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Working Memory Capacity, Attentional Focus, and Problem Solving

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Abstract

Attentional focus is important for many cognitive processes, including problem solving. In this article, we discuss working memory capacity (WMC), a construct related to the ability to focus attention, and its differential effects on analytic and creative problem solving. One of the main ways in which WMC benefits analytic problem solving seems to be that it helps problem solvers to control their attention, resist distraction, and narrow their search through a problem space. Conversely, several lines of recent evidence have shown that too much focus can actually harm performance on creative problem-solving tasks.

Keywords

working memory capacity, problem solving, creativity

In an early attempt to understand the processes underlying mental arithmetic, Hitch (1978) used several experiments to outline the contributions of the working memory system to mathematical problem solving. Multidigit problems, such as 325 + 46, were presented orally, and participants were asked to report their solution strategies, which involved breaking the solution process into sequential stages. Hitch's analysis showed that mental arithmetic requires the temporary storage of initial information and partial results, the retrieval of information from long-term memory (LTM), and the selection and use of strategies. The focus on these research themes has continued into the present day. Although Hitch's study did not examine individual differences in working memory capacity (WMC; a measure of attentional control; Engle, 2002; Hasher & Zacks, 1988), it provided theoretical groundwork explicating the role of WMC in analytic problem solving. More recently, research has also addressed WMC's role in creative problem solving. In this article, we will consider some potential differences between these two types of problem solving (Wiley & Jarosz, 2012).

Mathematical Problem Solving

The most straightforward relationships between WMC and analytical problem solving have been studied using mathematical problem-solving tasks. Dual-task studies have demonstrated that the disruptive effects of performing a concurrent task are particularly acute on multidigit problems that require a sequence of steps, carrying, or borrowing. Similarly, errors are particularly likely when problem solving involves intermediate solutions or nested goals. Studies using individual-differences approaches have shown that WMC predicts multidigit problem solving (Seyler, Kirk, & Ashcraft, 2003). Further, WMC demands are highest in the early stages of mathematical-skill acquisition (Geary, Hoard, Byrd-Craven, & DeSoto, 2004). However, the performance of concurrent executive tasks has also been found to disrupt the ability to solve even single-digit arithmetic problems, which suggests that WMC may relate to the ability to successfully retrieve math facts from LTM. In turn, recognizing the likelihood of successful retrieval may also affect the strategies that people choose. Low-WMC students continue to use counting strategies to compute solutions to problems even when those solutions are already present in LTM, and they may also be more susceptible to interference when retrieving number facts (Geary et al., 2004). In a direct test of this idea, Mattarella-Micke and Beilock (2010) found that WMC helps reduce conflict from irrelevant operations (e.g., sums when products are required).

An alternative explanation links differences in retrieval to differences in the quality of the encoding of math information in LTM. For answers to addition problems to be stored in LTM, both the addends and sums have to be present in WMC simultaneously. Because low-WMC children use slow counting procedures, they may develop weaker problem-answer associations (Geary et al., 2004).

Word-problem solving also seems to depend on WMC to help with interpreting problem statements, resisting distraction from irrelevant problem information, and transforming problem representations (Wiley & Jarosz, 2012). For example,

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word problems involving comparisons of quantity are notoriously difficult to solve, a fact attributed to wording that is inconsistent with the operations that are required for solution (e.g., the phrasing of the word problem "How many marbles does Jane have more than Mary?" implies addition, but the problem requires subtraction). These problems may be particularly difficult for individuals with low WMC, either because of this inconsistency between wording and required operations or the lack of a verbal cue suggesting the correct operation, or because the problems require the creation of multiple simultaneous representational expressions (Thevenot & Oakhill, 2006). Other work has suggested that WMC relates to the ability to mentally transform the order of information in problem statements (e.g., when the to-be-solved entity comes before the equal sign).

WMC also seems related to the accurate classification of problems—for example, recognizing when a problem requires a particular operation (e.g., subtraction) or solution strategy (e.g., isolation; Swanson, Cooney, & Brock, 1993)—and is thus necessarily related to the ability to select important information to include in a problem representation. Just as WMC may aid the retrieval or encoding of math facts in LTM, differences in WMC may also relate to differences in the retrieval or encoding of problem classifications or schemas.

A final, burgeoning area of research has been exploring different types of stressors (Ashcraft & Krause, 2007). As might be expected, math anxiety relates negatively to mathematical problem solving. Although anxiety has little effect on the ability to solve simple addition and multiplication problems, it has larger effects on the ability to solve more complex problems, including mixed fractions, algebraic equations, and carry operations. Anxiety effects may stem from a functional decrease in WMC due to rumination, which effectively adds an additional task to any target activity. Even a subtle stereotype threat can significantly decrease both WMC and success in solving complex problems. Although one might suspect that individuals with lower WMC should be more vulnerable to the negative effects of anxiety or threat, it is high-WMC individuals whose performance seems to be the most harmed by high-pressure conditions (Beilock & Carr, 2005).

In summary, attentional focus, or WMC, is helpful in many ways for mathematical problem solving. For solving even simple problems, WMC matters. WMC-related differences may result from differences in encoding or retrieval of math-related knowledge structures in LTM, in the ability to deal with interference from competing information, in the ability to limit distraction from irrelevant problem features, and in the ability to generate or manipulate mental problem representations.

Creative Problem Solving

As outlined in the preceding section, several processes underlying effective analytic problem solving are aided by WMC. One of WMC's main benefits to problem solving seems to be that WMC helps solvers to focus their attention, resist distraction, and narrow their search through a problem space. However, one can imagine that these aspects of WMC might harm the ability to solve problems that require a broad search. A critical distinction between creative and analytic problem solving is that in creative problem solving, the most dominant solutions or most obvious solution paths will lead to initial failure (i.e., *impasse*) rather than success. When a creative problem is not immediately solvable, reaching the solution seems to require either a completely original approach (i.e., restructuring) or a novel combination of diverse bits of information through remote associations in memory. Several lines of evidence have now shown that too much focus can actually harm creative problem solving.

Some studies have shown that WMC does not play the same role in creative problem solving as in analytic problem solving. Ash and Wiley (2006) explored the role of WMC in both the initial search phase of problem solving and the subsequent phase of solution following impasse. To do this, they developed two versions of a set of insight problems, one with many moves available (MMA) before impasse and one with few moves available (FMA) before impasse. WMC predicted success in solving MMA, but not FMA, problems. Because FMA problems isolated the restructuring component of the problems, these results suggest that restructuring during creative problem solving did not require controlled attention, whereas the search through the initial problem space in the MMA problems did. Fleck (2008) demonstrated that WMC uniquely predicted analytic problem solving over and above the effects of short-term memory (STM), whereas creative problem solving was uniquely related only to STM. Similarly, Gilhooly and Fioratou (2009) found that attentional control, as measured by task-switching measures, predicted performance only on analytic problems, not insight problems. Thus, several findings have demonstrated that attentional control plays a greater role in analytic problem solving than in creative problem solving.

Other studies have supported a more extreme conclusion: Some of the very mechanisms that allow for successful analytic problem solving might actually impair creative problem solving. This was first demonstrated not by a study on WMC, but rather by a study examining the effects of domain-specific knowledge on creative problem solving (Wiley, 1998). Expertise generally aids problem solving by allowing solvers to restrict their attention to promising alternatives and to search only a portion of the solution space. However, when solutions reside outside the range of typical responses, expertise can misdirect solvers, leading them to focus their search in incorrect areas and thereby retarding or preventing solution.

Indeed, solvers with domain-specific knowledge related to misleading solutions were less likely to find creative solutions to problems on the Remote Associates Test (RAT), which requires solvers to generate a word that forms a common compound phrase with each of three presented words. On a RAT problem in which the three words presented were "plate," "broken," and "shot," baseball experts were more likely to be stuck on the incorrect solution "home" and were less likely to find the correct solution, "glass." A follow-up investigation revealed that high-WMC participants who were fixated by their prior baseball knowledge were the least likely to overcome their mental sets and reach novel solutions (Ricks, Turley-Ames, & Wiley, 2007). In related work, Beilock and DeCaro (2007) found that high-WMC participants experienced greater Einstellung on the Luchins water-jugs task. These participants persisted in using a complex solution that worked on initial problems and were less likely to find a simpler means of solving once it was possible, whereas the low-WMC participants found it immediately. Similarly, patients with lateral prefrontal cortex lesions seem to experience less fixation from prior knowledge on matchstick arithmetic problems. Normal adults experience great difficulty when trying to move just one matchstick to make III + III = III into a correct arithmetic statement, but these patients are twice as likely to find a solution (Reverberi, Toraldo, D'Agostini, & Skrap, 2005). A growing number of findings have suggested that high-WMC individuals may employ complex strategies when simpler, more elegant, or more direct approaches are available (DeCaro & Beilock, 2010).

Other studies have suggested that low attentional control can also benefit creative problem solving by increasing sensitivity to peripheral cues. Older adults tend to exhibit low WMC and poor attentional control, but this can benefit their problem solving when "distracting" information actually provides solution-related cues (Kim, Hasher, & Zacks, 2007). And performance on the RAT has been found to correlate with the ability take advantage of peripherally presented cues (Ansburg & Hill, 2003). Thus, a deficit in attentional control positively predicts performance on creative-problem-solving tasks, which suggests that "leaky" attention can sometimes be a good thing: It allows external cues to prime a range of solutions during the creative-problem-solving process.

One recent study demonstrated a link between attentional control and creative problem solving in yet another way: through a manipulation of attentional control via alcohol intoxication (Jarosz, Colflesh, & Wiley, 2012). After their blood alcohol content level had reached .075, participants experienced a significant deficit in WMC but showed improvements in creative problem solving. Instead of narrowing the focus of attention, drinking appears to make attention more diffuse, allowing intoxicated individuals to better access remote solutions. Convergent findings have come from studies using differences in cognitive-control systems stemming from time of day, sleep, mood, and affective states (Cai, Mednick, Harrison, Kanady, & Mednick, 2009; Rowe, Hirsh, & Anderson, 2007; Wieth & Zacks, 2011). Even prompting solvers to "use their gut" during creative problem solving seems to encourage a more intuitive, less analytic, or less focused approach that improves performance (Aiello, Jarosz, Cushen, & Wiley, 2012).

In summary, these findings suggest that too much focus or attentional control may limit creative problem solving—it may limit the scope of solutions that are explored and lead solvers to adopt or persist in nonoptimal strategies. A more passive approach to problem solving, or a more diffuse or leaky attentional state, may be better for creative problem solving.

A Little of Each

Our main goal in this overview has been to highlight dissociations between analytic and creative problem solving in their relation to attentional focus as measured by WMC. Although a main conclusion is that creative problem solving may rely on constructs such as diffuse or broad attention to a greater extent than analytic problem solving does, in the end, it must be recognized that most cases of real-world problem solving will likely require a mix of convergent and divergent processes (Martindale, 1995). Said another way, most problem solving may require a mix of non-goal-directed associative processes and more controlled, attention-demanding processes (Smallwood & Schooler, 2006).

It is not the case that people with low WMC are always necessarily better creative problem solvers. Rather, the tendency to allocate attention in a diffuse way may be an individual difference that serves to promote creative problem solving (Mendelsohn, 1976). Alternatively, advantages in creative problem solving may be related to individual differences in the ability to flexibly switch between different modes or types of processing. This has long been an attractive idea, but there is not yet a definitive paradigm that allows for the measurement of individual differences along these lines. Some promising leads have demonstrated that bilinguals have an increased likelihood of solving insight versus analytic problems, whereas monolinguals show the opposite pattern (Cushen & Wiley, 2011). Bilinguals have also been suggested to possess superior switching abilities (Bialystok, Craik, Green, & Gollan, 2009). Other studies have also found that individual differences in the rate of ambiguous figure reversal, the ability to identify hidden figures or objects, or the ability to generate novel patterns can predict creative problem solving (Wiseman, Watt, Gilhooly, & Georgiou, 2011). A tentative explanation for these results is that a greater tendency to perform well on these tasks may actually be due to a greater ability to switch between global and local, or passive and analytic, modes of processing, and that this flexibility may promote successful creative problem solving (Smallwood & Schooler, 2006).

The WMC-related findings discussed above largely indicate that at least some processes underlying creative problem solving are distinct from those involved in analytic problem solving. As such, the results are consistent with findings from other perspectives that suggest a distinction between the two types of problems in relation to metacognitive access to solution progress, initial problem representations (Ash & Wiley, 2008), and patterns of brain activation (Kounios & Jung-Beeman, 2009). The recognition that creative problem solving may be harmed by attentional focus also supports the need for a dual-process model of problem solving that incorporates both analytic and nonanalytic processes. This review at the intersection of WMC and problem solving demonstrates that a second, less-goal-directed and less-controlled route is needed to explain key findings in this body of literature.

Conclusions

WMC influences problem solving, but not always positively, and not always negatively. This is because WMC is not just the size of one's buffer. STM storage functions are important, and they do underlie basic processes in both analytic and creative problem solving. However, differences in WMC also reflect differences in attentional focus and control. In analytic-problem-solving contexts, such as mathematical problem solving, the greater focus and control associated with higher WMC generally support more successful problem solving. Yet some processes involved in creative problem solving do not depend on these executive functions, and their success can be harmed by too much focus.

Successful problem solving depends on the needs of the situation. Sometimes focus is needed, sometimes a lack of focus is needed, and sometimes a solver would do best to seek out contexts that help promote one or the other (e.g., drinking, sleeping, altering his or her mood, or problem solving at different times of day). Revising our thinking about WMC by recognizing that attentional focus may have both positive and negative repercussions, as well as revising our thinking about problem solving by recognizing that it requires both analytic and nonanalytic processes, will provide a better understanding of both.

Recommended Reading

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Declaration of Conflicting Interests

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