Associative learning predicts intelligence above and beyond working memory and processing speed

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3. **ABSTRACT**

Recent evidence suggests the existence of multiple cognitive mechanisms that support the general cognitive ability factor (g). Working memory and processing speed are the two best established candidate mechanisms. Relatively little attention has been given to the possibility that associative learning is an additional mechanism contributing to g. The present study tested the hypothesis that associative learning ability, as assessed by psychometrically sound associative learning tasks, would predict variance in g above and beyond the variance predicted by working memory capacity and processing speed. This hypothesis was confirmed in a sample of 169 adolescents, using structural equation modeling. Associative learning, working memory, and processing speed all contributed significant unique variance to g, indicating not only that multiple elementary cognitive processes underlie intelligence, but also the novel finding that associative learning is one such process.

4. Ассоциативное научение предсказывает интеллект помимо рабочей памяти и скорости элементарных умственных процессов.

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5. На сегодняшний день предполагается наличие комплекса когнитивных механизмов, лежащих в основе генерального фактора способностей g. Рабочая память и processing speed – два основных "кандидата" этих механизмов. Сравнительно небольшое внимание уделялось возможности рассмотрения ассоциативного научения как дополнительного механизма, определяющего фактор g. Настоящее исследование посвящено проверке гипотезы, что ассоциативное научение, может вносить свой вклад в дисперсию g помимо рабочей памяти и processing speed. Данная гипотеза подтверждена в ходе исследования 169 испытуемых с использованием структрурно-линейного моделирования. Ассоциативное научение, рабочая память и processing speed вносят дифференцированный вклад в дисперсию g, показывая, что в основе интеллекта лежат не только элементарные когнитивные процессы, но также и ассоциативное научение.

6. Гипотеза исследования: **Ассоциативное научение, может вносить свой вклад в дисперсию g помимо рабочей памяти и скорости протекания простых умственных процессов.**

Цель: **Определить вносит ли ассоциативное научение вклад в дисперсию g помимо рабочей памяти и скорости протекания простых умственных процессов.**

Задачи: Провести измерение к способности ассоциативного научения, измерение рабочей памяти, измерение скорости элементарных когнитивных процессов, измерение психометрического интеллекта, вербальных способностей. На основании измеренного, путем структурно-линейного моделирования, проверить гипотезу исследования.

Испытуемые: 169 человек (54 муж и 116 жен) в возрасте 16-18 лет. Студенты Кембриджа.

Процедура: Тестирование проводилось в группах (полуторачасовые сессии). Испытуемые проходили тесты в одинаковой для всех последовательности. Участие оплачивалось по 20 фунтов стерлингов.

Используемы методики:

ASSOCIATIVE LEARNING TASKS

1. Three-term contingency learning (Williams & Pearlberg, 2006)

The Three-Term Contingency Learning (3-Term) task consists of four learning blocks, each followed immediately by a test block. In each learning block, participants were presented with 10 unique words. Each word was associated with three different words, contingent on a key press. The participants' task was to learn the word associated with each stimulus-response pair. For instance, on one trial the word “LAB” might show on the screen with the letters “A”, “B”, and “C” listed underneath. When participants selected “A”, they saw one association (e.g., PUN), when they selected “B”, they saw a second association (e.g., TRY), and when they selected “C” they saw a third association (e.g., EGG). The duration of exposure to each association was self-paced (max 2.5 s) with changeover intervals set at 0.2 s. After the single presentation of all ten stimulus words with the 30 outcome words, subjects were immediately presented with a test block.

The test blocks were identical to the learning blocks with one exception: instead of typing the letters “A”, “B”, or “C” to produce the outcome words on the screen, a stimulus word appeared on the screen along with one of “A”, “B”, or “C”, and participants were required to type in the outcome word corresponding to that stimulus-response pair. Together with feedback on their answer, the correct association was shown to the participants until they pressed “ENTER”, when the next stimulus word was presented. Once the test block was completed, participants immediately moved to a second learning block in which the same stimulus words were presented in a different order. Across the four test blocks, possible overall scores ranged from 0 to 120.

2. Paired–associates (PA) learning (Williams & Pearlberg, 2006)

In this task, participants were presented with 30 pairs of words. A cue word was presented until the participant pressed ENTER, or until 2.5 s elapsed, after which the cue's pair appeared on the screen. They then remained together on screen, again until the participant pressed ENTER, or until 2.5 s elapsed, after which both disappeared and the next cue word was displayed. The test phase was identical to training, except instead of pressing “ENTER” to view the second word of each pair, subjects were required to type that word. Together with feedback on their answer, the correct association was shown to the participant until they pressed “ENTER”, when the next word cue was presented. Once the test phase was completed, participants immediately moved to a second learning block in which the same stimulus words were presented in a different order. In total, there were four learning and four test blocks, with possible overall scores ranging from 0 to 120.

GENERAL COGNITIVE ABILITY TESTS

To create a good latent g factor we used one verbal test, one perceptual reasoning test, and one mental rotation test. Using one of the largest batteries of cognitive tests ever collected, Johnson and Bouchard (2005) demonstrated that, below the g factor, there are three separable second-stratum domains of cognitive ability: verbal, perceptual, and mental rotation. Use of one test from each domain should produce a well balanced g.

1. Raven's advanced progressive matrices test, set II (RAPM)

The RAPM (Raven, Raven, & Court, 1998) is a measure of abstract perceptual reasoning. Each item consists of a 3×3 matrix of geometric patterns with the bottom right pattern missing. The participants' task is to select the option that correctly completes the matrix. There are eight alternative answers for each item. The test is presented in increasing order of difficulty. After two practice items with feedback, participants were then given 45 min to complete 36 items.

2. DAT verbal reasoning test

The verbal reasoning section of the Differential Aptitudes Test (DAT-V, The Psychological Corporation, 1995) was administered to each participant. Each problem consisted of a sentence with two words missing, and participants chose a pair of words from the answer options that were related to the words in the sentence in some way. After two practice items, participants had 15 min to complete 40 problems.

3. Mental rotations test, set A (MRT-A)

The MRT-A (Vandenberg & Kruse, 1978) contains 24 problems and measures mental rotation ability, which appears to be a distinct component of intelligence at the same level as verbal ability and perceptual ability (Johnson & Bouchard, 2005). Each problem in the MRT-A shows a three-dimensional target figure paired with four choice figures, two of which are rotated versions of the target figure. To score a point, both rotated versions must be identified. After two practice items with feedback and an explanation, the first 12 problems were attempted in 4 min with a 2 min break before attempting the second 12 in another 4 min. The maximum score is 24.

Mean scores on the three cognitive ability measures (RAPM, DAT-V, and MRT-A) suggested a mean IQ for the entire sample in the range of 100 to 110.

PROCESSING SPEED TESTS

1. Verbal speed test (Speed-V)

An English adaptation of a sub-test from the Berlin model of Intelligence Structure (BIS; Jaeger, 1982, 1984). The task was to fill in the missing letter from a 7-letter word; 60 s were given to complete the 57 items. The score is the number completed correctly in 60 s.

2. Numerical speed test (Speed-N)

The Speed of Information Processing sub-test from the British Ability Scales (Elliot, 1996). The task was to cross out the highest number in each row of five numbers; 60 s were given to complete 48 items. The score is the number completed correctly in 60 s.

3. Figural speed test (Speed-F)

Digit-Symbol, Coding, a sub-test of the WAIS-R that loads on the "processing speed" factor (Deary, 2001). The test was to enter the appropriate symbol (given by a key at the top of the form) beneath a random series of digits; 90 s were given to complete 93 items. The score is the number completed correctly in 90 s.

WORKING MEMORY

1. Operation span task (Turner &Engle, 1989)

The Operation Span (Ospan) task requires participants to store a series of unrelated words in memory while simultaneously solving a series of simple math operations, such as "Is (9/3) — 1=1?". After participants selected the answer, they were presented with a word (e.g., DOG) to recall. Then participants moved on to the next operation-word string. This procedure was repeated until the end of a set, which varied from two to six items in length. Participants were then prompted to recall all the words from the past set in the same order in which they were presented by typing each word into a box, and using the up and down arrow keys on the keyboard to cycle through the boxes.

Before the main task, participants encountered three practice problems with set size two, where they received feedback about their performance. During these practice trials, we calculated for each participant how long it took them to solve the math operations. Consistent with the methodology of the Automated Ospan task (Unsworth, Heitz, Schrock, & Engle, 2005), we did this to control for individual differences in the time required to solve the math operations. Their mean performance time to solve the equations, plus 2.5 SD was used as the time limit for the presentation of the math equations during the main task.

The Ospan score is the sum of all correctly recalled words in their correct positions. The number of operation word-pairs in a set was varied between two, three, four, five, and six with three sets of each. Overall score could range from 0 to 60. Prior research has demonstrated significant correlations between Operation Span and g (e.g., Unsworth & Engle, 2005a) and a high loading of Operation Span on a general working memory factor (Kane et al., 2004).

В результате проведенного эксперимента было выявлено, что результаты первого прохождение обоих тестов на ассоциативное научение (AL) значимо хуже, чем по следующим трем (табл.1). В этой связи, учитывая "ровные" показатели по 2, 3 и четвертому прохождению тестов на AL, в линейно-структурное моделирование небыли включены данные по первому прохождению тестов на AL.

Для выявления независимых предикторов фактора g использовалось структурно-линейное моделирование с использованием программы Amos7.0. Структурная модель представлена на Fig.1. Ковариационная матрица модели представлена в Appendix A.

Как видно из представленных на Fig.1 результатов, ассоциативное научение, рабочая память и скорость выполнения простых умственных операций вносят независимый вклад в фактор g. В целом, модель объясняет около 40% общей дисперсии фактора g.

Авторы указывают, что основной целью их работы являлось определить фактор, вносящий вклад в G помимо рабочей памяти и скорости выполнения простых умственных операций. В целом, можно говорить о том, что выдвинутая гипотеза о независимом вкладе ассоциативного научения в фактор g подтвердилась.

7. **ПРИЛОЖЕНИЯ**

Table 1
Descriptive statistics for learning trials on 3-Term and PA ($N=169$).

	Mean	S.D.	Min	Max	Correlation with g
3-Term trial 1	3.28	3.50	0	21	.19*
3-Term trial 2	9.27	6.61	0	30	.34**
3-Term trial 3	14.62	7.91	0	30	.33**
3-Term trial 4	18.82	8.17	0	30	.33*
PA trial 1	11.85	6.65	1	28	.19*
PA trial 2	20.54	7.36	2	30	.29**
PA trial 3	24.08	6.73	2	30	.27**
PA trial 4	25.79	5.85	5	30	.29**

*$p<.05$; **$p<.01$.

Table 2
Correlations, means, and standard deviations of observed variables ($N=169$).

Measure	1	2	3	4	5	6	7	8	9
1. RAPM (/36)	–								
2. DAT-V (/40)	.53**	–							
3. MRT-A (/24)	.59**	.43**	–						
4. Ospan (/24)	.30**	.42**	.24**	–					
5. Speed-V (/57)	.17**	.24**	.14	.22**	–				
6. Speed-F (/90)	.24**	.15*	.17*	.15	.24**	–			
7. Speed-N (/48)	.25**	.10	.21**	.10	.14	.51**	–		
8. 3-Term (/90)	.32**	.35**	.21**	.21**	.09	.16*	.02	–	
9. PA (/90)	.31**	.23**	.14	.14	.17*	.17*	−.05	.64**	–
Mean	21.72	24.52	13.21	44.53	41.36	64.70	30.90	42.70	70.42
S.D.	5.53	5.86	5.34	7.61	9.05	10.50	4.19	21.37	19.15
Reliability	.81	.78	.85	.73	.60	,60	.60	.93	.95

Notes: All reliability analyses are alpha coefficients, except for the three processing speed tests, in which the Spearman–Brown split-half coefficient was calculated across all three tests. The parenthetical next to each test refers to the total score for each test.
*$p<.05$, **$p<.01$.

Table 3
Correlation matrix of latent variables in structural model ($N=169$).

Measure	1	2	3	4
1. g	–			
2. Working memory (WM)	.48**	–		
3. Processing speed (Gs)	.38**	.24*	–	
4. Associative learning (AL)	.45**	.22*	.17	–

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

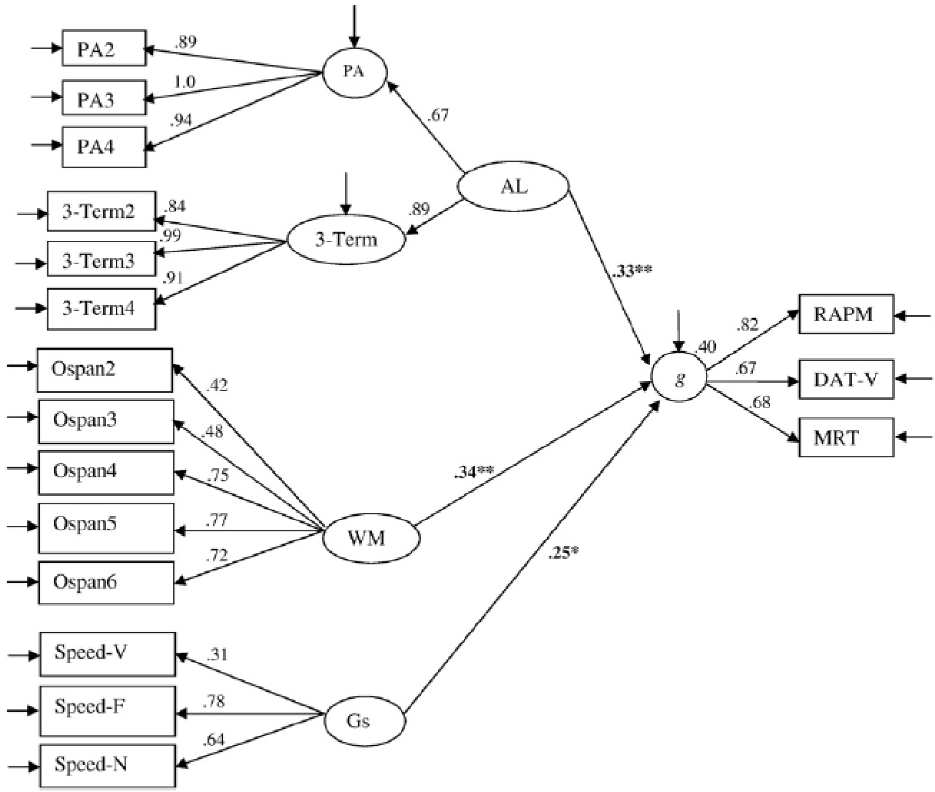

Fig. 1. Associative learning, working memory capacity (WM), and processing speed (Gs) independently predict g. See Table 3 for correlations among latent predictors. $N = 169$. $\chi^2 = 175.21$, $df = 111$, $p < .001$, CFI = .96, TLI = .95, RMSEA = .059, $p_{(close)} = .189$. $^*p < .05$, ** $p < .01$.

Appendix A. Full covariance matrix used to fit SEM model ($N = 169$).

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
RAPM	–																		
DATV	.53	–																	
MRTA	.59	.43	–																
SPEEDV	.17	.24	.14	–															
SPEEDF	.24	.15	.17	.24	–														
SPEEDN	.25	.10	.21	.14	.51	–													
Ospan2	.12	.25	.11	.20	.11	.08	–												
Ospan3	.24	.21	.18	.19	.09	.03	.33	–											
Ospan4	.23	.41	.23	.19	.12	.13	.35	.38	–										
Ospan5	.27	.34	.21	.22	.16	.11	.27	.37	.56	–									
Ospan6	.21	.30	.16	.10	.08	.03	.25	.26	.55	.60	–								
ThreeTerm1	.17	.18	.12	.86	.23	.05	.07	.10	.08	.16	.17	–							
ThreeTerm2	.32	.30	.21	.84	.15	−.01	.07	.11	.04	.16	.15	.72	–						
ThreeTerm3	.30	.35	.20	.10	.14	.01	.12	.10	.07	.16	.20	.57	.84	–					
ThreeTerm4	.30	.34	.17	.07	.16	.05	.15	.14	.11	.20	.20	.46	.74	.90	–				
PA1	.20	.20	.07	.14	.18	−.04	.05	.08	.05	.09	.19	.48	.58	.67	.59	–			
PA2	.30	.25	.12	.16	.19	−.02	.05	.09	.03	.12	.17	.33	.52	.65	.65	.84	–		
PA3	.28	.20	.14	.16	.15	−.05	.03	.10	.01	.15	.12	.24	.45	.58	.64	.69	.89	–	
PA4	.30	.22	.15	.16	.14	−.08	.04	.11	.02	.18	.10	.21	.44	.55	.61	.60	.82	.94	–