The Path Less Taken: When Working Memory Capacity Constrains Insight

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Abstract

Higher working memory capacity (WMC) supports performance on a wide variety of complex cognitive and academic activities (Barret, Tugade, & Engle, 2004). However, a growing body of research demonstrates that higher WMC can have disadvantages—leading individuals to employ complex performance strategies that are less optimal for a given task (cf. DeCaro & Beilock, 2010). We examine this possibility in the domain of insight problem solving. Participants (*N*=84) completed Matchstick Arithmetic problems thought to either rely on controlled search and retrieval processes (non-insight problems) or diverging from known mathematical constraints (insight problems). Consistent with a large body of research on WMC, higher WMC was associated with higher non-insight problem accuracy. However, higher WMC led to significantly worse insight problem-solving. Although higher WMC supports complex problem-solving strategies, relying on these may lead individuals to miss associatively-driven solutions that are important for insight.

Keywords: Working memory capacity; attention; insight; problem solving.

Introduction

A great deal of work has demonstrated that higher working memory capacity (WMC) is advantageous to an array of complex cognitive and academic activities, such as reasoning, comprehension, and problem-solving (see Barrett, Tugade, & Engle, 2004, for a review). Indeed, WMC—the ability to hold and manipulate information in a temporary active state—has been said to be "so central to human cognition that it is hard to find activities where it is not involved" (Ericsson & Delaney, 1999, p. 259). However, a growing body of research demonstrates that higher WMC can have disadvantages—leading individuals to employ complex performance strategies that are less optimal for a given task (see DeCaro & Beilock, 2010, for a review). In the current work, we examine the possibility that higher WMC can hinder creative thinking in the form of insight problem-solving. Specifically, we examine the hypothesis that those who have the ability to implement complex problem-solving strategies may be more likely to miss associatively-driven solutions that are important for insight.

Working Memory Capacity

WMC supports the ability to suppress distractors and guide attention toward relevant information in goal-directed tasks (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). The predictive power of WMC as a construct stems from this domain-general capacity for attentional control, and individual differences in WMC emerge primarily when that capacity is challenged (Engle, 2002). So-called "executive attention" is accomplished via controlled processing, which is important in novel or interference-rich situations and when goals come in conflict with prepotent responses (Unsworth & Engle, 2007).

A large body of research has been built around the well-established differences in performance outcomes of individuals who fall toward either extreme of the WMC scale. Kane and Engle (2000) found that individuals with lower WMC demonstrated a greater vulnerability to proactive interference, and were more likely to lose track of task goals than their higher WMC counterparts (Unsworth & Engle, 2007). Additionally, studies have found that individuals with lower WMC display higher rates of attentional capture (Conway, Cowan, & Bunting, 2001; Kane, Bleckley, Conway, & Engle, 2001), and have greater difficulty discriminating relevant and irrelevant information (Unsworth & Engle, 2007).

It is no surprise that the ability of higher WMC individuals to control attention leads to greater ability to implement more difficult, multi-step problem-solving strategies (Engle, 2002). Indeed, the ability to execute complex strategies may lead individuals to select strategies in line with their ability—even if the task does not call for a controlled processing approach. Beilock and DeCaro (2007) explored this idea by examining the strategy selection of higher and lower WMC individuals completing Luchins' (1946) water jug task. This task requires individuals to use three depicted water jugs with varying capacities (e.g., Jug A=23, Jug B=96, and Jug C=3) to fill a "goal" jug with a certain capacity (e.g., 67). For example, one might fill Jug B, then pour that amount into Jug A, and then pour the remaining amount into Jug C twice (i.e., B-A-2C). Participants were explicitly instructed to mentally derive the answers (i.e., without the use of paper), and use the simplest strategy possible. The first few problems were solve-able using a single complex formula (B-A-2C). The final few problems could also be solved using this formula (e.g., Jug

A=34, Jug B=72, Jug C=4; Goal=30). However, a much simpler strategy could also be applied (e.g., A-C). On these final problems, individuals with higher WMC were more likely to employ the complex algorithmic strategy (i.e., B-A-2C), even though more efficient strategies were available. Individuals with lower WMC were instead quicker to abandon an algorithmic approach and adopt a less-demanding shortcut strategy relying on a more diffuse focus of attention.

These findings demonstrate that individuals higher in WMC may tend to use more complex strategies even when simpler ones are more efficient for a given task. Such overreliance on complex strategies can harm performance on some tasks (e.g., Gaissmaier, Schooler, & Rieskamp, 2006; Wolford, Newman, Miller, & Wig, 2004). For example, when associative responses guide well-learned skill execution, as with proceduralized tasks, controlled attention can disrupt performance (DeCaro, Thomas, & Beilock, 2008). Additionally, various situational and task-specific factors such as performance pressure (Beilock & DeCaro, 2007; DeCaro, Thomas, Albert, & Beilock, 2011) and expertise (Ericsson & Delaney, 1999; Wiley, 1998) have been shown to moderate the role of controlled processing in learning and performance situations. A better understanding of when and why less WMC can prove advantageous is necessary to fully grasp the limitations of this pervasive system of cognitive constraint.

Insight Problem-Solving

An area in which this question is being explored with great interest is research in insight problem-solving. The link between WMC and insight is not well understood, and there has been much debate over how best to facilitate the type of creative thinking insight problem-solving requires. One approach looks at the role of attention in problem-solving.

Insight problems require the use of strategies that diverge from obvious approaches, and are supported by a more diffuse focus of attention (Ansburg & Hill, 2003). *Non-insight problems*, conversely, are best solved by following a progressive series of analytic steps, which requires controlled processing and relies on WMC. According to *Representational Change Theory* (Ohlsson, 1992), insight problems generally trigger an inadequate mental representation of the problem situation and solution criteria. Explicit search processes reinforce this faulty representation, and are unlikely to lead to the correct solution path. Instead, unsuccessful solution attempts often result in impasse, a state characterized by an apparent dearth of viable problem operators. It is only through a reappraisal of the initial representation that the correct solution path becomes accessible to the solver, often in a sudden and transparent manner (Kounios et al., 2006; Kounios & Beeman, 2009; but see also Ash, Cushen, & Wiley, 2009).

Much of the research on insight problem-solving has focused on questions surrounding the phenomenon of impasse, specifically why impasse occurs and how it is overcome (Ohlsson, 1992; Jones, 2003). One explanation is that the problem solver unwittingly imposes unnecessary and/or misguided constraints on the problem space (Knoblich, Ohlsson, Haider, & Rhenius, 1999). Additionally, preoccupation with more familiar problem operators (i.e., ones that have worked in the past) can make it difficult to access more novel operators that are critical for insight (Knoblich, Ohlsson, & Raney, 2001). To the extent that one continues to implement strategies based on these constraints, one will fail to reach an insight solution (Wiley, 1998).

Working Memory and Insight Problem-Solving

Because of their reliance on associatively-driven problem-solving solutions, insight problem-solving may be less benefited by the use of complex, algorithmic problem-solving strategies. Indeed, the use of such strategies can actually hinder the ability to derive a solution (Schooler, Ohlsson, & Brooks, 1996; Wiley & Jarosz, 2012). Studies have shown that WMC is related to the ability to solve novel problems and adapt to new situations (Barrett et al., 2004). However, if individuals higher in WMC have a tendency to rely on a more controlled attentional focus and inhibit peripheral information, they may also neglect potentially relevant information held outside of the perceived problem space (cf. Ansburg & Hill, 2003). Thus, counter-intuitively, one might expect higher WMC individuals to perform worse on insight problem-solving tasks.

Support for this idea comes from a range of studies demonstrating that less focused (i.e., more diffuse) attention benefits insight problem-solving, whereas applying more controlled attention hinders the ability to derive insight solutions. For example, moderate alcohol intoxication both reduces WMC and improves insight problem-solving (Jarosz, Colflesh, & Wiley, 2012); solving insight problems at one's non-optimal time of day improves performance (Wieth & Zacks, 2011); and patients with frontal lobe impairment demonstrate better insight-problem accuracy (Reverberi, Toraldo, D'Agostini, & Skrap, 2005). In contrast, verbalizing the problem steps during solving decreases insight performance, possibly by "overshadowing" insight processes (Schooler et al., 1996).

Current Study

The current study examines the role of individual differences in WMC in solving both non-insight and insight problems, using the Matchstick Arithmetic task (Knoblich et al., 1999). *Matchstick Arithmetic problems* are false arithmetic statements written using matchsticks. The matchsticks represent Roman numerals, arithmetic operators, and equal signs. Each matchstick problem is composed of three roman numerals separated by two arithmetic signs, and has a unique solution consisting of a single move.

Participants were given three types of matchstick arithmetic problems, shown in Figure 1. *Standard type* (ST) matchstick problems are solved by moving a matchstick representing a value of 1 from its position in a given roman numeral to a different position in the same or a different numeral on either side of the equal sign. The “I” matchstick is considered a “loose chunk” because it can be removed without invalidating the remaining figure and is easily appended to many others (Knoblich et al., 1999). The simple manipulation of loose chunks in ST problems is consistent with prior knowledge that reordering values in an equation leads to success (Öllinger, Jones, & Knoblich, 2008). ST problems do not involve impasse (Knoblich et al., 2001), or restructuring (Öllinger et al., 2008), considered defining features of insight problems (Ohlsson, 1992). Consistent with Öllinger et al. (2008), we refer to ST problems as non-insight problems.

Constraint relaxation (CR) matchstick problems require transforming the initial false statement (e.g., III + III = III) into a correct, but tautological, statement by changing the plus sign into an equal sign (III = III = III). Solving CR problems is thought to be achieved by relaxing the constraint that correct arithmetic statements cannot contain more than one equal sign. These are commonly considered insight problems (Knoblich et al., 1999).

Finally, *chunk decomposition* (CD) problems require the solver to decompose a “tight chunk” in order to identify the decisive move. A tight chunk was defined as a single roman numerical figure composed of two matchsticks that together form a meaningful unit (e.g., V, X). For example, when participants see the incorrect arithmetic statement IV = III + VI, they must transpose the V into an X by sliding one matchstick to find the solution IX = III + VI. CD problems are typically considered insight problems. However, findings from these problems do not always correspond to the findings from CR problems, making it difficult to determine if these problems are of the same nature (Knoblich et al., 1999; Knoblich et al., 2001; Öllinger et al., 2008). Thus, although we explored performance on CD problems, we were unable to derive clear hypotheses about the relationship between performance on these problems and WMC.

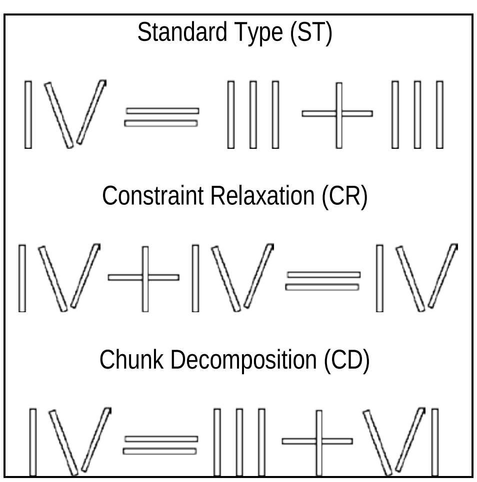

Figure 1. Example Matchstick Arithmetic Problems

We predicted that higher WMC would be associated with increased non-insight (ST) problem-solving accuracy. However, we predicted the opposite pattern for insight (CR) problems, that higher WMC would lead to lower insight problem-solving accuracy. Such findings would be consistent with a growing body of research demonstrating that more working memory capacity can lead to controlled problem-solving approaches that overshadow more optimal associatively-driven solution paths (Wiley & Jarosz, 2012).

Method

Participants

Participants were 84 undergraduate students enrolled in psychology classes (63 female; age *M* = 21, *SD* = 4.6; range 18-46 years). An additional 3 people were excluded from the study because they had been exposed to matchstick arithmetic problems before. One person was excluded for errors on more than 20 percent of the sentence task of the aRspan (Conway et al., 2005). Participants received course credit for participation.

Materials

Problem-solving task Participants completed Matchstick Arithmetic problems (Knoblich et al., 1999), consisting of false arithmetic statements written with Roman numerals (I, II, III, etc.), arithmetic operators (+, −), and equal signs depicted as matchsticks (see Figure 1). Problems were completed on paper. Participants were instructed to transform the initial false arithmetic statement into a true arithmetic statement while adhering to the following rules: (a) only one matchstick can be moved, (b) no matchstick can be discarded, (c) upright sticks and slanted sticks are not interchangeable, and (d) the result must be a correct arithmetic statement. Each matchstick problem was composed of three roman numerals separated by two arithmetic signs, and had a unique solution consisting of a single move. Participants were given eight matchstick arithmetic problems divided across two problem sets containing four problems each. Problems sets were divided into two categories (non-insight; insight) based on the move required for solution: the non-insight problem set consisted of four ST problems, and the insight problem set consisted of 2 CR problems and 2 CD problems. Problem sets were administered in counterbalanced order.

Working memory measure Working memory capacity was measured using the Automated Reading Span task (aRspan; Unsworth, Heitz, Schrock, & Engle, 2005; Redick et al., 2012). In the aRspan, an attention-demanding processing task is interleaved between items presented for serial recall. Participants are shown a sentence and instructed to judge whether it makes sense or not; then they are shown a letter. After a sequence of sentence-letter strings ranging from 3-7 in length, participants are asked to recall the letters in order. All participants complete a total of 15 sequences of sentence-letter strings, including 3 of each length, presented in random order. ARspan scores range from 0-75, with higher scores denoting greater levels of attentional control (Unsworth & Engle, 2007). The task takes 15-20 minutes to complete.

Procedure

After providing informed consent, participants completed the experimental tasks individually. Participants were first introduced to the problem-solving task, and were given a maximum of 10 minutes to solve each of two sets of problems (i.e., 20 minutes total). After completing both problem sets, participants were given a questionnaire asking about previous experience with the matchstick task. Participants then completed the aRspan on a computer. Finally, participants completed a demographic questionnaire and were debriefed.

Results

Preliminary analyses revealed that accuracy on CD problems (M = .69, SD = .41) was positively correlated with accuracy on both non-insight (M = .68, SD = .30), r = .32, p = .003, and CR type insight problems (M = .13, SD = .34), r = .25, p = .021. Because the CD problems did not appear discriminatory of either insight or non-insight problem types, they were excluded from further analyses. Accuracy on CR type insight problems was not correlated with accuracy on non-insight problems, r = .06, p = .566, consistent with previous studies using matchstick arithmetic (Knoblich et al., 1999).

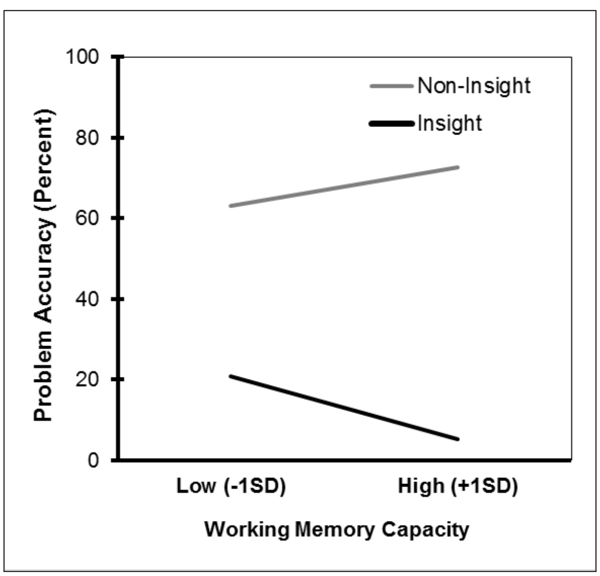

Figure 2. Non-insight and insight problem-solving accuracy as a function of working memory capacity. Low and high working memory points are plotted at ±1SD below and above the mean.

We evaluated whether the effect of insight and non-insight problem-solving accuracy depends on WMC using an ANCOVA, in order to treat WMC as a continuous variable. Problem type (insight versus non-insight) was included as a within-subjects factor. WMC and a WMC × problem type interaction term were included in the model as covariates.

A significant main effect of problem type was found, $F(1, 82) = 297.39$, $p < .001$, $\eta_p^2 = .78$. There was no main effect of WMC, $F < 1$. The interaction between problem type and WMC was significant, $F(1, 82) = 5.65$, $p = .02$, $\eta_p^2 = .06$.

In order to examine the nature of this interaction, follow-up analyses were conducted using simple regression. As shown in Figure 2, higher WMC was associated with generally better non-insight problem-solving accuracy, although this relationship did not reach significance (B = .016, SE = .011, p = .153). In contrast, higher WMC was associated with significantly lower CR insight problem-solving accuracy (B = -.013, SE = .006, p = .041).

Discussion

The current results support the prediction that less attentional control is better for insight problem-solving. Using the Matchstick Arithmetic task, we found that higher WMC was associated with somewhat better non-insight problem-solving but significantly worse insight problem-solving. The latter finding is counterintuitive in light of a great deal of literature demonstrating that more attentional control contributes to better performance on a range of higher-order cognitive tasks (c.f., Conway et al., 2005). These findings are, however, consistent with a growing body of research finding that lower WMC is advantageous on tasks relying on more associative or procedural processes (DeCaro & Beilock, 2010).

Although a diffuse focus of attention is important for creative problem-solving processes such as insight (Jarosz & Wiley, 2012), the relationship between WMC and insight has been inconsistent across studies. For example, Ash and Wiley (2006) found that WMC predicted performance on insight problems when the problems required an extended initial search phase. WMC was not related to performance on insight problems in which the search phase was shorter, presumably leading to impasse and restructuring more quickly (see also Fleck, 2008). These findings lend support to the *spontaneous restructuring* account of insight, which proposes that a necessary change in an initial problem representation is achieved through automatic processes and therefore does not depend on WMC. This finding converges with other evidence demonstrating that associative and divergent thinking rely on automatic processes that occur outside conscious awareness (Dijksterhuis & Meurs, 2006).

Spontaneous accounts of insight do not, however, preclude the argument that attentional control may disrupt those processes that are important for restructuring. Associative processes are better for creative problem-solving but, critically, are supported by decreased latent-inhibition (Carson, Peterson, & Higgins, 2003). The abilities that facilitate performance on non-insight problems and are supported by controlled processing may therefore be inappropriate for solving insight problems, and may harm performance. Too much focus can unnecessarily constrain the problem space, limiting the field of viable operators for solution and hindering the ability to achieve insight. Additionally, an overreliance on complex strategies may contribute to persistence within a faulty problem representation.

Some have proposed alternate routes by which creative solutions are achieved: one that is flexible, associative, and is characterized by lower levels of cognitive control, and another that is persistent, deliberate, and supported by a more focused analytic approach (De Dreu, Nijstad, Baas, Wolsink, & Roskes, 2012). Which pathway is more readily accessible may depend on interactions between individual difference and task-specific factors. Research in strategy selection suggests that differences in WMC may be an important factor in determining which path an individual is likely to take (e.g., Beilock & DeCaro, 2007; Gaissmeier et al., 2006). The current results suggest that higher WMC leads individuals to select a more focused analytic approach to insight problem-solving. However, future research is needed to examine the actual problem-solving strategies used by individuals of varying WMC.

Future research should also consider additional factors that may impact success at insight problem-solving, including boundaries to the current results. For example, if it is possible to achieve insight through methodical analytic persistence, then individuals with higher WMC could eventually attain insight—they would just require more time in order to exhaust and reject more obvious solution paths before identifying the correct one. Another factor likely to moderate strategy selection is goal transparency. Insight problems are ambiguous by design, and the challenge of these problems often hinges on this occlusion of decisive task objectives. If individuals with higher WMC know to consider everything as potentially relevant, they may be less likely to filter out important parts of the problem (e.g., Colflesh & Conway, 2007; Conway, Cowan, & Bunting, 2001).

Although we demonstrate that higher WMC can lead to lower insight, certain situational factors may therefore improve the ability of higher-capacity individuals to select more appropriate problem-solving strategies. By considering the interaction between individual differences and situational factors on the focus of attention, we may be better able to predict when insightful thinking will be best supported.

References

Ansburg, P. I., & Hill, K. (2003). Creative and analytic thinkers differ in their use of attentional resources. *Personality and Individual Differences, 34,* 1141–1152.

Ash, I. K., Cushen, P. J., & Wiley, J. (2009). Obstacles in investigating the role of restructuring in insightful problem solving. *The Journal of Problem Solving, 2,* 7−42.

Ash, I. K., & Wiley, J. (2006). The nature of restructuring in insight: An individual differences approach. *Psychonomic Bulletin & Review, 13,* 66–73.

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

Beilock, S. L., & DeCaro, M. S. (2007). From poor performance to success under stress: Working memory, strategy selection, and mathematical problem solving under pressure. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 983–998.

Colflesh, G. J. H., & Conway, A. R. A. (2007). Individual differences in working memory capacity and divided attention in dichotic listening. *Psychonomic Bulletin and Review, 14,* 699-703.

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., 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.

DeCaro, M. S., & Beilock, S. L. (2010). The benefits and perils of attentional control. In M. Csikszentmihalyi & B. Bruya (Eds.), *Effortless attention: A new perspective in the cognitive science of attention and action* (pp. 51–73). Cambridge, MA: MIT Press.

DeCaro, M. S., Thomas, R. D., Albert, N. B., Beilock, S. L. (2011). Choking under pressure: Multiple routes to skill failure. *Journal of Experimental Psychology: General, 140,* 390–406.

DeCaro, M. S., Thomas, R. D., & Beilock, S. L. (2008). Individual differences in category learning: Sometimes less working memory capacity is better than more. *Cognition, 107,* 284–294.

De Dreu C, Nijstad B, Baas M, Wolsink I, Roskes M. (2012). Working memory benefits creative insight, musical improvisation, and original ideation through maintained task-focused attention. *Personality and Social Psychology Bulletin, 38,* 656–669.

Dijksterhuis, A., & Meurs, T. (2006). Where creativity resides: The generative power of unconscious thought. *Consciousness and Cognition, 15,* 135–146.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science, 11,* 19–23.

Ericsson, K. A., & Delaney, P. F. (1999). Long-term working memory as an alternative to capacity models of working memory in everyday skilled performance. In A. Miyake, & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 257–297). New York: Cambridge University Press.

Fleck, J. I. (2008). Working memory demands in insight versus analytic problem solving. *European Journal of Cognitive Psychology, 20,* 1-38.

Gaissmaier, W., Schooler, L. J., & Rieskamp, J. (2006). Simple predictions fueled by capacity limitations: When are they successful? *Journal of Experimental Psychology: Learning, Memory & Cognition*, *32*, 966–982.

Jarosz, A. F., Colflesh, G. J. H., & Wiley, J. (2012). Uncorking the muse: Alcohol intoxication facilitates creative problem solving. *Consciousness and Cognition*, *21*, 487–493.

Jones, G. (2003). Testing two cognitive theories of insight. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 1017–1027.

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., & 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*, 333–358.

Knoblich, G., Ohlsson, S., Haider, H., & Rhenius, D. (1999). Constraint relaxation and chunk decomposition in insight problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 1534–1555.

Knoblich, G., Ohlsson, S., & Raney, G. E. (2001). An eye movement study of insight problem solving. *Memory & Cognition*, *29*, 1000–1009.

Kounios, J., & Beeman, M. (2009). The Aha! moment: The cognitive neuroscience of insight. *Current Directions in Psychological Science*, *18*, 210-216.

Kounios, J., Frymiare, J. L., Bowden, E. M., Fleck, J. I., Subramaniam, K., Parrish, T. B., & Jung-Beeman, M. J. (2006). The prepared mind: Neural activity prior to problem presentation predicts subsequent solution by sudden insight. *Psychological Science*, *17*, 882–890.

McCabe, D. P., Roediger, III, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The relationship between working memory capacity and executive functioning: Evidence for a common executive attention construct. *Neuropsychology*, *24*, 222–243.

Ohlsson, S. (1992). Information processing explanations of insight and related phenomenon. In M. Keane & K. Gilhooly (Eds.), *Advances in the psychology of thinking* (pp. 1–44). London: Harvester-Wheatsheaf.

Öllinger, M., Jones, G., & Knoblich, G. (2008). Investigating the effect of mental set on insight problem solving. *Experimental Psychology*, *55*, 269–282.

Redick, T. S., Broadway, J. M., Meier, M. E., Kuriakose, P. S., Unsworth, N., Kane, M. J., & Engle, R. W. (2012). Measuring working memory capacity with automated complex span tasks. *European Journal of Psychological Assessment*, *28*, 164–171.

Reverberi, C., Toraldo, A., D'Agostini S., & Skrap, M. (2005). Better without (lateral) frontal cortex? Insight problems solved by frontal patients. *Brain*, *128*, 2882–2890.

Schooler, J. W., Ohlsson, S., & Brooks, K. (1993). Thoughts beyond words: When language overshadows insight. *Journal of Experimental Psychology: General*, *122*, 166–183.

Unsworth, N., & Engle, R.W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*, *114*, 104–132.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, *37*, 498–505.

Wieth, M. B., & Zacks, R. T. (2011). Time of day effects on problem solving: When the non-optimal is optimal. *Thinking & Reasoning*, *17*, 387–401.

Wiley, J. (1998). Expertise as mental set: The effects of domain knowledge in creative problem solving. *Memory & Cognition*, *26*, 716–730.

Wiley, J., & Jarosz, A. (2012). How working memory capacity affects problem solving. *Psychology of Learning and Motivation*, *56*, 185–227.

Wolford, G., Newman, S. E., Miller, M. B., & Wig, G. S. (2004). Searching for patterns in random sequences. *Canadian Journal of Experimental Psychology*, *58*, 221–228.