Effects of Working Memory Capacity on a Remote Associates Task

Travis Ricks[1] (tricks2@uic.edu)
Kandi Jo Turley-Ames[2] (turlkand@isu.edu)
Jennifer Wiley[1] (jwiley@uic.edu)

[1]Department of Psychology
1007 W. Harrison St. M/C 285
University of Illinois, Chicago
Chicago, IL 60607 USA

[2]Department of Psychology
Campus Box 8112
Idaho State University
Pocatello, ID 83209 USA

Abstract

For creative problem solving, often the most obvious solutions do not work and other paths or problem representations need to be considered. In these cases prior attempts may interfere with further solutions. The present study examines how working memory capacity (WMC), which has been conceptualized as the ability to retrieve and process information in the face of interference, relates to the ability to solve remote associate task (RAT) problems. A positive relation between WMC and the ability to solve RAT problems was found. Additional findings suggest a trend for higher WMC to constrain solution when problem solvers are fixated by misleading solution attempts.

Remote Associates and Creative Solutions

Creativity is required for many problems we face in our everyday lives. As opposed to problems that may be well-structured, with more or less obvious routes to solution, many everyday problems are ill-structured, meaning there is no one straightforward way to represent or solve such problems. In these cases we may need to generate many alternative solutions or representations until one fulfills our needs. Critically, it is often important to move beyond the most obvious or salient approaches to solving a problem, and consider a broad range of more remote possibilities. The present study is concerned with how individual differences in working memory capacity may interact with the generation of remote associates in a particular creative problem solving context.

The remote association task (RAT) was created by Mednick (1962) as a quantifiable creative problem solving assessment. RAT items consist of three words that appear unrelated to one another such as: wild, dark and fork. Participants are then asked to generate a fourth word which may form a meaningful compound or phrase with each of the words. In this case, a good solution would be "pitch" which would form the phrases wild pitch, pitch dark, and pitchfork. The ability to solve Mednick's RAT items requires individuals to engage in a broad search of long term memory (LTM) to find a word that forms a meaningful phrase with all three unrelated words. It is easy to find many words that can form meaningful phrases with one or even two of the words. Thus finding a word that fits with all three other words requires participants to test and reject many different possible solutions. An example of a word that forms a meaningful phrase with only two of the words is "horse". Horse can be used to make the phrases "wild horse" and "dark horse", but it does not work with fork. For this RAT item, individuals must be able to abandon the word "horse" and continue a search of LTM to find other words that might represent a good solution to the problem. To do this successfully, individuals must be able to both generate a broad range of attempts and perhaps most importantly, inhibit failed attempts to solve the RAT items. Since working memory capacity has been identified as an important factor in an individual's ability to retrieve items from long term memory, as well as to resist interference during processing (Rosen & Engle, 1998; Stoltzfus, Hasher & Zacks, 1996), the current study investigates the role working memory capacity (WMC) might play in the process of solving RAT items.

What is Working Memory Capacity?

Daneman and Carpenter (1980) developed a reading span task that was one of the first measures of WMC with a processing component, reading a sentence, and a memory component, remembering the final word of the sentence. More recent assessments of WMC use complex span tasks where the processing and storage component are distinct (Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005). RSPAN asks participants to read sentences and remember a list of letters. OSPAN, developed by Turner and Engle (1989) involves solving elementary math problems as a processing component, and remembering a list of unrelated words as a memory component.

Working memory (WM) has been conceptualized as a mental workspace in which activated memory representations are available in a temporary buffer for manipulation by the individual during cognitive processing (Stoltzfus, Hasher, & Zacks, 1996). Unlike other memory components, sensory memory and LTM, WM is limited in capacity. Differences in performance on complex span tasks represent a measure of the capacity of WM. Performance on complex span tasks have been explained in several ways: the capacity reflects the amount of activation available to the WM system (Engle, Cantor, & Carullo, 1992), or the efficiency of encoding and retrieving information (Ericsson & Delaney, 1999; Ericsson & Kintsch, 1995), or the ability to process new information while inhibiting irrelevant information (Rosen & Engle, 1998; Stoltzfus, Hasher & Zacks, 1996).

Rspan and Ospan have shown reliable relationships with performance on many higher-order cognitive tasks as well as with measures of general fluid intelligence, which has been defined as the ability to solve novel problems and adapt to new situations (Cattell, 1943, Hambrick & Engle, 2002, Kyllonen & Christal, 1990). Kyllonen (1996) conceptualized WMC as the central component behind general fluid intelligence.

We were interested in whether WMC would relate to individuals' ability to successfully search LTM and inhibit attempted solutions as they solve RAT items. To further test how WMC may be related to RAT problem solving, we used two sets of RAT problems. One set of items was called the Baseball-consistent version (Wiley, 1998) where the solution is cued by a baseball-related phrase (such as the example given at the start of this paper). A second set of the problems was called the Baseball-Misleading RAT (Wiley, 1998). We were especially interested in performance on these problems which we felt would make the probability of producing a misleading solution to RAT problems even more likely. If WMC allows solvers to overcome interference from prior solutions, then the relationship with WMC should be stronger in this condition.

For the Baseball-Misleading RAT, Wiley (1998) created ten RAT items that contained a first word that was part of a familiar baseball phrase (such as wild pitch). The second word in the problem also formed a meaningful phrase with this solution (such as pitch dark). However, a third word was introduced so that it did not work with the baseball-solution word (in this case, sense). Sense pitch or pitch sense are not meaningful phrases. At this point, the candidate solution "pitch" must be abandoned, ignored or inhibited in some way, and generation must continue until the solution (horse) can be found. Thus, these items were termed "baseball misleading." Because the baseball-misleading RAT items are specifically designed to activate a misleading solution attempt that individuals would be required to inhibit or abandon, it is of interest to see if WMC plays an increased role in solving the baseball-misleading items. This result would follow directly from the work of Stoltzfus, Hasher, and Zacks (1996) who found that individual differences in WMC are a result of participants' ability to inhibit irrelevant information. One might also expect solvers with high WMC to perform better on all problems as WMC has been linked to the efficient retrieval from LTM, which would also be beneficial in solving RAT items (Rosen & Engle, 1997).

An interesting alternative however, is that high WMC might actually impair a solver's ability to get out of a misleading solution attempt. Another view of WMC is that it relates to the ability to focus one's attention (Conway, Cowan, & Bunting, 2001). In their study on the cocktail party effect, Conway, Cowan, and Bunting (2001) observed that high WMC participants were actually less likely than low WMC to hear their name in an unattended channel. Thus, it appears that high WMC participants' ability to focus their attention can also limit the breath of their awareness, and can constrain the range of information that they might consider or process. Although this ability has obvious advantages for filtering out irrelevant information, in the case of creative problem solving, where a broad search for solution is required, some negative consequences might be expected. If high WMC solvers focus too much on the misleading solution attempts, they might actually do worse than low WMC solvers, who may have broader activation of LTM, which would translate into better problem solving.

In sum, if WMC relates to the ability to retrieve information from memory, it could be predicted the there will be a positive effect of WMC across all types of RAT items because of high spans' superior ability to search and retrieve relevant information from LTM.

An additional prediction is that an interaction will exist between WMC and condition. This would be the result of high spans outperforming low spans by a greater margin in the baseball-misleading condition, because of high spans' ability to inhibit no longer relevant information.

However, if WMC relates to the ability to focus one's attention, then high spans may not show the highest level of performance, and they may be especially harmed on the misleading problems. Further, high knowledge participants, who will be more likely to experience fixation on the baseball-misleading problems (Wiley, 1998), may be most likely to show a negative effect of WMC.

Method

Participants. Participants were volunteers from introductory psychology classes at Idaho State University. Participants received course credit for their participation. Data from 120 participants was collected. Four participants were removed from analyses due to missing data, and one was removed as an outlier for solving an exceptional number of problems (over 3 SD above the mean).

Materials. An operation span test (Turley-Ames & Whitfield, 2003) and Wiley's (1998) adapted version of Mednick's (1962) RAT was used in the present research. Three tests developed by Hambrick and Engle (2002) were used to assess knowledge of baseball rules, regulations, and terminology.

Procedure. First, participants were administered the OSPAN task in which the math operations and words were presented via a moving window (Turley-Ames & Whitfield, 2003). Operation-word sequences were presented in increasing set size. Set size increased from two operation-word sequences to six operation-word sequences. At the end of each set, participants were asked to recall the words that were presented after each math problem. Participants completed three trials at each set size and had seven seconds to complete each operation-word sequence. In order to receive one point towards an individual's WM span score, the math problem needed to be performed correctly and the word correctly recalled. The maximum WM span score was sixty points.

Following OSPAN, participants were administered the adapted RAT. The first word for each of the RAT items appeared in the middle of the computer screen for five seconds. The second word then appeared underneath the first word for 7.5 seconds. Following the 7.5 seconds, the third word appeared underneath the first and second words, and participants had 30 seconds to enter a solution. If the 30 seconds elapsed without a solution being entered, the words disappeared, and participants were instructed to enter a solution. Participants had 20 seconds to respond before the next RAT item was presented.

Participants were randomly assigned to one of two RAT conditions. The baseball-misleading condition consisted of 20 RAT items, 10 of which were baseball-misleading and 10 were neutral based on Mednick's original items. The baseball-congruent condition consisted of 20 RAT items, 10 of which could be solved with a baseball-related term, and 10 which were neutral.

Response time was measured by computer from the presentation of the third word until the participant typed a solution and hit the enter key, or until 30 seconds had elapsed. Participants then completed the baseball tests.

Results

Hierarchical regression analyses were conducted to evaluate the main and interactive effects of baseball knowledge, WMC, and condition on RAT performance. For use as predictor variables, working memory span test scores were converted to Z-scores. Baseball knowledge scores were created by averaging the Z-scores for the multiple choice task and the fill-in-the-blank task, since these two tasks are most closely related to the Spilich, Vesonder, Chiesi and Voss inventory used in the Wiley (1998) study, and because only these two baseball knowledge tasks had high reliability in the Hambrick and Engle (2002) study. Working memory span scores ranged from 19 to 57, with a mean of 37.3 (SD 8.4). Scores on the baseball multiple choice test ranged from 3 to 19, with a mean of 9.91 (SD 4.05). Scores on the baseball fill-in-the-blank test ranged from 0 to 20, with a mean of 7.88 (SD 5.5). No outliers were found on these variables.

Hierarchical analysis was carried out in three steps. RAT condition, baseball knowledge and WMC were entered in the first step to evaluate the main effect of each predictor variable on performance. Cross-product terms representing the baseball knowledge x WMC, baseball knowledge x RAT condition, and WMC x RAT condition two-way interactions were entered in the next step. A cross product of baseball knowledge x WMC x RAT condition representing the three-way interaction was entered in the third step. To ease interpretation of the regression results, graphs displaying the relation of WMC to RAT performance, as a function of condition and baseball knowledge are presented along with the regression analyses for correct solutions.

Correct Solutions

The relation of working memory capacity to RAT performance as a function of condition and baseball knowledge is presented in Figure 1. Table 1 reports the outcome of the hierarchical regression for correct solutions. Review of Table 1 reveals that that WMC, baseball knowledge, and condition together accounted for 20% of the total variance in RAT performance, F (3, 110) = 9.24, $p < .001$, and that both WMC and RAT condition were significant unique predictors of correct solutions. Higher levels of WMC were associated with superior RAT performance, and the baseball-misleading RAT condition was more difficult then the baseball-consistent condition. None of the two-way interactions were significant. The three-way interaction accounted for an additional 2% of the variance in RAT performance, F (1, 106) = 2.97, $p < .08$, although this was only marginally significant.

Table 1

Hierarchical regression analysis for RAT performance

Variable	Inc. R^2	*F* value	*B*	*t* value	β
Step 1	**.201**	**9.24****			
WMC			.615	2.82**	.271
BK			.200	0.91	.087
Condition			-.624	3.20**	-.275
Step 2	**.012**	**.55**			
WMC X BK			-.026	.118	-.011
WMC X Condition			.063	.284	.027
BK X Condition			-.272	1.24	-.119
Step 3	**.021**	**2.97***			
WMC X BK X Condition			-.375	-1.72*	-.174

Note. Inc. R^2 = increase in variance accounted for; B = unstandardized regression coefficient; β = standardized regression coefficient; WMC = working memory capacity; BK = baseball knowledge; *$p < .10$, **$p < .05$.

The nature of the three way interaction is best seen in Figure 1. As shown in the upper panel of Figure 1, low knowledge individuals showed a positive relation between WMC and correct solutions in both the baseball-consistent (upper regression line) and baseball-misleading condition (lower regression line). If anything, the relation between WMC and performance was greater in the misleading condition.

As shown in the bottom panel of Figure 1, high knowledge individuals only showed a positive relation between WMC and correct solutions in the baseball-consistent condition (upper regression line). Separate curve fit analyses revealed that a quadratic function provided the best fit for high knowledge participants in the misleading condition. (lower regression line: linear fit = .03, quadratic fit = .35) with the high knowledge individuals with intermediate levels of working memory capacity performing best on misleading problems. (The quadratic did not significantly improve over linear fit for any of the other 3 regression lines.)

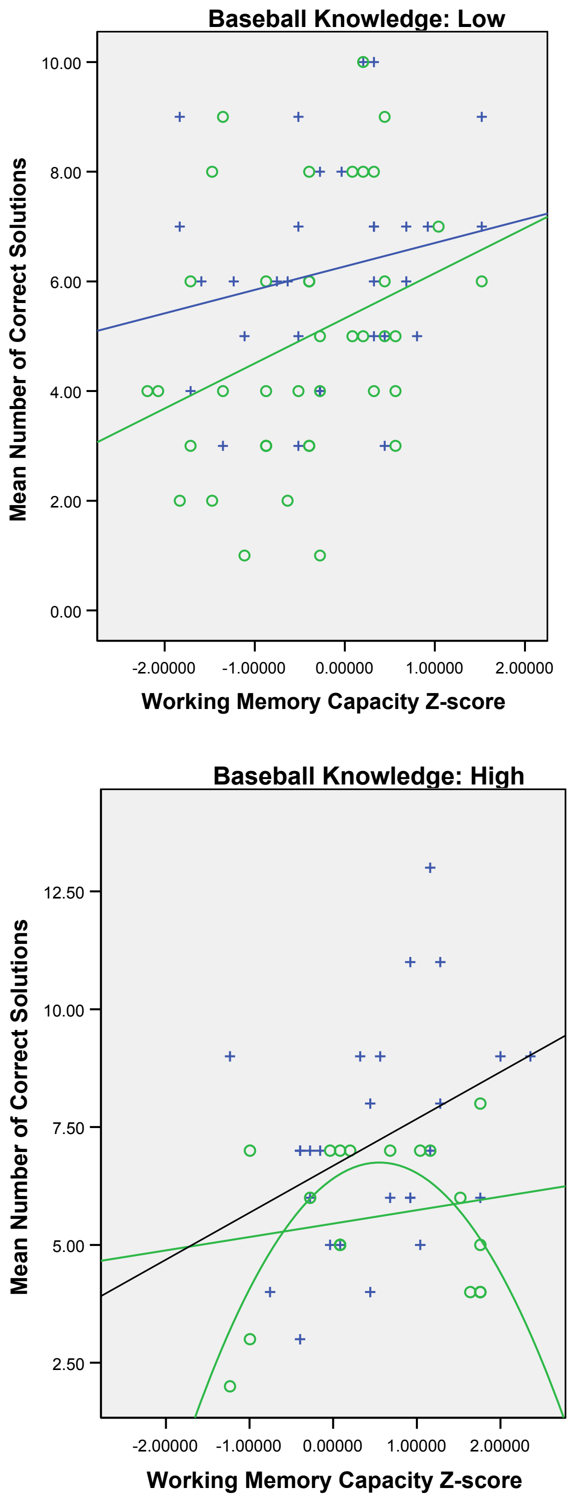

Figure 1: Average number of correct solutions for low knowledge (top panel) and high knowledge (bottom panel) solvers, for baseball consistent (plusses) and baseball inconsistent (circles) conditions.

Response Time for Items Solved Correctly

Table 2 reports the outcome of the hierarchical regression for response times on correctly solved items. Review of Table 2 reveals that that WMC, baseball knowledge, and condition together accounted for 12% of the total variance in RAT solution times, F (3, 110) = 5.16, $p < .002$. WMC and RAT condition were both significant predictors of solution time, while the effect of baseball knowledge was marginal ($p < .09$). Higher levels of WMC were associated with faster solution times for RAT items. Solution times were longer in the baseball- misleading condition than in the baseball-consistent condition, while higher baseball knowledge tended to lead to longer solution times. None of the two-way interactions reached significance. The baseball knowledge x condition interaction was closest to reaching significance at p<.12. Baseball knowledge tended to lead even longer solutions times in misleading versus consistent conditions. The three way interaction did not reach significance for correct solution times.

Table 2

Hierarchical regression for correct times to solution.

Variable	Inc. R^2	F value	B	t value	β
Step 1	**.123**	**5.16****			
WMC			-1.32	2.82**	-.284
BK			0.80	1.72*	.173
Condition			1.03	2.46**	.221
Step 2	**.028**	**1.17**			
WMC X BK			-.403	0.87	-.083
WMC X Condition			-.625	1.34	-.134
BK X Condition			.714	1.53	.153
Step 3	**.013**	**1.64**			
WMC X BK X Condition			.596	1.28	.136

Note. Inc. R^2 = increase in variance accounted for; B = unstandardized regression coefficient; β = standardized regression coefficient; WMC = working memory capacity; BK = baseball knowledge; $^*p < .10$, $^{**}p < .05$.

Discussion

In summary, the current study did find a positive effect of working memory capacity on RAT problem solving, especially in the baseball-consistent condition. However, in the baseball misleading condition, there was a trend in which the relation of working memory capacity to RAT performance tended to differ between high and low knowledge solvers. For low knowledge participants, there was again a positive relation between working memory capacity and performance. However, for high knowledge individuals, high working memory capacity did not lead to the best level of performance on the misleading items.

The current results are consistent with previous work on WMC in a number of ways. First, the overall advantage in RAT problem solving due to WMC is consistent with Rosen and Engle (1997) who linked WMC to efficient retrieval from LTM.

On the other hand, there was a hint of support for the alternative prediction that when participants' are being fixated by a solution attempt, that too much WMC may actually harm creative problem solving by causing solvers to focus too much on the misleading solution. When one examines the relation between WMC and RAT problem solving among high knowledge participants on misleading items (Figure 1), high knowledge participants at intermediate levels of WMC appear to be doing the best. It does seem that high knowledge participants at higher levels of WMC may do worse than those with intermediate levels when it comes to escaping fixation. Thus, while WMC may improve creative problem solving in general, it may actually impair a solvers' ability to get out of fixation imposed by a misleading solution attempt. This would be consistent with the findings of Conway, Cowan and Bunting who demonstrated that WMC can sometimes cause too much attentional focus (Conway, Cowan, & Bunting, 2001).

The findings from this study suggest that high knowledge participants who have high WMC may be at a disadvantage when they experience mental sets due to their prior knowledge (Wiley, 1998). WMC may help low knowledge participants to resolve interference arising from solution attempts in the misleading condition, but it does not seem to help the high knowledge participants resolve fixation created by their domain knowledge. Further research will attempt to directly address this issue with more powerful designs.

The present results do suggest that WMC may be an important variable to consider in relation to creative problem solving performance. It may relate to the number of solution attempts that can be generated or retrieved from LTM, as well as to whether a solver is able to move past initial attempts to solve the problem. And, WMC may have different effects on performance depending on whether interference comes from the problem solving task itself or from prior knowledge. However, regression models including WMC and domain knowledge left a considerable amount of variance in performance on this creative problem solving task unexplained. Discovering other possible individual differences that may predict creative problem solving is yet another interesting direction for future research. (c.f. Ash & Wiley, 2006).

Acknowledgements

The research reported here served as part of the first author's thesis submitted to the Department of Psychology, Idaho State University in partial fulfillment of requirements for the M.S.

References

Ash, I. K., & Wiley, J. (2006). The nature of structuring in insight: An individual-differences approach. *Psychonomic Bulletin and Review.* 13(1), 66-73.

Cattell, R. B. (1943). The measurement of adult intelligence. *Psychological Bulletin,* 40, 153-193.

Conway, A. R. A., Cowan, N. C., & Bunting, M. F. (2001). The cocktail party phenomenon revisited: The importance of working memory capacity. *Psychonomic Bulletin and Review,* 8(2), 331-335.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., and Engle, R. (2005). Working memory span tasks: A methodological review and users guide. *Psychonomic Bulletin and Review,* 2(5), 769-786.

Conway, A. R. A., Tuholski, S. W., Shisler, R. J., & Engle, R. W. (1999). The effect of memory load on negative priming: An individual differences investigation. *Memory & Cognition,* 27, 1042-1050.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning & Verbal Behavior,* 19, 450-466.

Engle, R. W., Cantor, J., & Carullo, J. J. (1992). Individual differences in working memory comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* 9, 972-992.

Ericsson, K. A., & Delaney, P. F., (1998). Working memory and expert performance. In R. H. Logie., K. J. Gilhooly., & E. Hove (Eds.), *Working memory and thinking* (pp. 93 – 114). United Kingdom: Psychology Press/Erlbaum.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review,* 102, 211-245.

Hambrick, D . Z., & Engle, R. W. (2002). Effects of domain knowledge, working memory capacity, and age on cognitive performance: An investigation of the knowledge is power hypothesis. *Cognitive Psychology,* 44(4), 339-387.

Kyllonen, P. C. (1996). Is working memory capacity Spearman's G? In I. Dennis & P. Tapfield (Eds.), *Human abilities: Their nature and measurement* (pp. 49-75). Mahwah, NJ: Lawrence Erlbaum.

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability (is more than) working memory capacity?! *Intelligence*, 14, 389-433.

Mednick, S. (1962). The associative basis of creative problem solving process. *Psychological Review,* 69, 200-232.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General,* 126, 211-227

Stoltzfus, E. R., Hasher, L., & Zacks, R. T. (1996). *Working memory and aging: Current status of the inhibitiory view.* New York, New York, Oxford University Press.

Turley-Ames, K. J., & Whitfield, M. M. (2003). Strategy training and working memory task performance. *Journal of Memory and Language,* 49(4), 446-468.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language,* 28, 127-154.

Wiley, J. (1998). Expertise as mental set: The effects of domain knowledge in creative problem solving. *Memory and Cognition,* 26 (4), 716-730.