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# Solution strategies and gender differences in spatial visualization tasks

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This study examined solution strategies and gender differences in a Spatial Visualization (Vz) task. Two kinds of strategies, *analytic* and *holistic* or *spatial manipulation*, were operationalized by a self-report questionnaire and three time based variables obtained in a computerized form board task, the *R-E*. The variables were: time of initial encoding of the target stimulus, duration of processes that follow the first encoding, including visual comparisons and mental movements, and total time for each item. Seventy-five women and 77 men completed Vz tests, the R-E and the self-report measure. Neither level of Vz in marker tests nor gender were associated with strategy choice.

**Key words:** Gender Differences, Spatial Ability, Visualization, Solution Strategy, Reaction Time.

The cognitive study of abilities has tried to identify mental structures, processes, representations and strategies that underlie test performance (Pellegrino, 1988). The psychometric perspective inferred the mental operations involved in test solution from test content and factor analysis, a strategy that does not permit direct hypothesis testing (e.g. Carroll, 1989, Sternberg, 1977). If an ability construct can be explained in terms of key mental components, then individual and group differences can also be linked to those particular cognitive factors.

In the spatial abilities domain, in contrast to the mental rotation - *Spatial Relations* factor (*SR*) connection (Mumaw, Pellegrino, Kail and Carter, 1984), cognitive research about the Visualization factor (*Vz* ) has not disentangled the

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"key" component for individual and group differences (Salthouse, Babcock, Mitchell, Palmon and Skovronek, 1990). One possible explanation is the fact that *Vz* tasks, more complex than *SR* ones, admit various solution strategies, as documented by psychometric research with self-report instruments (Lohman and Kyllonen, 1983, Schultz, 1991), confirmatory factor analysis (Embretson, 1997), information processing studies (Kyllonen, Lohman and Woltz, 1984, Deffner, 1985) and regional cerebral blood flow (Wendt and Risberg, 1994). Different strategies involve different solution algorithms, so the cognitive components could be different for each strategy. Studies that have examined the relationship between strategy and ability suggest that a subject's ability profile plays a role in solution strategy choice and efficiency (Lohman and Kyllonen, 1983, Kyllonen, Lohman y Snow, 1984, Kyllonen *et al.*, 1984, Wendt and Risberg, 1994). Especifically, it has been suggested that subjects high on ability could be employing real "spatial" processes, while the others try to solve the problems in a more analytical way. In a study measuring regional cerebral blood flow, subjects with better performance in a *Vz* task showed more cerebral activation in the posterior right hemisphere, compared with those who employed a strategy that required more bilateral involvement (Wendt and Risberg, 1994). By another account, the individuals' ability pattern (along the verbal - spatial distinction) determines not only choice of strategy but also efficiency of implementation (Kyllonen, Lohman and Snow, 1984). Interventions meant to raise performance must adjust to strategic preferences and cognitive profile to achieve the desired effect.

Gender differences in spatial ability, favoring males, are well established. The largest gender difference can be found in tests of the *SR* factor, but in tests of the *Vz* factor the differences are small or null (Linn & Petersen, 1985,Voyer, Voyer & Bryden, 1995). The issue is not only of theoretical significance, since the pattern of abilities is directly related to vocational or occupational selection when done with psychometric instruments such as the GATB battery used by the United States Department of Labor, the SAT battery employed for college entrance in the USA, or even the Wechsler Adult Intelligence Scales (Hunt, 1995). Gender differences in spatial abilities add up to other psychological and social factors responsible for different career paths. For example, it has been shown that spatial ability plays a role in gender differences on the SAT - M score, a mathematics test used for college selection in USA (Casey, Nuttall, Pezaris and Benbow, 1995).

Strategic variance could be a factor in the absence of gender differences in *Vz* ability. If men and women differ in their cognitive strengths and weaknesses, they could be arriving at the correct solution by approaching the task in different ways. Prominent authors in this area have suggested that there could be such gender difference (Linn and Petersen, 1985; Halpern, 1992). But research on this topic has been very scarce (Allen and Hogeland, 1978, Cochran and Wheatley, 1989) and inconclusive. From an educational perspective, given that training improves performance on spatial tasks, especially for less abled subjects and for women (Regian and Shute, 1993; Okagaki and Frensch, 1994; Subrahmanyam and Greenfield, 1994; Kass, Ahlers and Dugger, 1998) it is important to know if both sexes need to be trained in a different way.

The present study has examined strategic and gender differences in solving a Vz task. Two general kinds of solution strategies for *Vz* tasks are described in the literature. One is an *analytic* or *feature comparison* approach, in which the examinee seeks to verify the identity of key features of the probes to match them with the target stimulus. A variant of this analytic strategy is verbal labelling of the features. The other is a *holistic* or *spatial manipulation* strategy, which involves mental movements of the probes, such as rotation, translation, synthesis, etc. We have focused in a typical *Vz* task, the puzzle or form board. In this case, an analytic strategy consists of comparing features (sides, angles, form of parts) of the target stimulus with features of the alternative parts. The holistic approach involves putting together all or some of the alternative parts in order to form a mental image which is compared with the target stimulus. Deffner (1985), employing eye fixation recordings in a form board task, has shown that the latter takes longer times than the former.

We have employed a traditional self-report measure, but we have also included time variables, a more objective index of information processing. These latter variables were obtained with a previously designed and validated computerized puzzle or form board task, the *Rompecabezas - Estrategias* (*R-E* ), in which several time indexes (TM1, TM2 and TT) are associated with solution strategy (Burin, Prieto and Delgado, 1995). In this task, the subject must decide if a target figure, shown in the first screen, can be composed with a set of supposed parts, shown in a second screen. The subject can freely alternate looks between screens. TM1 equals to the mean time elapsed since the onset of the figure to be composed, to the moment the subject looks at the parts of the figure. It reflects the time to initially encode the target stimulus. TM2 is the mean time spent looking at the target figure and the parts, subtracting TM1, and divided by the number of alternations between the figure and the parts. It includes the processes that follow the first encoding; in the analytic case, time of selecting features and performing mental visual comparisons; in the holistic case, it also includes the selection of at least two contiguous parts and mentally rearranging them to compose a section of the target figure. TT records the mean total time spent in the items. In theory, the analytic subject will select a feature of the target figure and check it in the corresponding part, rapidly alternating looks to the figure and the parts. In contrast, the holistic subject will take longer, since he or she must perform mental manipulations on more complex images. In Burin *et al.* (1995) these measures had concurrent validity with think aloud protocols in a sample item. Subjects who reported a spatial manipulation strategy spent significantly longer mean times in the first look at the target figure (TM1), executing processes that follow the first encoding (TM2), and mean total time in each item (TT). In addition, items showed good internal consistency ($\alpha$ Hoyt = 0.74) and total correct items were positive and significantly correlated with performance on reference *Vz* tests.

In sum, the present study has operationalized solution strategy in two ways: a self-report measure, and, as a cognitive component, with time variables collected with the R-E task. We have applied this methodology to look for solution strategy and gender differences in solving a *Vz* task.

## METHOD

**Subjects**. One hundred and fifty-two (75 women and 77 men) psychology students at the Psychology College (*Facultad de Psicología*), University of Buenos Aires volunteered to participate. Reward in terms of confidential feedback was given to those participants who asked for it. The mean age was 23.03 years (SD = 4.24).

**Materials.** Three psychometric paper-and-pencil tests were selected to measure *Vz* ability: (1) a reduced version of the Spanish adaptation of the *DAT-SR* (Bennet, Seashore & Wesman, 1990); (2) a reduced version of the Spanish adaptation of *Mac Quarrie's Block Counting* (Mac Quarrie, 1925); and a Spanish puzzle test, *Rompecabezas Impresos* (Yela, 1974). The first one,*DAT-SR*, is a surface development test that shows a two-dimensional model and requires the examinee to determine which three-dimensional object would result from its folding. The second one, *Block Counting*, depicts a stack of tiles and asks the subject to count the number of tiles, taking into acconunt the hidden ones. The last one, *Rompecabezas*, is a form board test that shows empty poligons which the subject must fill with given parts.

The computerized R-E was administered in a Macintosh LCII computer. Briefly, it consists of 36 items in which the examinee must decide if a target figure can be formed out of a set of figures that are supposedly parts of the target one. As we tried to elicit subjects' preferred solution strategy, we controlled known sources of strategic change, such as the differences in which the "no" answers are based, the number of parts, their form and angles, their situation, and the transformations involved, for example, excluding rotation (see Burin *et al.*, 1995). In half of the items the target figure can be formed, and in the other half, it cannot. These latter "no" answers have been designed so that in half of them the difference lies in a feature, and in the other half it lies in relative size of one of the parts. Each item is composed of two screens: the first screen shows the target figure, and the second, the array of supposed parts. A small arrow at the bottom center of the first screen takes the examinee to the screen with the set of parts. This screen also shows a similar arrow in the same location, which points backwards, and two small equidistant buttons labeled "yes" and "no" (Figs. 1 and 2) . In this way, times spent on each screen and number of changes are controlled by the subject's clicking on the buttons. An intermediate screen appears between items, to standardize the position of the mouse at the beginning of each trial and to interfere with visual short-term memory. Movements with the mouse are minimal and subjects without experience are trained in order to minimize time differences attributable to this factor.

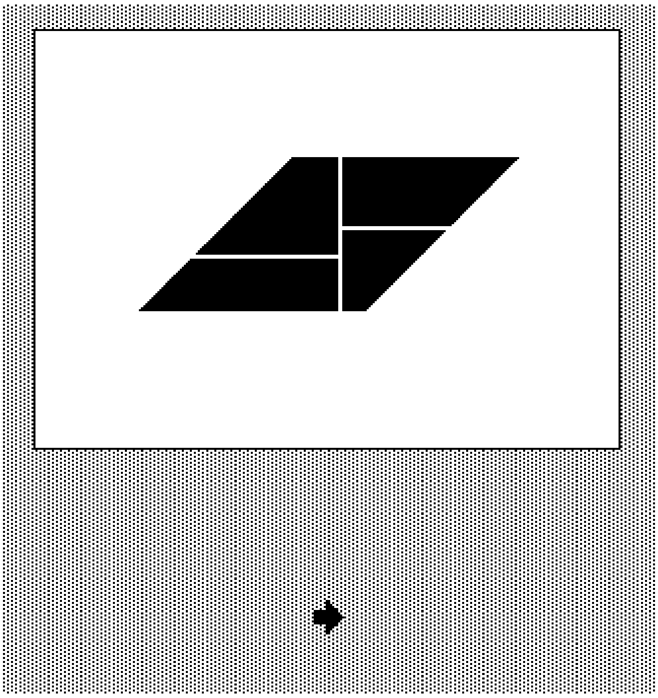

**Figure 1.** Example of R-E item, first screen (target figure)

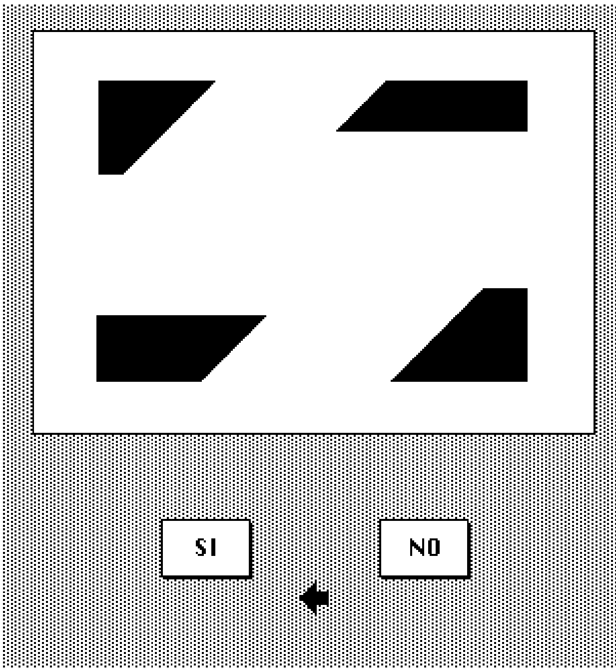


**Figure 2.** Example of R-E item, second screen (array of parts)

Strategies have been operationalized by the variables:

TM1: Mean time looking at the first screen.

TT: Mean total time in the item.

TM2: Mean of (TT - TM1) / VA, where VA is the number of screen changes in each item.

As explained above, variable TM1 reflects the initial encoding of the target figure. Variable TM2 is assumed to index the subsequent processing, even better than TT, which also reflects the more general speed-accuracy trade-off (Burin *et al.*, 1995).These variables are calculated only on correct positive items, due to the difficulty of modelling negative or failed trials.

Subjects also completed the CER (Solution Strategies Questionnaire), an adaptation of Schultz's *SSQ* (1991). This questionnaire elicits the subject's preferred strategy in solving the R-E, and it elicits the same strategies obtained with think-aloud protocols in a previous study of the task. The questionnaire asks the subject if he or she has employed a key feature strategy, a move object strategy or other, describing them in short sentences. Schultz (1991) showed that this reduced version had concurrent validity with protocols and longer versions of the questionnaire, and also had good retest reliability.

**Procedure.** Subjects completed first the *Vz* tests, individually or in small groups. In a second session, individually, they were first trained with the mouse, and then they were introduced to the R-E. After instructions, subjects had 12 practice items with feedback and demonstration of correct responses in case they had failed, so that subjects could adopt a strategy to maximize their performance. Afterwards, they completed the 36 items. Finally, they answered the CER. When finished, the examiner explained the study and offered feedback regarding the subject's performance on the spatial tests.

## RESULTS

Means and standard deviations of all R-E variables as a function of gender, self-report strategy and level of *Vz* ability appear on Table 1. *Vz* ability level is expressed as the mean standard score on the three *Vz* tests (LVz). As time variables (TM1, TM2, TT) had a non-normal distribution, we performed a logarithmic transformation in order to calculate parametric statistics. We have also analyzed results excluding far outliers, but they did not differ from those including them.

**Table 1.** Means and standard deviations (in brackets) in TM1, TM2, TT and R-E corr for Gender and Self-report Strategy; means and standard deviation for the covariable level of Vz (LVz) also shown.

| | Holistic | | Analytic | |
|---|---|---|---|---|
| | Men (n= 27) | Women (n=22) | Men (n=50) | Women (n=53) |
| LVz | 0.28 (0.73) | 0.02 (0.88) | 0.22 (0.74) | -0.35 (0.83) |
| R-E Variables | | | | |
| TM1 | 7.73 (4.15) | 8.39 (5.101) | 3.22 (2.21) | 3.73 (2.48) |
| TM2 | 7.26 (4.36) | 9.37 (6.76) | 4.15 (2.09) | 5.39 (2.79) |
| TT | 38.37 (17.04) | 43.09 (20.10) | 24.74 (10.32) | 22.35 (7.03) |
| R-E Corr | 28.44 (2.69) | 28.41 (4.67) | 28.74 (3.41) | 27.26 (3.35) |

Table 2 shows the correlations among the *Vz* ability level (LVz) and R-E variables. As can be seen, time variables have a positive and significant correlation with each other, but not with ability, excepting total time spent on the items which is also significantly correlated with accuracy on the task and with ability. Notice that TT-TM1 and TT-TM2 are part-whole correlations. Scores on the R-E are positively and significantly correlated with ability. The correlation between ability level and TT is moderate and significant for women ($r = 0.33$, $p < 0.01$) but small ($r = 0.12$) and nonsignificant for men. Otherwise, the correlation matrix for men and women is similar.

**Table 2.** Correlations among R-E variables and level of Vz (LVz), time variables in Logs. ** $p < 0.01$

| | TM1 | TM2 | TT | LVz | R-E Corr. |
|---|---|---|---|---|---|
| TM1 | 1.00 | | | | |
| TM2 | 0.74** | 1.00 | | | |
| TT | 0.54** | 0.44** | 1.00 | | |
| LVz | 0.05 | -0.01 | 0.26** | 1.00 | |
| R-E Corr | -0.01 | -0.05 | 0.45** | 0.53** | 1.00 |

Regarding the self-report measure, the CER, 68% of the subjects said they employed an analytic strategy and 32 % reported using an holistic one (three examinees had marked "other" and were eliminated from the sample prior to all analyses). There was no significant association between gender and self-reported strategy choice ($\chi^2 = 0.57$, *ns* ).

Given that the R-E variables are significantly correlated, and that in theory time variables refer to one construct, strategy, we conducted a MANOVA of the effect of gender X self-report strategy on the R-E variables (R-E Corr, TM1, TM2, TT). LVz was entered as a covariable to partial out gender differences in ability ($t = -3.75$, $p < 0.001$) while examining ability level effects. There was a significant effect of strategy (*Wilks' Lambda* = 0.62, corresponding $F_{4, 144} = 21.87$, $p < 0.01$) and of the covariate LVz (*Wilks' Lambda* = 0.73, corresponding $F_{4, 144} = 13.18$, $p < 0.01$), but the effect of gender and of the interactions did not reach significance (for gender: *Wilks' Lambda* = 0.94, corresponding $F_{4, 144} = 2.18$, *ns*; for the interaction of gender X strategy: *Wilks' Lambda* = 0.99, corresponding $F_{4, 144} = 0.52$, *ns* ). The magnitude of gender's effect on time variables was: for TM1, $h^2 = 0.01$; for TM2, $h^2 = 0.05$; for TT, $h^2 = 0.01$. We inspected significant effects for the individual dependent variables through univariate ANCOVAs, with alfa set at 0.0125 due to the Bonferroni correction. As can be seen on Table 3, self-report strategy had a significant effect on all the R-E time variables, but not on accuracy. Conversely, the effect of *Vz* ability level was significant on accuracy but not on time variables.

Although the MANOVA for gender was not significant, precluding further analyses, we inspected gender, strategy and ability effects on TT, given the significant correlation between *Vz* ability level and mean total time on an item for females but not for males. We performed an analysis of variance examining the effect of gender and self-report strategy on TT, with level of *Vz* as a covariable. Gender had no significant effect, neither alone nor in combination with the other variables (interactions were nonsignificant).

**Table 3.** Effects of Level of Vz (LVz) and Self-reported Strategy (Strat) on the R-E Variables, Size of Effect ($h^2$) also shown. * $p < 0.0125$, *df* (1, 147)

| Variables R-E | FLVz | $\eta^2$ | F Strat | $\eta^2$ |
|---|---|---|---|---|
| TM1 | 0.01 | 0.00 | 60.25* | 0.29 |
| TM2 | 0.01 | 0.00 | 38.12* | 0.21 |
| TT | 5.96[1] | 0.04 | 53.25* | 0.27 |
| R-E Corr | 51.92* | 0.26 | 0.01 | 0.00 |

## DISCUSSION

We have examined strategic and gender differences when attempting a *Vz* task. We have replicated and extended previous results concerning the R-E task, showing that accuracy is associated with *Vz* ability level, while time variables, with solution strategies. Ability had a significant multivariate effect on the R-E variables, explaining 26% of the variance of correct number of items. Conversely, self-reported strategy had a significant multivariate effect on the R-E variables, accounting for 21% to 29% of the time variables' variance. This pattern described as a result of the multivariate analysis of variance can also be seen in the correlation matrix, which shows high correlations among time variables (although the correlations TM1-TT and TM2-TT are part-whole correlations) and also a moderate correlation between ability level and precision on the R-E task.

This pattern of results suggest that choice of strategy is not related to *Vz* ability level. Previous literature had linked strategic choice with ability profile. Since we have only measured level on *Vz,* not the whole abilities spectrum, we could not assess the extent to which broad aptitude patterns determine strategic choice, as suggested by the literature. On the other hand, the R-E task was deliberately stripped off those components that impose a particular mode of processing or strategic changes within the test (such as rotation, or variable number of parts) in order to elicit subjects' preferred strategies. Therefore, the results could obey to task-specific factors. The R-E also included a long practice with feedback, which could have changed subjects' initial choice of solution method.

We have not found a significant association between gender and strategy. The study had enough power to find a significant difference given an effect of at least small-to-medium size, but the variance of time variables associated with gender was very small, less than 5% in the best case (TM2). Again, the lack of a significant difference could be related to task-specific factors.

In gender differences research, it has been suggested that women's worse performance on spatial ability tests arises from response tendencies, response styles or "performance factors" (Goldstein, Haldane and Mitchell, 1990). These factors refer to a postulated female preference to work more slowly and to omit rather than guess on spatial tasks, due to lack of experience and/or poor self-confidence. Studies with large samples have shown that modifying the way scores are computed or allowing more time does not eliminate gender differences in *SR* or *Vz* (Resnick, 1993; Stumpf, 1993; Delgado and Prieto, 1996). In the present study the response tendencies hypothesis would have predicted an effect of gender on the mean total time spent on each item (TT) and / or an interaction of gender and *Vz* ability on TT. In this study we have found a significant correlation of TT and level of *Vz* for women but not for men. Nevertheless, the methodological "guidelines for avoiding sexism in psychological research" (Denmark, Russo, Frieze and Sechzer, 1988) explicitly prohibit reporting gender differences "when a significant correlation is found between two variables for one sex and an insignificant correlation is found for the other sex" (p. 584). Only gender differences that are supported by appropiate statistical tests should be reported, and we have found that the effect of gender on TT is nonsignificant and very small (less than 1%). Moreover, the prediction of an effect of the interaction of gender and ability on TT has not been supported either. Therefore, we have to conclude that our evidence is not favorable to the response tendencies hypothesis.

In sum, this study has found that, in concordance with previous literature, *Vz* tasks are often solved with an non-spatial approach. But, at least in this particular task, strategy of choice is not related with *Vz* ability level or gender. Whether this result extends to other *Vz* tasks and samples remains an open question.

## RESUMEN

**Solution Strategies and Gender Differences in Spatial Visualization Tasks.**
El presente estudio ha examinado las estrategias de resolución y las

diferencias entre géneros en una tarea de Visualización Espacial (Vz). Se operacionalizaron dos tipos de estrategias, *analítica* y *holística* o *de manipulación espacial*, por medio de un cuestionario de auto-informe y de tres variables temporales obtenidas en una tarea computarizada de rompecabezas, llamada *R-E*. Estas variables fueron: el tiempo inicial de codificación del estímulo - objetivo, la duración de los procesos siguientes a la primera codificación, incluyendo comparaciones visuales y movimientos mentales de las piezas, y el tiempo total para cada ítem. Setenta y cinco mujeres y 77 varones completaron tests de referencia de Vz, el R-E y el cuestionario de auto-informe. Ni el nivel de aptitud de Vz en los tests de referencia ni el género resultaron asociados con la elección de estrategia de resolución.

**Palabras clave:** Diferencias entre sexos, Aptitud Espacial, Visualización, Estrategia de Resolución, Tiempo de Reacción

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