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Gender Differences in the Relationship Between Spearman's "g" Factor and a Measure of Executive Cognitive Function

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ABSTRACT - A growing body of evidence suggests that executive cognitive functions (ECF), putatively reflecting abilities traditionally associated with the prefrontal cortex, may be related to Spearman's "g" factor. Although some studies suggest that no gender differences exist in "g" or ECF, gender differences in the relationship between "g" and ECF have yet to be investigated. Thirty eight boys and thirty nine girls (mean age of 13.4 years) completed the Raven's Progressive Matrices (RPM), as a measure of "g", and the Spatial Conditional Associative-Learning Task (SCALT), as a measure of abilities associated with ECF. Results indicated no significant gender differences in scores on the RPM and SCALT. A significant association was found between scores on the RPM and the SCALT for the combined male and female sample. However, gender differences were found in this association, as RPM was significantly associated with SCALT only with boys, and not with girls. These results are in agreement with other findings suggesting no gender differences in "g" or ECF, and that g may be a reflection of ECF. In addition, these results suggest that although no gender differences may be found in "g" or ECF, it is important to consider gender differences in their interrelationship.

A multitude of abilities usually associated with the prefrontal cortex have often been referred to as the executive cognitive functions (Giancola, 1995; Roberts, Robbins & Weiskrantz, 1998). Although this construct is yet to be fully and satisfactorily defined, it is thought to encompass capacities involved in the initiation and maintenance of goal-directed activity (Giancola, 1995; Lezak, 1985). These include, but are not limited to, the organization and planning of behavior, conditional learning, problem solving, working memory, abstract reasoning, and the modulation of behavior in light of expected consequences (Lezak, 1985; Pihl, Assaad & Hoaken, 2003, Welsh and Pennington, 1988; Damasio, 1979; Fuster, 1989).

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Despite the nature of the abilities associated with the prefrontal cortex, it is generally accepted that the latter is not particularly involved with conventional psychometrically defined intelligence or IQ (Assaad & Exum, 2002). Duncan and colleagues (1995) reported that evidence supporting this view has been accumulating at least since the 1940s, consisting of patients with major frontal lobe lesions whose WAIS scores remain essentially preserved. Frontal patients are therefore usually regarded as having deficiencies in the abilities reflecting the executive cognitive functions, while their IQ scores remain intact.

Duncan and colleagues (1995) have suggested that this paradox of preserved "intelligence" despite deficits in executive cognitive functions may be resolved through a closer examination of the definition and measurement of intelligence. In particular, the distinction between fluid and crystallized intelligence should be made. Crystallized intelligence reflects a base of declarative knowledge and skills, previously acquired through schooling or experience (Carpenter et al, 1990). Thus, traditional tests of intelligence, such as the WAIS, rely more on crystallized intelligence. Fluid intelligence refers to reasoning and novel problem solving ability, without relying on crystallized intelligence (Carpenter et al, 1990). Classic tests of fluid intelligence include the Raven's Progressive Matrices (RPM) and Cattell's Culture Fair tests. Such tests strongly correlate with Spearman's g factor (Carroll, 1993). Although never precisely defining g, Spearman (1927) theorized that some "general" or g factor contributes to the success of a large set of diverse mental abilities. Duncan and colleagues (1995) therefore suggested that the executive functions may be more related to g (fluid intelligence), as opposed to crystallized intelligence. Recent results from positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) studies support the latter, suggesting that g may be subserved by neural mechanisms involving the prefrontal cortex (Duncan et al, 2000; Gray, Chabris & Braver, 2003).

Gender differences in g and executive cognitive functions should also be addressed, considering evidence suggesting gender dimorphism in both activity and volume of certain areas of the frontal lobes. For example, an MRI study assessing sexual differences in cortical regions found that women had 23.2% greater dorsolateral prefrontal cortex and 12.8% greater superior temporal gyrus grey matter percentages than did men (Schlaepfer et al., 1995). As for frontal lobe activity, regional cerebral metabolic rate of glucose utilization was lower in men than in women in the orbital frontal area (Andreason et al., 1994), and global cerebral blood flow was higher in women during certain frontal lobe tasks, but not during sensorimotor control tasks (Esposito et al., 1996). Nevertheless, studies on gender differences in psychometrically assessed g and executive cognitive functions generally suggest that no gender differences exist (Colom & Garcia-Lopez, 2002; Rucklidge & Tannock, 2002). However, considering the above mentioned gender dimorphisms in certain aspects of the frontal areas, it is possible that the strength of the relationship between g and executive cognitive functions will differ between males and females.

The present study was therefore designed to test the hypotheses that (a) no significant gender differences will be found in Spearman's g factor as measured in this study by the RPM (Raven, 1962) or executive cognitive functions as measured by performance on the Spatial Conditional Associative-Learning Task (SCALT: Petrides, 1985); (b) performance on the RPM will be associated with performance on the SCALT; and (c) gender differences will be found in the *relationship* between the RPM and the SCALT.

Method

Participants

The subject pool consisted of a sample of children who participated in a substance abuse prevention program study when they were in fifth and sixth grades (Vitaro, Dobkin and Tremblay, 1994). Of the original sample, 38 boys and 39 girls, with a mean age of 13.4 at the time of testing, participated in the present study. Available parents (n = 47) were also asked to complete a questionnaire, including information on total familial revenue.

Materials and Procedure

Trained research assistants carried out all experimental procedures at the University of Montreal (Quebec, Canada). Questionnaires were completed by the parents and their children, and the latter were administered several different tasks. This study will focus on the RPM, the SCALT, as well as the Paired Associates and Digit Span subtests of the Wechsler Memory Scale.

The RPM consists of 5 sets of 12 visual analogy problems. Each problem involves a figure with a missing piece. Specifically, the figure consists of eight "sections" arranged in a three by three matrix, with the ninth bottom right section omitted. Each section consists of figural elements, such as lines or geometric forms. The subject's goal is to solve the problem by determining what rules govern the arrangement of the sections within the three by three matrix, and then selecting the missing section from among eight possible responses placed below the figure. As previously mentioned, the RPM is a good indicator of g (Duncan et al., 2000).

In the SCALT, each of six small identical lamps grouped in a circular array have been arbitrarily associated to one of 6 identical cards placed 2 by 3 in front of the subject. The subjects are not initially informed of the pairings. The lamps are randomly lit one at a time. Thus at each trial, when a lamp is lit, the subject must touch one card after another, until the one paired with the lamp in selected. The subject's goal is thus to learn by trial and error which card is associated with which lamp, until the correct cards are chosen following the presentation of the given lamps. Completion criteria were set at 15 consecutive correct matches, or 180 trials. Z-score transformations were calculated for the total number of errors and the total number of trials, which were summed to obtain a cumulative z score for each participant. The SCALT is thought to require abilities usually associated with executive cognitive functions, such as the ability to adapt behavior to meet external demands, as well as the frontal mediation of memory. This test has been found to be significantly correlated with other putative tests of executive cognitive function in a sample of young boys (Harden and Pihl, 1995) as well as in a group of healthy normal men (Lau et al, 1995). In addition, neurological patients with unilateral frontal-lobe damage perform poorly on this task (Petrides, 1985). Lastly, PET MRI research found that performing a modified version of the SCALT activates the posterior aspect of the dorsolateral frontal cortex (cytoarchitectonic area 8) (Petrides, et al., 1993).

In the Digit Span subtest of the Wechsler Memory Scale (Wechsler, 1987), subjects are orally presented a set of digits, which is then required to be immediately repeated. Following this "digits forward" section of the task, the "digits backwards" section requires participants to repeat the numbers in reverse order. The total score is the sum of the total number of successful trials for each section. This task has been traditionally viewed as a task of verbal memory (Lezak, 1983). The Paired Associates task is also a verbal memory subtest from the Wechsler Memory Scale (Wechsler, 1987). It consists of 10 word pairs, orally presented three times to each subject. Six word pairs are easy and four are difficult to associate, and participants are required to remember the second word in each pair. The total score is the sum of the number of hard pairs recalled and half of the number of easy pairs recalled. A total verbal memory score was computed by summing the Z transformed total scores of Digit Span and Paired Associates.

Results

Separate one way Analyses of Variance (ANOVAs) revealed no significant gender differences in age, family revenue or Digit Span. Significant gender differences were found in Paired Associates, $F(1,75) = 7.56$, $p = 0.007$ and sum of Z scored Paired Associate and Digit Span, $F(1,75) = 4.75$, $p = 0.032$ (See Table 1 for means and standard deviations). In support of this study's first hypothesis, separate one way ANOVAs revealed no significant gender differences in RPM, SCALT errors and trials, and the sum of Z scored SCALT errors and trials (See Table 1). Pearson correlation coefficients of the tasks for the total, male and female samples are presented in Tables 2a, 2b and 2c.

Table 1

Means and Standard Deviations for Age, Family Revenue, RPM (Raven's Progressive Martices), Paired Associates, Digit Span, Sum of Z Scored Paired Associate (PA) and Digit Span (DS), CALT Errors, CALT Trials, Sum of Z scored CALT Errors & Trials, for Boys and Girls

	Boys			Girls			
	M	*SD*	*N*	*M*	*SD*	*N*	
Age (years)	13.32	0.47	38	13.38	0.59	39	
Family Revenue	9.75	3.63	24	8.43	4.27	23	
RPM	43.11	6.74	38	45.26	6.77	39	
Paired Associate	18.05	1.83	38	19.10	1.51	39	**
Digit Span	13.97	3.15	38	14.46	3.83	39	
Sum of Zscored PA & DS	-0.38	1.54	38	0.37	1.44	39	*
CALT errors	59.86	47.19	37	60.26	45.89	39	
CALT trials	90.89	46.01	37	101.05	44.25	39	
Sum of Zscored CALT errors & Trials	-0.12	1.97	37	0.11	1.86	39	

Note: Family revenue scale ranges from 1 to 13, 1 representing salaries less than $5,000, 2 representing $5,000 to $9,999 and so on (increases of $5,000 increments) until 13 representing over $60,000.
* $p < 0.05$ ** $p < 0.01$

To test the second hypothesis, a linear regression analysis was performed to examine the amount of variance in RPM accounted for by the SCALT. Thus, scores on the RPM were the dependent variable. In order to reduce the number of independent variables, as well as to control for verbal memory (i.e. the sum of z scored Paired Associate and Digit Span), the independent variable was created by taking the standardized residual scores derived from a linear regression analysis with the sum total of z scores of number of errors and number of trials to completion for the SCALT as the dependent variable and the sum of *z* scores of digit span and paired associates tasks as the independent variable. The resulting standardized residual scores thus reflected scores on the SCALT while controlling for the results of the verbal memory tasks. It is important to eliminate the influence of verbal memory from the independent variable in this manner, as basic memory abilities required for verbal learning are also prerequisites for certain tasks (such as the SCALT) thought to reflect executive cognitive functions (Séguin, Pihl, Harden et al., 1995). For the total sample, the standardized residual scores of the SCALT controlling for the effect of verbal memory accounts for 6.0% of the variance in RPM scores ($F = 4.74, p = 0.033$). Table 3 summarizes the analysis for the total sample.

Table 2a

Pearson Correlation Coefficients Among Tasks for the Total Sample (n = 77)

Test	zSCALT[a]	RPM	DS	PA
RPM	-.29**			
DS	-.19	.29*		
PS	-.18	.11	.17	
zDS-PA	-.24*	.26*	.76**	.76**

[a]*n*=76 for zSCALT * $p < .05$ ** $p < .01$

Table 2b

Pearson Correlation Coefficients Among Tasks for the Male Sample (n = 38)

Test	zSCALT[a]	RPM	DS	PA
RPM	-.43**			
DS	-.45**	.38*		
PS	-.28	.26	.24	
zDS-PA	-.46**	.40*	.75**	.82**

[a]*n*=.37 for zSCALT * $p < .05$ ** $p < .01$

Table 2c

Pearson Correlation Coefficients Among Tasks for the Female Sample (n = 39)

Test	zSCALT	RPM	DS	PA
RPM	-.19			
DS	.02	.21		
PS	-.12	-.16	.07	
zDS-PA	-.05	.06	.80**	.65**

** $p < .01$

Notes for Tables2a-2c: **zSCALT:** Sum total of zscores of number of errors and number of trials to completion for the Spatial Conditional Associative-Learning Task; **RPM** : Raven's progressive Matrices; **DS** : Digit Span; **PA** : Paired associates; **zDS-PA:** Sum total of zscores of digit span and paired associates tasks.

To test the third hypothesis that gender differences will be found in the *relationship* between the RPM and the SCALT, two separate a priori analyses consisting of linear regression analyses (one for boys and one for girls) were performed. As with the total sample, the dependent variable was RPM scores, and the independent variable was the standardized residual scores of the SCALT controlling for the effect of verbal memory. For the male sample, the standardized residual scores of the SCALT accounts for 13.8% of the variance in RPM scores ($F = 5.63$, $p = 0.023$). For the female sample, the standardized residual scores of the SCALT controlling for the effect of verbal memory non-significantly accounts for 3.1% of the variance in RPM scores ($F = 1.19, p = 0.283$). Table 3 summarizes the analysis for the male and female samples.

Table 3

Summary of Regression Analysis with g (Reflected by Scores on the Raven Progressive Matrices) Predicted by Executive Cognitive Function (Reflected by the Standardized Residual Scores of the SCALT [a] Controlling for the Effect of Verbal Memory [b]), for the Total (n = 76), Male (n = 37) and Female (n = 39) Samples

Variable	R^2	*B*	*SE B*	β	*N*
Total Sample					
Residual Score (SCALT scores[a] controlling for the effect of verbal memory[b])	0.060	-1.62	0.74	-0.25 *	76
Male Sample					
Residual Score (SCALT scores[a] controlling for the effect of verbal memory[b])	0.138	-2.4	1.01	-0.37 **	37
Female Sample					
Residual Score (SCALT scores[a] controlling for the effect of verbal memory[b])	0.031	-1.18	1.08	-0.18	39

[a] SCALT as defined by the sum of zscores of number of errors and number of trials to completion.
[b] Verbal memory as defined by the sum of zscores of digit span and paired associates tasks.
* $p < 0.035$ ** $p < 0.025$

Discussion

The results of this study indicate that in a sample of 13 year old boys and girls, performance on the SCALT (controlling for the effect of verbal memory), putatively reflecting executive cognitive functions, is significantly, albeit modestly, related to the RPM, a task highly correlated with Spearman's g factor. A gender difference in this relationship was also revealed, as SCALT scores (controlling for verbal memory ability) significantly accounted for the variance in RPM scores in boys, but not girls.

These results can be interpreted in several ways. The gender differences found in the relationship between the RPM and the SCALT may simply be related to a lack of statistical power resulting from the division of the total sample. However, this seems unlikely, as although no significant association was found in the female sample, significant findings were detected in the equivalently sized male sample. Another tentative explanation, based on the studies reviewed in the introduction reporting gender dimorphism in both activity and volume of certain areas of the prefrontal cortex is plausible. These dimorphisms may also be related to gender differences in abilities assessed by psychometric tests, such as the finding that males perform better than females in spatial and mathematical tasks (de Courten-Myers, 1999). If this is the case, it is not surprising to find that both boys and girls performed similarly on tasks in this study, but that the relationship between the task performances differed between sexes, where performance in the RPM was associated with the SCALT in boys but not in girls. Thus, despite the lack of gender differences in tasks putatively reflecting g and abilities related to executive cognitive functions, boys may be relying relatively more on executive cognitive functions to solve the RPM visual analogy problems as compared to the girls.

Based on the results from the total sample, it might be argued that this study offers additional support for the notion that g is a reflection of executive cognitive functions, as scores on a task reflecting executive cognitive functions significantly accounted for the variation in scores on a task reflecting g. However, a large portion of the variance in the scores on the RPM remained unexplained. This may be related to the suggestion that the SCALT is thought to be specifically sensitive to the posterior aspect of the dorsolateral frontal cortex. It may be that other areas of the prefrontal cortex are involved in the mediation of g. Thus, the involvement of other structures seems likely. Furthermore, it is probable that both the RPM and SCALT are imperfect measures of overlapping area(s), construct(s), or abilities(s).

The results confirmed that performance on the RPM was not confounded by verbal, or basic learning abilities, as the effects of verbal memory was partialed out of the SCALT tasks by the use of residual scores. It was important to contrast, in this manner, verbal memory and executive abilities, as the memory abilities required for verbal learning are prerequisites for the working memory abilities measured by the tasks reflecting executive cognitive functions. Had this not been controlled for, the variance explained by the SCALT would have been confounded by verbal memory abilities.

Future studies should consider testing different age populations. Although the results of the present study are apparent at age 13, they may not hold into adulthood. This is suggested by a study by Overman and colleagues (1996), who found that gender differences in cognitive tasks was evident in very young children but was not evident in older human subjects. These authors suggest this may be related to gender differences in androgens which influence the maturation rate of specific brain systems.

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