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Evaluation of the Spatial Visualization Ability of Entering Students in a Brazilian Engineering Course

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Abstract. Graphical Engineering and its applications require advanced abilities of visualization. The visualization ability and spatial reasoning are essential qualities for engineers due to their importance in the process of graphical communication and these professionals' need for solving spatial geometric problems. Yet, there is still no consensus on the exact components that constitute spatial visualization ability. Questions related to increasing students' spatial aptitude have motivated research on evaluation methods, as well as on the existing differences between males and females. Besides gender, differences in the spatial visualization ability and its acquisition have been attributed to a number of variables, including age, cognitive development, spatial experiences and genetic evolution. This work describes an experiment carried on through the execution of a computerized battery of two spatial visualization tests (Mental Rotation Test – MRT and *Test de Visualización* – TVZ), with the purpose of evaluating the entering students' spatial visualization ability in the Engineering courses of the Escola Politécnica of the University of São Paulo and to verify the existing differences between age groups and between genders, as well to analyze the behavior of the performance of the participants in the tests by testing some hypotheses.

Key Words: Spatial visualization ability, gender differences, Mental Rotation Test, *Test de Visualización*

MSC: 51N05

1. Introduction

Abilities result from multiple combinations of ideas, thoughts, data, previous knowledge and tasks that an individual is capable to perform and the useful information that he/she gets from these combinations. Spatial ability or intelligence involves the process of thinking about

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images, as well as the capacity to perceive, to transform and to recreate different aspects of the visual and spatial world [4], and is required by innumerable artistic, scientific and technical professions [16]. Many studies show that there is great variability of this ability in the population and that there is a significant and consistent difference between genders, with lower level of spatial ability in the feminine sex [16, 6, 8, 7]. Some investigations showed that hormones like estradiol and testosterone had some influence on visualization performance [9, 20]. The cause for gender differences in performance on space tests is object of controversies. Although this difference is well documented, its extension and the explanations for it have been the target of a considerable debate and social, biological and cultural explanations are offered. In addition to gender, differences in the ability of spatial visualization and its development have been attributed to a number of variables, including the cognitive development, spatial experiences, aptitude [2] and age [14].

2. Spatial visualization ability

Spatial ability can be defined as the ability to generate, retain, retrieve, and transform well-structured visual images [11]. According to [3], the spatial abilities include three distinct categories: mental rotation, spatial perception and spatial visualization. *Mental rotation* is the ability to mentally manipulate, rotate, twist, or invert objects in different positions [13]. The *spatial perception* relates to the ability to determine spatial relationships from visual information. The *spatial visualization* consists of the manipulation of complex visual problems imagining the relative movements of the internal parts of an image. In addition to the categories presented in [13], [12] in [10] refers to the spatial relations and the spatial orientation. *Spatial relations* consist of the relations that can be established through elements in the environment and reference points (landmarks). The *spatial orientation* consists in the ability to orient oneself in space as objects or events are presented [15]. Entering students in engineering courses usually do not show adequate development in their spatial abilities, regardless the fact that this skill is essential to the engineering profession. Two main factors are listed as cause of this problem [19]. The first one relates to the change in the habits of children and teenagers, since they now find their objects of interest ready or virtually ready, with no need for assembling. The second is about their inadequate previous teaching due to the depreciation of the graphical area in all educational levels.

3. Objectives

The present study aimed to describe the spatial visualization abilities of entering engineering students; to assess the association between the spatial abilities with gender and age; to analyze the correlation between two visualization tests (MRT and TVZ); and to assess the effect of the order the two tests were taken on the scores.

4. Methods

The research evaluated the spatial skills of entering engineering students of the Escola Politécnica of the University of São Paulo (EPUSP), in the beginning of the first semester of 2006, through a sequence of computerized visualization tests. Both MRT (Mental Rotation Test) and TVZ (*Test de Visualización*) were applied.

4.1. Subjects

The samples were composed of 605 students in the MRT test and 587 students in the TVZ, all of them entering students in the engineering courses of the Escola Politécnica of the University of São Paulo.

4.2. Spatial abilities tests

Spatial aptitude tests consist of instruments to evaluate the level of ability of space visualization of an individual. Most of them are composed of perspective figures showing rotated objects that an individual, through its ability to make mental rotations and comparisons, must recognize in order to tell if it is or not the same object as a supplied reference.

Two of the most common types of spatial abilities tests are [16]:

- Spatial Visualization Tests: testing time is not very short as emphasis is put on precision and not on execution speed. The proposed tasks are mainly focused on internal manipulation of the stimulus.
- Mental Rotation Tests: execution time is constrained. Their tasks demand comparisons of simple 2D or 3D stimuli for determining if they are representations of the same stimulus or not.

The *MRT – Mental Rotation Test* [18] was developed to determine the mental rotation ability of the individual being evaluated. The task is to find, among four alternatives, the two figures that represent the reference object. The test is applied within a time limit of 10 minutes. In half of the questions, the incorrect alternatives are rotated mirror images of the reference figure and in the other half, they are from different objects. Using a system with two correct alternatives and two incorrect ones for each question eliminates the need for correction factors that account for guessing. The total score is calculated as the sum of the 40 correct responses and can range from 0 to 40, with higher scores indicating higher spatial visualization skills. Fig. 1 shows an example from the 20 questions of the MRT.

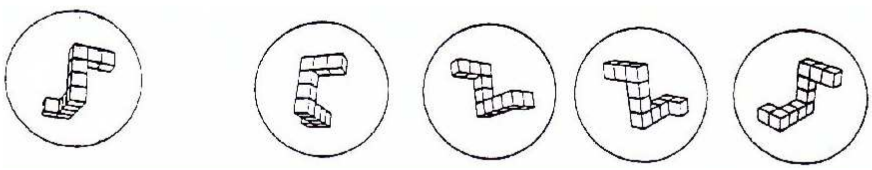

Figure 1: MRT sample question

The *TVZ – Test de Visualización* [1], developed by Professor Gerardo Prieto Adanez of the College of Psychology of the University of Salamanca, Spain, is applied within a time limit of 30 minutes and has 18 questions involving the unfolding of a cube. The objective is to identify which letter and in which position it appears in a certain face of the unfolded cube. Based on a cognitive system of spatial visualization, its items are well specified and they represent a scale of difficulty which is tied with the abilities that it aims to measure. The difficulty level is related to the distance of the requested face and the demanded rotation for detecting it. The rotation and distance are variables which have a strong impact in the processing difficulty. Another important characteristic is that all the faces are referenced and there is no question which does not require at least one rotation, compelling the student to execute all the cognitive process planned. The total score is calculated as the sum of the 18 items and can range from 0 to 18, with higher scores indicating higher spatial visualization skills. Fig. 2 shows an example of a question of the TVZ.

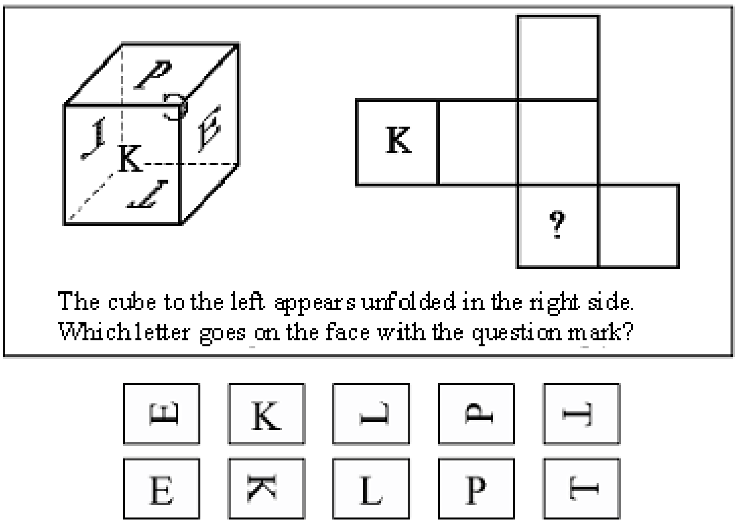

Figure 2: TVZ sample question

4.3. Experiment

In the experiment reported here, tests were administered to students in two computer labs (24 seats each, with 21"-monitor workstations) using software developed by the authors. The MRT and TVZ test questions were coded as web forms. Proper timing was automatically kept by the system. The experiment was performed in the first two weeks of classes. 18 groups were divided in two sets, in a way that the first set of students took the MRT in the first week and the TVZ in the second week, and vice versa for the other set. Only one participant occupied a computer of the laboratories during each test. Scoring, sequence and question representation were all kept the same as in the original paper and pencil tests. The interface was adapted to an electronic format and test timing as well as grading were automated. The images from the paper tests were scanned keeping the same quality in the electronic version. The time allowed for MRT testing was 5 minutes for each part. The maximum test time for TVZ was fixed in 30 minutes.

4.4. Statistical Analyses

Data was stored and analyzed using SPSS 13.0 (Statistical Package for the Social Sciences). Adherence to the normal distribution of total sample and gender partitions were examined through the application of the Kolmogorov-Smirnov test. P-values greater than 0.05 indicate that the variable adheres to the normal distribution [5]. When testing all the other hypotheses in this paper, the results were considered statistically significant if the p-value < 0.05, for a confidence interval of 95%. Statistical significance of differences in means were assessed either with Student's t-test (for normal distributions) or with Mann-Whitney U test (non-normal distributions). Correlations among test scores and age were evaluated using Spearman's rank correlation coefficient, as non-normal distribution samples were involved.

5. Results

The subjects participated on the tests in March, 2006. The total population of entering students of EPUSP is 750 individuals/year. The sample that took the MRT was composed by 95 (15.7%) women and 510 (84.3%) men, with mean age of 18.3 years. The TVZ sample had 89 (15.2%) women and 498 men (84.8%) with mean age of 18.4 years. This composition reflects well the entering engineering student population's gender and age. Figs. 3 and 4 illustrate histograms of participants' scores on MRT and TVZ respectively. Horizontal axes show score ranges.

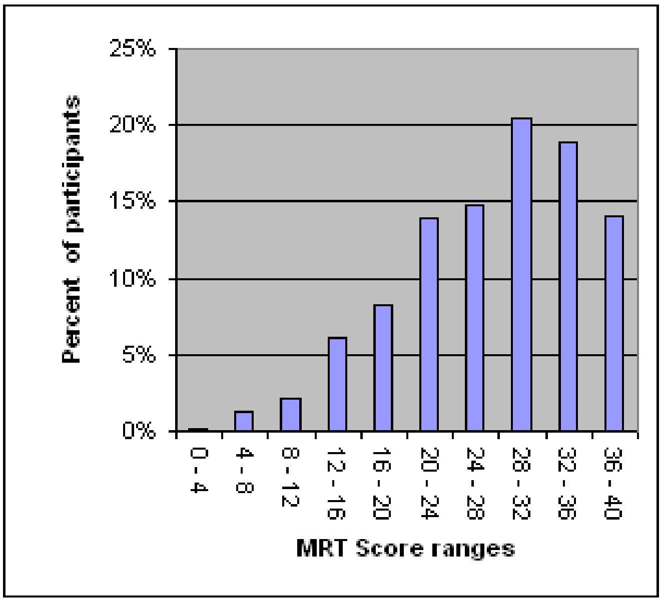

Figure 3: Total sample MRT scores

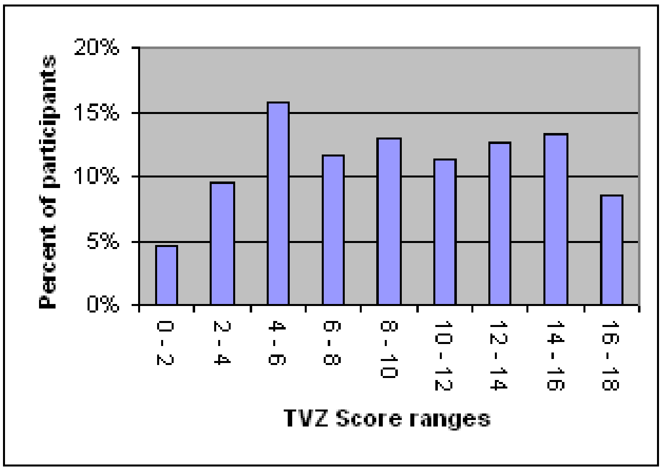

Figure 4: Total sample TVZ scores

5.1. Adherence to normal distribution

From the data shown on the Table 1, it is clear that only the samples for the female gender adhered to the normal distribution. This assessment was important for using the proper statistical tests on further analyses.

Table 1: Assessment of the adherence to normal distribution

	Total Sample		**Female**		**Male**	
	Test*	p-value	Test*	p-value	Test*	p-value
MRT	2.40	<0.001	0.665	0.768	2.20	<0.001
TVZ	2.27	<0.001	1.030	0.240	2.28	<0.001

*Kolmogorov-Smirnov Test

5.2. Gender differences

The shapes and distributions on histograms on Figs. 5 (MRT scores of Female / Male samples) and 6 (TVZ scores of Female / Male samples) indicate possible different probability distributions for male and female scores, both on MRT and TVZ.

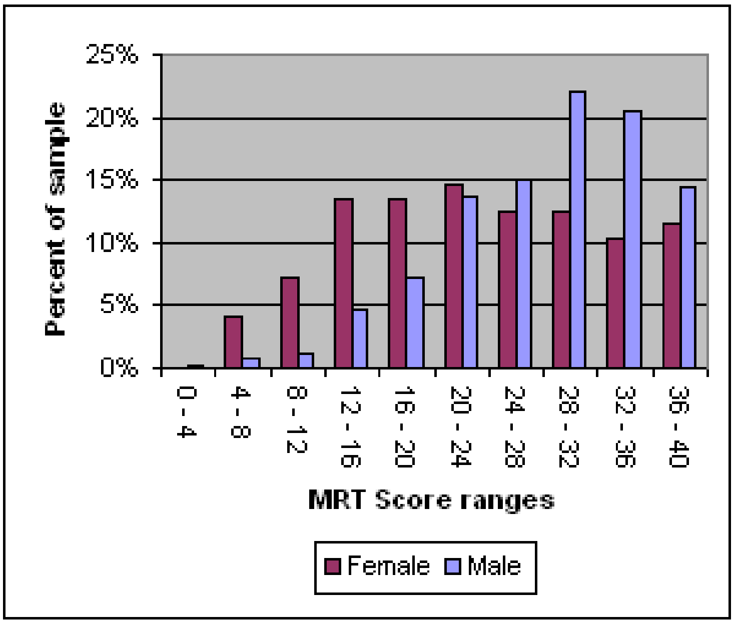

Figure 5: Gender differences in MRT score

Table 2: Spatial visualization scores in the total and gender partition samples

	Total Sample			**Female Sample**			**Male Sample**			Test* (p-value)
	Mean	SD	n	Mean	SD	n	Mean	SD	n	
MRT	28.00	7.99	605	24.01	9.22	95	28.75	7.52	510	16858.5 (<0.001)
TVZ	9.87	4.68	587	8.51	4.47	89	10.11	4.68	498	21418.5 (0.004)

*Mann-Whitney U test on difference of score means between female and male samples

A hypothesis concerning gender differences on test scores was assessed using Mann-Whitney U test. Its results are shown in Table 2 along with sample's statistics – Mean, Standard Deviation (SD) and sample size (n).

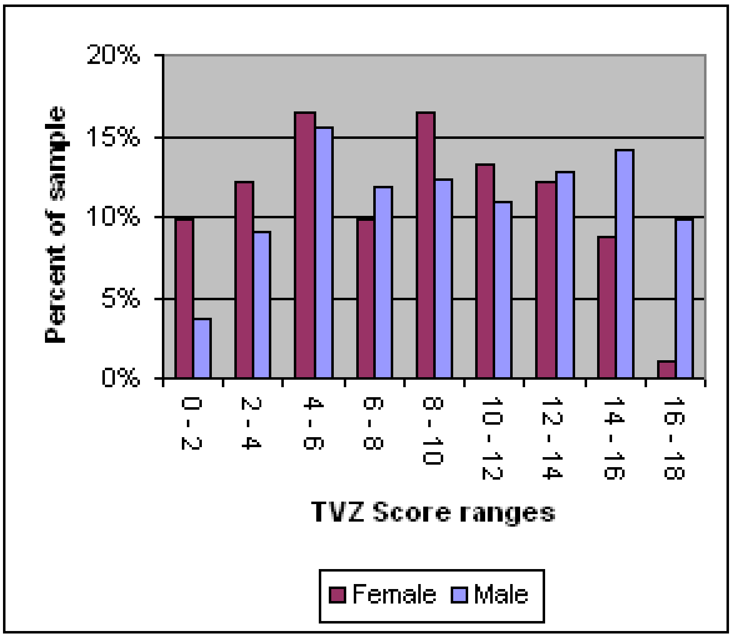

Figure 6: Gender differences in TVZ score

Data presented on Table 2 shows that there is a statistically significant difference on both visualization test score means. Thus, it can be concluded that gender influences participants' scores on MRT and on TVZ tests with higher scores for males. This result is consistent with many other reports [16, 6, 8, 7, 17] which also found that males, on average, have a higher spatial ability level than females.

5.3. Influence of test order on scores

As the two visualization tests were applied in two different orders, it is advisable to check if the sequence that tests were taken influences the obtained scores. Data for checking this issue is shown on Table 3.

Table 3: Comparison of the order of application of spatial visualization tests

Visualization Test	**Taken as 1^{st} test**			**Taken as 2^{nd} test**			
	Mean	**SD**	n	**Mean**	**SD**	n	
			Total Sample				**Test* (p-value)**
MRT	27.82	8.17	379	28.31	7.70	226	41664.5 (0.576)
TVZ	10.06	4.81	316	9.64	4.53	271	40416.5 (0.240)
			Female Sample				**Test† (p-value)**
MRT	23.37	9.18	63	25.28	9.30	32	-0.957 (0.341)
TVZ	8.41	4.65	51	8.63	4.28	38	-0.228 (0.820)
			Male Sample				**Test* (p-value)**
MRT	28.71	7.67	316	28.81	7.31	194	30626.5 (0.987)
TVZ	10.37	4.78	265	9.81	4.56	233	28650.0 (0.165)

*Mann-Whitney U test, †Students' t-test.

The data show no significant differences in any case. Therefore, it can be concluded that the order participants took the tests had no significant influence on their scores.

5.4. Age influence on test scores

The age range in the full sample was 16 to 37 years, but 98% of participants were 21 or younger. The age 20 years was chosen as the threshold for dividing the sample in two groups as shown on Table 4.

Table 4: Visualization scores by age groups

Visualization Test	**Age < 20 years**			**Age ≥ 20 years**			**Test***	**p-value**
	Mean	**SD**	***n***	**Mean**	**SD**	***n***		
MRT	28.15	7.95	541	26.78	8.29	64	15688.0	0.219
TVZ	9.91	4.62	520	9.51	5.15	67	16670.0	0.565

*Mann-Whitney U test

Data indicate that age has not influenced the performance of participants as no statistically significant difference on score means between the two age groups was detected. Although the literature reports findings on (negative) correlation of age and visualization abilities [14], the age difference of the subjects (and corresponding effect size) on this sample is too small to be detected.

5.5. Correlations among MRT, TVZ, and age

Lastly, the possible correlation of the performance on the two visualization tests was verified, as well as a possible correlation with age, as shown on Table 5.

Table 5: Correlation coefficients among age, MRT and TVZ scores

	Age		**MRT**		**TVZ**	
	r_s^*	**p-value**	r_s^*	**p-value**	r_s^*	**p-value**
Age	1.000	-	-0.037	0.365	-0.043	0.300
MRT	-0.037	0.365	1.000	-	0.538	< 0.001
TVZ	-0.043	0.300	0.538	< 0.001	1.000	-

*Spearman's rank correlation coefficient.

Again, it was not found any significant correlation between age and visualization scores. However, a moderate correlation ($0.4 < r_s < 0.6$) between both test scores was indicated by calculated parameters ($r_s = 0.538$, p–value < 0.001).

6. Conclusions

This work presented an analysis of the spatial visualization performance of entering students in the engineering course of EPUSP, where a computerized sequence of MRT and TVZ tests was applied. The main purpose of the work consisted on verifying some research questions.

Because of the good sample size, most of the results found were very significant (p-values far from the significance threshold). The results indicated a significant difference between men's and women's visualization test scores, with higher level of spatial visualization ability in the masculine gender, as predicted by published literature. The application order of the tests had no influence on the obtained scores. This information is useful for guiding experiment planning on further research. As the age dissimilarity among the experiment participants was very small, no statistically significant test score difference was detected between age groups or correlation between age and test scores. A moderate positive correlation between MRT and TVZ scores was found.

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