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ABSTRACT

Individual differences in verbal/analytic and nonverbal/holistic cognitive strategies were studied in relationship to performance levels in spatial tasks, sex and handedness. Analytic processes are described as sequential, resulting in decomposition of stimulus information, and holistic processes, as parallel, involving information synthesis. Sixty-five undergraduates were given two spatial ability tests and a 55 item Spatial Strategy Questionnaire (SSQ) developed using theoretical hypotheses and previous research in holistic and analytic cognitive processing. Males scored significantly higher than females on one spatial test, but not other sex or handedness effects were found. High spatial performance was found to be significantly related to holistic processing, especially in the perception of test stimuli as three dimensional objects. Three dependent scoring measures calculated from the SSQ responses are discussed in the analysis of the hypothesized relationship between holistic processing and spatial ability. (Author/CM)

Cognitive Strategies in Spatial Performance

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Running head: Cognitive Strategies

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Abstract

The distinction between verbal/analytic and nonverbal/holistic cognitive processes is widely accepted and is generally supported by the literature. This research investigated individual differences in cognitive processes and their relationships to spatial ability, sex, and handedness. Sixty-five undergraduates were given two spatial ability tests and a spatial strategy questionnaire (SSQ) based on theory and previous research. Males scored significantly higher than females on one spatial test, but no other sex or handedness effects were found. The SSQ data supported the hypothesis that high spatial performance was significantly related to holistic processing, especially to perception of the test stimuli as three-dimensional objects.

Cognitive Strategies in Spatial Performance

For nearly three decades, studies of imagery and non-verbal processes have significantly influenced psychology and education. Common conceptions of these processes as distinct from verbal and analytic cognitive processes have arisen from research in several areas. First, factor analytic analyses of psychometric data have consistently revealed a fundamental distinction between tests assessing linguistic and verbal abilities, and those assessing non-verbal abilities that allow individuals to deal with problems in three-dimensional space and to visualize and manipulate such information (McGee, 1979). Major intelligence tests and many current aptitude batteries (e.g., Bennett, Seashore, and Wesman 1959) assess non-verbal, spatial, or performance factors in addition to verbal abilities; and the predictive importance of non-verbal processing for success in mathematics and science fields is well documented (Sherman and Fenema, 1977) and continues to foster research.

Second, verbal and non-verbal processes have also been investigated within cognitive psychology. Paivio (1971) has amassed extensive research on the relationship between imagery and verbal processes; and postulates two basic encoding mechanisms, one verbal and one imaginal. The dual encoding hypothesis is based on evidence from simplif[illegible] cognitive tasks, such as identification and recall of pictures and [illegible]ds, but it has nevertheless stimulated a vast amount of research. Brooks (1968) further supported the separation between verbal and nonverbal processes by showing that two verbal tasks or two visual (imagery) tasks performed at the same time would interfer with each other and increase the time necessary to perform the tasks.

When one verbal and one nonverbal task was performed, however, little interference resulted.

Third, well known research on hemisphere lateralization (Gazzaniga, 1970), provides evidence that the distinction between verbal and nonverbal processes may be related to neurological organization. Voluminous data, primarily from investigations of visual and auditory perceptual processes, have shown that the right cerebral hemisphere more accurately perceives and stores nonverbal information such as spatial patterns and relationships; and that the left hemisphere more accurately perceives linguistic information (Dimond & Beaumont, 1974). Levy (1974) and others (Cohen, 1973; Nebes, 1974) have concluded that the difference between the two hemispheres is reflected in more than simply the type of information processed. It has been frequently proposed (e.g,, Levy, 1974) that that right hemisphere synthesizes information, evaluates it as a whole, and performs processes in parallel; whereas the left hemisphere perceives information sequentially over time, performs processes in succession, and analyzes information into elements. Das, Kirby, and Jarman (1979) have also focused on a similar distinction between simultaneous and successive processing, although their conception is not directly related to hemisphere function.

Thus, in general, there appears to be a widespread acceptance of the notion that some tasks tap verbal/analytic processes that are sequential and result in decomposition of stimulus information; whereas other tasks tap nonverbal/holistic processes that occur in parallel, are involved in information synthesis (the term Gestalt is often used), and are frequently related to visual processes.

More recently, the task and stimulus dependent nature of these processes has been questioned. It has become clear that for some tasks, even relatively simple ones, the cognitive processes or strategies used to perform the task are not necessarily identical for all individuals. Furthermore, these process differences appear to be so widely divergent that they include both verbal/analytic and nonverbal/holistic processes; and may, in fact, be related to level of performance.

Both Cooper (1976) and Hock and Marcus (1976) have investigated individual differences in same-different reaction-time (RT) matching tasks. Cooper (1976) found two basic patterns in RT data. For Type I subjects, overall reaction time (RT) was faster than for Type II subjects. Also, for Type I subjects, "same" RTs were faster than "different" RTs; but the amount of similarity between the standard figure and the test figure did not effect "different" RTs. For the Type II subjects, "same" RTs were slower, overall, than "different" RTs; and the "different" RTs were longer when the test figure was highly similar to the standard and linearly decreases as the similarity decreased. Cooper concluded that the data could best be explained by hypothesizing a holistic comparison process for the Type I subjects, and a sequential comparison process for the Type II subjects. The linear relationship between RT and stimulus similarity in the latter case can be explained if all features of the two shapes are specifically checked for equality; and in the high similarity situation, the number of features which must be checked is higher, and therefore the process takes longer than in the low similarity situation.

Hock and Marcus (1976) have shown that manipulation of the familiarity of the stimulus (through rotation of the stimulus) affected the "same" RTs of some subjects but not others. They describe postulated process differences between "structural" subjects who organize stimulus information into wholes, and "analytic" subjects who break down stimuli into a set of detailed features. Although the similarity of Hock's structural and analytic subjects to Cooper's Type I and Type II subjects is striking, major methodological differences between the two paradigms preclude the conclusion that they are the same. Nevertheless, these data do show that individual differences in cognitive processing affect even same-different matching tasks.

Individual differences in cognitive strategies have also been investigated in more complex tasks, especially those that are assumed to require high levels of spatial ability, such as the types of problems found on spatial ability tests. French (1965) demonstrated that the factor loadings of specific tests changed substantially for subsamples of subjects reporting use of different strategies on the tests. For example, for individuals using analytic strategies on Thurstone's Cubes Test, the loading of the test on a spatial-visualization factor dropped significantly. French concluded that the same ability test may measure different cognitive processes in different individuals. Also, Talsma and Wheatley (Note 1) provide evidence that spatial ability tests may vary on the extent to which they are susceptible to individual differences in processing strategies.

Willis, Wheatley, and Mitchell (1979) presented a series of tasks hypothesized to vary from analytic to holistic and recorded

EEG data from individuals during problem solving. Analytic tasks showed more left hemisphere activity while holistic tasks showed more right hemisphere activity; and females tended to show more left hemisphere activity at parietal regions than males for all tasks. Ability levels only effected activity in the right hemisphere where high ability subjects showed more temporal than parietal activity.

The most frequent approach to the investigation of strategies in spatial tasks has been to ask subjects how they solved typical problems. Talsma and Wheatley (Note 1) found a variety of strategies in the performance of eight major spatial ability tests in in-depth interviews of 8th grade students. The relationship between strategy type and performance level was assessed by comparing strategy frequencies for students above and below the median on a total spatial score which was the sum of the individual scores on all eight tests. No significant differences were found in strategy frequency across either sex or ability level. These results are consistant with the notion that more than one strategy can produce high spatial performance, but they do not confirm the hypothesis because there may be alternative reasons for the lack of significance irrelevant to the hypothesis.

Allen (1974; Allen & Hogeland, 1978) has focused on sex differences in cognitive strategies, and used questionnaires to assess volunteers' ratings of the percentage of time they used specific strategies on several spatial tests. Although females were found to use significantly more concrete cues and more guessing, the overall correlation between strategy frequencies for males and females were significant. Allen concluded that lower female spatial performance was due to more concrete and less efficient strategy use.

Several problems exist in Allen's research. First, the questionnaires used are not fully described and no reliability data are given. Second, the Rod and Frame Test, a measure of field independence (Witkin, Dyk, Faterson, Goodenough, & Karp, 1974), is used as a measure of spatial ability, the adequacy of which is questionable (Cochran, Note 2). Third, only frequency of strategy use is assessed, and finally, procedures are incompletely reported and therefore cannot be evaluated.

These results by no means show reliable differences in spatial problem solving strategies, but they do suggest that further investigation would be informative. Too often, verbal reports of strategy use are assumed to be reliable; and frequency and difficulty of strategy use has not been compared. Also, strategy use has not been adequately related to performance level. The present study was thus conducted to provide information regarding verbal/analytic and nonverbal/holistic cognitive strategies and their relationships to performance levels on spatial tasks, sex, and handedness.

Method

Subjects. The Ss were 65 undergraduate students (49 women and 16 men) enrolled in an introductory educational psychology course.

Materials. A self-report Spatial Strategy Questionnaire (SSQ) was constructed to assess problem solving strategies on the Space Relations subtest of the Differential Aptitude Test (Bennett, Seashore, and Wesman, 1959). The 55 items on the questionnaire were based on information from three sources: 1) theoretical hypotheses regarding holistic and analytic cognitive processes, 2) strategies already reported in the literature, and 3) strategies reported in in-depth interview conducted with four adult subjects.

The four subjects interviewed were graduate and undergraduate students. They were shown the DAT Space Relations subtest, responded to several specific items, and then verbalized their approaches to solving the problems. The strategies reported were incorporated into the questionnaire. Although two of the subjects claimed to have high spatial ability, and two claimed to have low spatial ability, the level of their spatial performance was not formally assessed.

Each of the items on the questionnaire was scored using two 5-point scales. Subjects were asked to report both the frequency with which they used the approach described, and how difficult the approach was or would be for them to use. Examples of approaches tapped by SSQ items included visualization of test stimuli as three-dimensional objects, mental manipulation and rotation of stimuli, and analysis of components of stimulus information. The extent to which Ss double checked their answers, how well they felt their strategies could be verbalized, and their confidence of their answers were also assessed.

Procedure. The students were tested in three groups of approximately 20 each. The DAT Space Relations subtest (Form T), the SSQ, and the Visualization of Rotations (ROT) subtest of the Purdue Spatial Viaualization Test (Guay, 1977) were given in that order, and 5-alternative computer scan answer sheets were used for all three instruments. Students were asked to code their sex, and writing hand on the answer sheets.

Presentation of the DAT followed standardized instructions; directions and example items in the test booklet were read to the

Ss. The major deviation from standardization occurred with the use of a different answer sheet. Students were given 25 minutes to complete the 60-item test. After test booklets and answer sheets were collected, the SSQ and another answer sheet were distributed. The following directions were read:

> This questionnaire contains a list of statements that describes ways of solving the types of problems which you have just completed. You are to make two kinds of responses to each statement. Please fill in the appropriate circle on the answer sheet to indicate how difficult it is for you to use the particular approach described in the statement, and how frequently or how often you used the approach in solving the problems. Do you have any questions?

Students were given ample time to complete the SSQ, and most were finished within ten minutes.

Finally, a 20 item version of the ROT was given. The items on this test require the S to determine the rotation of a complex three-dimensional form, and to apply the same rotation to a new form. Standard instructions in the test booklet were read and a ten minute time limit was imposed. At the completion of the ROT, students were thanked for their participation, handed a debriefing sheet, and dismissed. The total testing time was one hour.

Results

Spatial Ability Test Data. Performance on the DAT and ROT was measured by the total number of correct items in correspondence with standardized DAT scoring procedures. No corrections for guessing were made.

Sex and handedness differences were assessed by t-tests for both the DAT and ROT. The only significant difference found was a higher mean score for males on the ROT ($t(63) = -2.55$, $p < .05$). Table 1 shows descriptive statistical data from the present sample for the DAT and ROT. Reliabilities for the present sample were found to be .91 and .82 using KR_{20} for the DAT and ROT, respectively. The correlation between the two tests was significant ($r = .72$, $p < .05$).

Insert Table 1 About Here

SSQ Data. Responses on the SSQ were assessed using a weighted multiple scoring procedure. Each item was scored by assigning the appropriate number of points corresponding to the position of the response on the 5-point scale. Three dependent measures were then calculated from the SSQ responses; a total score (TOT), a frequency score (FREQ), and a difficulty score (DIFF). The TOT score was the sum of the individual items scores for all 55 items on the SSQ. The DIFF and FREQ scores were based on 19 and 24 items respectively. The items on these two scales were those for which the responses of individuals using holistic processes could be unambiguously predicted on the basis of theory or previous research. The DIFF and FREQ scores

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Insert Table 2 About Here

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were calculated such that high values were indicative of holistic processing; that is, high FREQ and DIFF scores showed that a S used holistic processing more frequently and found holistic processes easy rather than difficult. Reliabilities of the TOT, FREQ, and DIFF scales were determined to be .80, .49, and .86, respectively, using Cronbach's alpha coefficient.

Table 2 presents the correlations among the three SSQ measures, and shows that both the DIFF and FREQ scales are significantly related to the TOT scale (p's $<$ .001). The correlation between the two subscales approaches significance (p = .06). Since it would be expected that ease of holistic processing would result in a higher frequency of its use, it seems likely that the correlation between the FREQ and DIFF scales is attenuated by the low reliability of the FREQ scale. Table 2 also reveals that all three SSQ measures significantly correlate with DAT performance, and that the TOT and DIFF scales also significantly correlate with ROT performance, thus supporting the major hypothesis that level of spatial performance is related to holistic processes.

Sex and handedness differences in strategy use were examined using t-tests between these groups for the three SSQ measures. No significant differences were found.

To investigate spatial performance level differences, scores on the DAT were rank ordered and divided at the median to produce a high spatial ability group (n=36) and a low spatial ability group (n=29). Reliabilities on the SSQ were found to be similar for the high and low groups (Cronbach's alpha = .74 and .83, respectively). Reported problem solving strategies for both groups were compared with t-tests on each of the SSQ measure . Significant differences were found for the TOT score ($t(63)$= 3.69, $p<$ .05) and the DIFF score ($t(63)$= 3.45, $p<$ .05), and the FREQ score approached significance ($t(63)$= 1.83, p <.08) in two-tailed tests.

Since a number of SSQ items were not included in the DIFF or FREQ scales, two-tailed t-tests were performed on the remaining 12 items. Since no apriori hyptheses were made concerning these items, an overall significance level of p <.05 was maintained through the Bonferroni method and each test was conducted at p <.004. Significant differences between the two ability groups were found for two items. These differences indicated that the high spatial group a) reported less guessing on the DAT items than the low spatial group ($t(63)=-3.06$) and b) was more confident of their answers than the low ability group ($t(63)= 3.36$). Since guessing and confidence is frequently related to performance in many tasks, it is not unusual that significant ability differences were found.

Exploratory analyses of several additional items were conducted by means of further t-tests, also using the Bonferroni method. These analyses showed differences between high and low spatial ability groups on three SSQ items; and suggested that the high spatial group found it easier to a) perceive the five alternatives as three-dimensional objects ($t(63)= 3.81$, $p < .004$), b) fold up the pattern in their minds as if it were a piece of paper ($t(63)= 3.10$, $p < .004$), and c) determine if the proportions of the sections were the same in the pattern and in the alternatives ($t(63)= 3.51$, $p < .004$).

A final attempt to clarify the responses on the SSQ was made by means of a factor analysis of the SSQ items. A varimax rotation factor analysis was performed (Nie, Hull, Jenkins, Steinbrenner, and Bent, 1975) and revealed 17 factors, the first eight of which accounted for 5% or more of the variance each. An attempt was made to interpret only the first eight factors since the remaining factors represented only very small proportions of the variance. Furthermore, as a result of the exploratory nature of this analysis as a whole, a conservative criterion of selecting items with significant factor loadings was used, resulting in relatively few items for each factor. Loadings of at least $\pm.40$ (Child, 1970) were considered significant.

These resulting factors and their tentative interpretations are presented in Table 3. The percentage of variance accounted for by each factor is given in parentheses and the total variance accounted for by the eight factors is 73.7%.

Insert Table 3 About Here

The first factor appears to reflect analytic processing in that it describes the use of verbal labels which is actually considered to be the result of analytic processes. The second factor is more difficult to unravel. Since three of the items on this factor include descriptions of strategies based on section or details, a seemingly analytic approach; and the remaining two items focus on a more holistic, refolding approach; this factor is interpreted as representing a mixed approach, possibly somewhat more analytic than holistic. Factors 3, 4, 6, and 7 appear to reflect holistic strategies, focusing on perception of the pattern and alternatives as three-dimensional objects, and on the folding and the rotating of the figures. Factor 5 assesses guessing and confidence, and Factor 8, based on elimination of alternatives, would seem to reflect overall test-taking skills; that is, the processing of choosing an alternative per se, not necessarily reflecting the strategy by which the choice is made.

To investigate the relationship between these factors and spatial ability, indices for each factor (each composed of the sum of the scores for the items loading on that factor) were entered into stepwise regression programs to predict DAT and ROT scores. Two factors emerged as significantly predictive of DAT scores: the holistic factor reflecting perception of the test figures as three-dimensional objects ($F(1,63) = 19.357$, $p < .001$), and the guessing and confidence factor ($f(2,62) = 4.314$, $p < .05$). Only the three-dimensional perception factor was significantly predictive of ROT performance ($F(1,63) = 14.259$, $p < .001$).

It is clear from the analysis that there is no evidence of separate difficulty and frequency factors. Indeed, most of the factors contain items from both frequency and difficulty indices, and often the frequency and difficulty items based on the same stem or strategy description are paired together. Thus these factors do appear to reflect strategic approaches for solving spatial problems on the DAT.

Conclusions and Implications

The significant correlations between the SSQ measures and spatial ability, and the significant differences between high and low ability groups on the SSQ, support the hypothesis that holistic processing is related to spatial ability test performance. More specifically, since the FREQ scale was found to be somewhat less reliable, it can be concluded that the difficulty of holistic processing strategies is related to spatial ability test performance.

It is unclear whether the low FREQ scale reliability is characteristic of the procedure used to measure frequency of holistic strategies in the present study alone, or whether it is a more common phenomenon. Since frequency has been used to investigate holistic processing in previous research (Allen, 1974; Allen and Hogeland, 1978; French, 1965), that is an important question. Current efforts are underway to improve the FREQ scale reliability. One possibility, should the unreliability be found to be a more general phenomenon, is that strategy use is extremely flexible, and it may be the case that different strategies are used for different items on the tests. This would mean that the assessment of an overall strategy would be difficult, unreliable, and possibly even meaningless. An important implication is therefore, that strategy flexibility, the ability of learners to evaluate possible strategy success, and utilize appropriate strategies, might very well be a significant determinant of performance on spatial tasks. Further investigation into this question would seem to be worthwhile.

Although the significantly higher performance on the ROT for males is typical of previous findings (Maccoby and Jacklin, 1974), the lack of sex and handedness differences in strategy use in the present study appears to be inconsistent with previous data. Allen and Hogeland (1978) specifically focused on sex differences and concluded that females tend to use concrete strategies more often than males; and Freedman and Rovegno (1981) found that both males and right-handed individuals used more imagery on a mental rotation task. These inconsistencies are most likely attributable to either the unreliability of the SSQ FREQ scale, the relatively small numbers of males (16) and left-handers (9) in the present study, or both. Also, since the SSQ was based on items from the DAT and no sex differences in performance level on this test were found, it is not surprising that sex differences in strategies were nonsignificant.

Analysis of individual SSQ items also supports the hypothesized relationship between holistic processing and spatial ability. Perception of the stimuli as three dimensional, ease of mental manipulation of the patterns, and ease of comparison of proportions, were all significantly related to DAT performance. Furthermore, the factor reflecting perception of the test figures as three-dimensional predicted both DAT and ROT scores.

The implications of these results are threefold. First, the confirmation of strategy differences between individuals who are successful in solving spatial problems and those who are less successful, may be valuable for constructing methods and materials for teaching learners to deal more effectively with these types of problems. Furthermore, the questionnaire method might facilitate identification of those learners who would benefit by such specialized or concentrated training.

Secondly, these data have implications for laterality research. Bryden (1978) reviews strategy factors in the assessment of hemispheric asymmetries, and concludes that the way in which a subject approaches a task can profoundly effect the results. The exact nature of the relationship between hemisphere function and cognitive strategies is still somewhat unclear. Although the assumption is frequently made that left hemisphere superiorities reflect verbal strategies and right hemisphere superiority reflects holistic strategies, the relationship between strategy utilization and hemispheric processing is not firmly established.

Finally, investigations of the relationships between individual differences in strategy utilization on verbal as well as spatial tasks and other individual difference variables, including cognitive style variables, might be informative. For example, consistent strategy use might very well be associated with field independence (Witkin and

Goodenough, 1981), the serialist-holist dimension postulated by Pask (Pask and Scott, 1972), or a general tendency to perform conceptually based versus stimulus based processes (Lindsay and Norman, 1977).

As a final note, it is suggested that imformation processing paradigms be more fully explored as approaches for answering questions like those posed here regarding individual differences in cogntive processes. More detailed information will facilitate understanding of these differences, their relationships to cognitive theory in general, and application of this knowledge to educational situations.

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Table 1

Spatial ability test statistics.

	DAT		ROT	
	$\overline{X}$	SD	$\overline{X}$	SD
Females (n = 49)	37.939	9.442	10.878	3.930
Males (n = 16)	42.188	9.101	14.000	5.164
Total (n = 65)	38.985	9.470	11.646	4.435

Table 2

Correlations among spatial tests and SSQ measures.[a]

	DAT	ROT	TOT	DIFF
ROT	.72***			
TOT	.56***	.42***		
DIFF	.51***	.38**	.91***	
FREQ	.30*	.13	.53***	.23

[a] $n = 65$

*** $p < .001$

** $p < .01$

* $p < .05$

Table 3

Item descriptions, loadings and interpretations for SSQ factors.

Item	SSQ Index	Loading	Interpretation
Factor 1 (18.8%)			
15. Use of words for sections	-	.847	
16. Use of words for section relationships	-	.826	Use of words (analytic)
35. Use of words for sections	FREQ	.830	
36. Use of words for section relationships	FREQ	.747	
40. Refolding in a different way	FREQ	.426	
Factor 2 (13.4%)			
13. Which sections next to each other	DIFF	.742	
17. Eliminating alternatives using details	DIFF	.711	
*14. Determine proportions of sections	DIFF	.498	Focus on sections and details
39. Refolding - different orientation	FREQ	.420	
40. Refolding in a different way	FREQ	.421	(somewhat analytic)
Factor 3 (9.3%)			
8. Fold pattern all at once	DIFF	.591	
41. Put together with out alternatives	DIFF	.835	Folding up the pattern with
61. Put together with out alternatives	FREQ	.547	out the altern- atives
* 5. Fold up pattern like paper	DIFF	.532	(holistic)
Factor 4 (7.8%)+#			
3. Perceive the pattern as an object	DIFF	.740	
* 4. Perceive alternatives as three dimensional	DIFF	.572	Perceive patterns and
21. Form a mental picture of pattern	FREQ	.432	alternatives as three dimension-
23. Perceive pattern as an object	FREQ	.754	al objects
24. Perceive alternatives as three dimensional	FREQ	.470	(holistic)

Table 3 (continued)

Factor 5 (7.2%)#			
*48. Guessing	-	.667	Guessing and confidence
*50. Level of confidence	-	.737	
18. Eliminating alternatives using overall shape	DIFF	.407	
34. Determine proportions of sections	FREQ	.524	
Factor 6 (6.1%)			
26. Rotate pattern in mind	FREQ	.818	Rotation of the pattern (holistic)
62. Rotate - including details	FREQ	.772	
6. Rotate pattern in mind	DIFF	.472	
42. Rotate - including details	DIFF	.602	
Factor 7 (5.6%)			
1. Form a mental picture of pattern	DIFF	.445	Refolding and rotation of an image (holistic)
19. Refolding - different orientation	DIFF	.689	
20. Refolding in a different way	DIFF	.724	
42. Rotate - including details	DIFF	.602	
Factor 8 (5.4%)			
18. Eliminating alternatives using overall shape	DIFF	.594	Elimination of alternatives
37. Eliminating alternatives using details	FREQ	.699	
38. Eliminating alternatives using overall shape	FREQ	.771	

* Significantly differentiates between high and low spatial ability groups
\# Significant predictor of DAT performance
\+ Significant predictor of ROT performance