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Short communication

Learning, working memory, and intelligence revisited

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Abstract

Based on early findings showing low correlations between intelligence test scores and learning on laboratory tasks, psychologists typically have dismissed the role of learning in intelligence and emphasized the role of working memory instead. In 2006, however, B.A. Williams developed a verbal learning task inspired by three-term reinforcement contingencies and reported unexpectedly high correlations between this task and Raven's Advanced Progressive Matrices (RAPM) scores [Williams, B.A., Pearlberg, S.L., 2006. Learning of three-term contingencies correlates with Raven scores, but not with measures of cognitive processing. Intelligence 34, 177–191]. The present study replicated this finding: Performance on the three-term learning task explained almost 25% of the variance in RAPM scores. Adding complex verbal working memory span, measured using the operation span task, did not improve prediction. Notably, this was not due to a lack of correlation between complex working memory span and RAPM scores. Rather, it occurred because most of the variance captured by the complex working memory span was already accounted for by the three-term learning task. Taken together with the findings of Williams and Pearlberg, the present results make a strong case for the role of learning in performance on intelligence tests.

Keywords: Intelligence; Learning; Three-term contingency

1. Introduction

Although psychologists generally agree on the importance of assessing intelligence, there has never been a consensus as to the exact nature of this construct (Intelligence and its Measurement: A Symposium, 1921; Neisser, 1981; Neisser et al., 1996; Sternberg and Detterman, 1986). There is even a lack of agreement on whether intelligence is comprised of one factor ('*g*'; Jensen, 1968; Spearman, 1927), two factors, (e.g., fluid vs. crystallized; Horn and Cattell, 1966), or many factors (e.g., either multiple factors or a hierarchy of factors; Carroll, 1993; Sternberg, 1985).

Recently, there has been growing interest in the relation between working memory and intelligence. Indeed, some researchers (e.g., Engle et al., 1999; Engle, 2002; Kyllonen and Christal, 1990) have claimed that working memory capacity *is* intelligence. In contrast, Ackerman et al. (2002, 2005) argued, based on both a single study including an unusually large number of ability measures and a meta-analysis of 86 samples, that working memory and intelligence are not isomorphic, and that working memory is just one of a number of highly correlated abilities.

In the midst of the controversy concerning the role of working memory and intelligence, a new study by Williams and Pearlberg (2006) suggests that learning, in particular learning three-term contingencies, may be even more predictive than working memory in predicting intelligence (Snow et al., 1984). The Williams and Pearlberg findings stand in contrast to early findings showing low correlations between learning on laboratory tasks and intelligence test scores (Woodrow, 1938, 1946), which caused many researchers to dismiss the role of learning in intelligence.

In their first experiment, Williams and Pearlberg (2006) found that their three-term learning task correlated with the Raven's Advanced Progressive Matrices (RAPM) (Raven et al., 1998), but two other learning tasks (i.e., free recall and paired associates) did not. In a second experiment, they observed that the three-term learning task did not correlate with working memory and processing speed, despite the fact that these measures also correlated with the RAPM, which is the "gold standard" measure of fluid intelligence. Taken together, these findings strongly suggest that learning may be an important contributor of unique variance in intelligence test scores, contrary to previous reports

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that individual differences in working memory capacity explain nearly all of the variance.

Most studies examining the correlations among several cognitive tests report positive correlations between all cognitive measures (for a review, see Ackerman et al., 2005), which are presumed to indicate the existence of a general ability ("*g*") common to all measures (Spearman, 1927). Williams and Pearlberg's failure to find significant correlations between their learning task and speed and working memory is contrary to such findings. To further test whether learning and working memory make independent contributions to predicting performance on intelligence tests, the present study examined the relation between three-term contingency learning (using both a verbal and nonverbal version of this task), working memory (using both verbal and nonverbal), and fluid intelligence (using the RAPM).

2. Method

2.1. Participants

Sixty Washington University undergraduates (30 male and 30 female) participated. Participants completed a health questionnaire form to screen for visual problems, neurological disease, and depression. In addition, a near vision acuity test was administered using a Wormington Card (Guilden Ophthalmics, Elkin Parks, PA) to ensure that participants would be able to accurately perceive the stimuli on the computer screen.

2.2. Apparatus

Stimuli for the computerized tasks were presented on a 30 cm × 23 cm flat screen monitor equipped with Touchware Software S64 SR4 (3M Touch, St. Paul, MN). All computerized tasks were programmed in E-prime 1.1 (Psychology Software Tools, Pittsburgh, PA). Responses were made either using a computer mouse, the computer keyboard, or vocally (and recorded using an Olympus VN-900PC digital recorder).

2.3. Procedure

Each participant completed a 2-h session individually. Following the health questionnaire and vision test, participants performed the following sequence of tasks: the WAIS – III vocabulary test (Psychological Corporation, 1997), the verbal three-term learning task, a verbal working memory task, the RAPM, a nonverbal three-term learning task, and two nonverbal working memory tasks. Participants were given a brief break every 30 min throughout the session.

2.3.1. Verbal three-term contingency learning task

In this verbal learning task (Williams and Pearlberg, 2006), participants were told to learn the associations between each of the ten cue words (e.g., lie) and the list of three associated memory items (e.g., fan, rim, dry). There were four blocks of learning trials, each of which was followed by a test block. Both the learning and test blocks were self-paced.

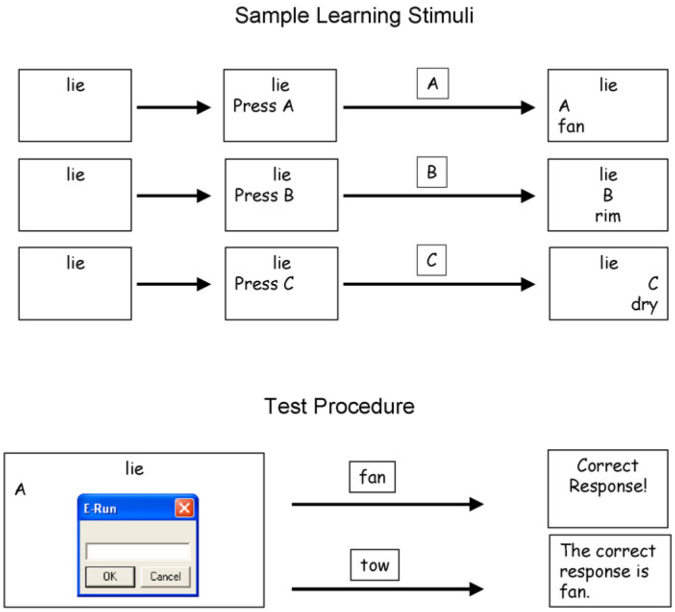

Fig. 1. Examples of learning and test trials from the verbal three-term learning task.

On learning trials, participants were first shown a cue word (e.g., lie) followed by the prompt, "press A", as shown in Fig. 1. Once the participant pressed the cued letter, the prompt disappeared and the cued letter "A" and the associated memory item (e.g., fan) appeared in the bottom right hand of the screen. The cue word, letter, and the memory item remained on the screen until the participant pressed the enter key. Then, the cue word (i.e., lie) was shown again followed by the second prompt (i.e., "press B") and after pressing the cued letter, the letter "B" and the second memory item (e.g., rim) remained on the screen until the participant pressed enter. The third prompt (i.e., "press C") then appeared beneath the cue word. Again, the prompt disappeared once the participant pressed the cued letter, and the letter "C" and the third memory item (e.g., dry) appeared in the bottom left of the screen. For each learning block, this cycle was repeated until all of the 10 cue words with their 3 associated memory items had been presented. The order of presentation for the 10 cue words and their associated memory items was different in each of the 4 learning blocks.

On test trials, the participant viewed a cue word and the first prompt (i.e., "A"), as well as a textbox located in the bottom center of the screen (see Fig. 1). The participant was asked to recall the word associated with the cue word and prompt by typing the correct word into the textbox. For example, if the participant saw the cue word *lie* and the letter *A*, then the correct response was to type the word *fan* into the textbox. Alternatively, the participant could type the letter "x" into the textbox if the associated memory item could not be recalled. Participants were given feedback after each response (see Fig. 1). Next, the participant was shown the same cue word followed by the second prompt (i.e., "B") and a textbox and then the third prompt (i.e., "C) and a textbox. The 10 cue words and the 3 prompts constituting the test block were presented in the same order as in the preceding learning block. Following Williams and Pearlberg (2006), performance

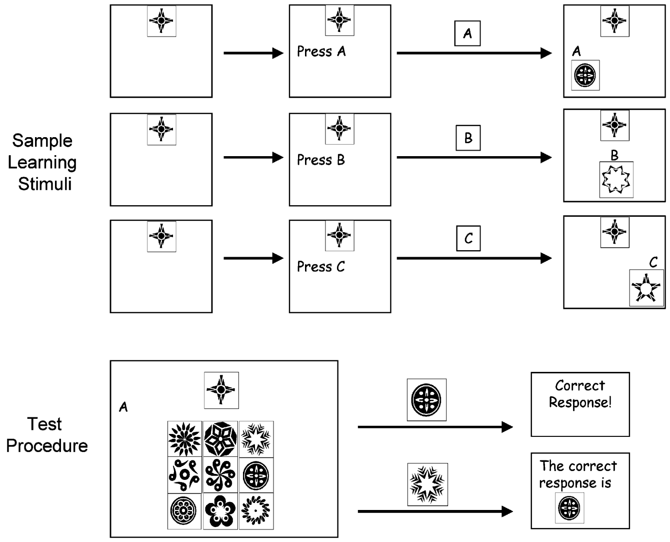

Fig. 2. Examples of learning and test trials from the nonverbal three-term learning task.

was measured as the number of items correct, summed across all four-test blocks.

2.3.2. *Nonverbal three-term contingency learning task*

This task was a nonverbal adaptation of the verbal three-term learning task that was also self-paced and consisted of four learning blocks, each of which was followed by a test block. The procedure for this task was identical to the procedure for the verbal three-term learning task with the exception that the stimuli were patterns and the test trials involved recognition rather than recall (see Fig. 2).

Test trials began with the participant seeing a cue pattern and the first prompt, “A.” Instead of a text box, however, the participant had to select the correct pattern, using the computer mouse, from nine different patterns (eight of which were distractors) displayed in a ‘pattern recognition’ box in the center of the screen (see Fig. 2). Alternatively, the participant could select the letter “x” if none of the patterns seemed to be correct. As in the verbal learning task, participants were given corrective feedback after each response. The participant then saw the same cue pattern with the second prompt and recognition box followed by the third prompt and recognition box. The patterns in the recognition box were different for each cue pattern and prompt but remained constant across trials although the locations of the patterns within the recognition box varied randomly. Participants completed a total of four learning trials and four test trials.

2.3.3. *Operation span*

In this verbal working memory task (Turner and Engle, 1989), participants were shown a series of arithmetic equations, some correct and some not (e.g., $(2 \times 2) + 1 = 4$), each of which was followed by a word to be recalled at the end of the series. Series length ranged from two to seven items. The series lengths were presented in a random order, which was the same for each participant, with two trials at each series length. Participants completed 6 practice trials with equations only followed by 10 practice trials with both equations and memory items before beginning the actual test trials.

Each series began with presentation of a green fixation cross, which remained on the screen until the participant pressed the spacebar to begin, at which point an arithmetic equation appeared. The participant then read the equation aloud and indicated whether it was correct or not by pressing either the right or left mouse button, respectively. If the participant failed to respond within 10 s, an error was recorded. Following each equation, a word was presented in the center of the screen for 1.5 s, and the participant read the word aloud. At the end of the series, participants were asked to recall all of the words in the order in which they had appeared. After recalling as many words as possible, participants pressed the spacebar to begin the next series. Performance was measured as memory span, defined as the longest series length that could be reliably recalled in correct order (for details of the scoring procedure, see Hale et al., 1996).

2.3.4. *Grid span*

In this nonverbal working memory task, each series began with a green fixation cross that remained on the screen until the participants touched the cross to begin. Participants then saw a series of 4 × 5 grids, with a red X appearing in a random location in each grid. Each grid was presented for 1750 ms followed by a blank screen for 1 s. At the end of each series, participants were shown an empty green grid and touched all of the locations where an X had appeared that they could recall. Series length ranged from 2 to 11 items. Participants completed four practice trials before beginning the test trials, consisting of two trials at each series length presented in a random order. Performance was measured as memory span, defined as the longest series length that could be reliably recalled, irrespective of order (Hale et al., 1996).

2.3.5. *Align span*

This nonverbal working memory task was similar to the grid span task except that participants performed a secondary task between grid presentations. Participants saw a series of 4 × 5 grids containing a red dot and two white dots and indicated aloud whether the dots formed a straight line or not. Each grid was presented for 2 s followed by a blank screen for 1 s. At the end of each series, an empty green grid was presented, and the participant touched all the red dot locations that could be recalled. Series length ranged from two to eight items. Participants completed four practice trials before beginning the test trials. Performance was measured as memory span, defined as the longest series length that could be reliably recalled, irrespective of order (Hale et al., 1996).

2.3.6. *Raven’s Advanced Progressive Matrices (RAPM)*

A computerized adaptation of the second set of 36 problems from the RAPM was used. On each trial, participants saw a 3 × 3 matrix of patterns from which the lower right-hand pattern was missing. Participants used the mouse to indicate which pattern out of eight choices best completed the matrix. Alternatively, they could select a “do not know” option. Participants

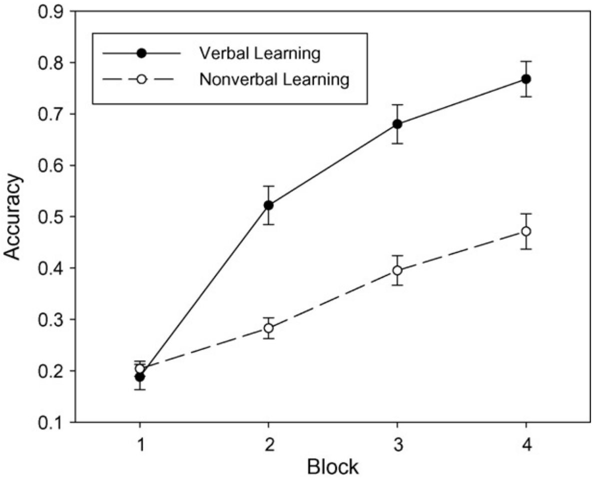

Fig. 3. Accuracy (proportion correct) by block on the verbal three-term learning task and the nonverbal three-term learning task. Error bars indicate standard errors.

Table 1
Descriptive statistics for experimental tasks

Task	Mean	S.D.	Range
Operation span	3.7	1.2	1.0–6.5
Grid span	9.2	2.5	3.0–14.0
Align span	5.1	1.7	1.0–8.0
RAPM	22.8	5.9	10.0–33.0
Verbal learning, total correct	64.7	28.4	5.1–116.1
Nonverbal learning, total correct	40.6	19.9	3.9–93.9

were given 30 min to complete this task. Prior to this deadline, if a participant failed to answer five out of the last six consecutive trials correctly, the task was automatically terminated.

3. Results

Performance on both the verbal and nonverbal three-term contingency learning tasks improved over blocks, but it improved at a faster rate for the verbal learning task (see Fig. 3). Performance on both tasks was highly consistent across the last three blocks (Cronbach's alpha = .96 and .89, respectively). There was a wide range of individual performance on all tasks (see Table 1).

The total score on the verbal learning task was highly correlated with the RAPM (see Table 2 for the inter-correlations for all the tasks). Total score on the nonverbal learning task was also correlated with the RAPM, although this correlation was somewhat lower. Performance on both learning tasks was also correlated with two of the three working memory measures: operation span and grid span. The correlation between the verbal learning task and the third working memory measure (align span) was at the trend level ($p = .078$).

Table 2
Intercorrelations between variables

	1	2	3	4	5	6
1. Operation span	1					
2. Align span	.258*	1				
3. Grid span	.391**	.598**	1			
4. Verbal learning, total	.457**	.229	.399**	1		
5. Nonverbal learning, total	.324*	.124	.292*	.628**	1	
6. RAPM	.395**	.122	.439**	.489**	.369**	1

$^{*}p < .05$; $^{**}p < .001$.

Table 3
Summary of hierarchical regression analysis for variables predicting fluid intelligence

Variable	ΔR^2	B
Step 1	.25**	
Grid span		.34*
Operation span		.26*
Step 2	.08**	
Grid span		.25*
Operation span		.15
Verbal learning, total		.32*
Nonverbal learning, total		.08

$^{*}p < .05$; $^{**}p < .001$.

Multiple regression analyses were conducted in order to determine the relative contributions of learning and working memory to predicting fluid intelligence. Because three-term contingency learning and working memory were correlated (Table 2), we conducted a hierarchical regression analysis to determine whether learning made a unique contribution to predicting fluid intelligence. To this end, grid span and operation span (the working memory measures correlated with the RAPM) were entered in the first step, and the verbal and nonverbal learning tasks were entered in the second step. As shown in Table 3, working memory accounted for 25% of the variance in RAPM scores (Step 1), and the learning tasks accounted for an additional 7.5% of the variance (Step 2).

In order to determine why the operation span task and the nonverbal learning task were not significant predictors of fluid intelligence at Step 2 in the preceding analysis, another analysis was conducted to examine how these two measures were related to performance on the verbal learning task. Regression analysis revealed that both operation span and nonverbal learning were significant predictors of verbal learning performance, together accounting for 47% of the variance. Operation span contributed only 7.2% of unique variance, whereas nonverbal learning uniquely accounted for 25.7% of the verbal learning-related variance. In addition, both operation span and nonverbal learning shared considerable variance (13.7%). Taken together, these results suggest that the verbal three-term learning task itself reflects a general learning ability that is partially dependent on working memory capacity.

These results suggest that in Step 2 of our first regression analysis, the verbal three-term learning task accounted for the all of the same variance as the operation span task and the nonverbal three-term learning task, and in addition, contributed a substantial portion of unique variance. Given that only verbal learning and grid span were significant predictors of fluid intelligence in Step 2, a final set of regression analyses were conducted using only these two variables as predictors of fluid intelligence, one with verbal learning entered first and the other with grid span entered first. Together these variables accounted for 31.0% of the variance in RAPM scores. The two tasks shared a considerable portion (12.2%) of this variance and the verbal learning task uniquely accounted for an additional 11.7%, whereas the unique contribution of the grid span task was 7.1%.

4. Discussion

The correlation between the verbal three-term contingency learning task and performance on the RAPM was nearly .50, comparable to the correlation reported by Williams and Pearlberg (2006) and substantially stronger than what is typically reported for operation span (Conway et al., 2005). In the present study, the correlation between operation span and RAPM was nearly .40, yet it did not account for any variance in RAPM performance over and above that explained by the verbal learning task. The failure of the operation span task to uniquely contribute to prediction of RAPM performance is due in part to the correlation between the verbal learning task and operation span, so that the verbal three-term learning task explained all of the RAPM variance that could be explained by operation span as well as additional variance.

Thus, although Williams and Pearlberg's (2006) three-term contingency learning task appears to be a good predictor of fluid intelligence, our findings suggest that it is not unique in the sense suggested by their original results. That is, contrary to their findings, the verbal three-term learning task is correlated with other cognitive measures, and shares considerable RAPM-related variance with them. Not only was the verbal learning task correlated with operation span, it was even more strongly correlated with grid span, a simple span task measuring nonverbal (visuospatial) working memory. Moreover, grid span accounted for both unique and shared variance in RAPM scores, replicating the relation between visuospatial working memory tasks and reasoning ability reported by other researchers (Ackerman et al., 2005; Kane et al., 2004; Lecerf and Roulin, 2006).

Surprisingly, align span, a complex visuospatial span task, was not significantly correlated with the RAPM or with either of the two learning tasks in the present study. Previous studies have reported significant correlations between the RAPM and other complex visuospatial span tasks (Ackerman et al., 2005; Kane et al., 2004; Lecerf and Roulin, 2006), and further research will be needed to determine why align span failed to conform to this pattern.

The nonverbal three-term contingency learning task correlated with the RAPM, but less strongly than either the verbal learning task or the grid span task, a nonverbal working memory measure. Moreover, the nonverbal learning task failed to contribute unique variance to RAPM scores, over and above that explained by the verbal learning task. These results, taken together with the strong correlation between the two learning tasks (>.60), suggest that the verbal learning task was able to capture a general learning ability that predicts RAPM, a nonverbal measure of fluid intelligence.

The fact that the nonverbal three-term learning task was not as highly correlated with the RAPM as the verbal three-term learning task may reflect the restricted range of scores arising from the difficulty of the nonverbal task as well as motivational problems arising from its greater difficulty (see Table 1 and Fig. 3). Indeed, nine participants' performance on the nonverbal learning task actually declined from the first to last test trial, whereas all participants improved on the verbal learning task. Moreover, when these nine participants were excluded from the analysis, the correlation between the nonverbal learning task and RAPM increased from .37 to .43. An important goal for future research will be to develop a version of the nonverbal learning task that is more comparable to the verbal learning task in terms of the level of the difficulty. This will make it possible to better determine whether the nonverbal learning task can account for as much RAPM-related variance as the verbal learning task and the extent to which that variance is shared between verbal and nonverbal learning.

Williams and Pearlberg (2006) have argued that three-term contingencies are basic units of learning, and that the strength of the relation between performance on the RAPM and word association task, which is based on such contingencies, is due to their unique characteristics. Williams and Pearlberg reported that simple learning tasks such as paired associate learning do not correlate with RAPM while the three-term contingency learning task does, but it remains unclear whether the strong correlation between this new learning task and RAPM is due to "three-term contingency learning." One alternative interpretation might be that it is the structure of the learning material, which could be thought of as 10 lists of 3 words each, that is critical. Recently, however, Williams (personal communication) has conducted additional experiments that make this 'list of lists' interpretation less likely. Future research including additional three-term contingency tasks, particularly ones which are more similar to the kinds of contingencies studied in research on operant conditioning, will be needed in order to establish a relation between three-term contingency learning and fluid intelligence. We would emphasize, however, that while the best interpretation of the relation between the verbal learning task and fluid intelligence is still unclear, what is clear is that the verbal three-term contingency learning task does correlate exceptionally well with the RAPM and captures unique variance that is not captured by other cognitive measures.

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