore, the tasks appear to reflect a common construct because they account for similar variance, all load on the same factor in a factor analysis, and all fit a relatively tight latent variable in a structural equation analysis (Engle, Tuholski, Laughlin, & Conway, 1999).

The reading span was the first task used to study WM capacity and its relationship with reading comprehension. Daneman and Carpenter (1980) asked participants to read sets of sentences and recall the last word of each sentence. My lab generally used a modified version of this task to avoid concerns that individual differences in comprehension of the sentences lead to differences in ability to generate or reconstruct the words on the basis of the gist of the sentence rather than recall them. In my version, participants read aloud sentences shown centered on a computer monitor while trying to remember unrelated words printed at the end of each sentence. The set of words recalled typically varies from two to seven. For example, Exhibit 16.1 presents three sentences—participants see one sentence at a time, read the sentence aloud, and then read aloud the word in capital letters. At that point, the experimenter presses a key causing the next sentence to be presented. After the last sentence in each set, a set of question marks cues the recall of the words shown

EXHIBIT 16.1

Example of a reading span trial

For many years, my family and friends have been working on the farm. *SPOT*
Because the room was stuffy, Bob went outside for some fresh air. *TRAIL*
We were 50 miles out at sea before we lost sight of the land. *BAND*

in capitals. To ensure that a participant takes the sentence reading task seriously, after recall of the words he or she answers a question about one of the sentences from the set.

The operation span task was developed to be similar in format to the reading span but to involve reading per se only in the broadest sense (Turner & Engle, 1989). Participants see individual operation–word strings (see Exhibit 16.2) centered on the monitor of the computer. They read aloud and solve the math problems, each of which is followed by a word; after a set of such operation–word strings, they recall the words. For example, in the following set size of three strings, the participant reads aloud "Is (8/4) – 1 = 1?" and answer *yes* if the equation is correct or *no* if the equation is incorrect; then the participant reads aloud the word *bear*. After hearing *bear*, the experimenter presses a key, resulting in the presentation of the next string. This procedure allows adequate time for each individual to process the operation and word but serves to reduce the time for rehearsal.[1] After the last operation–word string in the set (in this case, the third string), the participant sees a set of question marks centered on the screen, which is the cue to write down the words in order.

The counting span task used is a form of a task first used by Case, Kurland, and Goldberg (1982). In my version of the task, the experimenter initiates the presentation of the first display of the type shown in Exhibit 16.3. Each display consists of 3–9 dark blue circles, 1–9 dark blue squares, and 1–5 light blue circles, all randomly arranged (without overlap) on the monitor. Participants count the number of dark blue circles aloud and repeat the digit corresponding to the final tally. For example, if the display contains three dark blue circles, the participant says aloud "1–2–3–3." When the "3" is repeated, the experimenter presses the key that causes the immediate presentation of the next display, and the participant begins to count immediately. After up to eight displays, a cue occurs for the participant to recall in order the digits corresponding to the number of targets on each display. It should be noted that the memory component of this task is essentially a digit

EXHIBIT 16.2

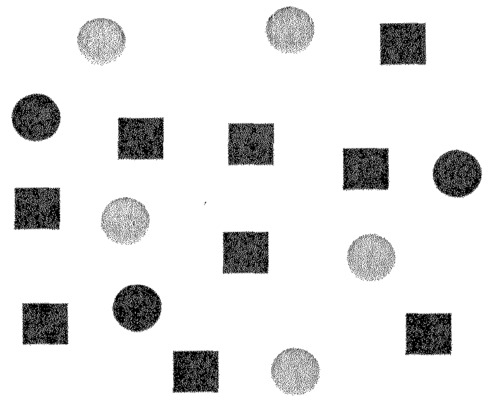
Example of an operation span trial

Is (8/4) – 1 = 1? *bear*
Is (6 × 2) – 2 = 10? *Dad*
Is (10 × 2) – 6 = 12? *beans*

[1]An interesting question is the extent to which individual differences in rehearsal lead to the predictive nature of these tasks. In a recent study, Kandi Jo Turley (1998) demonstrated that a procedure that equated rehearsal on the task led to an increase in correlation between operation span and reading comprehension.

EXHIBIT 16.3

Example of a single counting span display



span task, with the counting of objects interleaved with the "presentation" of the digits to be recalled.

These tasks and many others of similar form clearly reflect some fundamental aspect of cognition. Scores on these tasks can predict a range of cognitive functions, including reading and listening comprehension (Daneman & Carpenter, 1980), language comprehension (King & Just, 1991), following directions (Engle, Carullo, & Collins, 1991), vocabulary learning (Daneman & Green, 1986), note taking (Kiewra & Benton, 1988), writing (Benton, Kraft, Glover, & Plake, 1984), reasoning (Barrouillet, 1996; Kyllonen & Christal, 1990), bridge playing (Clarkson-Smith & Hartley, 1990), and computer-language learning (Shute, 1991).

Why Do Working Memory Tasks Work?

These WM capacity tasks were originally thought to work because they reflected the level of skill in performing the processing component of the task, which, in turn, determined the residual available storage capacity. However, it is now known that beyond a minimal level, individual differences on the processing portion of the task are relatively unimportant to the covariation of these tasks with higher order tasks. Engle, Cantor, and Carullo (1992) measured the time it took participants to solve equations in the operation span task and to read the sentences in the reading span task. If skill or expertise on the processing portion of the task is an important factor in the relationship to higher level tasks, then covarying the time to solve the arithmetic string and to read the sentences out of the correlation between span and higher order cognition should lead to an elimination of or at least a reduction in that correlation. However, the WM span–reading comprehension correlation was not reduced by partialling out the estimates of processing expertise, suggesting that skill on the processing component is not the critical factor in whether a task works.

Conway and Engle (1996) used a different approach to the same question. They pretested participants on operation strings representing 15 levels of difficulty. Then each participant received operation spans with the operations adjusted to equate difficulty of the arithmetic across participants. Each participant performed three different operation spans created with strings that they had performed correctly at the 75%, 85%, and 95% accuracy level in the pretest. If individual differences on the processing component of the complex span task was what accounted for the relationship between the span score and higher order cognition, then matching participants on processing should have eliminated or at least statistically reduced the correlation. However, this manipulation did not reduce the span–comprehension correlation; in fact, it rose slightly. Thus, it does not appear that the complex span tasks reflect individual differences in skills or expertise that are common to those skills used in performing the higher level tasks. But what do they reflect that causes them to work?

I believe that I can safely draw several generalizations about these tasks. The tasks that reliably work in predicting higher level cognition are, at base, dual tasks. The operation span task involves solving equations and trying to remember words. The reading span involves reading sentences and trying to remember words. The counting span involves controlled counting and trying to remember digits. One or both of the components of the tasks require controlled processing. One component involves retention of some information (the individual words or digits in the emerging list) over a delay that is filled with distraction (typically the so-called processing portion of the task). In this sense, the tasks are similar to the Brown–Peterson procedure with a fixed delay, and the tasks may work well because they reflect the participants' ability to do the mental work necessary to resist the effects of interference from one trial to the next and across sets. Note that I am not suggesting that WM capacity reflects differential vulnerability to interference per se (cf. Hasher & Zacks, 1988) but that people differ in the ability to do the mental work necessary to resist interference. I have more to say on this issue later.

The term *capacity,* as used in discussions of STM, often conjures up images of a fixed number of items (e.g., 7 ± 2). However, my sense is that WM capacity is not about a limitation in number of items in some limited set of metaphorical bins but is instead about limitations in the ability to use controlled processing to maintain information in an active, quickly retrievable state. Thus, I can talk about WM capacity as being important in retention of a single representation, such as a goal or the status of a changing variable, just as well as how many representations can be maintained. WM capacity is not about storage and processing but is about retention over a period in which there is distraction or shift of attention away from the stored information. The need for this quick accessibility is particularly salient when there is interference from competing information. WM capacity is not directly about memory—it is about attention. WM capacity is about memory only indirectly. WM capacity is about attention in the service of memory. Greater WM capacity means that more items can be maintained in the focus of attention, but it also means that information can more effectively be blocked from the focus of attention.

I think that helping one deal with the effects of interference is one of the primary functions of WM. The reality is that without the effects of interference, most of the information one knows and needs to function in the world could be retrieved from long-term memory sufficiently quickly to perform even complex cognitive functions. Keppel and Underwood (1962) found that the Brown–Peterson retention function does not hold for the first or even second trial in an experiment, and this finding should be informative to us. Crowder (1983) certainly found it informative. The effects that are generally attributed to STM or to active memory are likely to be observed only when the effects of interference force one to maintain information in an active state. It is in those conditions in which WM capacity is important and in which individual differences manifest themselves.

Negative Priming

Larger WM capacity leads to better ability to block information from the active state either by increased attention to task-relevant information or to active suppression of potentially intrusive task-irrelevant information. For example, Engle, Conway, Tuholski, and Shisler (1995) demonstrated that the negative priming effect was eliminated by a secondary load task. Participants were shown two slightly overlapping letters, one green and one red, and asked to name the green one as rapidly as possible. When the green letter had been the red letter on the previous trial, participants were slower to name the letter, a result known as the *negative priming effect.* One interpretation of this phenomenon is that when faced with two competing action schemas such as saying both letters, one suppresses the weaker one, which makes one slower to say the corresponding letter on the next trial. When participants in the Engle et al. study performed this task while trying to remember a list of words, the negative priming effect was eliminated. Conway, Tuholski, Shisler, and Engle (2000) conducted a negative priming study with individuals classified as high or low in WM capacity.[2] Conway et al. observed that only high-WM participants showed the negative priming effect. Furthermore, their negative priming effect was eliminated when they also tried to remember either a list of words or a list of irregular shapes. Those with low spans did not show the negative priming effect with or without load.

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[2]In this study and the other studies I discuss throughout the chapter, high- and low-WM participants were classified as such by scoring in the upper and lower quartile, respectively, on the operation span task.

My interpretation is that suppression of competing information requires attention-demanding mental work and that participants with high WM have superior capability to suppress competing intrusions.

Proactive Interference

Rosen and Engle (1998) reached a similar conclusion using a different procedure. Participants learned three paired-associate lists in which they were shown one word and were to say aloud a different word as a response. Rosen and Engle measured the time to make the oral response to the cue and response accuracy. In one experiment, the instructions emphasized accuracy, and they anticipated that participants would vary in speed of responding. The experimental participants learned three 12-item lists with the same 12 cue words for every list. Thus, participants might learn *bird–bath* as 1 of 12 items for list 1 and *bird–dawn* for list 2 and relearn *bird–bath* for list 3. Participants with high and low WM took a similar number of trials to learn list 1, supporting the idea that they were not different when performing in the absence of interference. However, on list 2, participants with low spans made many more errors than did those with high spans, specifically, intrusions of the responses from list 1. For list 3, participants simply relearned list 1. If those with high spans actively suppressed the responses from list 1 during the learning of list 2, then they would be slower to give *bath* in response to *bird* than would the control participants, who learned *bird–bath* for the first time in list 3. Not only did we find that participants with high WM were slower than the control participants to make responses on list 3, those with high spans were also slower to give *bath* as a response to *bird* on list 3 than they were themselves on list 1. Those with low spans were actually faster to make list 3 responses than were the control participants. Rosen and Engle found that those with low WM showed greater effects of proactive interference as evidenced by the greater number of intrusions from list 1. Our interpretation was that during the learning of list 2, high-WM participants were better equipped to do the necessary mental work required to suppress the response *bath* to the cue word *bird* so that they could give the weaker *dawn* as a correct response. However, that came back to haunt those with high spans when *bath* was needed again in list 3 because, for them, retrieval of *bath* was much slower.

Kane and Engle (2000) conducted a set of experiments using a modification of the Wickens, Born, and Allen (1963) paradigm that supported the idea that resisting interference is a result of processes requiring executive attention. Participants had three trials in which they saw 10 words to recall, performed a rehearsal preventative task for 16 s, and then tried to recall the 10 words. Participants with high and low spans were nearly identical in recall of list 1 at about 60%, which is well below ceiling. However, those with low spans showed steeper declines in recall over trials than did those with high spans, reflecting greater proactive interference (PI) for those with the low spans. When participants performed a secondary load task at either encoding or retrieval, the PI function for those with high spans looked just like that of those with low spans where PI function was unaffected by load. Therefore, the finding that those with high spans were hurt by divided attention suggests that under normal conditions, participants were actually using attentional control to combat the effects of PI. In contrast, the lack of a load effect on PI for those with low spans suggests that participants do not normally allocate attention to resist interference.

WM, STM, and General Fluid Intelligence

My argument is that individual differences in WM capacity correspond to individual differences in a construct similar to the supervisory attention system proposed by Shallice and Burgess (1993) and that this is critical for dealing with interference, potentially distracting information, or both. So what is the evidence for this claim? One source of evidence comes from a regression study by Engle et al. (1999) directed at Cowan's (1995) distinction between STM and WM. Cowan assumed that STM is a subset of WM. STM is a storage component consisting of those memory units active above some baseline, whereas WM refers to a system consisting of the storage component plus an attention component. I submit that all WM and STM tasks reflect elements of both constructs. Conceptually, variance shared between WM tasks and STM tasks should reflect the STM component and the extent to which executive attention is required in the STM tasks. Therefore, the variance left over in WM, that is, the residual in WM tasks after removal of variance common to the two types of tasks, should reflect an estimate of the role of controlled or supervisory attention. Of course, that residual would be a conservative estimate of the attention component because even the common variance removed would likely include some variance attributable to capability for controlled processing on the STM tasks as well.

Engle et al. (1999) also addressed questions about the relationship between STM, WM, and general fluid intelligence (Horn & Cattell, 1967). A connection has been made between STM and intelligence (Bachelder & Denny, 1977), between WM capacity and intelligence (Kyllonen & Christal, 1990), and between controlled processing and intelligence (Duncan, 1995). By Cowan's (1995) logic, one should be able test among those three possibilities to the extent that latent constructs for STM, WM, and controlled attention can be isolated.

Engle et al. (1999) asked three questions:

1. Do WM tasks reflect the same underlying construct?
2. Do WM capacity tasks measure something different from traditional STM tasks and, if so, what makes them different?
3. What is the relationship between these constructs and general fluid intelligence?

Participants performed 14 different tasks, but those germane to the three questions were the three WM tasks I described above, the three simple span tasks thought to reflect STM, and the two measures of general fluid intelligence that I used as my criteria for higher order cognition. Factor analyses show that the three WM tasks I described above loaded on one factor and that the three STM tasks loaded on a different factor. A structural equation analysis shows that whereas the WM and STM constructs were highly correlated, a model with separate constructs for WM and STM fit the data significantly better than a model with a single construct for WM and STM.

Although the latent variables for both WM and STM correlated with the latent variable for fluid intelligence, that does not tell the source of the relationships. If my logic is correct, one should be able to determine whether STM has a relationship with intelligence separate from that of WM or whether the relationship is driven by controlled attention. By that logic, removal of the variance common to the WM and STM constructs would leave a residual from WM that reflects controlled attention. The model that results from this common factor removal is shown in Figure 16.1. The boxes reflect manifest variables or specific tasks, and the numbers and arrows pointing to those boxes reflect task-specific error variance. The circles represent latent variables (i.e., hypothetical constructs), and the numbers and arrows between rectangles and circles and between circles reflect standardized regression coefficients. Solid lines reflect significant links and dotted lines reflect nonsignificant links.

When the variance common to the WM and STM latent variables was removed, the correlation between the residual remaining from the WM variable and the construct for general fluid intelligence was substantial and significant (.49). However, the residual from the STM variable, which by my logic should include only error, did not significantly correlate with intelligence. Although measures of WM capacity are certainly not pure, these results are consistent with the idea that the latent variable resulting from those tasks reflects a mechanism one might think of as executive attention and that that mechanism is strongly related to general fluid intelligence.

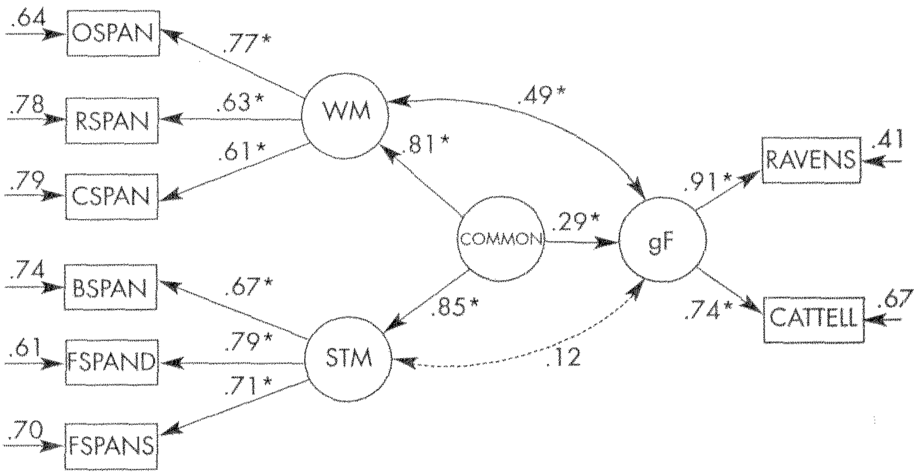
Antisaccade Task

Shallice and Burgess (1993) proposed that the supervisory attention system (SAS) comes into play whenever the action schema generated by the relatively automatic contention scheduling system conflicts with the goals of the current task. Thus, if the automatically elicited response in a given situation does not fit with the current goals for the situation, SAS leads to increased activation of the more appropriate action and that can lead to inhibition of the inappropriate action.

The antisaccade task is almost perfectly suited to model this feature of the SAS. In that task, the participant must respond to information presented to either side

FIGURE 16.1

*Path model for relationship among STM, WM, and gF. STM = short-term memory; WM = working memory; gF = general fluid intelligence; OSPAN = operation span; RSPAN = reading span; CSPAN = counting span; BSPAN = backward span; FSPAND = forward span with dissimilar words; FSPSANS = forward span with similar sounding words; RAVENS = Ravens Standard Progressive Matrices Test; CATTELL = Cattell Fair Test of Intelligence; * = significant path. From "Working Memory, Short-Term Memory, and General Fluid Intelligence: A Latent Variable Approach," by R. W. Engle, S. W. Tuholski, J. E. Laughlin, & A. R. A. Conway, 1999,* Journal of Experimental Psychology: General, 128, *p. 324. Copyright 1999 by the American Psychological Association. Reprinted with permission.*



of a display. However, just before the information is presented, a cue of some type occurs to the opposite side of the display. The relationship is perfectly lawful; the cue always predicts that the target information will occur on the opposite side of the display. However, the cue is designed to naturally capture the participants' attention, so the prepotent tendency is to shift gaze to the wrong side of the display. Optimal performance in the task requires that this tendency be blocked. As a control, most experiments also include a prosaccade condition in which the cue occurs on the same side of the display as the subsequent target. Thus, the prepotent tendency to look at the flashing cue facilitates processing of the target when it occurs in the prosaccade condition but hurts performance in the antisaccade condition. Roberts, Hager, and Heron (1994) showed that performance in the prosaccade condition was not hurt when the participants also performed a concurrent memory load task. However, performance in the antisaccade task was substantially hurt by the load task. Participants who were also performing an attention-demanding concurrent task were much more likely to shift their eyes to the cue and then not be able to do sufficient processing of the target when it occurred on the opposite side of the display.

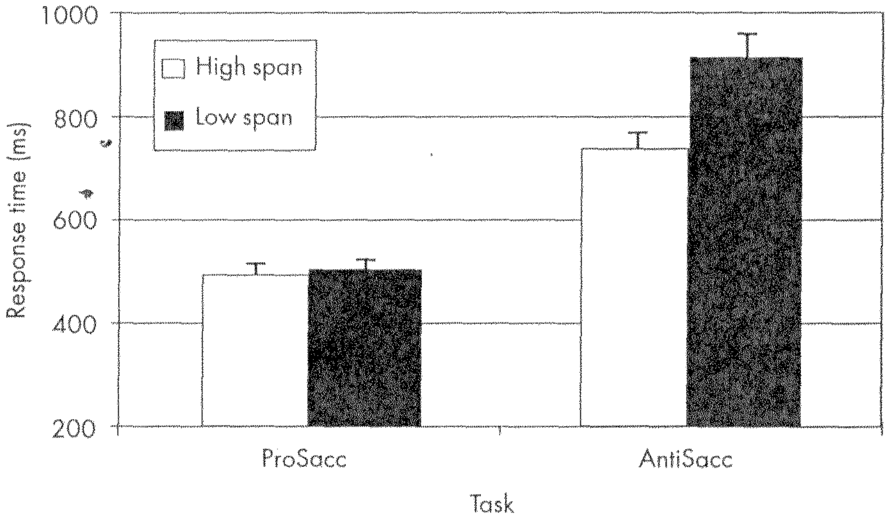
If my logic about individual differences in WM capacity corresponding to differences in the executive attention is correct, then we should see a relationship between performance on measures of WM capacity and performance on the antisaccade task. Specifically, participants with high and low WM will not differ on the prosaccade condition. However, whereas both groups would be worse on the antisaccade condition, participants with low WM span would be hurt much more by the need to maintain the goal to look opposite to the cue and to block the prepotent response to look in the direction of the cue. Kane, Bleckley, Conway, and Engle (in press) performed two studies to test this prediction. In the first study, participants with high and low spans were tested in prosaccade and antisaccade conditions. A trial began with a central fixation that persisted for a period of 200–2,200 ms and was followed by a blinking "=," which was displayed 11.33° of visual angle randomly to the left or right of center for a total of 250 ms. In the prosaccade condition, that cue was followed by presentation of a B, P, or R in the space immediately above the "=." The letter was displayed for 100 ms and then masked until the response. Participants were to press one of three keys indicating the identity of the letter. In the antisaccade condition, the letter and mask were displayed 11.33° of visual angle from the fixation point to the side opposite the cue. Saccade condition was a within-subjects variable with half the participants doing the block of prosaccade first and half doing the antisaccade first.

There was a three-way interaction of WM group, saccade condition, and order of saccade condition; we examined each of the saccade conditions performed first. Figure 16.2 shows the time to identify the letters for the saccade condition performed first, and one sees that the predictions were supported. Participants with high and low WM did not differ in the prosaccade condition but, although both were slowed in the antisaccade condition, those with low WM were slowed substantially more. The three-way interaction mentioned above reflects the fact that, whereas participants with high WM were relatively unaffected by order of task, participants with low spans who performed antisaccade first were significantly slowed to perform prosaccade later. That is, once they had adjusted to the antisaccade condition and were moderately successful in blocking the prepotent tendency to look in the direction of the misleading cue, they persisted in that tendency even when it was maladaptive to do so in the prosaccade condition. This is similar to what is referred to as perseveration behavior in individuals with frontal-lobe damage and represents another one of many instances in which the pattern of performance for participants with low WM and patients with frontal-lobe damage is similar (Engle & Oransky, 1999).

In the second study, participants' eye movements were monitored during performance of an extended set of antisaccade trials. As with the first study, those with

FIGURE 16.2

Response time in the letter task as a function of span group and saccade condition. ProSacc = prosaccade task; AntiSacc = antisaccade task.

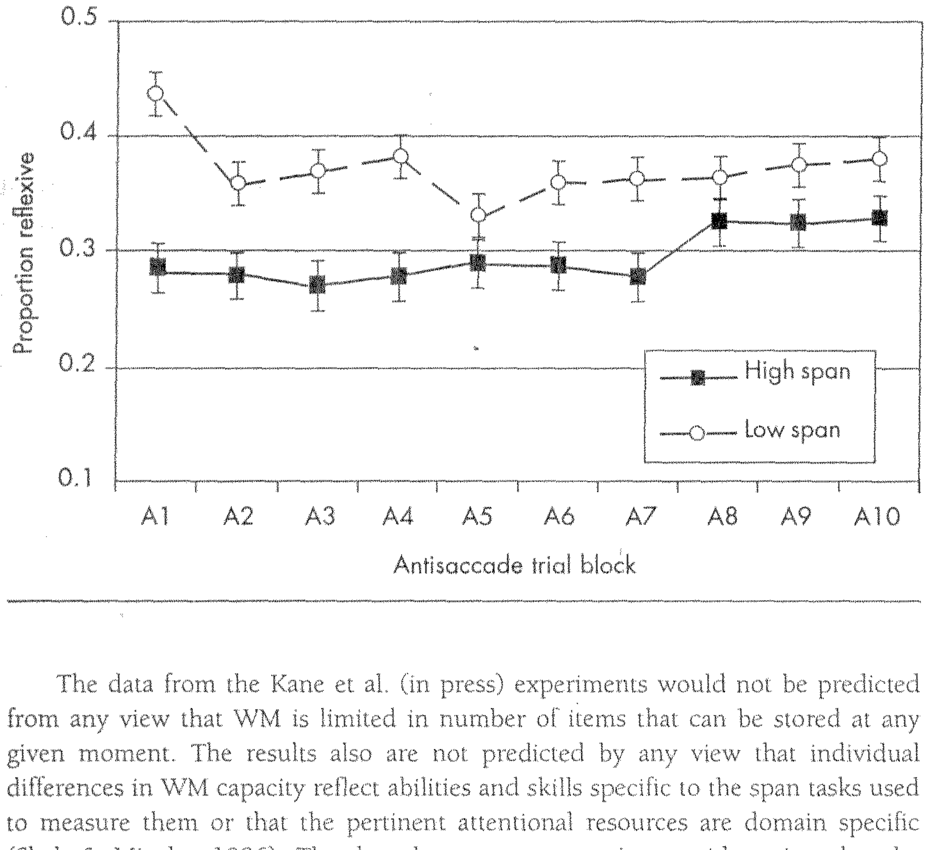


low WM were substantially slower to perform the letter identification than were those with high spans. The eye movement data in Figure 16.3 show that those with low spans were much more likely to follow their reflexive predisposition and look in the direction of the cue. Increasingly over trials, they were slower to make the initial saccade.

After 10 blocks of antisaccade trials, participants were presented with a block of prosaccade trials with explicit instructions that the letter would now be presented in the same location as the cue, so they should look in that direction when the cue occurred. They also had a block of practice trials on prosaccade. In spite of those elaborate instructions and the practice trials, both low- and high-span participants made a substantial number of errors on the initial saccades in the prosaccade condition by looking away from the cue. However, those with low WM made more saccades in the wrong direction (mean proportion errors = .28) than did those with high spans (mean proportion errors = .20). Further, the initial saccades for those with low spans, both correct and incorrect, were slower. In fact, those with low spans were as slow to initiate prosaccades as they were to make antisaccades in the previous block. This was not true for those with high spans. Thus, participants with low WM appear to have greater difficulty establishing and maintaining a set to behave in opposition to a prepotent response, but they also have greater difficulty abandoning that set when the task changes, even when it changes so that the formerly prepotent response is now appropriate.

FIGURE 16.3

Proportion of initial eye movements to the misleading cue in the antisaccade condition as a function of span group and block of trials.



The data from the Kane et al. (in press) experiments would not be predicted from any view that WM is limited in number of items that can be stored at any given moment. The results also are not predicted by any view that individual differences in WM capacity reflect abilities and skills specific to the span tasks used to measure them or that the pertinent attentional resources are domain specific (Shah & Miyake, 1996). The data, however, are consistent with a view that the underlying construct responsible for the relationship between measures of WM capacity and higher order cognitive tasks is a domain-free executive attention system similar to that described by Shallice and Burgess (1993). Whereas individuals possessing different WM capacities show differences in number of items stored in a variety of memory tasks, this is a result of differing ability to maintain and inhibit information, particularly in the face of distraction and proactive and retroactive interference.

Stroop Task

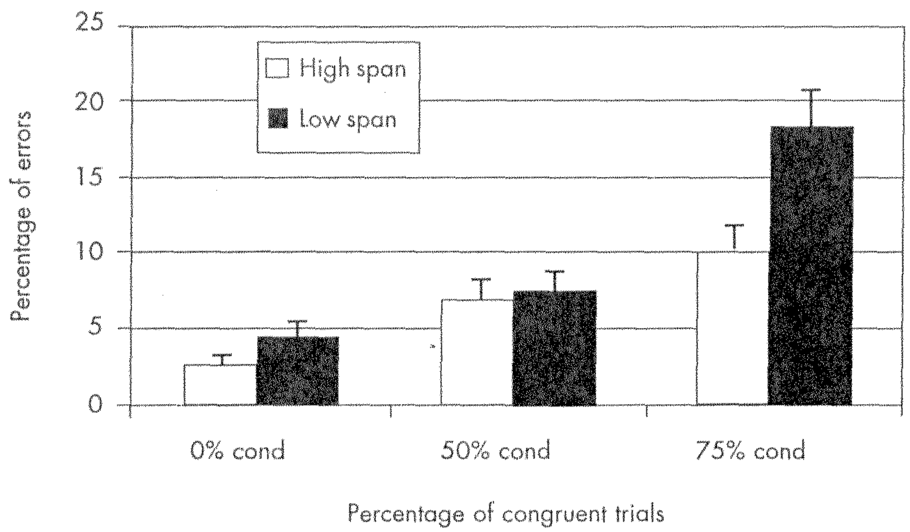
The beauty of this view is that it leads one to consider situations that other views would not think of as involving WM: situations that require maintenance of a single crucial goal or production in WM. If that goal or production must compete with a preternaturally stronger goal that happens to be inappropriate for the current task or if the task environment elicits a strong response tendency that is inappropriate for current conditions, then one should see lawful differences between participants with high and low WM on that task. Furthermore, even participants with high WM should suffer on that task if they perform the task under the load of another task that also demands executive attention.

The Stroop task is one situation in which a strong predisposition to make a task-inappropriate response—saying the word—can hurt performance on the task, which is to say the color of the ink in which the word is printed. My view predicts that performance on the Stroop task should rely on executive attention to maintain the goal of saying the name of the color of the letters even when the word elicits a stronger response tendency to say the name of the word. Maintaining the appropriate goal in a highly active state should be particularly difficult when some of the trials are congruent, that is, the ink color and the word correspond. It is likely easier to maintain the goal if no congruent trials are presented, which is often the case in neuropsychological administration of the task. In such cases, the immediate demands of the task serve to continually remind the participants about the goal to block the word and to say the ink color. However, it should be harder to maintain the goal in active memory if the environment or context presents many trials on which performance can be successful without the necessity to maintain the goal to block the tendency to say the word. If maintaining the goal in active memory requires mental work, and participants with high WM are better equipped to do that work, then they should be more likely to maintain the goal in active memory in such conditions. Moreover, by manipulating such a contextual variable, one can test whether individual differences in WM capacity result from a relatively pure and invariant inhibitory capability or whether inhibition varies with the need to maintain the task goal. If WM capacity simply reflects differences in ability to inhibit information (Hasher & Zacks, 1988), then span differences would occur in all Stroop contexts; but if goal maintenance is critical (O'Reilly, Braver, & Cohen, 1999), then span differences may only be observed when goal maintenance is difficult.

Kane and Engle (2000) conducted a study in which high- and low-span participants named the color of the print for strings of random letters (*jkm, fdtmq,* etc.) and color names (red, blue, or green) that were printed in the colors red, blue, or green. The percentage of trials on which the color name and word name matched or were congruent was 0%, 50%, or 75% and was a between-subjects variable. In the 0% condition, goal maintenance should be easiest because no trials present matching ink color and words, and in 75% congruent trials, maintenance should be most difficult because the word name can be used to speak the color of the ink on the vast majority of trials. Kane et al. (in press) found that time to name the color did not differ between high- and low-span participants, but the number of errors differed substantially. As can be seen in Figure 16.4, although both groups showed increased errors as the proportion of congruent trials increased, high- and

FIGURE 16.4

Percentage of errors in the Stroop task as a function of span group and percentage of congruent trials.



low-WM participants did not differ in errors with 0% or 50% congruent trials. It was only when 75% of the trials were congruent that high- and low-WM subjects differed in number of errors, with low-span participants making almost twice as many errors as high-span participants. Thus, high- and low-span differences do not represent overall inhibition differences in all situations but only when the context makes it difficult to maintain the appropriate task goal.

Dichotic Listening Task

Yet another attention task in which WM capacity has been shown to be important is the venerable dichotic listening task. Conway, Cowan, and Bunting (in press) had high- and low-WM participants shadow unrelated words in one ear while ignoring unrelated words spoken to the other ear. The experimenters had recorded the participant's first name before the experiment, and the name occurred as a word in the ignored message after 4 min. and again after 5 min. The question was whether participants would report hearing their name at the end of the study. I argue that participants with high WM will be better at blocking the distracting information and therefore less likely to report hearing their name than low spans. Conway et al. found that high- and low-span participants were equivalent in performance on the shadowing task on trials preceding their names. However, although only 20%

of participants with high spans reported hearing their name, 65% of those with low spans reported hearing their name. Again, the conclusion is that those with low spans are less capable of doing the mental work necessary to block the distracting information.

Conclusion

I have presented an argument that tasks of WM capacity reflect a common construct, that that construct is fundamentally important to higher order cognition, that it is distinguishable from a construct for STM, and that it is at least related to, if not isomorphic to, general fluid abilities and executive attention. I have further argued that one particularly important function of the WM system is for keeping information quickly retrievable and usable under conditions in which there is interference from information that is strongly elicited by task context but that nevertheless would lead to a response inappropriate for the current task. I have described the results of several studies showing that individual differences in WM capacity are important in tasks that would not seem to rely on the number of things a person could remember but that would rely on the ability to keep one piece of information highly active. WM capacity is not about memory per se; it is about individual differences in executive attention.

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