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Working Memory and Executive Attention: A Revisit

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Abstract
In this follow-up to my 2002 article on working memory capacity, fluid intelligence, and executive attention in *Current Directions in Psychological Science*, I review even more evidence supporting the idea that the ability to control one's attention (i.e., executive attention) is important to working memory and fluid intelligence. I now argue that working memory tasks reflect primarily the maintenance of information, whereas fluid intelligence tests reflect primarily the ability to disengage from recently attended and no longer useful information. I also point out some conclusions in the 2002 article that now appear to be wrong.

Keywords
memory, attention

Current Directions in Psychological Science is unique among psychology journals. First, the articles are nearly all invited from authors who have earned a reputation for doing leading-edge research. Second, the articles are very short reviews of that research and are written for a broad nonspecialist, even nonpsychologist, audience. The invitation to write my 2002 article (Engle, 2002) was an honor, and it gave me a chance to describe my research program to scholars in areas beyond mainstream cognitive psychology, where nearly all my work had been published. As a result of that article, my work was read and cited by researchers in many different areas of psychology, education, and medicine. Second, the work was read and cited more frequently by international scholars.

My research is a bit unusual in that it combines both of the two major approaches to psychological research: experimental and differential (Cronbach, 1957). My research question was "What is the relationship between our capacity to keep information in active short-term or working memory and our ability to perform complex real-world tasks, and what mechanisms are responsible for that relationship?" The *Current Directions* article was a review of my attempts over 15 years to answer those questions.

In the article, I reported on some studies that used a quasiexperimental approach in which we preidentified individuals who were in the upper quartiles (high spans) and lower quartiles (low spans) on complex span measures of working memory capacity (WMC) and tested them on various manipulations to see whether they were different when doing various cognitive tasks. Some of those studies showed that the high- and low-span individuals differed greatly in performing real-world tasks, such as reading and listening comprehension, language comprehension, ability to follow directions, vocabulary learning, note taking, writing, reasoning, bridge playing, and learning to write computer programs (Engle, 2001). Obviously, WMC is an important individual-difference variable in a huge number and variety of real-world tasks.

Attention Control

Of the studies I reviewed, others were attempts to understand the underlying mechanisms responsible for the role of WMC in those tasks. In one of those studies (Rosen & Engle, 1997), we performed a series of experiments in which individuals were given a category name such as "animals" and were asked to retrieve as many different examples of the category as they could in 10 min and under various load conditions. High-span individuals retrieved many more animal names than did

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low-span individuals even in the first minute, and this discrepancy was unlikely to be due to differences in the number of animal names known to the two groups. Cognitive load reduced the number of animals recalled by the high-span individuals but had negligible effect on the low-span individuals. Furthermore, we showed evidence that a major factor in the results was that low-span individuals reretrieved many more items that they had already recalled than did the high-span individuals. We argued that this was because the low-span individuals were less good at blocking the already-retrieved items from consciousness, and thus those items were retrieved again. This finding provided support for our idea regarding one major factor in why individuals differed in WMC and in the role that this factor played in performing real-world tasks. The idea was that differences in WMC reflected differences in ability to control endogenous attention—the ability to maintain attention on critical tasks and to avoid having attention captured by either internally generated thoughts ("gee, what's for lunch?") or externally generated events ("ooh, pretty butterfly") that lead to thoughts that compete with performance on the task.

The *CDPS* article also reported the results of numerous studies supporting the idea that individual differences in ability to control attention were an important factor contributing to the importance of individual differences in WMC in performance of complex tasks. One of the tasks that we have used to test this idea is the antisaccade task. This task relies on the fact that a flickering figure in our visual periphery suggests movement; our nervous system has evolved to have our attention captured by events that suggest movement. Things that move can eat you or you can eat them—both important to our survival. In this task, there are two conditions. Subjects fixate on the center of a computer screen and there are two boxes—one in the periphery to each side of the fixation point. At some unpredictable point, one of the boxes flickers. In the prosaccade condition, the task is for the subject to look at the flickering box because a letter will be very briefly presented in that box, and the subject must identify the letter. We (Kane, Bleckley, Conway, & Engle, 2001) had predicted that high- and low-WMC subjects would not differ in the prosaccade condition because attention control was not necessary. The primitive part of the subject's nervous system should respond automatically to the flickering cue and lead to a response of looking at the box that flickered. This is a rather "thoughtless" action, so individual differences in WMC should not play a role. In the other condition, the antisaccade condition, when one of the boxes flickered unpredictably, the letter to be identified was presented very quickly in the box on the opposite side of the screen. To do well in this condition, the subject must control attention, resist having attention captured by the primitive response to an event that affords movement, and force attention to the box on the side opposite to the flickering box. Here, we predicted that if attention control is an important factor in individual differences in WMC, then low-WMC individuals should be much more likely to follow the primitive system and look toward the flickering cue, which would lead to more errors in identifying the letter in the box on the opposite side of the screen. High-WMC individuals should make fewer errors if they can use top-down control to prevent their attention from being captured by the flicker.

That is exactly what we found. Low-WMC individuals made many more errors on the letter task than did high-WMC individuals. Although it was our inference that more errors indicated that low-WMC subjects were captured by the automatic attention response to the flickering box, we subsequently proved that to be the case in another set of studies using the antisaccade task. In this study, the task was simply to look at the box on the side of the screen *opposite* the flickering box. There were no letters to report or buttons to press. The individual simply had to look at a box. We measured eye movements during the task (Unsworth, Schrock, & Engle, 2004) so we could determine whether low-WMC individuals were more likely to make an error by looking at the flickering box despite instructions to immediately look at the box on the opposite side of the screen. As you can see in Figure 1, there was no difference between high- and low-WMC individuals for the prosaccade task. However, in the antisaccade condition, high-WMC individuals were much less likely to make an eye movement toward the flickering box.

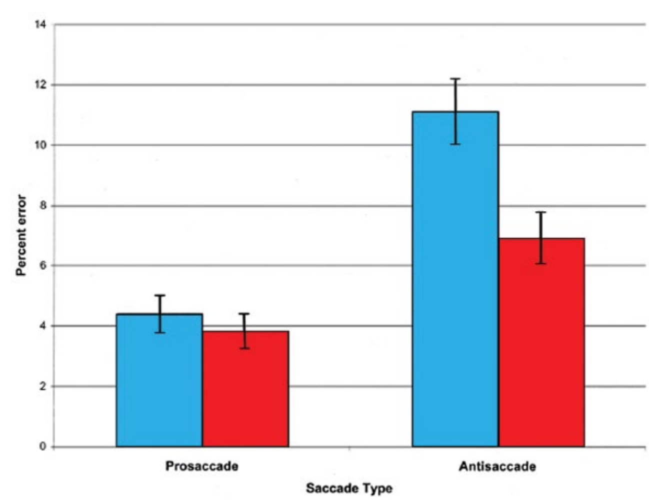

Fig. 1. Mean percentage of direction errors as a function of working memory span and saccade type for Experiment 1. Blue bars indicate low-span participants; red bars indicate high-span participants. Error bars represent ±1 *SEM*.

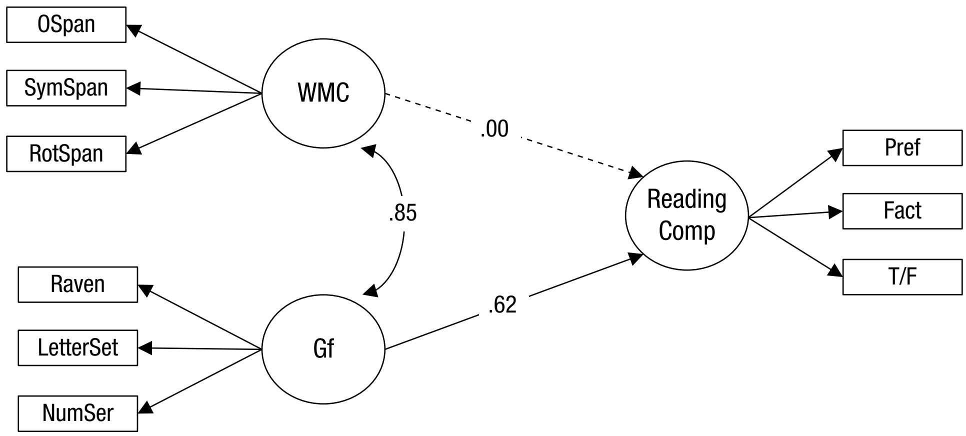

Fig. 2. Relationship of working memory capacity and fluid intelligence to reading comprehension as reflected by pronominal reference (Pref), fact, and true/false (T/F) questions about paragraphs read by subjects. OSpan = operation span; SymSpan = symmetry span; RotSpan = rotation span; Raven = Raven's Progressive Matrices; LetterSet = letter set; NumSer = number series; Gf = fluid intelligence. Source: Martin et al. (2017).

The antisaccade task is one of our most reliable tasks in showing attention-control differences related to differences in WMC and other constructs related to attention control (Shipstead, Harrison, & Engle, 2016). This finding strongly suggests that the mechanisms underlying the relationship between WMC and performance on a huge array of real-world tasks reflects differences in the ability to control domain-general attention.

One of the things I argued in the 2002 article was that individual differences in WMC possibly play a causal role in fluid intelligence. I based that argument on the strong relationship, on the order of .6 to .8, between WMC and fluid intelligence at the construct level. I now think that argument was wrong. In fact, several of the arguments I made in the 2002 article are, I now believe, wrong. Those arguments were based on quasiexperimental studies with groups of high- and low-WMC individuals. The problem with that approach is that when subjects are chosen on the basis of tests of WMC, because of the high correlation between WMC and fluid intelligence, high-WMC individuals also tend to be high in fluid intelligence. Separating out these two individual-difference variables requires studies in which the full range of each variable is measured so that the two variables can be contrasted with each other. This requires a statistical procedure called structural equation modeling, which involves testing many more people than is required by quasiexperimental approaches. In such studies subsequent to the 2002 article, we found that some effects we attributed to WMC in 2002 are really due to differences in fluid intelligence and not WMC. For example, the Rosen and Engle studies with high- and low-WMC individuals found large differences in performance on measures of fluency (e.g., how many animal names can be retrieved). However, in a subsequent large-scale study on many WMC tasks and many fluid-intelligence tests, we found that the effects on fluency (number of animal names recalled) were due totally to fluid intelligence and not WMC (Shipstead et al., 2016). We have also found that, whereas earlier work on WMC showed a strong link between WMC and reading comprehension (Daneman & Carpenter, 1983), when studies are done with a large sample so that the two variables can be safely contrasted, the relationship is really between the mechanisms underlying fluid intelligence and comprehension, not WMC (Martin et al., 2017; see Figure 2).

Other large-scale studies, however, show that WMC is the more important variable for some types of tasks. For example, Redick et al. (2016) tested the role of fluid intelligence and WMC in multitasking. They used a variety of multitasking tasks with different formats and subtasks and yet found evidence for a multitasking ability common to the tasks. However, for some of the tasks, WMC was more important in predicting performance, and for other tasks, fluid intelligence was more important.

How I Think About It Now

This set of findings has led to perhaps the biggest difference in how I wrote the 2002 article and the way I would write it today. I now think that the tasks used to measure WMC largely reflect an ability to maintain information in the maelstrom of divergent thought. Tasks measuring fluid intelligence largely reflect the converse of that—the ability to think of something that may be important at the moment, but when it shortly proves to be unimportant or wrong, to disengage or unbind that information and to functionally forget it. These two constructs are therefore to a great extent contradictory, so why are they so strongly correlated, in the range of .6 to .8 at the construct level? The answer is that both abilities rely on the ability to control attention to do the mental work necessary to either maintain information or to disengage from information. Indeed, WMC tasks also rely on disengagement to some extent, but they more reflect the maintenance of information. Likewise, fluid-intelligence tasks such as Raven's Progressive Matrices (Raven, 2000) also rely to some extent on maintenance of information. They much more reflect the ability to entertain a hypothesized solution and, when it is later proven to be in error, to disengage from that hypothesis and test new and different hypotheses. Individuals low in fluid intelligence are much more likely to re-retrieve previously tested and failed hypotheses. In the same way, Rosen and Engle showed that low-WMC individuals reretrieved many more previously recalled animal names. We now know that it was really the lower fluid intelligence that was leading to that finding (Shipstead et al., 2016; Martin et al., 2017).

According to Google Scholar, my 2002 article has been cited nearly 2,000 times. Why has that little article, written to be understood by undergraduates, had such impact? The executive attention in the title has turned out to be central to issues in nearly every area of psychology. I think the article attempted to address some rather complex issues and complex methods in relatively simple terms that were at the core of human thought, emotion, and behavior. I think it was also because the article tackled individual differences in both experimental and differential terms and, as Cronbach (1957) argued, the conversation between and convergence of those two approaches are rare.

Declaration of Conflicting Interests

The author(s) declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

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