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When Higher Working Memory Capacity Hinders Insight

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Higher working memory capacity (WMC) improves performance on a range of cognitive and academic tasks. However, a greater ability to control attention sometimes leads individuals with higher WMC to persist in using complex, attention-demanding approaches that are suboptimal for a given task. We examined whether higher WMC would hinder insight problem solving, which is thought to rely on associative processes that operate largely outside of close attentional control. In addition, we examined whether characteristics of the insight problems influence whether this negative relationship will be revealed. In Experiment 1, participants completed matchstick arithmetic problems, which require a similar initial problem representation for all problems. Higher WMC was associated with less accurate insight problem solving. In Experiment 2, participants completed insight word problems, which require substantially different representations for each problem. Higher WMC was again negatively associated with insight, but only after statistically controlling for shared variance between insight and incremental problem-solving accuracy. These findings suggest that WMC may benefit performance on fundamental processes common to both incremental and insight problem solving (e.g., initial problem representation), but hinder performance on the processes that are unique to insight (e.g., solution and restructuring). By considering the WMC of the individual, and the nature of the insight task, we may better understand the process of insight and how to best support it.

Keywords: working memory, attention, problem solving, insight

A great deal of research has demonstrated that higher working memory capacity (WMC) is associated with better performance on a wide variety of complex cognitive 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 insight problem-solving processes. Specifically, we examine the hypothesis that those who have the greatest ability to implement complex problem-solving strategies may be most likely to miss associatively driven solutions that are important for insight problem solving. We further investigate when this negative impact of WMC on insight problem solving might be most apparent, by examining the relationship between WMC, insight problem solving, and solving incremental problems with characteristics that overlap with insight problems.

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Working Memory Capacity

WMC supports the ability to suppress distractors and guide attention toward relevant information in goal-directed tasks (e.g., McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). The predictive power of WMC stems from this domain-general capacity for attentional control, and individual differences in WMC emerge primarily when that capacity is challenged (Engle, 2002). For example, 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 therefore not surprising that the ability of higher WMC individuals to control attention leads to greater ability to implement more difficult, multistep problem-solving strategies (Hambrick & Engle, 2003; Wiley & Jarosz, 2012a). Indeed, the ability to execute complex strategies may lead higher WMC individuals to select strategies in line with their ability—even if the task does not call for a controlled processing approach (DeCaro & Beilock, 2010). For example, Beilock and DeCaro (2007) examined the strategy selection of higher and lower WMC individuals completing Luchins's (1942) water jug task. The water jug task is commonly used to assess the effects of mental set—or perseveration with complex strategies after previous experience using these strategies. The water jug 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). Beilock and DeCaro instructed participants to mentally derive the answers (i.e., without the use of paper), and use the simplest strategy possible. The first few problems were solvable 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 formula, 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 less controlled focus of attention.

These findings demonstrate that individuals higher in WMC tend to use more complex strategies even when simpler ones are more efficient for a given task. Such overreliance on complex strategies has been shown to harm performance on tasks that rely on more associatively driven approaches (e.g., Gaissmaier, Schooler, & Rieskamp, 2006; Wolford, Newman, Miller, & Wig, 2004). For example, proceduralized skills that operate optimally outside of explicit attentional control, such as soccer dribbling or skilled typing, are performed suboptimally when attention is devoted to task execution (e.g., Beilock, Carr, MacMahon, & Starkes, 2002; Logan & Crump, 2009; see also DeCaro, Thomas, Albert, & Beilock, 2011; Maddox, Love, Glass, & Filoteo, 2008). Moreover, higher WMC individuals are more likely to employ this suboptimal level of attentional control on certain proceduralized skills (e.g., DeCaro, Thomas, & Beilock, 2008). Thus, higher WMC may lead individuals to engage controlled attention, which can be counterproductive depending on whether the task is best executed with more controlled or associative processes.

Insight Problem Solving

Certain types of problems are also thought to be optimally solved using more algorithmic versus associative processes. Analytic, or *incremental*, problems are thought to require a progressive series of steps to reach a solution (Simon, 1978; Simon & Reed, 1976; Sternberg, 1982; Thomas, 1974). Incremental problem solving therefore relies on controlled attention processes to keep track of both the final goal and the incremental subgoals required to transverse the problem space and reach a solution (Gilhooly & Fioratou, 2009; Hambrick & Engle, 2003; Hills, Todd, & Goldstone, 2010; Raghubar, Barnes, & Hecht, 2010).

In contrast, according to a special-process view, *insight* problems generally differ from incremental problems in their underlying solution processes (see Figure 1; Bowden, Beeman, Fleck, & Kounios, 2005; Chein & Weisberg, 2014; Ohlsson, 2011; Schooler, Ohlsson, & Brooks, 1993; Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995). Specifically, when solving an insight problem, individuals tend to experience an "aha" moment that leads to the solution but does not follow the step-by-step incremental nature of analytic problems. According to the special-processes account, insight problem solving often involves an initial *misrepresentation* of the problem, which leads the solver to an *impasse*, a point at which no progress can be made until they *restructure* their initial representation of the problem (Ohlsson, 1992). It is thought that successful restructuring (i.e., that which leads to a correct solution) occurs via associative processes, such as spreading activation in semantic memory, that operate largely outside of conscious attentional control (Bowden & Beeman, 1998; Bowden et al., 2005; Bowers, Regehr, Balthazard, & Parker, 1990; Durso, Rea, & Dayton, 1994; Ohlsson, 1992; Schooler et al., 1993; Siegler, 2000). Solvers relax the initial constraints imposed on the problem, and consider more peripheral aspects of the problem (Knoblich, Ohlsson, Haider, & Rhenius, 1999; Ohlsson, 1992). In doing so, solvers often experience an "aha" moment, when the new representation enables the solution to become suddenly apparent (Ohlsson, 1992, 2011; Schooler et al., 1993; Smith & Kounios, 1996).

In support of the special-process view, studies have found a diverging impact of WM on incremental versus insight problems. More specifically, it has been shown that higher WMC is positively related to incremental problem solving, but unrelated to insight (e.g., Fleck, 2008). Similarly, a WM load negatively impacts incremental problem solving, but has no impact on insight problem solving (Lavric, Forstmeier, & Rippon, 2000). The finding that insight problem solving is not related to WM lends support to the special-process view—suggesting that insight problem solving, unlike incremental problem solving, relies on associative processes that operate outside of attentional control.

Other findings contradict the special-process view of insight, leading some to espouse a business-as-usual view of insight problem solving (e.g., Ball & Stevens, 2009; Chein, Weisberg, Streeter, & Kwok, 2010; Chronicle, MacGregor, & Ormerod, 2004; Chronicle, Ormerod, & MacGregor, 2001; Klahr & Simon, 1999;

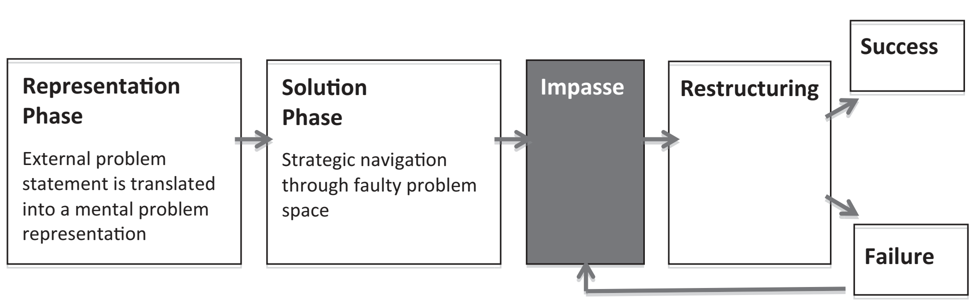


Figure 1. Stages of insight problem solving. Adapted from Ash & Wiley (2006) and Wiley & Jarosz (2012b).

MacGregor, Ormerod, & Chronicle, 2001; Perkins, 1981; Thevenot & Oakhill, 2005, 2006, 2008; Weisberg, 2006, 2013). Specifically, researchers argue that insight problems rely on similar underlying processes as incremental problems. For example, the problem solver may use attention-demanding retrieval strategies in response to an unsuccessful solving method (Chein & Weisberg, 2014; Davidson, 1995; Kaplan & Simon, 1990). Indeed, solvers may not even reach a state of impasse; instead solvers may reassess the solution prior to reaching a failure point, incrementally altering the solution approach over a number of solution attempts (MacGregor et al., 2001).

If, consistent with the business-as-usual view, both insight and incremental problem solving rely on ability to restrict attention to a series of problem-solving steps, then WMC should have a positive impact on performance of both problem types. Consistent with this idea, Chein and Weisberg (2014) found a positive correlation between WMC and insight problem solving, even on problems for which participants explicitly reported using an insight strategy (see also Chein et al., 2010; Gilhooly & Fioratou, 2009; Ricks, Turley-Ames, & Wiley, 2007).

A third possibility, suggested by the WMC literature reviewed above, is that WMC could have a negative impact on insight problem solving. To the extent that higher WMC individuals persist in using complex strategies in line with a faulty initial representation, this approach may delay, or inhibit, the solver from reaching an impasse as well as restructuring (Gilhooly & Fioratou, 2009). Although this idea has not been examined based on individual differences in WMC, support comes from a variety of studies demonstrating that less focused (i.e., more diffuse) attention benefits insight problem solving. For example, moderate alcohol intoxication both reduces WMC and improves insight problem solving (Jarosz, Colflesh, & Wiley, 2012); solving problems at one's nonoptimal time of day, when reductions in WMC are generally seen (e.g., West, Murphy, Armilio, Craik, & Stuss, 2002), improves insight problem solving and impairs incremental problem solving (Wieth & Zacks, 2011); and patients with frontal lobe impairment demonstrate better insight problem accuracy (Reverberi, Toraldo, D'Agostini, & Skrap, 2005). These studies therefore suggest that less focused attention, characteristic of those with lower WMC, is actually more beneficial to insight than the more focused attention seen in higher WMC individuals.

Insight Problem Characteristics

In the current studies, we examined the impact of WMC on insight, while also investigating one factor that may have been overlooked in previous studies showing no effect of WMC on insight problem solving: problem characteristics. We propose that different stages of insight problem solving may benefit from, or be hindered by, WMC (see Chein et al., 2010; Howard-Jones & Murray, 2003; Jones, 2003; Schooler & Melcher, 1995; see Figure 1). In particular, we argue that problems that isolate the solution and restructuring phases of insight will be most likely to reveal a negative relationship between WMC and problem accuracy.

Both insight and incremental problem solving require the solver to first represent the problem, by comprehending the task instructions and interpreting the problem statements (Gick & Lockhart, 1995; Hambrick & Engle, 2003; Mayer & Hegarty, 1996; Novick & Bassock, 2005; Wiley & Jarosz, 2012b). This process involves reading comprehension (Hambrick & Engle, 2003; Kintsch, 1998; Kintsch & Greeno, 1985), selecting relevant from irrelevant problem information (Pasolunghi, Cornoldi, & De Liberto, 1999; Wiley & Jarosz, 2012b), and forming a mental model (Ash & Wiley, 2008; Thevenot, 2010). Because these processes are generally thought to rely on WMC (Kintsch, 1998; Lee, Ng, & Ng, 2009; Thevenot, 2010), initial problem representation may be one stage of problem solving at which higher WMC may benefit problem-solving performance, in that individuals higher in WMC will be quicker to form an initial problem representation (Jones, 2003).

In contrast, higher WMC may hinder progress in the solution or restructuring phases. Higher WMC individuals have been shown to select and persist in using complex hypothesis testing and solution processes, whereas lower WMC individuals are quicker to abandon such complex strategies (e.g., Beilock & DeCaro, 2007; DeCaro et al., 2008; Gaissmaier et al., 2006; Wolford et al., 2004). Thus, higher WMC individuals may take longer in the initial solution process, and therefore reach the important restructuring phase less quickly, if at all (see Wiley, 1998; Wiley & Jarosz, 2012b). Moreover, higher WMC individuals may be more likely to attempt to restructure using an attention-demanding search process (e.g., Fleck & Weisberg, 2004; Weisberg, 2006), which may hinder insight, depending on the extent to which successful restructuring depends on more associative approaches (but see Ash & Wiley, 2006).

If WMC helps with initial problem representation, but hurts the solution or restructuring phases of insight, then insight tasks that rely more heavily on problem representation may be less likely to reveal a negative relationship between WMC and problem solving. In other words, the benefits of WMC to problem representation may help mitigate any negative impact of WMC on other phases, resulting in no apparent relationship between WMC and accuracy. In contrast, problems that are more readily represented may be more likely to reveal a negative relationship between WMC and insight.

Current Studies

In the current studies, we examined the possibility that higher WMC can hinder insight. We further examined whether characteristics of the problem-solving task impact the extent to which this negative relationship is revealed. In Experiment 1, we held problem representation constant by using a matchstick arithmetic task to assess both insight and incremental problem solving (Knoblich et al., 1999; see Figure 2). In these problems, participants are introduced to the goal and constraints of the task at the beginning of the solving session. Once individuals initially represent the task parameters, this same basic representation is used for each problem. Insight and incremental problems differ only in the nature of the solution required. Because the initial representation phase is less critical in these problems, the solution and restructuring phases should be more important. To the extent that higher WMC hinders these latter phases of insight, accuracy should decrease.

To further determine whether problem characteristics impact the relationship between WMC and insight problem solving, in Experiment 2 we selected commonly used word problems to assess insight and incremental problem solving (e.g., Schooler et al., 1993; Wieth & Burns, 2006; see Table 1). Because each word

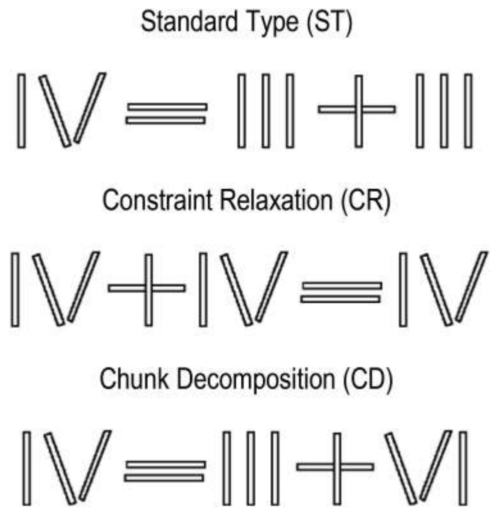


Figure 2. Example matchstick arithmetic problems used in Experiment 1.

problem was markedly distinct, we posited that initial representation (e.g., relying on reading comprehension, selecting relevant information, and forming a mental model) would be an important factor in solving these problems. Moreover, insight and incremental problem-solving success should both depend, in part, on individuals' ability to initially represent a problem. Thus, there may be shared variance between insight and incremental problems (i.e., a positive correlation; e.g., Cinan, Özen, & Hampshire, 2013; Gilhooly & Murphy, 2005; Schooler & Melcher, 1995). We hypothesized that a positive relationship between WMC and incremental problem solving would be found. But, because insight problems may benefit from WMC for problem representation but be hindered by WMC in the solution or restructuring phases, we predicted that no overall relationship between WMC and insight accuracy would be found. However, when statistically controlling for the shared variance between insight and incremental problem-solving accuracy, a negative relationship between WMC and insight may be revealed.

Thus, overall we predicted that higher WMC would be negatively related to insight problem-solving. However, this relationship may be most evident when isolating the role of problem representation. Investigating the role of problem characteristics may serve to further clarify the relationship between WMC and insight, helping to explain previous contradictory findings and inform theories of insight more generally. Moreover, this research may provide additional evidence regarding situations in which higher WMC can, counterintuitively, lead to less optimal task approaches.

Experiment 1

Experiment 1 examined the role of individual differences in WMC in solving incremental and insight problems, using the matchstick arithmetic task (Knoblich et al., 1999). *Matchstick arithmetic problems* are false arithmetic statements written using matchsticks representing 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 2. *Standard type* (ST) matchstick problems are solved by moving a matchstick representing a value of 1 ("I") from its position in a Roman numeral to a different position in the same or a different numeral. 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 an impasse (Knoblich, Ohlsson, & Raney, 2001), or restructuring (Öllinger et al., 2008), which are considered defining features of insight problems (Ohlsson, 1992). Therefore, we refer to ST problems as incremental problems (cf. Öllinger et al., 2008).

Constraint relaxation (CR) matchstick problems require transforming the initial false statement (e.g., IV + IV = IV) into a correct statement by changing the plus sign into an equal sign (IV = IV = IV). 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).

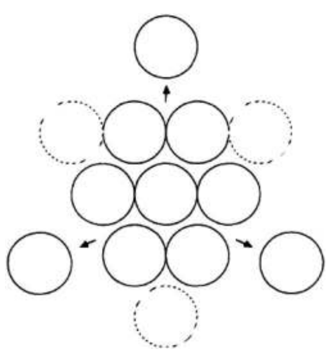
Finally, *chunk decomposition* (CD) problems require the solver to decompose a "tight chunk" in order to identify the correct move. A tight chunk was defined as a single Roman numerical figure composed of two matchsticks that together form a meaningful unit (i.e., "V", "X"). For example, when participants 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 involve the same processes (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.

We predicted that divergent effects of WMC would be seen for insight and incremental problems. Specifically, higher WMC would be associated with increased incremental (ST) problem-solving accuracy but lower insight (CR) 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, 2012b).

Method

Participants. Participants were 84 undergraduate students enrolled in psychology classes (63 female; age M = 21 years, SD = 4.6). One additional participant was excluded for errors on more than 20% of the sentence task of the ARspan (Conway et al., 2005). One participant was excluded for experimenter error. One participant was excluded because answers obtained

Table 1
Insight and Incremental Problems Used in Experiment 1

Insight problems	Incremental problems
Socks If you have black socks and brown socks in your drawer, mixed in the ratio of 4:5, how many socks will you have to take out to be sure of having a pair the same color? *Solution: 3 socks*	Cards Three cards from an ordinary deck are lying on a table, face down. The following information (for some peculiar reason) is known about those three cards (all the information below refers to the same three cards): • To the left of a queen there is a jack • To the left of a spade there is a diamond • To the right of a heart there is a king • To the right of a king there is a spade Can you assign the proper suit to each picture card? *Solution: jack of hearts, king of diamonds, queen of spades*
Lilies Water lilies double in area every 24 hours. At the beginning of the summer, there is one water lily on the lake. It takes 60 days for the lake to become completely covered with water lilies. On which day is the lake half-covered? *Solution: The lake is half-covered on the 59th day.*	Crime The police were convinced that either A, B, C, or D had committed a crime. Each of the suspects, in turn, made a statement, but only one of the four statements was true. • A said, "I didn't do it." • B said, "A is lying." • C said, "B is lying." • D said, "B did it." Who is telling the truth? And who committed the crime? *Solution: B is telling the truth, and A committed the crime*
Triangle Show how you can make the triangle below point downward by moving only three of the circles. *Solution:* 	Bachelor Five bachelors, Andy, Bill, Carl, Dave, and Eric, go out together to eat five evening meals (Fish, Pizza, Steak, Tacos, and Thai) on Monday through Friday. It was understood that Eric would miss Friday's meal due to an out of town wedding. Each bachelor served as the host at a restaurant of his choice on a different night. The following information is known: • Carl hosted the group on Wednesday. • The fellows ate at a Thai restaurant on Friday. • Bill, who detests fish, volunteered to be the first host. • Dave selected a steak house for the night before one of the fellows hosted everyone at a raucous pizza parlor. Which bachelor hosted the group each night and what food did he select? *Solution: Monday Bill Tacos, Tuesday Dave Steak, Wednesday Carl Pizza, Thursday Eric Fish, Friday Andy Thai*

Note. Sources: Schooler, Ohlsson, & Brooks (1993); Wieth & Burns (2006).

were technically correct but not the intended response. Participants received course credit for participation.

Materials

Working memory measure. WMC was measured using the computer-administered Automated Reading Span (ARspan; Redick et al., 2012). In this task, participants were shown a sentence and instructed to judge whether it made sense or not. After each sentence, participants were shown a letter. After a sequence of sentence–letter strings ranging from 3–7 in length, participants were asked to recall the letters in order. All participants completed a total of 15 sequences of sentence–letter strings, including three of each length, presented in random order. This task required 15–20 minutes to complete. Scores consisted of the total number of correct letters recalled, in any order (see Conway et al., 2005). Scores ranged from 0–75 ($M = 55.39$, $SD = 11.99$), with higher scores denoting greater levels of attentional control (Unsworth & Engle, 2007).

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 2). 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. One problem set consisted of four ST problems, and the other problem set consisted of 2 CR problems and 2 CD problems. Problem sets were administered in counterbalanced order. Order did not have any main effects or interactions, and this variable was not included in any analyses reported below.

Procedure. Participants completed the experimental tasks individually. After providing informed consent, participants were 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 and Discussion

Accuracy and scale reliabilities are presented in Table 2. Accuracy on CD problems was positively correlated with accuracy on both ST type incremental, $r(82) = .32$, $p = .003$, and CR type insight problems, $r(82) = .25$, $p = .021$. Thus, CD problems did not appear to discriminate between insight and incremental problem types. Accuracy on CR type insight problems, however, was not correlated with accuracy on ST type incremental problems, $r(82) = .06$, $p = .566$, consistent with previous studies using matchstick arithmetic (Knoblich et al., 1999).

CR type insight problem accuracy was non-normally distributed, with a skewness of 2.22 ($SE = .263$). To address this violation, and for consistency across problem types, participants were categorized for each problem type as either nonsolvers (ST scores = 0 or 1 out of 4: 21.5% of participants; CD scores = 0 out of 2: 21.4% of participants; CR scores = 0 out of 2: 86.9% of participants) or solvers. We evaluated whether the impact of WMC on problem-solving accuracy differed between CR type insight, CD, and ST type incremental problems, using separate binary logistic regression models. As shown in Figure 3, higher WMC was associated with significantly better ST type incremental problem-solving accuracy (odds ratio = 1.058; $p = .025$; Nagelkerke $R^2 = .104$). In contrast, higher WMC was associated with significantly lower CR insight problem-solving accuracy (odds ratio = .949; $p = .049$; Nagelkerke $R^2 = .086$). Higher WMC was not associated with CD problem accuracy (odds ratio = .985; $p = .552$).

In summary, Experiment 1 demonstrated a negative impact of WMC on insight problem solving. Greater ability to focus attention may unnecessarily constrain the problem space, limiting the field of viable operators for solution and hindering the ability to achieve insight (Wiley & Jarosz, 2012b). In addition, an increased ability to execute complex problem-solving strategies may lead one to persist within a faulty problem representation (e.g., Beilock & DeCaro, 2007). Thus, although higher WMC is generally beneficial to a range of higher-order cognitive tasks (cf. Conway et al., 2005), this ability may be counterproductive for important elements of insight.

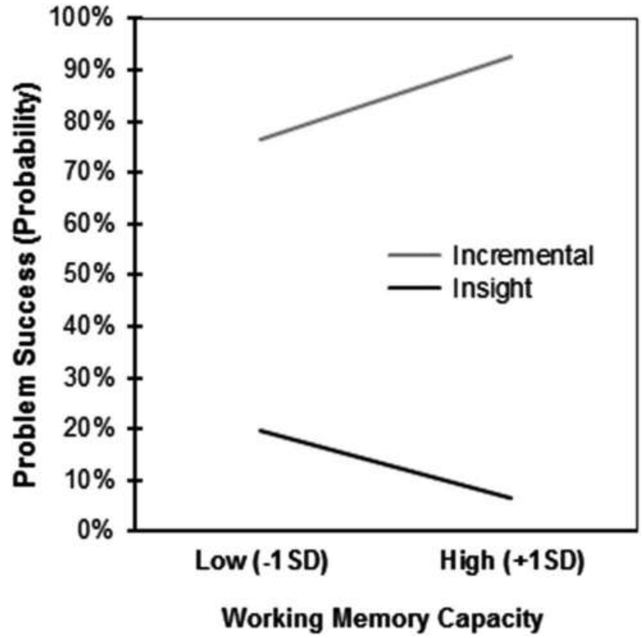


Figure 3. ST type incremental and CR type insight problem-solving success as a function of working memory capacity in Experiment 1. *Note.* Low and high working memory points are plotted at ± 1 *SD* below and above the mean.

Table 2
Descriptive Statistics for Experiments 1 and 2

	Percent Accuracy Mean (*SD*)	Reliability
Experiment 1 (matchstick problems)		
ST problems (incremental)	67.9 (30.0)	0.58
CR problems (insight)	13.1 (33.9)	1.00
CD problems	69.1 (41.0)	0.74
Experiment 2 (word problems)		
Incremental problems	54.5 (31.6)	0.31
Cards	70.0 (46.2)	
Crime	43.0 (49.7)	
Bachelor	51.0 (50.2)	
Insight problems	54.8 (35.5)	0.51
Socks	59.0 (49.4)	
Lillies	52.0 (50.2)	
Triangle	54.0 (50.1)	

Note. Reliability calculated using Cronbach's alpha.

The findings of Experiment 1 are consistent with studies demonstrating that less WMC can benefit performance on some tasks that require more procedural or associative processes (cf. DeCaro & Beilock, 2010), and with studies in the problem-solving literature demonstrating that situational factors that reduce WMC can benefit insight problem solving (cf. Wiley & Jarosz, 2012b; Wieth & Zacks, 2011). However, other studies in the problem-solving literature have demonstrated that WMC has no impact on insight (Ash & Wiley, 2006; Fleck, 2008). In Experiment 1, we chose matchstick problems because initial representation is consistent across problems. Thus, we were able to provide evidence that the negative relationship between WMC and insight problem solving may be particularly evident during the solution and/or restructuring phases.

Experiment 2 was designed to test whether we could replicate the null relationship between WMC and insight problem-solving demonstrated in the literature (e.g., Ash & Wiley, 2006; Fleck, 2008). We used word problems that must be individually represented, and thus rely on WM resources for initial problem representation. Because these problems require both WM-demanding processes (i.e., problem representation), and processes for which WMC may hinder performance (i.e., solution and restructuring), we expected to find no association between WMC and insight. However, we also employed incremental problems that similarly require problem representation processes for each problem. To further examine the role of problem representation, we statistically controlled for the shared processes between insight and incremental problem solving. If problem representation is important to solving both insight and incremental problems, and this shared variance is partialed out, then a negative relationship between WMC and insight should again be demonstrated.

Experiment 2

Participants completed measures of WMC, followed by both insight and incremental problems. Word problems were adapted from Schooler et al. (1993) and Wieth and Burns (2006). As described previously, we predicted that WMC would benefit incremental problem solving. We also predicted that there would be no overall effect of WMC on insight problem solving. However, when accounting for shared variance with incremental problem accuracy, we expected to find that higher WMC is associated with decreased insight problem solving.

Method

Participants. Participants were 112 undergraduate students enrolled in psychology classes (78 female; age $M = 19$ years, $SD = 1.1$). An additional two participants were excluded for errors on more than 20% of the sentence task of the ARspan or the math task of the AOspan (e.g., Conway et al., 2005). Five participants were excluded for incorrect responses on the practice problem of the problem-solving task. Ten participants were excluded because they reported that they remembered the answer to at least one of the insight problems from a previous experience. Eight participants were excluded for experimenter error or for not completing the entire experiment. Finally, one participant's WMC score was identified as an outlier in the regression model, using diagnostic tests for influence (Aguinis, Gottfredson, & Joo, 2013), and was excluded from further analyses. Individuals received course credit for participation.

Materials

Working memory measures. Working memory capacity was measured using the Automated Reading Span task used in Experiment 1 (ARspan; Redick et al., 2012) and the Automated Operation Span task (AOspan; Unsworth, Heitz, Schrock, & Engle, 2005). The AOspan operates exactly like the ARspan, except that instead of judging sentences, participants are shown a simple mathematical equation and instructed to determine whether it is correct. Total ARspan and AOspan scores were averaged to create a composite WMC score ($M = 59.86$, $SD = 9.05$).

Problem-solving task. The problem-solving task was adapted from Schooler et al. (1993) and Wieth and Burns (2006) (see also Davidson & Sternberg, 1984; Metcalfe & Wiebe, 1987). All problems are listed in Table 1. Participants completed three insight problems (socks, lilies, triangle) and three incremental problems (cards, crime, bachelor). In addition, participants completed one easy incremental problem (fussy eaters) as practice. Schooler et al. (1993) and Wieth and Burns (2006) tested these problems with a college-student sample and determined that mean accuracy was approximately 50%. Problems were displayed in random order individually on a computer screen, and participants were given individual sheets of paper on which to write their answers and to use to work through the problems, if necessary. Five minutes were allotted for each problem. Once participants believed they had solved the problem, they pressed the spacebar on the computer keyboard, and a tone sounded. The experimenter entered the room and checked the answer. If the answer was correct, the experimenter gave the participant a new sheet of paper and displayed the next problem on the computer. If the answer was incorrect, the experimenter asked the participant to keep working on the problem until they either had another answer or time ran out. When time ran out, the experimenter entered the room and displayed the next problem.

Procedure. After providing informed consent, participants completed the experimental tasks individually. Participants first completed the AOspan and ARspan tasks (order counterbalanced between participants). Then participants were offered a short break, after which they were introduced to the problem-solving task. Finally, participants were given questionnaires asking about previous experience with the problems and demographic information.

Results and Discussion

Assumptions of normality were met, and problem-solving scores were therefore computed as the number of problems correctly solved (see Table 2 for descriptive statistics). We first evaluated the impact of WMC on insight and incremental problem-solving accuracy using an ANCOVA. Problem type (insight, incremental) was included as a within-subjects factor, and WMC and a WMC × problem type interaction term were included in the model as covariates. No significant main effects were found, Fs < 1. However, a significant WMC x problem type interaction was revealed, $F(1, 110) = 7.79$, $p = .006$, $\eta_p^2 = .07$.

We examined the nature of this interaction using simple regression analyses. As shown in Figure 4, higher WMC was associated with marginally greater incremental problem accuracy ($\beta = .181$, $SE = .003$, $p = .056$, $R^2 = .03$). In contrast, WMC was not significantly related to insight problem accuracy ($\beta = -.140$, $SE = .004$, $p = .141$, $R^2 = .02$). WMC appears to have had a divergent impact on incremental and insight problem-solving accuracy. Higher WMC supported incremental problem-solving, but had no significant impact on insight problem-solving.

We further examined the relationship between WMC and problem solving by testing the overlap in the processes used to solve incremental and insight problems. Insight problem solving may require some of the same processes as incremental problem solving, such as initial problem representation. Consistent with this idea, a significant correlation between insight and incremental problem-solving accuracy was found, $r(110) = .235$, $p = .013$. In general, participants who performed better on incremental problems also performed better on insight problems.

Using multiple regression, we explored whether accounting for this shared variance would reveal a negative relationship between WMC and insight problem solving. First, we entered WMC to predict insight problem solving as conducted previously. Then, we added incremental problem solving to the model, to examine the relationship between WMC and insight problem solving while controlling for the processes shared by both incremental and insight problem solving. Incremental problem-solving accuracy was a significant predictor (β = .269, *SE* = .104, *p* = .005). Moreover, its inclusion in the model revealed a significant negative effect of WMC (β = −.189, *SE* = .004, *p* = .045, R^2 = .09) and a significantly improved model fit (ΔR^2 = .07, $\Delta F(1, 109)$ = 8.395, *p* = .005). When accounting for the positive relationship between insight and incremental problem solving, we see that higher WMC is associated with lower insight problem-solving accuracy.

In summary, in Experiment 2, a significant interaction between WMC and problem type was found. Higher WMC was associated with marginally better incremental problem solving, but was not significantly related to insight problem solving, suggesting that insight does not depend as much on attentional control. These results are consistent with others (e.g., Ash & Wiley, 2006; Fleck, 2008; Gilhooly & Murphy, 2005). However, other studies indicate that higher WMC may actually hinder insight (e.g., Jarosz et al., 2012; Reverberi et al., 2005; Wieth & Zacks, 2011; see Wiley & Jarosz, 2012b). In an effort to reconcile these findings, we investigated the idea that WMC is most harmful to those insight processes that differ from processes used to solve incremental problems (e.g., during the solution and restructuring phases). Consistent with this idea, WMC was negatively related to insight problem solving when accounting for the shared variance between insight and incremental problem solving. These findings suggest that the overall relationship between WMC and insight problem solving may depend on the extent to which characteristics of the insight problems overlap with incremental problems.

General Discussion

In two experiments, we supported the prediction that less attentional control is better for insight problem-solving. In Experiment 1, we used the matchstick arithmetic task (Knoblich et al., 1999), for which insight and incremental problems all require the same general representation but are thought to differ in their solution and restructuring processes (e.g., Reverberi et al., 2005). Higher WMC was associated with better incremental problem solving but significantly worse insight problem solving.

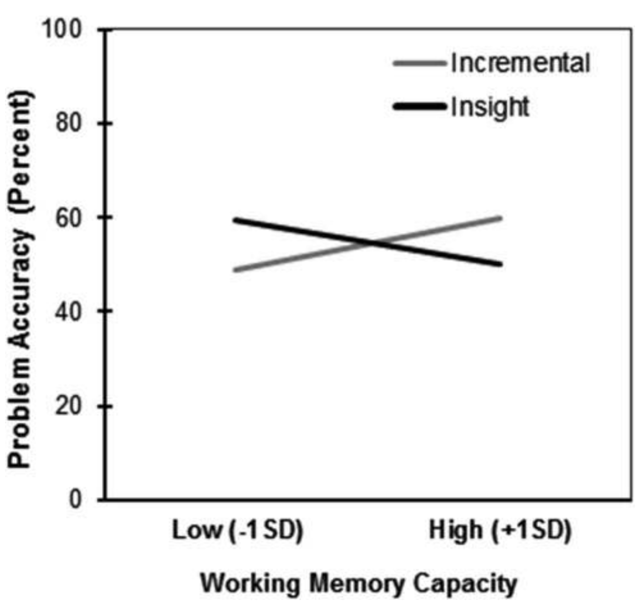


Figure 4. Incremental and insight problem-solving accuracy as a function of working memory capacity in Experiment 2. *Note.* Low and high working memory points are plotted at ± 1 *SD* below and above the mean.

In Experiment 2, using word problems to assess insight problem solving (e.g., Schooler et al., 1993; Wieth & Burns, 2006), we found no relationship between WMC and insight problem-solving accuracy. However, after statistically controlling for shared variance with incremental problem-solving accuracy, higher WMC was again associated with lower insight problem-solving accuracy. These findings suggest that WMC may benefit some processes shared between both incremental and insight problem solving, but hinder the processes that are unique to insight. We posit that the initial representation phase of problem solving is one likely source of overlap between insight and incremental problem solving in this task, as each word problem required the formation of distinct representations before solving could proceed.

The finding that WMC negatively impacted insight 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 (cf., Conway et al., 2005). However, these findings are consistent with a growing body of research demonstrating that lower WMC is advantageous to tasks relying on more associative or procedural processes (DeCaro & Beilock, 2010). These findings are also consistent with others in the problem-solving domain demonstrating that individual difference and situational factors that disrupt attentional control facilitate insight, such as frontal lobe impairment (Reverberi et al., 2005), moderate alcohol intoxication (Jarosz et al., 2012), or solving problems at one's nonoptimal time of day (Wieth & Zacks, 2011).

These results indicate that the nature of the WMC–insight relationship likely depends on characteristics of the insight task (Gilhooly & Murphy, 2005). Specifically, it is thought that insight tasks require both WM-demanding and associative processes (Martindale, 1995; Smallwood & Schooler, 2006; Wiley & Jarosz, 2012b). But different insight tasks may vary in the extent to which WM-demanding processes are required. The current results suggest, in particular, that the problem representation phase may place higher demands on WMC, whereas the solution and restructuring phases may benefit from more associative processes. These associative processes appear to be hindered by greater attentional control. Thus, tasks that place greater emphasis on problem representation (e.g., distinct word problems such as those used in Experiment 2) may benefit from WMC to some extent−leading to overall neutral (e.g., Fleck, 2008; Gilhooly & Murphy, 2005) or even positive associations with WMC (Chein & Weisberg, 2014; Ricks et al., 2007). In contrast, when the role of problem representation is minimized (e.g., in the matchstick arithmetic task used in Experiment 1), the negative impact of WMC may be more apparent (cf. Reverberi et al., 2005). By considering the attentional demands required for various phases of an insight task, we may improve our understanding of the process of insight and the tasks used to measure it. We may also better predict when, and how, WMC may hinder performance, and begin to reconcile conflicting reports on the role of WM in insight in previous studies.

Because higher WMC could have a negative impact at either the solution or restructuring phases of insight, we did not attempt to differentiate between them in the current work. Instead, we focused on isolating the initial representation stage, which was theorized to have the opposite (positive) relationship with WMC. More research is needed to determine the role of WMC for these latter stages of insight separately. Previous research suggests that higher WMC has no impact, either positive or negative, on the restructuring phase (Ash & Wiley, 2006). However, research also demonstrates that individuals can restructure using either more analytic or associative approaches (Chein & Weisberg, 2014; Fleck & Weisberg, 2004, 2013). It is possible that higher WMC individuals may be more likely to select analytic restructuring approaches, although the extent to which this approach may actually hinder restructuring is unknown. In contrast, it is known that higher WMC leads individuals to persist with complex problem-solving approaches, even when the task benefits from abandoning these approaches (cf. Beilock & DeCaro, 2007). Thus, it seems most likely that higher WMC has the greatest negative impact on the solution phase.

Although task characteristics appear to influence when higher WMC will be harmful to insight, future research is also needed to determine additional factors that impact whether higher WMC individuals will find insightful solutions. For example, it is possible that, with more time and opportunity to exhaust the problem space, higher WMC individuals would eventually attain insight (cf. DeCaro, Carlson, Thomas, & Beilock, 2009). In addition, higher WMC individuals may be highly successful at insight tasks when provided with hints that hone attention to the correct search space (Chein et al., 2010). Furthermore, trait individual differences in WMC are known to fluctuate depending on certain situational factors (e.g., fatigue, mood, alcohol consumption; Ilkowska & Engle, 2010; Jarosz et al., 2012). Situational factors that reduce the WM allocated to the task may help individuals attain insight, even if they have higher trait WMC. By understanding when higher WMC can benefit, or detriment, performance of various tasks, we may be better able to predict when insightful thinking will be best supported.

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