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RECONCILABLE DIFFERENCES

Working Memory Capacity Both Supports and Hinders Insight

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Introduction

Insight—the subjective experience of suddenly realizing a solution to a vexing problem—is thought to play a central role in creativity and innovation. These unexpected moments of revelation are credited for some of humankind's greatest achievements (Irvine, 2015). On a smaller scale, insight helps individuals restructure goals and overcome everyday obstacles (Hill & Kemp, 2016; Ovington, Saliba, Moran, Goldring, & MacDonald, 2018). Unfortunately, insight is not available on demand and often eludes even the most dedicated problem-solvers. For over a century, psychologists have sought to determine the conditions under which insight is most likely to occur (e.g., Köhler, 1925; Wertheimer, 1945/1959). Researchers have experimented with various techniques designed to enhance creative problem-solving, with modest success (see Beda, Smith & Orr, 2020, for a review).

Any reliable method for eliciting insight must be founded on an understanding of its cognitive mechanisms. To gain a better understanding of these mechanisms, studies typically examine the relationship between individual differences in cognitive abilities and insight problem-solving (Wiley & Jarosz, 2012a, 2012b). Studies often include non-insight, or *incremental*, problems for purposes of comparison in order to isolate associations unique to insight problems (Gilhooly & Fioratou, 2009; Gilhooly & Murphy, 2005). However, research examining the relationship between cognitive abilities and insight, and the distinction between insight and incremental problem-solving, has led to contradictory results. For example, the strength and direction of the relationship observed between working memory (WM) capacity and insight problem-solving appear inconsistent across studies, with some finding positive and others finding negative associations (DeCaro, 2018; Gilhooly & Webb, 2018).

The inconsistent and seemingly contradictory nature of the relationship between WM and insight problem-solving warrants special consideration, as WM has emerged as a key predictor of many important cognitive faculties (Barrett, Tugade, & Engle, 2004). In this chapter, we briefly review the conflicting research examining how individual differences and situational factors that influence WM capacity impact insight problem-solving. Then, we explore two possible explanations for this contradictory relationship: (1) WM may have different impacts at various stages of insight problem-solving, and (2) related but distinct

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WM mechanisms may have opposite associations with insight problem-solving. We conclude by discussing the potential implications of these explanations.

Working Memory and Problem-Solving: Conflicting Evidence

Traditionally, individual differences in WM capacity are conceptualized as the ability to focus attention toward the problem at hand while inhibiting distracting or irrelevant thoughts (Engle, 2002). WM capacity varies between individuals, in that some people have more WM capacity than others. Many studies have shown that WM capacity is positively associated with reasoning, intelligence, and academic skills, as well as activities such as following directions, planning ahead, and dealing with stress from life events (Conway, Kane, & Engle, 2003; Conway et al., 2005; Engle, Tuholski, Laughlin, & Conway, 1999; Unsworth et al., 2014).

Because higher WM capacity supports the ability to focus attention toward the task at hand, it makes sense that individuals with higher WM capacity show better problem-solving performance on incremental problems. These problems rely on a sequence of problem-solving steps to reach the goal state (Simon, 1978; Simon & Reed, 1976; Sternberg, 1982; Thomas, 1974). Higher WM capacity enables individuals to keep track of the goal and subgoals to successfully navigate the problem (Gilhooly & Fioratou, 2009; Hambrick & Engle, 2003; Hills, Todd, & Goldstone, 2010; Raghubar, Barnes, & Hecht, 2010).

Insight problems are less straightforward. Typically, these are problems for which individuals begin with a misleading or incorrect approach, often due to prior experience in thinking about the problem content in a certain way (e.g., Ash & Wiley, 2006; Knoblich, Ohlsson, Haider, & Rhenius, 1999; Knoblich, Ohlsson, & Raney, 2001; Weisberg, 2015; Wiley, 1998). Insight problems require the solver to take a new perspective, to "think outside the box." This approach requires more flexible or creative cognitive processes. Whether higher WM capacity supports such processes is debated.

Evidence that Working Memory Supports Insight

There are two primary, competing theories to explain how new insights during problem-solving are achieved. Each leads to different predictions about how WM is involved during insight. The *business-as-usual view* describes insight as accomplished through WM-demanding processes, just like incremental problems (e.g., Ball & Stevens, 2009; Chein, Weisberg, Streeter, & Kwok, 2010; Chronicle, MacGregor, & Ormerod, 2004; Chronicle, Ormerod, & MacGregor, 2001; Klahr & Simon, 1999; MacGregor, Ormerod, & Chronicle, 2001; Perkins, 1981; Thevenot & Oakhill, 2005, 2006, 2008; Weisberg, 2013). When conventional solutions fail, individuals search through memory to find new problem-solving approaches, eventually reaching a solution (Ball & Stevens, 2009; Chein & Weisberg, 2014; Davidson, 1995; Kaplan & Simon, 1990; MacGregor, Ormerod, & Chronicle, 2001). Higher WM capacity supports this approach by enabling individuals to evaluate and represent the problem, keep track of and inhibit already-used strategies, and search long-term memory for new strategies (e.g., Kane & Engle, 2003; Rosen & Engle, 1997; see Chein & Weisberg, 2014; Ricks, Turley-Ames, & Wiley, 2007).

Research supporting the business-as-usual view shows a positive association between WM capacity and insight problem-solving (e.g., Chein and Weisberg, 2014; Chein et al., 2010; De Dreu et al., 2012; Gilhooly & Fioratou, 2009). In addition, a dual-task study showed that insight problem-solving performance is reduced when individuals are given a second concurrent task (e.g., remembering five digits on every trial; De Dreu et al., 2012). These findings demonstrate that insight is hindered when WM is less available, suggesting that WM is necessary when solving insight problems.

Evidence that Working Memory Hinders Insight

In contrast, according to the *special-process view*, insight problems require different cognitive processes than incremental problems (e.g., Ball, Marsh, Litchfield, Cook, & Booth, 2015; Bowden, Jung-Beeman, Fleck, & Kounios, 2005; Chein & Weisberg, 2014; Ohlsson, 2011; Schooler, Ohlsson, & Brooks, 1993; Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995). WM is considered less necessary, and sometimes even hinders insight processes. Instead, insight is thought to be achieved when individuals relax their representation of the problem and consider new ideas (Bowden et al., 2005; Knoblich et al., 1999; Ohlsson, 1992; Seifert et al., 1995). This restructuring is supported by associative processes that operate largely outside of executive attention, such as spreading activation in long-term memory (Bowden & Jung-Beeman, 1998; Bowden et al., 2005; Bowers, Regehr, Balthazard, & Parker, 1990; Durso, Rea, & Dayton, 1994; Ohlsson, 1992; Schooler et al., 1993; Shen, Yuan, Liu, & Luo, 2017; Siegler, 2000). As such, individuals often experience difficulty verbalizing the steps they took to reach the solution (Ball et al., 2015; Bowden & Jung-Beeman, 1998; Weisberg, 2015). When the correct representation is achieved, individuals often experience an "aha!" moment (Ohlsson, 1992, 2011; Schooler et al., 1993; Smith & Kounios, 1996).

According to the special-process view, WM is less important for insight. Consistent with this view, research has shown a positive correlation between WM capacity and incremental problems but not insight problems (Fleck, 2008). Similarly, a dual-task study showed a negative impact on incremental but not insight problem-solving (Lavric, Forstmeier, & Rippon, 2000).

Other studies have even shown a negative impact of WM capacity on insight (Beilock & DeCaro, 2007; DeCaro, Van Stockum, & Wieth, 2016; Van Stockum & DeCaro, 2014). This negative effect is thought to occur for two possible reasons. One possibility is that higher WM capacity supports individuals in concentrating their focus of attention on the misleading problem representation (Chein & Weisberg, 2014; Ricks et al., 2007). Another possibility is that, because higher WM capacity supports the use of complex problem-solving strategies, higher-capacity individuals may be more likely to choose such strategies—even if simpler, more insightful ones are more appropriate. The longer higher-capacity individuals spend on such (incorrect) strategies, the longer it may take them to abandon this approach, hindering insight (Beilock & DeCaro, 2007; DeCaro, Carlson, Thomas, & Beilock, 2009; DeCaro, Thomas, & Beilock, 2008; Gaissmaier, Schooler, & Rieskamp, 2006; Wolford, Newman, Miller, & Wig, 2004).

Consistent with this view, situational factors that reduce WM capacity have been shown to improve insight (Wiley & Jarosz, 2012). For example, Wieth and Zacks (2011) showed that insight is improved at one's non-optimal time of day (e.g., a morning person tested at night). DeCaro and Van Stockum (2018) found improved insight when individuals were ego-depleted after completing a mentally taxing activity. Beilock and DeCaro (2007) found improved insight (reduced mental set) when individuals were faced with performance pressure that leads to anxious thoughts, co-opting WM resources. Jarosz and Wiley (2012) showed better insight when participants were mildly intoxicated with alcohol. Reverberi et al. (2005) demonstrated that individuals with damage to the prefrontal cortex solved insight problems better than a matched control sample. Ball et al. (2015) reported improved insight when participants engaged in dual tasks during solving, such as articulatory suppression (i.e., repeating the numbers one through seven over and over) or irrelevant speech (i.e., asked to ignore an irrelevant message—the numbers one through seven, repeated to them; but see Ball & Stevens, 2009).

Other studies have shown that situational factors leading to increased attention toward a problem-solving task decrease insight, supporting the idea that more reliance on WM hinders insight. For example, researchers have found lowered insight when solvers talk aloud while solving (Ball et al., 2015; Schooler et al., 1993) or while wearing a white lab coat associated with analytical thinking (Van Stockum & DeCaro, 2014). However, other studies contradict these findings (e.g., Ball & Stevens, 2009; Chein & Weisberg, 2014; Chein et al., 2010; Fleck & Weisberg, 2004, 2013; Gilhooly, Fioratou, & Henretty, 2010).

Individual differences can also influence the degree to which situational factors impact insight problem-solving. For example, higher-capacity individuals show improved insight when their greater WM capacity is co-opted by environmental factors (e.g., performance pressure; Beilock & DeCaro, 2007). Conversely, lower-capacity individuals exhibit worse insight when the situation leads them to increase attention toward the problem-solving task (Van Stockum & DeCaro, 2014). Together, these findings suggest that the relationship between insight and WM is not straightforward and depends on a confluence of factors, including individual differences and situational influences on WM. As discussed next, characteristics of the insight task itself may also play a role.

Working Memory and Phases of Problem-solving

Individual differences and situational factors that impact WM influence the extent to which an individual is likely to exert executive control to solve a given problem. Likewise, characteristics of the insight task may influence whether such executive control is likely to benefit or hinder insight (DeCaro, 2018; DeCaro, Van Stockum, & Wieth, 2017; Gilhooly & Webb, 2018).

The special-process view describes insight problem-solving as taking place over three phases: representation, solution, and restructuring (Ash & Wiley, 2006; Ohlsson, 1992). As shown in Figure 20.1, solvers first represent the problem, using reasoning and prior knowledge to determine the nature of the problem and likely paths to solution. Typically, individuals begin insight problems with an incorrect representation that leads them to plan faulty solutions. Solvers then work through the planned solution, reaching an impasse when this strategy does not lead to a correct answer. To overcome this stumbling block, solvers must

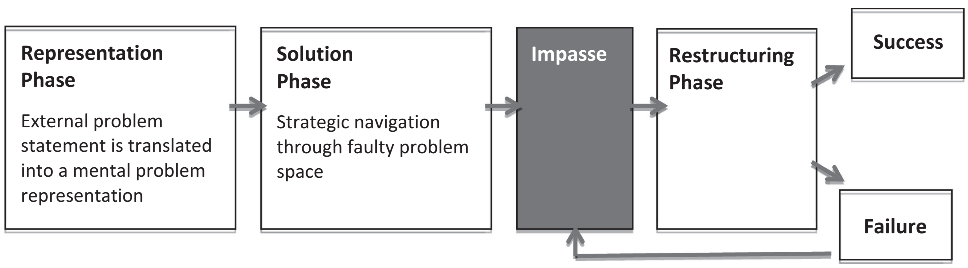

Figure 20.1 Phases of insight problem-solving

Source: DeCaro et al. (2016). Adapted from Ash and Wiley (2006) and Wiley and Jarosz (2012b).

restructure (or re-represent) the problem. Whether restructuring is successful depends on the generative or creative aspect of insight. Solvers must consider new, often peripheral, ideas. If unsuccessful, restructuring begins again.

WM may impact each problem-solving phase in different ways. Additionally, insight tasks likely differ in the extent to which they emphasize each phase. For example, some insight tasks require more cognitive effort to represent the problem than others (DeCaro et al., 2016). Thus, the extent to which representation, solving, and/or restructuring are critical for a given task may impact the likelihood that WM will have an overall beneficial, or negative, effect on reaching insight.

Representation Phase

Representing a problem requires interpreting the problem statement, goals, and rules (Gick & Lockhart, 1995; Hambrick & Engle, 2003; Mayer & Hegarty, 1996; Novick & Bassock, 2005; Wiley & Jarosz, 2012a). Such interpretation requires reading comprehension (Hambrick & Engle, 2003; Kintsch, 1998; Kintsch & Greeno, 1985), selecting relevant and inhibiting irrelevant problem information (Passolunghi, Cornoldi, & De Liberto, 1999; Wiley & Jarosz, 2012a), and forming an initial mental model of the problem (Ash & Wiley, 2008; Thevenot, 2010). Higher WM capacity is associated with greater ability on all of these tasks (Kintsch, 1998; Lee, Ng, & Ng, 2009; Thevenot, 2010). Therefore, higher WM capacity may better support individuals in forming an initial problem representation (DeCaro, 2018; Gilhooly & Fioratou, 2009; Jones, 2003; Wiley & Jarosz, 2012b). However, some tasks may place lower demands on problem representation, minimizing any potential benefit of WM (see Table 20.1).

Support for these ideas comes from DeCaro, Van Stockum, and Wieth (2016). We examined the relationship between WM capacity and problem-solving using two different types of insight tasks. In one type of insight task (matchstick task, Figure 20.2; Knoblich et al., 1999), all problems required the same basic problem representation. A set of rules for the task was presented at the beginning, and the same rules applied to all the problems in the study. The only differences between problems were the Roman numerals and operators used in each problem. Thus, solvers needed to represent the problem only once, and the demand of

Table 20.1 Impact of WM at Each Insight Problem-Solving Phase. *Source:* DeCaro, Van Stockum, and Wieth (2017)

		Insight Problem-Solving Phase		
		Representation	*Solution*	*Restructuring*
Impact of WM	**Beneficial**	Problem interpretation imposes high WM demand	Many or complex solution possibilities	Analytic strategies are optimal
	Neutral	Problem interpretation has low WM demand	Few or simple solution possibilities	Associative processes are optimal
	Detrimental		Simple solution possibilities are required but complex solutions are used	Associative processes are optimal but controlled strategies are used

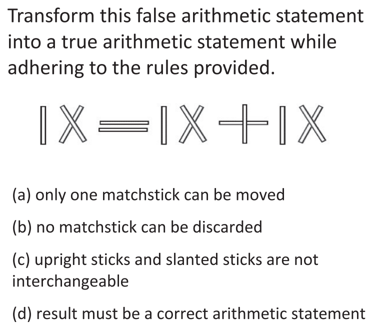

Figure 20.2 Example matchstick arithmetic problem used by DeCaro et al. (2016, Experiment 1)
Source: Knoblich et al. (1999).
Note: In this constraint relaxation problem, the solution is to switch the plus sign into an equals sign. Six problems were given (including both insight and non-insight problems), and all used the same provided rules.

Table 20.2 Example Insight and Incremental Problems used by DeCaro et al. (2016, Experiment 2)

Lilies	*Cards*
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.*	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, and queen of spades

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

representing the problems was diminished after reading the initial instructions. On this task, higher WM capacity was associated with lower accuracy on the insight matchstick problems (see also Van Stockum & DeCaro, 2014).

In a separate experiment, DeCaro et al. (2016) used both incremental and insight word problems that all differed in their problem representations, with different cover stories, use of numbers in the problems, length, etc. (Table 20.2). With this task, no relationship between WM capacity and insight accuracy was initially found. However, incremental and insight accuracy were correlated, and we reasoned that both problem types likely overlap in one important problem-solving phase—representation. Specifically, WM may be important for representing both insight and incremental problems (Korovkin, Vladimirov, Chistopolskaya, & Savinova, 2018). Thus, controlling for this shared variance should reveal the unique effect WM has on the other phases of insight. To test this idea, we re-examined the relationship between WM and insight accuracy while controlling for accuracy on incremental problems. Doing so, we uncovered a negative relationship between WM and insight. Together, these findings support the idea that insight tasks that require WM resources for initial problem representation will likely benefit from higher WM capacity—at least at this phase. Whether the overall effects of WM capacity will be revealed also depends on the next two phases.

Other factors may also change the role of WM during representation. For example, individuals appear to do better on insight tasks when they are given hints, are told that the task measures insight, are given verbal examples of answers to avoid, or are told to look for less complex solutions (DeCaro, 2018; DeCaro et al., 2017; George & Wiley, 2020; Luchins, 1942; see Ash, Cushen, & Wiley, 2009). In these instances, individuals may be less misled in the first place, and therefore "insight" problems may actually be represented and solved like incremental problems. In this case, higher WM capacity should be beneficial.

Solution Phase

During the solution phase, higher WM capacity should help solvers execute multistep problem-solving strategies, given their greater ability to keep task goals activated and distractions at bay. In this case, higher WM may aid insight problem-solving by helping solvers move more quickly through the solution phase to reach an impasse or solution (Table 20.1). Support for this idea comes from Ash and Wiley (2006), who showed that higher WM capacity was associated with better insight problem-solving when the solution space required multiple steps. When the solution phase was less complex, no relationship between WM capacity and insight problem-solving was found. Similarly, if the problem-solving task is interactive (e.g., one can do physical manipulation to solve the problems, such as with real matchsticks), then the WM requirements likely become lower as well (Vallée-Tourangeau, 2017; Vallée-Tourangeau, Steffensen, Vallée-Tourangeau, & Sirota, 2016).

However, because higher WM capacity supports the ability to perform complex solutions, higher-capacity individuals may also sometimes be more likely to choose complex strategies over simpler ones. Additionally, higher-capacity individuals may persist in using an erroneous strategy, given their superior ability to keep the associated goals activated (Table 20.1; see Wiley, 1998; Wiley & Jarosz, 2012a). Support for these ideas comes from Beilock and DeCaro (2007), who found that higher WM capacity was associated with greater use of complex strategies in both mathematical and insight problem-solving tasks. In the former, higher WM capacity was useful. In the latter, it led individuals to miss more insightful and simpler solution possibilities (see also Sovansky & Ohlsson, 2016).

Specifically, Beilock and DeCaro adapted Luchins's (1942) water jug task, which assesses the ability to "break" mental set. *Mental set* refers to the natural tendency of individuals to bias experience over exploration (Bilalić, McLeod, & Gobet, 2010). For example, when faced with a novel problem, the first answer that comes to mind is often one that has worked in the past. Novel problems, however, sometimes require novel solutions, and the past can be misleading (Knoblich, Ohlsson, Haider, & Rhenius, 1999). Like insight problems, the water jug task requires relaxing constraints based on prior experience with similar problems (Ohlsson, 1992; Öllinger, Jones, & Knoblich, 2008). For each water jug problem (six total), participants mentally derived a mathematical formula for obtaining a goal quantity from three jugs (A, B, and C) of varying capacities and a hypothetical limitless water supply (Figure 20.3). Participants were informed that there may be more than one way to derive the goal quantity for a given problem and instructed to find the simplest method possible. For each of the first three ("set") problems, the simplest method for deriving the goal was the same relatively complicated formula (B – A – 2C; Figure 20.3). For each of the final three ("critical") problems, this same formula resulted in the goal quantity. However, the simplest method for deriving the goal was much simpler in comparison, requiring only a single step

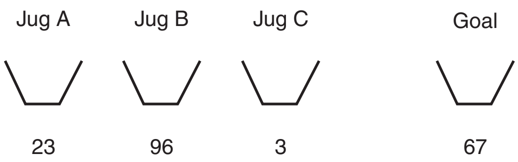

Figure 20.3 Example water jug set problem

(i.e., A + C or A – C). Of interest is whether, after correctly solving the first three problems and thus establishing a mental set for the multistep strategy, individuals switch to the single-step strategies when they become available (i.e., "break" mental set).

Higher-capacity individuals were more likely to be persistent in using the complex strategy during the critical problems, even though a simpler strategy was available. In contrast, lower-capacity individuals switched, potentially because the complex strategy was more taxing for them to complete, leading them to look for other options.

Restructuring Phase

According to the special-process view of insight, restructuring occurs by using associative processes, such as spreading activation in long-term memory. If this view is correct, then reliance on controlled attention processes may not affect the ability to achieve insight (Ash & Wiley, 2006; Chein & Weisberg, 2014). It is also possible that relying on controlled attention processes leads individuals to overshadow associative processing, hindering insight (Table 20.2; Beilock & DeCaro, 2007; DeCaro et al., 2016; Fleck & Weisberg, 2004; Weisberg, 2006). If a problem is best solved by "letting go," or letting the mind wander across semantic associations in long-term memory, then relying on controlled processes instead may impede this process.

In contrast, if restructuring best occurs by using a controlled search through long-term memory, then higher WM would support this process. Alternatively, individuals may begin this process in the solution phase instead. When encountering new information during the solution phase, solvers may begin a new search and restructuring process without encountering impasse at all (Chein & Weisberg, 2014; Fleck & Weisberg, 2004, 2013; Weisberg, 2015). This description is consistent with the business-as-usual view of insight. As mentioned previously, it is unknown which of these two theories best explains the restructuring process. Likely, both are correct, and whether associative or controlled processing best leads to insight depends on task parameters.

More research is needed to isolate the solution and representation phases of insight in order to determine how different task variables impact the best route to restructuring. One promising approach was used by Korovkin et al. (2018), who found that a secondary task (dot-probe) impacted insight problem-solving (word problems) less than incremental problem-solving in the latter phases of problem-solving. The secondary task affected both problem types equally in the first phase, which likely reflected a reliance on WM for problem representation (as in DeCaro et al., 2016, Exp. 2).

Overall Impact of Working Memory at Each Problem-Solving Phase

Table 20.1 summarizes how WM may impact each insight problem-solving phase (DeCaro et al., 2017). However, most insight studies do not examine performance as a function of each phase, instead relying on overall measures of accuracy or reaction time. Thus, the overall impact of WM on insight will likely depend on the combined influence of WM on each phase of problem-solving. For example, if an insight problem places heavy demands on WM at any phase (e.g., for representing the problem), then it is likely that a positive relationship between WM and insight will be found. If this WM demand is removed, a null relationship may be found (e.g., Ash & Wiley, 2006). If higher WM capacity leads individuals to use controlled attention resources when these are less optimal, a negative effect of WM may be found (DeCaro et al., 2016). A combination of effects across problem-solving stages could also occur. For example, if WM is useful for representation but harmful for restructuring, these effects may counteract each other, and no overall effect of WM may be shown (DeCaro, 2018).

These ideas are consistent with suggestions that insight may rely on a combination of WM-demanding and associative processes (Bowden et al., 2005; Chuderski, 2014; Gilhooly & Webb, 2018; Martindale, 1995; Schooler, 2002; Weisberg, 2015; Wiley & Jarosz, 2012a). Other research has demonstrated that the same insight problem may be solved in various ways by different people, potentially due to differences in prior knowledge or experience (Ash et al., 2009; Chein & Weisberg, 2014; Fleck & Weisberg, 2004, 2013; Wiley, 1998). Thus, problem characteristics likely interact with individual differences and situational factors to determine the overall impact of WM on insight.

Working Memory Processes: How Working Memory Is Measured

We have discussed how the relationship between WM and insight may change as a function of task characteristics. A complementary explanation for variations in this relationship is based on how WM is characterized across studies. In the previous sections, we have described WM capacity in keeping with the individual differences approach (e.g., Engle, 2002), as is common in the WM and insight literature (e.g., Beilock & DeCaro, 2007; DeCaro et al., 2016; Ricks et al., 2007). However, there are alternative ways of both describing and measuring WM capacity. Some insight studies use tasks that emphasize the controlled attention aspect of WM, whereas others use tasks that emphasize storage or updating processes. Recent studies suggest that WM is not a unitary construct, and thus different WM processes may diverge in their relationship with insight problem-solving (Van Stockum & DeCaro, 2020). By considering how WM is measured and conceptualized across studies, we may better understand how these processes impact insight.

Traditional Measures of Working Memory

Historically, WM capacity has been conceptualized as the maximum amount of information an individual can simultaneously store and process (Daneman & Carpenter, 1980). Individual differences in WM capacity are most commonly measured using complex span tasks (Redick et al., 2012). *Complex span tasks* are composed of a primary "storage" task (the measure of interest) and a secondary "processing" task designed to distract participants from the primary task. In one classic complex span task, the operation span task, the primary objective is to remember a series of letters in the order presented (i.e., serial recall). The secondary task is to solve simple math equations (Unsworth, Heitz, Schrock, & Engle, 2005). Critically, secondary task trials are interleaved between primary task trials (i.e., simple math equations are solved before and after each to-be-remembered letter). Participants are instructed to prioritize the primary task but also maintain accuracy on the secondary task (Conway et al., 2005). Together, storage and processing account for unique and shared variance in the prediction of higher-order cognition, including general fluid intelligence—the ability to reason through novel analytical problems (Bayliss, Jarrold, Gunn, & Baddeley, 2003; Unsworth, Redick, Heitz, Broadway, & Engle, 2009).

Other WM measures emphasize either storage or processing (Heitz, Unsworth, & Engle, 2005). For example, *simple span tasks* emphasize storage over processing, in that they require serial recall with no overt processing component (Conway et al., 2005; Unsworth & Engle, 2006). In the forward digit span (Blankenship, 1938), a common simple span task, participants are presented a series of digits, one at a time, of increasing length. After the final digit in a series, participants must recall the digits in the order they were presented (i.e., no manipulation is required). By emphasizing storage, simple span tasks are thought to estimate individual differences in short-term memory capacity, or the maximum amount of information that can be maintained at a given time (Cowan, 2001).

In contrast, *attention control tasks* emphasize processing over storage by minimizing the amount of information needed to successfully perform the task. For example, the antisaccade task (Hallett, 1978) requires maintaining a single goal, placing minimal demands on short-term memory (Kane, Bleckley, Conway, & Engle, 2001). In each trial of the antisaccade task, an asterisk appears on one side of the computer screen, and then one of two letters (O or Q) appears on the other. The stimuli are presented so quickly that, in order to discriminate between the two letters (the dependent measure), participants must avoid having their attention captured by the asterisk (which serves as both a cue and a distractor). Instead, they must immediately divert their gaze to the opposite side of the screen, where the target letter appears. To inhibit the tendency to look toward a flashing stimulus, participants must actively maintain the goal (i.e., "look away from the flash") and resist distraction. By emphasizing processing over storage, attention control tasks are thought to estimate individual differences in the ability to control domain-general attention (i.e., "executive attention"; Engle, 2002; Engle, 2018).

Each of these types of WM measures (i.e., complex span tasks, simple span tasks, and attention control tasks) has been used to examine the relationship between WM and insight problem-solving, with varying results. For example, Byrne and Murray (2005) found positive associations between insight problem-solving and complex span, simple span, and attention switching. However, insight problem-solving was unrelated to selective and sustained attention. Gilhooly and Fioratou (2009) found a positive association between insight problem-solving and complex span; however, insight problem-solving was unrelated to attention switching. Gilhooly and Fioratou additionally found incremental problem-solving to be positively associated with both complex span and attention switching. DeCaro et al. (2016) used a complex span measure in their studies, showing a negative relationship between WM and insight problem-solving (see also Van Stockum & DeCaro, 2014). Fleck (2008) found a positive association between incremental problem-solving and complex span; however, insight problem-solving was unrelated to complex span. Fleck (2008) additionally found simple span to be positively related to both insight and incremental problem-solving. Gilhooly and Murphy (2005) found that insight problem-solving was unrelated to both simple span and complex span.

These studies vary in the specific tasks used to measure WM in addition to the methods used to assess insight problem-solving. These inconsistencies across studies make it difficult to determine clear patterns. One observation is that insight problem-solving appears to be more consistently positively associated with simple span compared to complex span (Fleck, 2008; Korovkin et al., 2018). This observation suggests that insight problem-solving benefits more from greater storage than processing (see also Gilhooly & Fioratou, 2009; Wiley & Jarosz, 2012). However, inconsistencies are also found between studies using the same measures of WM, again confirming the idea that multiple factors are at play.

Additional examples further complicate matters. Chein et al. (2010) found that insight problem-solving was positively associated with one complex span task (operation span) but unrelated to another (symmetry span), concluding that verbal but not spatial WM is important for insight. However, multiple studies have demonstrated that operation span and symmetry span account for similar variance in verbal and spatial ability, suggesting that individual differences in WM capacity are predominantly domain-general (Kane et al., 2004; Unsworth et al., 2009). Consistent with the view that complex span tasks tap domain-general WM capacity, Ash and Wiley (2006) used composite scores averaging performance on two complex span tasks (reading span and operation span) and found that WM capacity was positively associated with insight problem-solving—but only for problems with many possible solution paths. These examples highlight how different conceptualizations of WM (i.e., domain-general executive attention versus domain-specific storage) also influence the interpretation of findings. Clearly, studies examining the relationship between WM and insight problem-solving would benefit from a more uniform or systematic approach.

Updated View of Working Memory Capacity

WM capacity is often treated as a unitary construct that reflects the overall effectiveness of the WM system (e.g., Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Mogle, Lovett, Stawski, & Sliwinski, 2008). However, recent studies have demonstrated that multiple sources of variance are needed to account for the predictive power of WM capacity (see Unsworth, 2016). Specifically, the independent contributions of three WM mechanisms were found to better explain individual differences in WM capacity and the relation between WM capacity and general fluid intelligence: attention control, primary memory, and secondary memory (Shipstead, Lindsey, Marshall, & Engle, 2014; Unsworth, Fukuda, Awh, & Vogel, 2014; see also Unsworth & Spillers, 2010). These contributions include those made by storage and processing (Unsworth et al., 2014). First, *attention control*, as described above, refers to the set of attentional processes that enable individuals to maintain goals, prioritize relevant information, and avoid distractions (McVay & Kane, 2012). Second, *primary memory* refers to the ability to maintain limited amounts of information for short periods of time (Unsworth & Engle, 2007). Effectively a synonym for short-term memory, the term primary memory is more inclusive of diverging theories of how storage capacity limits are reached (e.g., Cowan, 2001; Oberauer, 2002). For example, Shipstead et al. (2014) proposed that primary memory capacity depends on the ability to forget or "disengage" no-longer-relevant information in addition to the ability to remember or maintain relevant information (cf. Shipstead, Harrison, & Engle, 2016). Lastly, *secondary memory* is the ability to search for and retrieve information from long-term memory (Unsworth & Engle, 2007).

Complex span task performance can be explained in terms of the coordination of these three mechanisms. In the operation span task (Unsworth et al., 2005), participants rely on primary memory for actively maintaining the letters for subsequent recall. Recall accuracy may also depend on participants' ability to disengage no-longer-relevant letters (i.e., from previous trials) from primary memory (Shipstead et al., 2014). To meet the secondary task accuracy requirement (Conway et al., 2005), participants must devote sufficient attention to solving the math equations. Participants rely on attention control for maintaining the goal of prioritizing the primary task while resisting attentional capture by the secondary task. Finally, when the number of to-be-remembered letters exceeds primary memory capacity, some letters may become displaced from primary memory (e.g., while attention is directed to solving the math equations). Participants must then rely on secondary memory to recover these letters at recall (Unsworth & Engle, 2006).

This updated view of WM capacity as a multifaceted construct ("multifaceted view") may help explain the inconsistent and sometimes contradictory findings in the insight literature. Van Stockum and DeCaro (2020) proposed that such findings might reflect indirect evidence of a more complex relationship. The multifaceted view of WM capacity (Shipstead et al., 2014; Unsworth et al., 2014) allows for the possibility that different WM mechanisms predict the same outcome in opposite directions.

We (Van Stockum & DeCaro, 2020) tested this theory by revisiting the relationship between WM capacity and insight using the same water jug task as Beilock and DeCaro (Figure 20.3). As discussed previously, Beilock and DeCaro (2007) demonstrated a negative relationship between breaking mental set on the water jug task and WM capacity. Their study used composite scores averaging performance on two complex span tasks (operation span and reading span). We, instead, used multiple regression to estimate the unique contributions of attention control, primary memory, and secondary memory, as measured by the anti-saccade task, running span task (a classic short-term memory task; Pollack, Johnson, & Knaff, 1959), and operation span task, respectively.

We expected that switching to the single-step strategies when they become available would require disengagement from no-longer-relevant information (i.e., the complex strategy). We thus predicted a positive relationship between primary memory and breaking mental set (Shipstead et al., 2014). We predicted the opposite relationship for secondary memory. Specifically, we expected that greater secondary memory would hinder breaking mental set by facilitating retrieval of the complex strategy (Harrison et al., 2015; Verguts & De Boeck, 2002) and thus bias suboptimal persistence in this approach (Beilock & DeCaro, 2007). It is difficult to imagine a task for which some degree of goal maintenance is not required (Duncan & Owen, 2000; Engle, 2018). Therefore, we expected positive relationships with attention control.

Across multiple studies, we used multiple linear regressions to isolate the effects of each WM mechanism. The results were consistent with our predictions. Primary memory was positively associated with insight, whereas secondary memory was negatively associated with insight. Attention control moderated these effects, such that each relationship was strengthened for individuals with greater attention control. Thus, simple low/high WM capacity dichotomies, common in insight research, may limit understanding of a more nuanced relationship. In sum, WM processes have both unique and combined effects on insight, which can support or hinder performance.

Implications

[AU: Ref. "Weisberg & Suls 1973" is cited in text, but the corresponding reference is not in reference list. Please provide the reference for this citation or remove the citation.]

After nearly half a century of back and forth (e.g., cf. Dominowski, 1981; Ellen, 1982; Weisberg & Alba, 1981a, 1981b; Weisberg & Suls, 1973cf. Chuderski & Jastrzębski, 2017; 2018; DeCaro et al., 2016, 2017), the business-as-usual versus special-process debate has reached an impasse. Contradictory evidence is accumulating in the literature, and insight researchers are exploring new theories capable of accommodating both perspectives (DeCaro et al., 2016; Gilhooly, Ball, & Macchi, 2015; Gilhooly & Webb, 2018; Marsh, Threadgold, Barker, Litchfield, Degno, & Ball, 2021; Van Stockum & DeCaro, 2020). At this point, any claims to have definitively described the relationship between WM and insight are simply shortsighted (cf. Chuderski & Jastrzębski, 2017). The multifaceted view of WM capacity should motivate researchers to revisit previous findings and reexamine their assumptions (e.g., Engle, 2018; Sattizahn, Moser, & Beilock, 2016; Van Stockum & DeCaro, 2020). Prior and future research findings should be considered pieces of evidence that, together, may help to reveal the full picture of how insights occur.

In this chapter, we have argued that conflicting findings across studies are due to inconsistencies in how researchers conceptualize and assess both insight and WM. We maintain that researchers should consider aspects of the insight task itself. Different insight tasks vary in their reliance on WM for representing the problems (including whether the problems contain hints to consider novel approaches), whether multiple solution paths are possible, and whether associative or controlled processes are ideal for restructuring the problem, if needed. We must also consider what WM process is being measured (or manipulated) in a study, as new research now demonstrates that different WM processes can have opposing effects on insight. Measuring the individual and joint impacts of various WM processes reveals a much more complex relationship with insight than originally thought. Of course, this complexity will play out differently when using different insight tasks.

A deeper investigation of these cognitive processes that support insight can be mutually beneficial to both problem-solving and WM research. Problem-solving research can inform our understanding of WM (e.g., Harrison, Shipstead, & Engle, 2015; Shipstead et al., 2014; Wiley, Jarosz, Cushen, & Colflesh, 2012). WM research would likely benefit from the inclusion of insight problem-solving tasks in addition to those assessing general fluid intelligence (Smeekins & Kane, 2016).

In conclusion, higher WM capacity can both help and hurt insight. Different WM measures will capture the processes underlying flexible or fixed thinking in different ways. To better understand and predict insight, we must first understand the nature of the insight problem and the extent to which the performance context and individual differences in WM capacity impact how attention and memory are devoted to the task.

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