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The relation between complex associative learning and fluid intelligence: Is the fan effect responsible?

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THE RELATION BETWEEN COMPLEX ASSOCIATIVE LEARNING AND

FLUID INTELLIGENCE:

IS THE FAN EFFECT RESPONSIBLE?

by

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Abstract

Previous studies have shown that performance on the complex associative learning task is a good predictor of fluid intelligence. In this complex associative task, participants learn a series of primary words, each of which is associated with three secondary words. This task is similar in structure to the classic fan procedure, in which participants learn sentences to criterion and are then tested on how quickly they can recognize them. The fan effect procedure measures how efficiently one can access learned information, and many studies have shown that the more items associated together, the longer it takes to retrieve any of the items. This is known as the fan effect. The purpose of this study was to investigate the relation between complex associative learning, the fan effect, and fluid intelligence. Specifically, I looked at whether complex associative learning was correlated with the fan effect and whether the fan effect accounted for the relation between complex associative learning and fluid intelligence. Although the fan effect was correlated with performance on the first test block of the complex associative learning task, once participants were given practice with the associations the two were no longer significantly correlated. Complex associative learning was again found to be a predictor of fluid intelligence, but the fan effect did not account for this relation.

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Fluid intelligence, which generally is thought to refer to mental flexibility and the ability to solve novel problems, commonly is measured today in adults using Raven's Advanced Progressive Matrices (RAPM; Raven, Raven, & Court, 1998), a complex measure of abstract reasoning and problem solving. Many researchers have proposed specific processes or abilities that they believe to be important for successful RAPM performance. For example, Carpenter, Just, and Shell (1990) suggest that the ability to manage problem solving goals and consider multiple rules and answer choices at once in working memory is important, and Wiley, Jarosz, Cushen, and Colflesh (2011) point to the ability to switch between multiple rules required to solve the problems.

Many of the hypothesized abilities tapped by RAPM have a clear working memory component, but likely also rely somewhat on learning. For example, before one can consider multiple rules at once in working memory and switch between them, the rules must be learned. Although much of this previous research has focused on the relationship between working memory and fluid intelligence, there has been a revival of interest in learning ability. Recent studies have not only found a strong relationship between fluid intelligence and complex associative learning, they also suggest that complex associative learning correlates with intelligence as well or better than does working memory (Williams & Pearlberg, 2006; Tamez, Myerson, & Hale, 2008). In the complex associative learning task, participants learn ten primary words, each of which is associated with three cues (i.e., A, B, and C) that are then each paired with a secondary word (e.g., the primary word LIE is paired with A-fan, B-rim, C-day). At test, participants are given a primary word and a cue (A, B, or C), and must recall the secondary word. Participants are asked to form and maintain associations across four

learn-test cycles, and the number of correctly recalled secondary words across all four tests is taken as a measure of the ability to accumulate learned information over multiple exposures. Tamez et al. reported that complex associative learning was not only related to both working memory and fluid intelligence, but also that associative learning accounted unique variance in fluid intelligence beyond the contribution of working memory. This result was partially replicated by Kaufman, DeYoung, Gray, Brown, and Mackintosh (2009), who found that both associative learning and working memory predicted unique variance in intelligence.

Although these results are encouraging for researchers interested in understanding the correlates and components of intelligence, the nature of the relationship between complex associative learning and fluid intelligence has yet to be fully specified. One possibility is that the associative learning task is measuring individuals' ability to form and maintain associations over time. However, it is also possible that the task is measuring individuals' ability to retrieve previously learned information efficiently, especially under circumstances that require interference control.

Individual differences in retrieval from secondary memory have received an increasing amount of attention in the working memory literature, as these individual differences have been found to be an important component of complex working memory paradigms, in which participants are asked to remember items while also performing a secondary task (e.g., remember a list of words while also solving math equations). Because working memory capacity is limited, it is sometimes the case that information stored in primary memory must be replaced with new items, due to either the capacity demands of the secondary processing task or because the list of items exceeds the

capacity of primary memory. In such cases, the replaced items must later be retrieved from secondary memory.

Research has shown that both the ability to retrieve items from secondary memory and the ability to maintain information in primary memory are important for individual differences in working memory capacity (Unsworth & Engle, 2007b). Retrieval from secondary memory has also been found to be predictive of higher order cognitive abilities. For example, Unsworth and Spillers (2010) found, using confirmatory factor analysis, that attention control, working memory capacity, and secondary memory were best modeled with three correlated but distinct factors, and that all three were correlated with fluid intelligence. The Unsworth and Spillers results also suggested that much of the variance shared between working memory capacity and fluid intelligence was also shared by both secondary memory and attention control.

Successfully retrieving information from secondary memory involves restricting the search set to only relevant information and resisting interference from irrelevant information (Unsworth & Engle, 2007b). Individual differences in susceptibility/resistance to interference have also been reported as being related to higher order cognitive abilities. For example, when proactive interference is built up across trials of a complex working memory span task by including multiple lists of words from the same semantic category, the correlation between working memory and fluid intelligence increases with the level of proactive interference (Bunting, 2006). Additionally, Lustig, May, and Hasher (2001) demonstrated that when the amount of interference in a complex working memory task is reduced, the correlation between working memory and prose recall drops significantly.

Similarly, the complex associative learning task involves retrieval from secondary memory when participants are asked to recall previously learned associations. The task also may require some level of interference control, especially initially when associations are still rather weak given that there are ten words associated with each of the three cues (A, B, and C). It therefore seems possible that the relationship between complex association learning and fluid intelligence could at least be partially due to individual differences in retrieval ability, and it is the purpose of the current study to investigate this possibility. Retrieval ability is often measured using recall of word lists, picture memory, paired associate memory, or supraspan list lengths (Shelton, Elliot, Matthews, Hill, & Gouvier, 2009; Unsworth & Engle, 2007b; Unsworth & Spillers, 2010). However, these measures may also reflect differences in encoding that potentially could affect estimates of retrieval. Therefore, the verification task that is part of the fan effect procedure, in which retrieval of over-learned information is measured, was used as an independent measure of retrieval efficiency. Importantly, this verification task measures both of the aspects of retrieval (i.e., reactivation and interference control) cited previously as important in predicting fluid intelligence (Bunting, 2006; Lustig, May, & Hasher, 2001; Unsworth & Engle, 2007; Unsworth & Spillers, 2010). In addition, there are also structural similarities present between the complex associative learning task and the fan effect procedure.

The fan effect refers to the classic finding that the time required to verify information stored in memory increases with the number of associated items (i.e., fan size) (Anderson, 1974). In the traditional fan effect paradigm, a series of sentences are learned, each one with the structure, "The [person] is in the [place]." While either the

people or places can serve as the organizing dimension (Sohn, Anderson, Reder & Goode, 2004; Anderson, 1974), it is common for the task to be organized around the people. When this is the case, each person typically is then associated with one, three, or four places, and each place is also associated with multiple people (i.e., the places are also repetitive, creating overlap between the sentence sets). Individuals are asked to learn several groups of sentences at each fan size. Study-test cycles repeat until the sentences have been successfully learned, determined by the number of correct recollections, at which time a series of both studied and new sentences are presented for verification. It is in this verification stage when the fan effect is observed: On average, it takes more time to verify sentences about people who were associated with a greater number of places. A similar effect has also been found with error rates in that errors in the verification stage tend to increase with the number of associated places (Anderson & Reder, 1999).

Although other explanations now exist for the fan effect (e.g. the mental model theory, see Radvansky & Zacks, 1991; Radvansky, Spieler, & Zacks, 1993), the first was John Anderson's Adaptive Control of Thought (ACT) theory (Anderson, 1974), which has since been revised and is now the Adaptive Control of Thought – Rational (ACT-R) theory. This model suggests that the fan effect is the result of spreading activation in memory at retrieval: Activation spreads from the probe to the connected or associated items, and the time required to retrieve any of those items depends on the amount of activation (Anderson & Reder, 1999). While multiple variables may have an effect on an item's activation level (e.g., recency, frequency of study, and attentional weight), the one perhaps most relevant in the traditional fan effect is the number of items associated together. The amount of activation available in long-term memory is assumed to be

limited, and so as the number of associated items increases, the amount of activation available to spread to each decreases (Anderson & Reder, 1999). This then results in longer verification times for information with a greater number of associates. Importantly, the ACT-R theory suggests that competition among learned information, or interference, at retrieval plays an important role, and in fact, interference is a term used by Anderson and colleagues when summarizing the cause of the fan effect (Anderson & Reder, 1999; Sohn et al., 2004).

The fan effect has been shown to be quite robust at the group level, and it has been utilized to explore questions in numerous areas of psychological research, including prospective memory (Cook, Marsh, Hicks, & Martin, 2006) and cognitive aging (Radvansky, Zacks, & Hasher, 1996). However, relatively little research has been done on individual differences in the fan effect. A notable exception is a study by Cantor and Engle (1993), who addressed this issue in the context of a general capacity model of working memory, which suggests that limits seen in working memory capacity are primarily the result of limited activation in long-term memory. To measure potential individual differences in long term memory activation, Cantor and Engle calculated participants' response time slopes from the verification phase of the fan effect task. They reported these fan effect slopes were predictive of verbal ability, as measured by the verbal section of the SAT, and that the slopes accounted for the variance in verbal ability that would have been attributed to working memory. In addition, Cantor and Engle reported working memory span differences in the fan effect, in that low spans showed an exaggerated effect (i.e., low spans showed a greater increase in response time with

increases in fan size than did high spans). This was interpreted as evidence for low span

individuals having less activation available to them.

Overall, Cantor and Engle (1993) concluded that individual differences in long

term memory activation, as it relates to retrieval ability, was at least partially responsible

for the relationship between working memory and verbal ability. However, Bunting,

Conway, and Heitz (2004) came to a different conclusion regarding working memory and

the fan effect, one more consistent with the idea of the importance of interference control.

Bunting et al. were able to replicate the working memory span differences found in the

fan effect by Cantor and Engle, but went on to demonstrate that these span differences

largely disappear when interference among the learning sets is removed (i.e., each place

is made to be unique, and so only associated with one person). This suggests that what

appeared to be differences in the fan effect due to working memory may also be related to

differences in the ability to control interference among competing information. If the

associative learning task and the fan effect task are both tapping this aspect of retrieval,

this would at least partially explain why both predict fluid intelligence.

In addition, the complex associative learning task and the learning phase of fan

effect procedure have structural similarities. In both tasks, participants are asked to learn

items that are each associated with multiple other items. In the associative learning task,

these items are unrelated, one-syllable words: a series of ten primary words are each

associated with three secondary words. In the fan effect task, these items are the

sentences about people in places, with each person associated with between one and four

places. That multiple items are associated together creates competition and potential

interference at retrieval in both tasks. Additionally, in both tasks, learn-test cycles of the

same stimuli repeat multiple times, although the number of these repetitions differs. In the complex associative learning task, all participants complete four cycles, regardless of their performance, whereas in the learning phase of the fan effect procedure, participants complete as many cycles as necessary to reach a performance criterion, with the minimum number of required cycles being three. What is of primary interest in the two cases is also different: In the case of the complex associative learning task, it is the proportion of words correctly recalled, whereas in the case of the fan effect procedure the learning stage receives little attention and the focus is instead on the response times and error rates collected during the verification stage.

The learning phase of the fan effect procedure is clearly similar to the complex associative learning task, in that participants are asked to learn associative information. The learning phase of the fan effect procedure usually receives very little attention, however, because it is viewed as merely a way to ensure that participants have learned the sentences well enough so that when they move on to the verification stage, there will be enough correct responses to assess the fan effect. Instead, it is the response times during the verification phase that are thought to measure activation and retrieval ability, and it is these response times have been shown to be related to working memory and verbal ability (Cantor & Engle, 1993).

The purpose of the current study is to examine the relation between complex associative learning, the fan effect, and fluid intelligence by addressing two main questions. First, to what extent do the complex associative learning task and the fan effect task tap similar processes? If the complex associative learning task measures individuals differences in retrieval efficiency (i.e., the fan effect), then complex

associative learning performance will be correlated with individuals' response time

slopes in the verification phase of the fan effect task. Second, to what extent does the fan

effect explain, or at least partially explain, the relationship between associative learning

and fluid intelligence? If the predictive utility of the complex associative learning task for

fluid intelligence is due to retrieval efficiency, then fan effect task should attenuate the

relation between learning and fluid intelligence. However, if complex associative

learning is predictive of fluid intelligence because of learning as well as retrieval

efficiency, then the fan effect task should not fully attenuate this relation.

Method

Participants

Eighty-five undergraduates (46 female, mean age = 18.94, *SD* = .98) from

Washington University in St. Louis participated in this experiment to partially fulfill an

experimental credit requirement for psychology courses. Four additional participants

were not included in data analysis, one due to accuracy on the operation span task being

below the cut-off of eighty percent, and three because they did not complete the fan task.

Participants were excluded from participation if they had previously participated in

another study using the complex associative learning task. All participants reported

English as their primary language.

Materials

The experiment consisted of five computerized tasks and a pencil-and-paper

verbal SAT practice test. All computerized tasks were programmed using E-prime 1.2

(Psychology Software Tools, Pittsburgh, PA) and were presented to participants using a

17-inch touch screen LCD monitor. Participants made all responses in computerized tasks

using a computer mouse, the computer keyboard, or vocally (recorded using an Olympus VN-900PC digital recorder).

Procedure

Participants completed all tasks in one session, lasting approximately 2.5 hours. Participants performed the tasks in the following order: fan effect procedure, processing speed task, operation span, verbal SAT practice test, Raven's Advanced Progressive Matrices (RAPM; Raven et al., 1998), and complex associative learning task (Williams & Pearlberg, 2006). Participants were given a break after the operation span task, as well as when needed throughout the experimental session.

Fan effect procedure. This task was designed based on the fan effect procedure used by Cantor and Engle (1993), and the majority of the sentences used in the current study came from those experiments. However, the traditional paradigm only includes fan-size groups of one sentence, three sentences, and four sentences, with two groups at each fan-size level. In the current study, two fan-size groups of two sentences were added to increase the continuity of the data. Participants were therefore asked to learn a total of twenty sentences, organized into eight groups based on the number of places associated with the person in the sentences. The sentences for the two additional groups were taken from the material used by Bunting et al. (2004). Some of the sentences taken from Cantor and Engle were then adjusted to maintain the original structure of each place being associated with two people.

Participants first were instructed to learn a series of sentences, each with the structure, "The [person] is in the [place]" (e.g., The teacher is in the church.). Participants completed an initial study cycle in which sentences were presented grouped by person.

For example, participants saw all four sentences about the teacher on the same screen. The sentence groups were presented at a speed based on the size of the group, determined using the formula: $n(10s) + 10s$, where n was the number of sentences in the group (Cantor & Engle, 1993).

Once participants had been presented with all eight sentence groups, the initial recall stage began. Participants were shown the name of a person (e.g., teacher) at the top of the screen and were asked to type the sentences they remembered about that person one at a time into a text box. After typing one sentence, they pressed the Enter key and were then shown two boxes, one labeled "More" and one labeled "Done." If they remembered additional sentences about that person, participants were instructed to click "More," and if not, to click "Done" to move on to the next person. Participants recalled all sentences in this way for the duration of the task. Participants were not told at recall how many sentences there were for that person, and they did not receive feedback. Performance on the initial recall test was not included in the score.

Following the initial recall test, participants were presented with the same sentences one at a time and in a random order, at a pace of twenty seconds per sentence. Participants then were asked to again recall the sentences in the same way as was previously described. This cycle of learn-test was repeated until participants recalled all of the sentences in each sentence group correctly three times. As soon as this criterion was met for a sentence group, it dropped out of the cycle. Once participants reached the criterion for all sentence groups, they moved on to the final study phase, which was identical to the initial study phase (i.e., sentences were again presented in their respective groups, organized by person, rather than individually).

In the final phase of the task, the verification phase, participants were shown a series of both old (studied) and new (foil) sentences one at a time and were asked to respond as quickly and accurately as possible to the question, "Is this a sentence you studied?" Participants indicated their decision by pressing one of two keys on the keyboard. Foil sentences were again largely the same as those used in Cantor and Engle (1993), and included the same people and places as the studied sentences but were paired differently to create novel sentences. Where changes were made to accommodate the new sentence groups, the same pattern of novel pairing was used. The measure that is usually of primary interest in this task is the response times to studied and foil sentences during this final verification phase; the number of cycles required to reach the criterion for all sentences during the acquisition phase was also recorded.

Processing speed task. Participants were presented with words one at a time on the computer screen. Each word was either the name of an animal (e.g., bear) or a fruit/vegetable (e.g., lime). Participants were asked to respond to the question of whether or not each word was the name of an animal by pressing one of two keys on the keyboard. As soon as a response was made, participants were shown the next word. Participants were instructed to respond as quickly and accurately as possible, and response time and accuracy were recorded.

Operation span. In this verbal complex working memory task (Turner & Engle, 1989), participants were instructed to remember a series of words. Before the presentation of each word, participants were shown an arithmetic equation (e.g., $(4 \times 2) - 1 = 5$). They were instructed to read each equation out loud and decide whether the given solution was correct, indicating this decision by pressing one of two keys on the

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keyboard. At the end of each series, participants were prompted to recall all the words from that series out loud and in the exact order of presentation. Participants then pressed the spacebar to move on to the next series. The number of words per series ranged from two to seven, and participants completed two test trials of each length for a total of twelve trials. The series lengths were presented in a random order that was the same for all participants. Prior to the test trials, participants completed six practice trials consisting solely of equations and four practice trials that included both equations and words. A proportion correct scoring procedure (Unsworth & Engle, 2007a) was used, in which participants were awarded one point for each correctly recalled word in the correct serial position. Point totals were summed across the twelve trials for a measure of working memory capacity.

Verbal SAT practice test. In order to assess verbal ability, participants were asked to complete one verbal section of a SAT practice test (Section 2 of Practice Test 2; Robinson, Katzman, et al., 2009). This section was made up of eight sentence completion questions, four reading comprehension questions based on two short passages, and twelve reading comprehension questions based on one long passage. Participants had 25 minutes to answer as many of the 24 questions as possible. All participants completed all 24 questions in the allotted time. The questions used in the practice tests were taken from SAT tests from 1981-1984 and 1992. Performance was measured as the number of questions answered correctly.

Raven's Advanced Progressive Matrices (RAPM). This task was a computerized version of the odd items from the second set of RAPM (Raven et al., 1998). On each trial, participants saw a 3 x 3 matrix of patterns with the lower right hand pattern removed.

Participants were given eight possible solutions and were asked to choose the pattern that best completed the matrix. Participants were also given a "Do Not Know" option. Participants were given ten minutes to complete as many of the eighteen items as possible. Performance was measured as the number of problems answered correctly.

Complex associative learning task. In this task (Williams & Pearlberg, 2006), participants were instructed to learn associations between a primary word (e.g., lie) and three secondary words (e.g., fan, rim, day). Participants first saw the primary word, and then were prompted to press the "A" key. After pressing the "A" key, participants saw an associated secondary word, and were instructed to press "Enter" when they were ready. Participants were then instructed to press the "B" key and the "C" key, with each action resulting in the presentation of an associated secondary word. Participants saw ten primary words, each of which was associated with three secondary words, one for each of the three cues (i.e., A, B, and C), for a total of thirty word associations. After all thirty associations were presented, participants were tested. In the test trials, a primary word and one of the three cues (i.e., A, B, or C) appeared, and participants were asked to type the corresponding secondary word into a text box. Participants were tested over all associations, and then moved on to a second learning phase. The primary words were presented in a random order at test, and participants were prompted to recall all three secondary words for that primary word, in the A-B-C order, before moving on to another primary word. This learn-test cycle was repeated a total of four times. All trials were self-paced, and accuracy during the tests was recorded. The proportion of correct trials was averaged across the four tests and was used as a measure of learning ability.

Results

Descriptive statistics for performance on all six tasks are presented in Table 1.

Both accuracy and response time in the verification stage of the fan task were analyzed

using 2 (sentence type: studied and foil) x 4 (fan size: 1, 2, 3, and 4) repeated measures

ANOVAs. With respect to accuracy, there was no main effect of sentence type and no

interaction between fan size and sentence type, both Fs < 1.0. There was a main effect of

fan size, $F(3,252) = 4.66$, $p = .003$, reflecting the fact that accuracy decreased slightly as

a function of fan size, although it should be noted that accuracy was greater than 95%, on

average, for all fan sizes. Importantly, the decrease in accuracy with fan size is the

opposite of what would be expected if the fan effect on response times were a result of a

speed-accuracy tradeoff. With respect to response time, the repeated measures ANOVA

revealed main effects of both fan size, $F(3, 252) = 16.76$, $p < .001$, and sentence type,

$F(1, 84) = 86.76$, $p < .001$, but no size x type interaction, $F(3, 252) = 1.88$, ns. Although

response times to foil sentences were longer on average than studied response times,

response times increased with fan size to the same degree for both studied and foil

sentence. Therefore, following Cantor and Engle (1993), response times on studied and

foil sentences were combined when calculating slopes. At the individual level, response

times were strongly correlated with fan size (mean $r = .59$, $SD = .27$), indicating that the

slope of the regression of response time on fan size provided an appropriate measure of

the fan effect.

On the complex associative learning task, a one-way repeated measures ANOVA

revealed a significant effect of test block, $F(3, 252) = 385.17$, $p < .001$, reflecting the fact

that performance improved systematically across the four blocks (mean performance on

Table 1.
Descriptive Statistics for All Measures

Task	M	SD
Fan: Cycles to Criterion	4.54	1.2
Fan Size 1 RT	1443.6	413.8
Fan Size 2 RT	1610.1	449.1
Fan Size 3 RT	1720.1	469.5
Fan Size 4 RT	1688.5	437.4
Fan Slope	85.2	94.3
Associative Learning	.58	.21
RAPM	.65	.15
Verbal SAT	.79	.13
Operation Span	.46	.17
Processing Speed Tasks	609.1	67.6

Note. Fan Size RTs, Fan Slope, and Processing Speed data are in milliseconds. Learning, RAPM, SAT are measured as the proportion of items correct, and Operation Span as the proportion of items recalled correctly in the correct position.

the first test: .25, SD = .21; mean performance on the fourth test: .80, SD = .21).

Performance on the first test was taken as a measure of secondary memory, and following

Williams and Pearlberg (2006; see also Tamez, Myerson, & Hale, 2008), the average

number of items correct across all four tests was taken as a measure of learning (i.e., how

much information could be accumulated in secondary memory given repeated exposure

and retrieval practice).

The correlations among the various measures are presented in Table 2. Complex

associative learning was found to be correlated significantly with both working memory

and fluid intelligence, replicating previous studies. However, the current results did not

replicate Tamez et al. (2008) in that when submitted to a hierarchical regression analysis,

complex associative learning did not account for additional fluid intelligence variance

when added to the model after working memory (see Table 3, Models 1 and 2). There

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Table 2.
Correlations

Variable	1	2	3	4	5	6
1. Fan Cycles	-					
2. Fan Slope	-.20	-				
3. Assoc. Learning	-.33	-.13	-			
4. Operation Span	-.23	-.11	.52	-		
5. Secondary Memory	-.18	-.24	.84	.51	-	
6. Verbal SAT	-.25	-.03	.09	.24	.04	-
7. RAPM	-.29	-.14	.23	.32	.21	.31

Note. Significant correlations are in bold. Correlations >.21 are significant at $p < .05$; correlations >.29 are significant at $p < .01$.

was also a significant correlation between complex associative learning and the number of cycles required to reach the performance criterion during the learning phase of the fan effect task. This cycles-to-criterion measure was also correlated significantly with fluid intelligence (see Table 2), and hierarchical regression revealed that associative learning and cycles-to-criterion measure seem to be accounting for overlapping fluid intelligence variance. However, it was the case that associative learning did not account for any additional fluid intelligence variance when added to the model after cycles-to-criterion (see Table 3, Models 3 and 4). In addition, cycles-to-criterion was correlated with working memory performance, and did predict fluid intelligence beyond the contribution of working memory (see Table 3, Models 5 and 6).

Fan effect slopes were not significantly correlated with working memory, fluid intelligence, verbal SAT performance, or complex associative learning. When the correlations between the fan effect task and the four test blocks of the associative learning task were examined separately, however, the slopes were significantly correlated with performance on the first test block of the complex associative learning task ($r = -.244$),

Table 3.

Summary of Hierarchical Regression Analysis for Variables Predicting Fluid Intelligence

Predictor	R^2	ΔR^2	$F(\Delta R^2)$	df
Model 1				
1. Associative Learning	.05	.05	4.78*	1, 83
2. Working Memory	.11	.05	5.01*	1, 82
Model 2				
1. Working Memory	.10	.10	9.52**	1, 83
2. Associative Learning	.11	.01	0.56	1, 82
Model 3				
1. Associative Learning	.05	.05	4.78*	1, 83
2. Fan Cycles	.11	.05	4.79*	1, 82
Model 4				
1. Fan Cycles	.09	.09	7.76**	1, 83
2. Associative Learning	.11	.02	1.95	1, 82
Model 5				
1. Fan Cycles	.09	.09	7.76**	1, 83
2. Working Memory	.15	.07	6.52*	1, 82
Model 6				
1. Working Memory	.10	.10	9.52**	1, 83
2. Fan Cycles	.15	.05	4.84*	1, 82

Note. * $p < .05$, ** $p < .01$.

but not with the fourth and final block ($r = -.02$) or the average of all four blocks ($r = -.13$). As previously mentioned, performance on the first test in the associative learning task is considered to be a measure of secondary memory. Thus, it appears that the fan effect is related to secondary memory, as measured by performance in the complex associative learning task after a single exposure to associations, but not to complex associative learning as measured by the amount of information that can be accumulated in secondary memory with practice.

Both Cantor and Engle (1993) and Bunting et al. (2004) reported that individuals with low working memory span showed a greater fan effect than those with high working memory span. In the current study, a 2 (working memory span group: low quartile and high quartile) x 4 (fan size) ANOVA on response times did not provide evidence of such an interaction, $F < 1.0$. Although low spans were slightly slower than the high span group across all fan sizes, as can be seen in Figure 1, the main effect of span group was not significant, $F(1,42) = 1.63$, *ns*. Although they did not differ in the fan effect, the two working memory span groups did differ on other cognitive tasks. The high span and low span groups were significantly different in their performance on the RAPM, $t(42) = 3.48$, $p < .01$, the verbal SAT, $t(42) = 2.04$, $p < .05$, and the complex associative learning task, $t(41.62) = 4.52$, $p < .001$, with the high span group outperforming the low span group in each task. The low span group also took significantly ($t(42) = 2.09$, $p < .05$) more cycles to reach the criterion (i.e., recalling each sentence correctly three times) in the fan task than the high span group ($M = 4.95$, $SD = 1.21$, and $M = 4.27$, $SD = .94$, respectively).
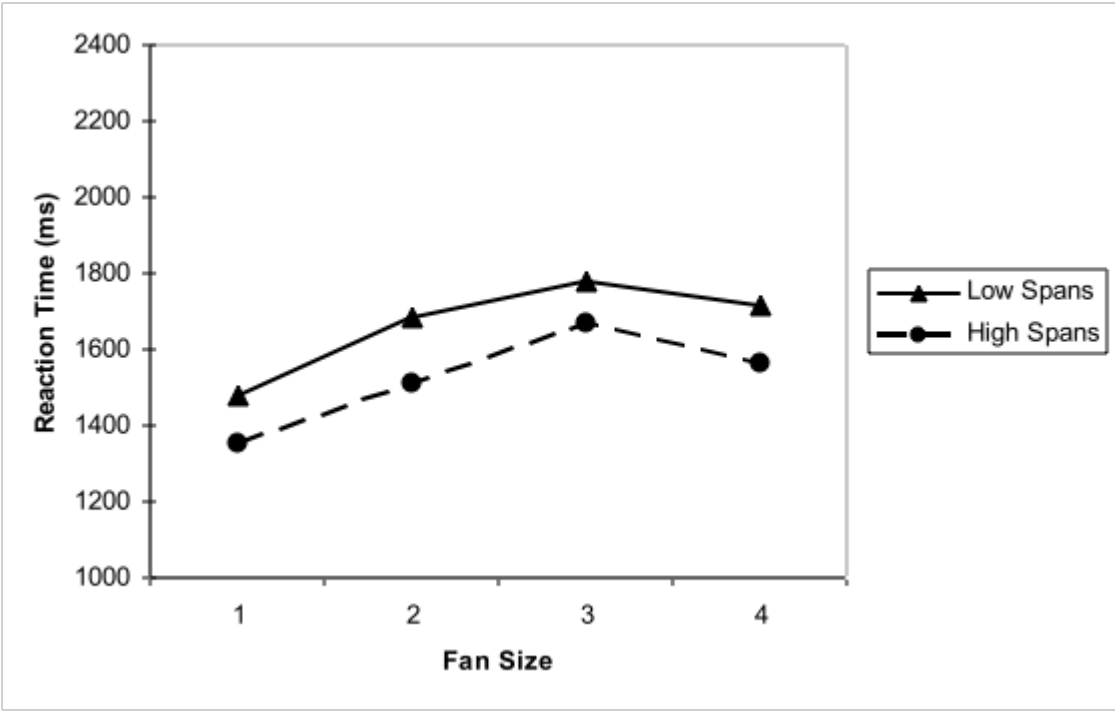
Figure 1. Mean response time (in milliseconds) in the verification phase of the fan task as a function of fan size for the low span and high span groups.

Discussion

The current study examined the relationship between complex associative learning, the fan effect, and fluid intelligence. More specifically, the aim was to test the hypothesis that the complex associative learning task is a good predictor of fluid intelligence because it is measuring the efficiency of retrieval in the face of competing associations.

The expected pattern of results within the task was found for both the complex associative learning task and the fan effect task, in that participants learned increasingly more associations across the four complex associative learning tests and that participants' response times during the verification phase of the fan effect procedure increased with fan size (i.e., the fan effect emerged). Consistent with previous findings, complex associative learning was correlated with both RAPM and working memory performance (Tamez et al., 2008; Kaufman, et al., 2009). Unlike Tamez et al., however, complex associative learning did not account for unique variance in RAPM beyond that accounted for by working memory. One possible reason for this is that Tamez et al. used the full RAPM (36 problems, 30 minutes to complete) whereas the current study used the half version of RAPM (18 problems, 10 minutes to complete) which necessarily resulted in the rules being repeated less often, potentially reducing the role of learning.

Importantly, the current study also found a significant correlation found between complex associative learning and the number of learn-test cycles participants took to reach the performance criterion in the learning phase of the fan effect procedure (i.e., the cycles-to-criterion measure), consistent with the structural similarity between the complex associative learning task and the learning phase of the fan effect procedure. That

is, in both cases participants are asked to learn multiple associations to individual items and then maintain these associations over time and multiple testing occasions. Thus, it appears that individual differences in the learning phase of the fan effect task may also be reflect individual differences in associative learning.

The complex associative learning task and the learning phase of the fan effect procedure are complementary measures of learning in that they each measure learning rate but in a different way. The complex associative learning task measures how many associations one can learn in a specified number of cycles, whereas the fan effect task measures how many cycles it takes for one to learn a specified number of associations. This cycles-to-criterion measure was also correlated significantly with RAPM, and so both learning measures were predictive of fluid intelligence. The fact that these two measures are correlated and that they are both correlated with RAPM to a similar degree is important, as these correlations suggest that the complex associative learning task really is tapping individuals' ability to learn associations. A multiple regression analysis revealed that when predicting RAPM, cycles-to-criterion accounted for unique variance beyond that accounted for by complex associative learning. When entered in the reverse order (i.e., cycles-to-criterion first), however, complex associative learning did not explain additional variance when added after cycles-to-criterion. While it is unclear why, in this case, the fan effect procedure's learning measure was more predictive of fluid intelligence than performance on the complex associative learning task, these results suggest the importance of learning for predicting individual differences in fluid intelligence.

In addressing the question of whether the complex associative learning task is measuring the efficiency of memory retrieval in the face of competing associations, one must consider the correlation between associative learning and individuals' fan effect slopes. This correlation was not significant, and so it does not appear that the complex associative learning task is tapping the same ability as the verification phase of the fan effect procedure. However, the fan effect slopes were significantly correlated with performance on the first test of the associative learning task, which is considered to be a measure of secondary memory. This suggests that retrieval efficiency may be an important component of the first test of the complex associative learning task. This may be because retrieval during this first test is perhaps most like retrieval during the verification stage of the fan effect procedure, in that associations are not yet tightly bound and cues are not yet distinctive, and so when participants are presented with a primary word and a cue (A, B, or C) during the first test of the complex associative learning task, multiple words may come to mind, as they do in the fan effect procedure.

When the associative learning task is considered as a whole (i.e., when performance is averaged across all four tests), however, the importance of retrieval efficiency decreases compared to when one only looks at performance on the first test. It is possible that it is one's ability to maintain the associative structure over time while also adding new information to it that becomes important in these later tests. While this question is still open, it does not appear that the complex associative learning task is simply measuring individual differences in the efficiency with which individuals can retrieve learned information.

The current study failed to replicate some of the findings reported by Cantor and Engle (1993), including differences in the fan effect between high and low working memory span groups. Although this is potentially concerning, there are some substantial differences between the current sample and that collected by Cantor and Engle. Cantor and Engle screened potential participants based on verbal SAT score, and chose them specifically to ensure a wide range of ability. Eight score ranges were targeted, ranging from 200-300 to 610 and above, with ten participants in each range. All participants in the current study completed a verbal SAT practice test, but in addition, those who had taken the SAT were asked to self-report their verbal scores. Out of the 85 participants, 53 reported a score, and 51 of these participants reported a score at or above 610, which would have put them in the top category in the Cantor and Engle study. Thus, the current sample appeared to represent a more restricted ability range, which may be responsible, at least in part, for the difference in the results. It may be noted that although Bunting et al. (2004) were able to replicate the working memory span differences in the fan effect reported in Cantor and Engle, they used a participant screening procedure based on working memory ability that, like Cantor and Engle, likely resulted in a greater range of ability than what was included in the current sample.

The current study also failed to replicate the correlations among fan effect slopes and other measures reported in Cantor and Engle, and this likely also reflects differences between the two samples. The current study's sample included a narrower and higher functioning range of ability than see in the general population, which may have resulted in reduced correlations. In addition, the sampling procedure used in Cantor and Engle

produced an artificially flat distribution, potentially inflating correlations and thus further exaggerating the differences between the two samples.

The complex associative learning task and the fan effect procedure are indeed structurally similar in that both ask participants to learn and maintain mutliple associations over time and deal with potential interference among learning sets. However, the idea that the complex associative learning task is measuring retrieval efficiency in a similar way as the verification phase of the fan effect task was not supported by the current results, as the correlation between associative learning performance and individuals' fan effect slopes was not significant. Overall, the results of the current study support the idea that complex associative learning is an important predictor of fluid intelligence. In addition, the results suggest that the associative earning task is similar to other measures of learning and may be complementary to measures such as the rate of acquisition in the learning phase of the fan effect procedure.

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