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ABSTRACT

This study investigated differential group performance on a spatial rotation test. A 19-item multiple-choice test was administered to a random sample of 107 students in grades 5 to 8 in an elementary school and a gymnasium (secondary school) in Cyprus. No gender differences were found on the overall score or on item-level performance. Items involving three-dimensional representations were on average more difficult than two-dimensional ones. Gymnasium students (grades 7 and 8) were more likely to answer more items correctly and scored significantly higher on the three-dimensional items. (Contains 4 tables, 2 figures, and 16 references.) (Author/SLD)

Age and gender differences in performance on a spatial rotation test

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INTRODUCTION

Understanding of space and spatial relationships and visual manipulation of spatial objects are important components in geometric and more broadly mathematical and scientific thinking. By its nature, spatial ability is a cognitive skill in perceiving spatial relationships and manipulating visual and non-visual material mentally; it may be considered a mathematical way of thinking (Connor and Serbin, 1985). In fact, using visualization and spatial reasoning and applying transformations are two of the standards included in the standards for school mathematics (National Council of Teachers of Mathematics, 2000).

Rotation is a transformation that involves reasoning about "turning" an object and visualizing it from different perspectives. It is a fundamental way of transforming and reasoning about space. In mathematical terms, a transformation is a rotation if and only if "it is the composite of two reflections through intersecting lines" (Jacobs, 1974, p.214). It is often defined in relation to the transformational process of reflection. To rotate a figure or an object, the center, the angle, and the direction of the rotation need to be defined. However, beyond the formal mathematical definition, children form intuitions about any spatial transformation. Before being taught or constructing any systematized knowledge on rotation, they come across the everyday concept of rotation, the informal notion of *turning*.

The purpose of this study is to investigate differential group performance on a spatial rotation test. Age and gender differences are examined on test- and item-level performance. Two- and three-dimensional representations are incorporated in the design to compare groups in that respect, as well.

THEORETICAL BACKGROUND

Researchers working within different theoretical frameworks have studied the nature and development of spatial abilities and reasoning. From a developmental perspective, there are two major lines of research that are concerned with the developmental nature of geometric concepts and thinking. Within the broader cognitive development of the child, Piaget and Inhelder (1956) described a stage-like progression. After children become capable of mentally representing objects, they enter the pre-operational stage during which they cannot perform any operations on those representations; their mental imagery is static. In the operational stage children can manipulate objects, transform representations, coordinate more than one dimension at the same time and take different perspectives. Abstract thinking is possible in the last stage of formal operations.

The van Hieles proposed a model with a sequence of developmental structures for geometrical reasoning (van Hiele, 1986). At the visualization level, students recognize objects and figures as total entities, and at the next level they can analyze figures to their parts. Proceeding to more sophisticated levels, students can then study and understand relationships between and properties of figures. The final two levels are concerned with deduction of theorems and rigorous comparison of axiomatic systems.

Performance on spatial tasks has been identified as an area where differential group performance occurs. Clements and Battista (1992) present numerous research findings usually tracing a gender gap on performance in geometry and spatial skills in favor of males. This arises even when females are found to outperform males in almost all school subjects (Mitchelmore, 1980). Other researchers note that only in some spatial tasks males perform better, and when significant differences are found they are small, while within sex variability is large (Fennema and Tartre, 1985).

Maccoby and Jacklin (1974) report that in studies involving spatial components, sex differences appear in adolescence. Connor and Serbin (1985) cite research findings to show that they appear to emerge at approximately 12-14 years. In the Second IEA Study of Mathematics males outperformed females in geometry and measurement – but not in algebra and computation – items at the age of 13 (Robitaille and Garden, 1989)

Males are reported to be more efficient in using non-verbal thinking strategies in contrast to females, who preferred verbal modes (Clements and Battista, 1992). This could imply that the difference in spatial performance might be due to strategy preference.

Fennema and Sherman (1977) question the validity of the studies suggesting the out-performance of males in mathematics achievement and spatial visualization and the widening of the gap between genders with age. By controlling variables such as previous background in mathematics (ibid.) and cognitive and affective variables (Fennema and Sherman, 1978), they found that sex-related differences in favor of males do not appear often and when they do they are not large. They did note however a differentiation towards negative attitudes in girls beginning the 10th grade, which contributes negatively to their relation to mathematics.

METHODOLOGY AND DATA SOURCES

The study was carried out in two middle-class schools in Cyprus. Out of 503 students in grades 5 to 8 (ages 10:2 to 14:1), 107 were randomly selected (see Table 1). The 5th and 6th graders attended the higher grades at an elementary school and the 7th and 8th graders attended the first two grades of a gymnasium.

TABLE 1

The sample by grade and gender groups

Grade	Boys	Girls	Totals
5	11	15	26
6	12	15	27
7	11	16	27
8	17	10	27
Totals	51	56	107

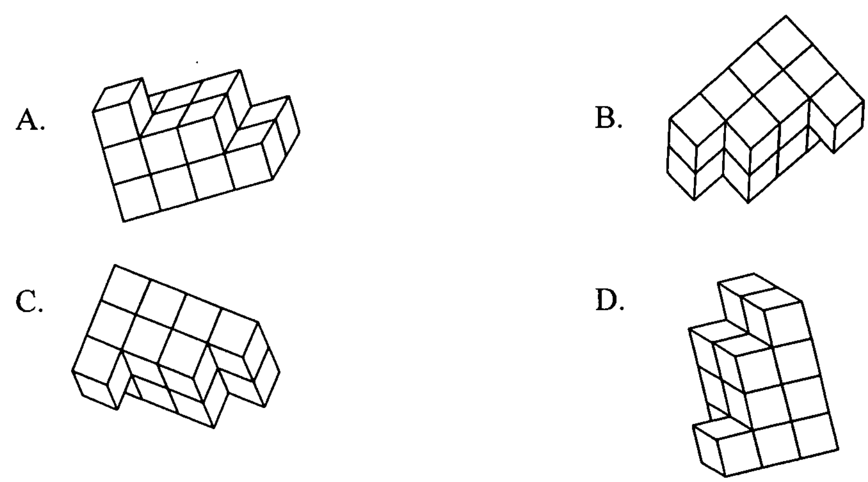
Rotations was not part of the formal curriculum for the students in the sample. These particular age groups were selected because they are assumed to include children of both Piagetian concrete and formal operations stages. Quantitative differences between concrete and formal operational children, in spatial ability, could be manifested in test performance. Secondly, students constituting the sample should not be restricted from understanding, reasoning, justifying and answering the questions by their linguistic abilities.

A test consisting of 19 multiple-choice items was constructed in order to test the spatial ability of mental rotation. Items were borrowed from standardized tests on figural and block rotation (Eliot and Macfarlane Smith, 1983) requiring test-takers to indicate which of several figures or blocks, when turned or rotated imaginatively, will be the same as or different from a given figure or block. The structure and the format of the questions were kept the same, but new, simpler pictures were constructed. The items were translated into Greek. Formal geometric terms and mathematical symbols were avoided. Figure 1 shows an example on one item.

FIGURE 1

A test item

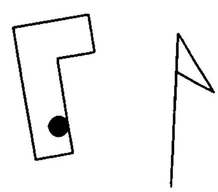
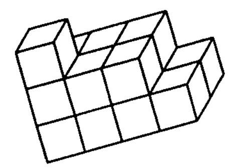
Among the 4 following shapes, there are 3 which show the same object from different viewpoints. One of the 4 shows a DIFFERENT object. Which one?



The items may be classified in two broad categories as in Table 2: figural rotation items (two-dimensional), and block rotation items (three-dimensional). Three-dimensional blocks are presented in two different ways: with the side faces either drawn with an outline, or sketched with different shades. All items present a prototype accompanied with four identical, or similar drawings in varied rotations. Instructions ask for identifying either the rotated mirror image and not the rotation of the original shape, or the only rotation and not the rotated mirror-image of the prototype. One item requires a 90^{o}-rotation to the left and another requires a rotation of the shape to view it from the back.

TABLE 2

Test items classified according to characteristics

	Two Dimensions Figural rotation	Three Dimensions Block rotation	
		Blocks	Shaded view
Examples of figures and blocks used			
Identify the same	4	3	1
Identify the different	5	2	2
90^{0} Rotation	-	1	-
View from the back	-	1	-
Totals	9	10	

A larger number of items were piloted before administering the test. Very easy and very difficult questions were rejected and alternative wordings and item formats were tried out. Students were also asked to draw a cube and to describe a two-dimensional representation of a pile of cubes, in order to verify that they could both represent and interpret three-dimensional relations in the forms used in the test. The students seemed to be familiar with the representations used in the test. Before administering the test, the researcher explained briefly some of the various meanings of the term *rotation* and presented an example of a rotation and of a reflection of a figure on the page.

RESULTS

Table 3 shows test descriptive statistics. Cronbach's α reliability coefficient for the test was 0.71.

TABLE 3

Test Descriptive Statistics

Group	N	Mean number-correct score	Standard deviation	Range (max = 19)
All	107	14.62	3.04	13
Male	49	14.73	3.32	13
Female	58	14.52	2.81	12
5th grade	26	14.12	2.89	12
6th grade	27	14.00	3.34	13
7th grade	27	15.00	2.97	10
8th grade	27	15.33	2.87	11
Primary school	53	14.06	3.10	13
Gymnasium	54	15.17	2.90	11

The mean of males and gymnasium students were slightly higher than those of the females and the primary-school students, respectively. A sign test was carried out to test the hypothesis that the proportion of items showing differences in the same direction differed from 0.5. For each of the 19 items the sign of the difference between the mean item scores of gender (and age) groups was calculated. A higher mean item score of females over males (and of younger over older students) was considered a success. The results of the sign test appear on Table 4. The hypothesis that females are likely to perform better on the same number of items as males is not rejected, but clearly older students are more likely to get more items correct on the test than younger students. In two-sample t-tests, no significant differences in achievement were found between gender groups, or between the two age groups (primary school and gymnasium children), although the latter was close to significance.

TABLE 4

Sign tests for gender and age differences

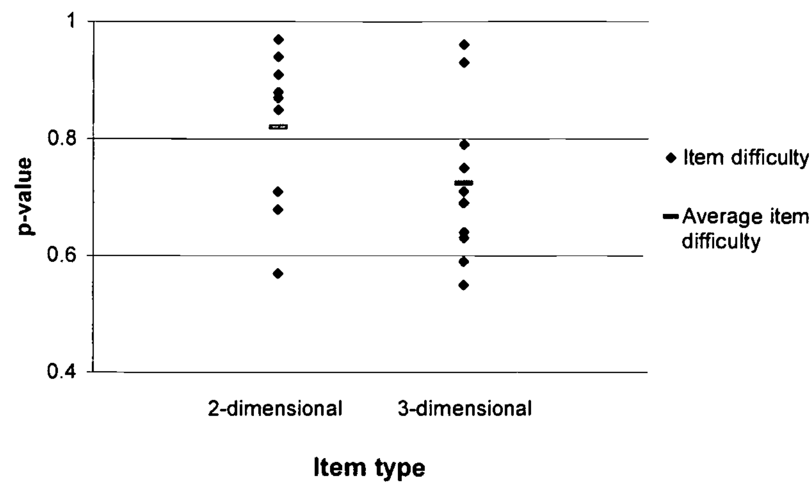
Tested Groups	Successes	Failures	Ties	p
Gender	11	7	1	0.481
Age	3	15	1	0.008

Two sub-scales were constructed: one consisting of the two-dimensional and one consisting of the three-dimensional items. Item difficulty values ranged from 0.55 to 0.97 ($\overline{p} = 0.77$). Figure 2 shows individual item difficulties (p-values) and average p-values by item type. Three-dimensional items were on average more difficult ($\overline{p}_{3d} = 0.72$ compared to $\overline{p}_{2d} = 0.82$). The overall performance on the two-dimensional items was higher than on the three-dimensional. The mean number-correct score in the two-dimensional part of the test was 7.38 out of 9 (SD = 1.67), compared to 7.23 out of 10 (SD = 1.88) for the three-dimensional. However, the difference was not statistically significant: a 95% confidence interval (-0.28, 0.47).

Gymnasium students scored significantly higher than elementary school students on the three-dimensional subscale only ($t = 2.14$, $p < 0.05$). The difference was more pronounced for males than for females. Gender differences were not significant on either of the two subscale scores overall or by school type separately.

FIGURE 2

Item difficulty values



Item level analysis of the 19 items revealed that males performed significantly higher on only one two-dimensional item and that gymnasium students scored significantly higher on two three-dimensional items.

Point-biserials for the items ranged from .20 to .58. Items with point-biserial below .3 were checked. 3 of them were too easy and almost all respondents chose the correct option. Only one question (item 5) had a distractor which attracted many answers (but still fewer than the correct option did). The correlation of that distractor with the test score was -.042.

The scores on the two components of the test were highly correlated with the overall test scores, the Pearson Correlation Coefficients being 0.84 and 0.87 respectively. A significant correlation was found between the scores in the two-dimensional items and the three-dimensional items, though not very high (r = 0.46), which increased to 0.86 with a correction for attenuation.

CONCLUSIONS LIMITATIONS AND IMPORTANCE OF THE STUDY

Test and item analysis did not show any differences between male and female test performance. The absence of gender differences is consistent with Gorgorió's (1998) and Fennema and Sherman's (1977, 1978) claims of occasional occurrence of gender differences in specific spatial tasks. There seems to be more variation in performance within gender groups than between them. Identification of gender differences in specific content areas is an interesting finding that can lead to further investigation into the causes giving rise to such differences. However, it could be that the features of each task were a much more decisive factor in student responses, than any group characteristic such as gender, age within the age range of the research.

In two-dimensional items younger and older students did not have a significantly different performance, while in the three-dimensional items older students scored significantly higher. This may suggest that the effect on the higher overall score for older students derives more strongly from the three-dimensional items. Mental rotation of three-dimensional shapes seems more difficult than rotating flat patterns (Corballis, 1982). Therefore, a difference is anticipated in the time each ability develops and in their degree of difficulty, since the mere interpretation of the representation of the former constitutes an additional effort. A rival hypothesis is that the low degree of difficulty for the two-dimensional items might have caused a "ceiling effect" and all students scored very high, thus not allowing much variability in item scores. The low disattenuated correlation between the two subscales also suggests that the two constructs (rotation in two and three dimensions) are somehow different.

From an educational perspective, knowledge about the influence of age on spatial reasoning can guide the design of instructional and assessment models suitable for specific age levels, as well as for concepts and procedures in geometry teaching. Teachers can adapt their teaching taking into consideration students' developmental difficulties on specific topics.

Using a test is a simple and convenient way to operationalize concepts (Wood, 1987). This test was designed and developed to test one aspect of spatial abilities only: rotation of figural patterns in two and three dimensions. Further research could investigate the performance and development of spatial thinking in younger children and other settings, as well as in other topics on space and geometry. Moreover, more in-depth, qualitative methodology can be used to describe the thinking strategies that are available to students when solving this type of tasks.

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