

Gender Differences in Spatial Ability of Young Children: The Effects of Training and Processing Strategies

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A sample of 116 children ($M = 6$ years 7 months) in Grade 1 was randomly assigned to experimental ($n = 60$) and control ($n = 56$) groups, with equal numbers of boys and girls in each group. The experimental group received a program aimed at improving representation and transformation of visuospatial information, whereas the control group received a substitute program. All children were administered mental rotation tests before and after an intervention program and a Global–Local Processing Strategies test before the intervention. The results revealed that initial gender differences in spatial ability disappeared following treatment in the experimental but not in the control group. Gender differences were moderated by strategies used to process visuospatial information. Intervention and processing strategies were essential in reducing gender differences in spatial abilities.

Spatial ability has a vital role in our daily interaction with environment, such as navigation, recognizing and manipulating objects, academic tasks, and recalling locations. Spatial ability is one of the several relatively autonomous human intellectual competencies (Gardner, 1983) and is considered essential to mathematics and scientific thinking (Delgado & Prieto, 2004), performance on standardized tests (e.g., the SAT; Casey, Nuttall, Pezaris, & Benbow, 1995), representing and manipulating of information, and problem solving. Proficiency in visuospatial ability has long been associated with success in cognitively demanding educational tracks and occupations such as engineering, architecture, physics, chemistry, and surgery (e.g., Snow & Yalow, 1982; Sorby & Baartmans, 2000) and is a salient characteristic of physical scientists (Gohm, Humphreys, & Yao, 1998; Humphreys, Lubinski, & Yao, 1993). Visuospatial ability is not routinely taught by schools and thus is not often developed and assessed in ways that influence students' educational and career plans (Webb, Lubinski, & Benbow, 2007). Adding spatial ability to identification procedures of talented students (currently restricted to mathematical and verbal ability) could uncover a neglected pool of math–science talent and holds promise for refining our understanding of intellectually talented youth.

Gender differences in spatial ability are well documented in the scientific literature (e.g., Coluccia & Louse, 2004; Halpern, 2007; Kimura, 1999; Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005; Voyer, Voyer, & Bryden, 1995). Early researchers in this area have traditionally reported a male advantage over female on standard tests of spatial ability, at least after adolescence (Maccoby & Jacklin, 1974). Recent research, however, showed that gender differences emerge around the time children enter kindergarten or begin first grade, which may be as early as children can reliably perform tasks that assess visuospatial abilities. Levine, Huttenlocher, Taylor, and Langrock (1999) found that, on average, preschool boys are more accurate than girls at spatial tasks that measure that accuracy of spatial transformations ($d = .31$) and score higher on the Mazes subtest of the Wechsler Preschool and Primary Scale of Intelligence ($d = .30$). They concluded that gender differences in favor of boys are present on spatial tasks by age 4½.

Meta-analytic studies suggested that spatial ability is not a unitary construct, and that the magnitude of gender differences deeply depend on a task's demands (Coluccia & Louse, 2004; Kimura, 1999; Linn & Petersen, 1985; Voyer et al., 1995). However, those reviews provided substantial evidence that the largest and the most robust gender

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differences arise on spatial tasks involving mental rotation, like the classical mental rotation test developed by Shepard and Metzler (1971). Gender differences in mental rotation tests are typically associated with some of the earliest disparities in strategies used by boys and girls in processing visual-spatial information (Cooper, 1976; Kramer, Leopard, Ellenberg, & Share, 1996). Recent studies with infants, using habituation techniques, demonstrated that already by the age of 3–5 months, there were gender differences in mental rotation (Moore & Johnson, 2008; Quinn & Liben, 2008). Quinn and Liben (2008) provided evidence showing that male infants were more likely than female infants to recognize as equivalent a two-dimensional figure rotated in the same way as was the figure shown during a familiarization phase. The male infants were also more likely than female infants to perceive a mirror image of that figure as novel. Similarly, Moore and Johnson (2008) demonstrated gender differences with 5-month-old infants using two-dimensional object representing three-dimensional object. The male infants discriminated the habituation objects from its mirror-image test objects whereas female infants treated both objects similarly. In both studies, the investigators conclude that in spite of the fact that gender differences in mental rotation are already apparent at infancy, more research should be carried out to explore the interacting factors that influence the development of mental rotation.

Several researchers reported that global-local strategies were inherently related to mental rotation performance (Bethell-Fox & Shepard, 1988; Bryden, George, & Inch, 1990; Johnson, 1990). Small effect sizes were reported for simple commonly used tasks whereas in more difficult tasks that require generating an image and maintaining it in working memory, results vary depending on the complexity of the image to be generated and the specific nature of the task, with observed differences ranging between $d = .63$ and $d = .77$ (Loring-Meier & Halpern, 1999). Mental rotation tasks that require maintaining a three-dimensional figure in working memory while simultaneously transforming it show very large gender differences, somewhere between 0.90 to 1.0 *SD* (Masters & Sanders, 1993; Nordvik & Amponsah, 1998), although some researchers have reported smaller effect sizes (Voyer et al., 1995).

Males' outperformance of females on measures of visuospatial abilities has been implicated as contributing to gender differences on standardized exams in mathematics and science (Halpern et al., 2007). An evolutionary account of gender differ-

ences in mathematics and science (e.g., Geary, 2007; Gur & Gur, 2007; Haier, 2007) supports the conclusion that although gender differences in math and science performance have not directly evolved, they could be indirectly related to differences in interests and specific brain and cognitive systems. Newcombe (2007) challenged the evolutionary approach, first, by showing logical inconsistencies and gaps in biological sex differences research and, second, by demonstrating that these differences are not immutable and can be eliminated by proper intervention.

In the present study, we address four important interrelated questions: (a) Do young children in first grade show gender differences on mental rotation tasks at an appropriate level of difficulty for their age? (b) To what degree does training of representation and transformation of perceptual stimuli, by viewing them from different perspectives, reduce initial gender differences? (c) Is the magnitude of the hypothesized gender differences influenced or moderated by global versus local strategies of representing and transforming visuospatial information? (d) What are the interactive effects of gender, training, and task difficulty (degree of rotation and test level) on performance of mental rotation tasks?

For the purpose of this study, we constructed a mental rotation test, which is based on the *Mental Rotation* subtest of the *Cognitive Modifiability Battery* (CMB; Tzuriel, 1995, 2000a, 2000b; Tzuriel & Egozi, 2006) and an intervention program aimed at training global strategies of representing and transforming of spatial information based on Wheatley's (1996) "Quick Draws" activities. According to Piaget and Inhelder (1956), these abilities are vital components in mental rotation performance. Representing and transforming spatial information requires to some degree an extension of working memory capacity proved to be essential for mental rotation performance. Coluccia and Louse (2004) in their extensive meta-analytic review have reached a conclusion that gender differences in spatial orientation emerge only when tasks require a high load of visuospatial working memory. Thus, males would show better performance in spatial orientation because of their larger visuospatial working memory span. When the orientation task does not involve a high load in visuospatial working memory, gender differences would disappear. Similarly, Feng, Spence, and Pratt (2007) showed that improvement in performance on a mental rotation task, following training composed of playing an action video game, was associated with improve-

ment in spatial attention. Furthermore, following training, females showed higher improvement than males on both spatial attention and mental rotation tasks. Vasta, Knott, and Gaze (1996) showed also that gender differences were eliminated by carefully conceptualized training.

In congruence with other researchers (Feng et al., 2007; Newcombe, Mathason, & Terlecki, 2002), our claim is that it is more important to determine whether gender differences may be reduced or eliminated by training than merely documenting them. Baenninger and Newcombe (1989) reported in their meta-analytic study that spatial ability can indeed be improved with training, with effect sizes ranging from $d = .40$ to $d = .80$, depending on the length and specificity of the training. However, no differential improvements were reported for boys and girls. A more recent meta-analysis of the effects of training and experience on spatial skills confirms the earlier findings (Marulis, Lui, Warren, Uttal, & Newcombe, 2007). However, the effects of training were similar for males and females; that is, both groups benefited about equally from the training; no evidence was found to show that the gap was closed or widened by training.

In a recent study by Tzuriel and Egozi (2006), gender differences in mental rotation were investigated among 5- to 6-year-old kindergarten children. The objectives were to investigate the interactive effects of gender, treatment, and task characteristics on spatial abilities tasks using a *dynamic assessment* (DA) procedure (Haywood & Lidz, 2007; Lidz & Elliott, 2000; Sternberg & Grigorenko, 2002; Tzuriel, 2001). The treatment was composed of teaching children to preserve the whole pattern of a model at different positions in space. This teaching strategy focuses on a global-holistic approach based on pattern conservation of the model and rotating it in the space as a whole unit, without fragmenting its components. Clinical experience showed the global-holistic strategies to be more efficient than analytic strategies, as children could use global-holistic strategies to circumvent the difficulty of defining verbally the problem's components. A verbal analytic strategy was given as a secondary strategy to support children who might have difficulty with the holistic approach. The findings revealed a significant improvement in mental rotation in both gender groups. A differential treatment effect on boys and girls was evident, however, when task characteristics (e.g., degree of rotation, pattern complexity) were involved. Contrary to the hypotheses, *boys responded more effectively to intervention at difficult levels of the tasks and improved their mental*

rotation more than did girls. The differential improvement of boys and girls was attributed to different strategies used by them (e.g., global), as evidenced by clinical observations during the teaching phase. In spite of the fact that all children were offered similar strategies, boys tended to use a global approach based on *conservation of patterns and rotation of the unit as a whole*, whereas girls showed a detailed analytic approach based on verbalization of location.

These findings and the clinical evidence showing the effectiveness of a global-holistic perceptual approach in representing visuospatial information were the basis of the current study. Unlike the short 1-hr intervention (teaching phase of a DA procedure) used earlier (Tzuriel & Egozi, 2006), in the current study we used a more intensive intervention approach composed of eight small group sessions (45 min each).

Following Tzuriel and Egozi's (2006) study, our main hypothesis was that initial gender differences in mental rotation will be reduced by the use of adequate training based on developing cognitive processing strategies of representation and transformation of visuospatial information. We also hypothesized that boys will show higher global strategies in processing visuospatial tasks than girls who will tend to show local strategies, and that the initial gender differences will disappear when Global-Local Processing Strategies (GLPS) are considered. With regard to the intervention program, we hypothesized that it would be more effective for high-level than low-level tasks (i.e., as degree of rotation increases).

Method

Participants

The sample was composed of 116 first-grade children (58 girls and 58 boys), recruited from Israeli public schools. Most children were of Jewish ethnic origin (89.66%) and the rest were Israeli-Arabs (10.34%). Children ranged in age from 6 years to 7 years 2 months ($M = 6$ years 7 months, $SD = 3.71$ months), with no significant age differences between boys and girls, $F(1, 113) = 1.81$, *ns*. All children were right-handed, with no history of developmental, neurological, or learning problems. The reason for including only right-handed children is based on recent neurological research showing different hemispheric activity among left- and right-handed individuals (Kim et al., 1993). Some researchers suggest controlling this variable

when studying gender differences in spatial ability (e.g., Kramer et al., 1996). The sampling process was carried out in three stages: (a) random selection of 10 of 34 public primary schools whose principals agreed to apply for an intervention program for the development of spatial abilities, (b) random selection of one first-grade class in each school, and (c) a random selection of 6 boys and 6 girls in each class. The parents were required to consent to the inclusion of their child in the study and provide basic information on the child's developmental history. During data gathering, 4 of the original sample of 120 children could no longer participate in the study because their families moved from the area.

A sample of 3 boys and 3 girls from each class were randomly assigned to experimental and control groups. The experimental group consisted of 60 children (30 each, boys and girls) and the control group consisted of 56 (28 each, boys and girls). Both groups were similar on socioeconomic status (SES) indices of parent occupation, $\chi^2(4) = 3.10$, *ns*, and years of education, $\chi^2(4) = 3.68$, *ns*. In both groups, about 50% of the parents graduated high school and held a professional occupation. In view of Levine et al.'s (2005) findings that gender differences are sensitive to SES differences, the similarity of the experimental to the control group in the current sample seems to be satisfactory. No significant differences were found between the groups on a composite score of the WISC-R95 Vocabulary and Concept Formation subscales, $F(2, 112) = .58$, *ns*.

Measures

Spatial Relations (SR) subtest from the Primary Mental Abilities–Children's Version (Thurstone & Thurstone, 1965). The SR is a standard measurement for the ability to visualize rotated objects in two-dimensional space and to identify the relation among them. The SR is composed of 27 items and four examples. In each item, the child is presented with a model figure that is a part of a square and has to determine which of the four given alternatives completes the square. The alternatives are positioned so that children must mentally rotate the parts to complete the square. A score of 1 is given for each correctly solved item.

Although standardized administration of the SR is in groups, with a time limit of 4 min, in the present study it was administered individually and without a time limit, to avoid test stress and anxiety. Johnson and Meade (1987) reported a split-

half reliability of .89, using the Spearman–Brown's formula among children in Grades 1–4. Correlations with other spatial ability tests ranged from .44 to .63.

The Windows Test (WT). Construction of the WT was based on the *Mental Rotation* subtest of the CMB (Tzuriel, 1995, 2000a, 2000b; Tzuriel & Egozi, 2006). Designed for children in first to fourth grades, it includes three difficulty levels (WT1, WT2, and WT3). In order to examine the adequacy of the WT for young children, a pilot study was carried out on Grade 1 children ($n = 32$). Based on the preliminary results where a floor effect was observed on the WT3 level, it was decided to administer only the first two levels (WT1 and WT2). For each test level, there are parallel versions that are administered in the pre- and postintervention phases, respectively.

In both test levels, children are presented with model figures of "houses with windows" arranged in a 3×3 patterns (nine windows); some windows are closed (blackened) whereas others are open. On turned-about houses, taking into account their rotation in space (see Figure 1), children are asked to mark the identical closed windows. The main difference between WT1 and WT2 is the clue for rotation, which is much more concrete and articulated in WT1 (red roof) than in WT2 (red basis line). For each level, there are 18 problems arranged according to the *degree of rotation* needed to solve the tasks (45° , 90° , and 180°), *complexity* (2, 3, and 4 closed windows), and *symmetry* (half are symmetrical and half are asymmetrical; see Figure 1). The unique design of the WT allows separate analyses of the child's responses according to test level, degree of rotation, complexity, and symmetry of the patterns. In the current study and for the sake of simplicity, we analyzed only the test level and degree of rotation.

Each correctly solved window is given a score of 1 (maximal score = 54). Cronbach alpha reliabilities in the pilot study were .79 and .82 for the WT1 and WT2, respectively. Test equivalency reliabilities for the WT1 and WT2 were .82 and .87, respectively. The Cronbach alpha reliabilities on the current Grade 1 sample, for pre- and postintervention, were: WT1 = .78 and .73, respectively; WT2 = .76 and .74, respectively. Test-retest correlations between pre- and postintervention in the experimental group were .60 and .66, respectively, and in the control group .79 and .79. Pearson correlations of the SR with WT1 and WT2 were .41 and .49, respectively. Construct validity was examined by analyzing the performance as a function of task

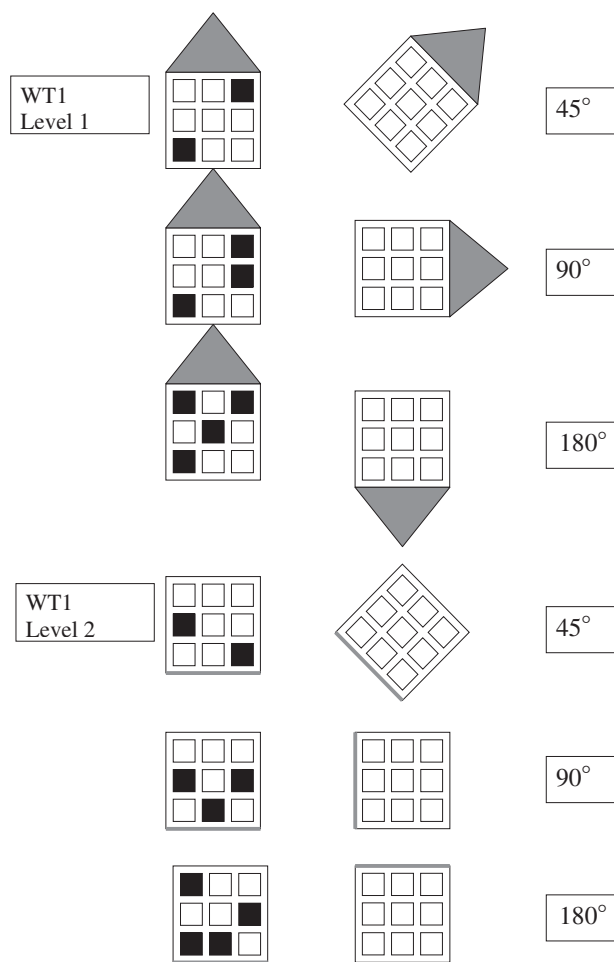


Figure 1. Mental rotation items from the Windows Test (WT).

characteristics. The findings of the pilot study showed clear linear decrease in performance as a function of degree of rotation, $F(2, 111) = 503.09$, $p < .001$, $\eta^2 = .90$; complexity level, $F(2, 111) = 28.53$, $p < .001$, $\eta^2 = .34$; symmetry, $F(1, 112) = 342.83$, $p < .001$, $\eta^2 = .75$; and test level (WT1, WT2), $F(1, 112) = 532.55$, $p < .001$, $\eta^2 = .83$. Findings on the initial composite WT scores, using the sample of the current study, also showed a significant performance decrease as a function of degrees of rotation, $F(2, 111) = 416.80$, $p < .001$, $\eta^2 = .88$, and test level, $F(1, 112) = 366.70$, $p < .001$, $\eta^2 = .77$.

Global-Local Processing Strategies. The GLPS (originally named Global-Local Judgment Tasks) was composed of 16 perceptual judgment tasks (stimulus cards) originally designed by Kimchi and Palmer (1982) for assessing visual-spatial processing styles among young children on a global-local dimension. Every stimulus card contained a standard figure at the top and two comparison figures

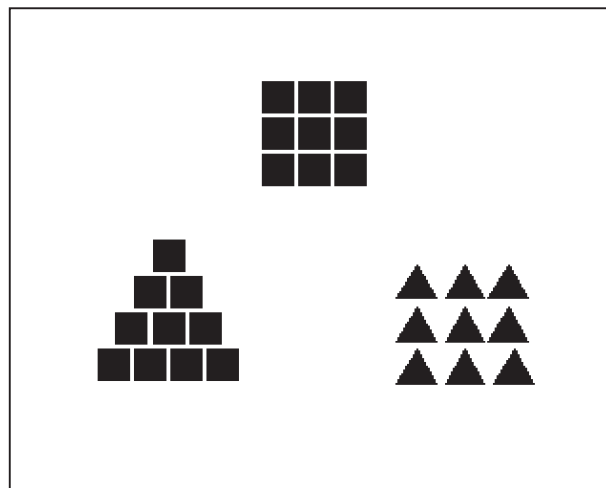


Figure 2. Example of a global-local task.

at the bottom (see Figure 2). All the standard and comparison figures consisted of a global shape composed of local shapes. On each card, one of the comparison figures had the same global shape as the standard figure but comprised different local shapes; the other comparison figure had the same local shapes but was arranged in a different global shape. As can be seen in Figure 2, the global comparison figure is a square but comprised triangles. The local comparison figure, on the other hand, has the same local shapes (squares) but arranged into different global shape (triangle). For each stimulus card, children were asked to point out to one alternative out of two, which looked most like the standard, based on their first and immediate impression; clear instruction was provided that there are no right or wrong answers. The cards were presented one at a time in a random order, at a distance of approximately 60 cm from the child. To control for habitual orientation, half of the cards appeared with the global alternative on the right, while appearing on the left for the other half. A response was credited a score of 1 if the local comparison was selected and 2 if the global comparison was selected. The total score ranged from 16 to 32. Cronbach alpha reliabilities in a pilot study and in the current sample were .92 and .94, respectively.

The "Spatial Sense" Intervention Program

The intervention program is based on Wheatley's (1996) "Quick Draws" activities, designed to promote spatial sense in the mathematics curriculum, with a focus on *representing and transforming spatial*

information, according to the standards of the American National Council of Teachers of Mathematics.

The training program was composed of eight sessions, given once a week in a small group setting (3 boys and 3 girls). In each 45-min session, four flash cards were presented and discussed in the group. The activities were documented by the trainers and by children in special notebooks that served also for follow-up. Each lesson was composed of three stages. In the first stage, the trainer exposed flash cards to the children on a screen using an overhead projector. Each card was exposed three times, each time for 3 s. In the second stage, children were asked, after each series of card exposure, to draw what they saw. As the figure on the flash card is not observable while drawing, children must make their drawings using mental images they have constructed. The figures can be interpreted in many different ways (see Figure 3). In the third stage, the trainer guided the children, during group discussion, to look at the figures from different points of view. The children were encouraged to take their peers' perspectives and suggest the

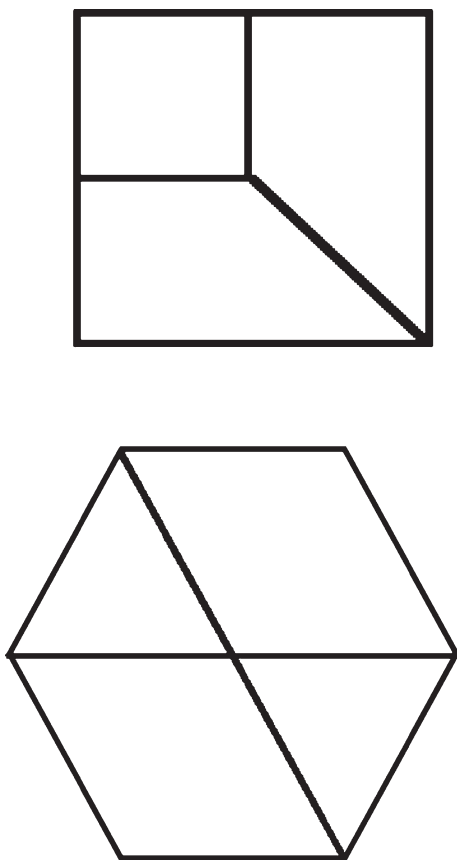


Figure 3. Training items from the "Spatial Sense" Intervention Program.

spatial imagery. The trainer allowed them to rotate the figures physically in order to demonstrate the image they perceived and drew. Typical descriptions given to the top picture shown in Figure 3, for example, were: a square with two trapezoids, two legs with shoes, a flower, a kite, a hat, a pyramid without top, a hallway, a room, a loudspeaker, back of a computer screen, and a popcorn box. Some of the descriptions were of a two-dimensional nature and some of three; some were constructed as an image of sections and others of joined segments. Typical descriptions given to the bottom picture shown in Figure 3, for example, were: hexagon with X, bow tie, two kites or diamonds, open envelope, a cube with some lines missing, and kind of a rollercoaster's seat.

It should be emphasized that children were not directly trained to mentally rotate the figures but rather to *perceive the stimuli as a whole from different angles, retain them in their working memory, and flexibly conceptualize them as representing different objects.*

The original program is constructed for use with primary school children in a class situation. It includes 168 shapes arranged in seven levels. For the purposes of the current study, and based on a pilot study that verified their adequacy in terms of graphic-motor level, associative accessibility, and verbal possibilities, we selected 32 of the shapes found to be appropriate for use with first-grade children.

This choice of program was based on the studies of Wheatley and colleagues (Brown & Wheatley, 1997; Wheatley, 1990, 1991, 1997; Wheatley & Reynolds, 1999; Yackel & Wheatley, 1990), who showed that such activities improve children's ability to represent and transform spatial information. Analysis of the type of activities in the program shows that they help in expanding visuospatial working memory skills found to be crucial for mental rotation tasks (Coluccia & Louse, 2004). The choice of program is also appropriate to Tzurriel's (2000a, 2000b, 2001) approach, according to which concrete manipulations used with young children can serve as a "bridge" for complex mental manipulations.

Procedure

The procedure included three stages: preintervention, intervention, and postintervention. In the preintervention stage, children were individually tested on the SR test and WT (WT1, WT2), GLPS tasks, and Vocabulary and Concept Formation subtests, in that order. Graduate students administered the tests during 45 min in a quiet schoolroom.

Children in the experimental group participated in the intervention program for about a 3-month period. The control children participated in a substitute program for the same number of sessions, group structure, and setting. The control children were presented the same flash cards shown to the experimental group but without the short exposures, and were encouraged to copy the figures, individually, as accurately as possible. The control procedure was focused on pictographic and fine-motor skills but did not include teaching, group discussion, or guidance related to creation of visual imagery and spatial skills vital to mental rotations. Six trained graduate students who were not aware of the study's hypotheses administered the intervention and substitute programs. In the postintervention stage, 5 months after the preintervention phase, the SR test and WT (WT1, WT2) were administered again during one 30-min session. The tests in the postintervention phase were administered under the same conditions as the preintervention phase. Examiners who were not aware of the study's goals and the children's group assignment scored all tests.

Results

The Effects of Training Program on Gender Differences in Mental Rotation

The major objective of the current study was to investigate whether training in spatial abilities will moderate the effect of gender. In addition, we were interested in the relation between GLPS as a moderating factor of gender differences in spatial abilities and in the interaction effects of training with task characteristics (e.g., test level, degree of rotation) in moderating gender effects. Because of the complexity of the study's design, which includes five variables, we will report only interactions that involve gender, treatment, and time (pre- and postintervention). In Table 1, we present the pre- and postintervention scores of WT1, WT2, SR, and GLPS tests of boys and girls in the experimental and control groups. Preliminary correlation analyses of the study's variables were carried out, separately, for boys and girls (Appendix A) and for experimental and control groups (Appendix B). The findings indicate a similar correlation pattern for boys and girls and for experimental and control groups, except for the correlation of GLPS with SR Post, which was lower for girls than for boys.

Table 1
Pre- and Postintervention Windows Test (WT) and Spatial Relations (SR) Scores of Boys and Girls in the Experimental and Control Groups

Gender	Experimental		Control		
	Pre	Post	Pre	Post	
WT Level 1					
Boys	<i>M</i>	46.63	50.07	45.89	47.14
	<i>SD</i>	4.41	3.06	3.98	3.77
Girls	<i>M</i>	43.93	49.83	41.86	43.89
	<i>SD</i>	5.38	2.63	5.49	5.62
WT Level 2					
Boys	<i>M</i>	39.00	45.00	37.07	38.79
	<i>SD</i>	5.99	4.58	6.72	5.34
Girls	<i>M</i>	34.77	43.17	34.14	35.11
	<i>SD</i>	6.07	4.43	5.35	5.98
SR test					
Boys	<i>M</i>	18.08	21.54	17.86	18.56
	<i>SD</i>	4.10	3.30	4.50	4.05
Girls	<i>M</i>	16.11	20.60	16.67	17.00
	<i>SD</i>	4.13	3.53	4.44	4.26

Analysis of WT scores. The effects of the training program were analyzed by a repeated measures nested design MANOVA of Treatment \times Gender \times Time \times Test Level \times Degree of Rotation ($2 \times 2 \times 2 \times 2 \times 3$), with treatment and gender as between-subjects factors and the last three variables as within-subjects factors; WT scores were the dependent variables.

The findings reveal a significant three-way interaction of Treatment \times Gender \times Time, $F(1, 112) = 4.73$, $p < .05$, $\eta_p^2 = .04$, as portrayed in Figure 4. Figure 4 shows that girls in the experimental group who scored much lower than boys did in the preintervention phase, improved their performance more than boys did and narrowed the gap in the postintervention phase. On the other hand, the girls in the control group scored equally lower than boys on both the pre- and postintervention phases. Post hoc analyses showed that in the experimental group, boys were higher than girls only in the preintervention phase, $t(1, 58) = 2.67$, $p < .01$, but not in the postintervention phase, $t(1, 58) = 1.11$, *ns*. In the control group, boys performed better than girls in both preintervention, $t(1, 54) = 2.55$, $p < .01$, and postintervention, $t(1, 54) = 2.83$, $p < .01$, phases. These findings support our main hypothesis by clearly showing that the intervention moderated and even canceled out the initial gender differences. Furthermore, in the postintervention phase, the experimental girls performed significantly higher than the control boys, $t(1, 56) = 3.79$, $p < .001$.

A significant three-way interaction of Treatment \times Rotation \times Time, $F(1, 112) = 13.51, p < .001, \eta_p^2 = .20$, shown in Figure 5, indicates that the gap between the experimental and control groups in the postintervention phase expands progressively with the increase in the degree of rotation. Post hoc analyses showed significant differences between the groups at $90^\circ, t(1, 114) = 6.15, p < .001$, and $180^\circ, t(1, 114) = 6.66, p < .001$, but not at $45^\circ, t(1, 114) = 1.29, ns$.

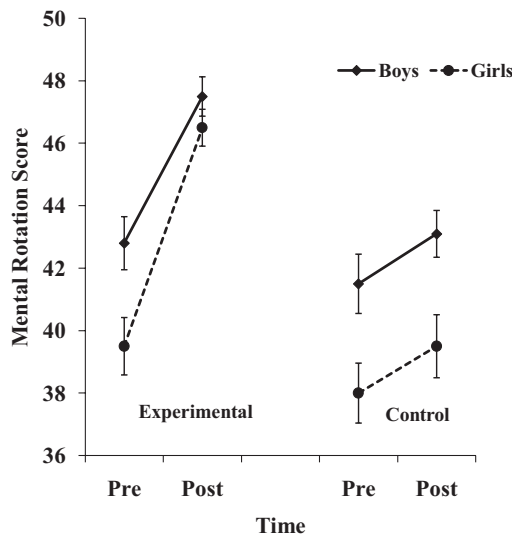


Figure 4. Pre- and postteaching performance on mental rotation among boys and girls in the experimental and control groups.

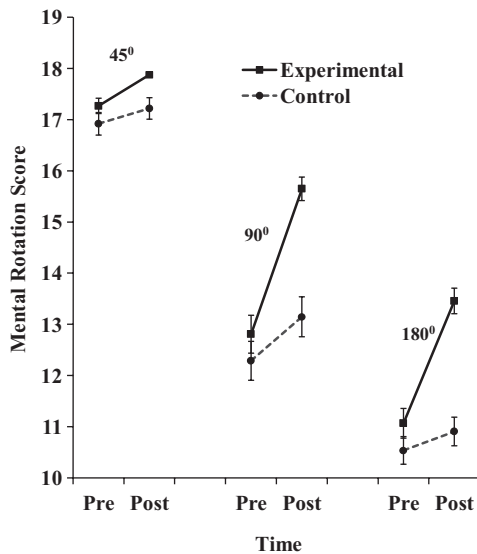


Figure 5. Pre- and postteaching performance on mental rotation in the experimental and control groups for each degree of rotation.

Another significant three-way interaction was of Treatment \times Test Level \times Time, $F(1, 112) = 8.69, p < .01, \eta_p^2 = .07$. This interaction, shown in Figure 6, indicates that the group differences in the postintervention phase were higher in Test Level 2 (WT2) than in Test Level 1 (WT1). Post hoc analyses showed that the experimental group scored significantly higher than control group in both Test Level 1, $t(1, 114) = 5.70, p < .001$, and Test Level 2, $t(1, 114) = 7.21, p < .001$. It is important to note that in Test Level 2, the experimental group showed much higher improvement, $t(1, 59) = 11.77, p < .001$, than the control group, $t(1, 55) = 2.31, p < .05$.

Analysis of SR test scores. We carried out separate analyses on the SR test as this test does not include task characteristics as the WT does. The means and standard deviations of boys and girls in the experimental and control groups are presented in Table 1. The effects of the training program were analyzed by a repeated measures MANOVA of Treatment \times Gender \times Time ($2 \times 2 \times 2$), with time as a within-subjects factor. The findings revealed a significant three-way interaction of Treatment \times Gender \times Time, $F(1, 112) = 71.80, p < .001, \eta_p^2 = .39$ (see Figure 7). As can be seen in Figure 7, gender differences in the experimental group decreased from pre- to postintervention, whereas in the control group, gender differences increased. Post hoc analyses showed that, in the experimental group, boys were higher than girls only in the preintervention, $t(1, 58) = 2.50, p < .01$, but not in the postintervention phase, $t(1, 58) = 1.19, ns$. In the control

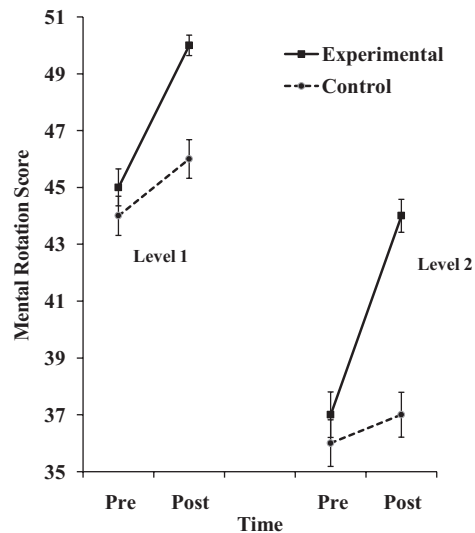


Figure 6. Pre- and postteaching performance on mental rotation in the experimental and control groups for each test level.

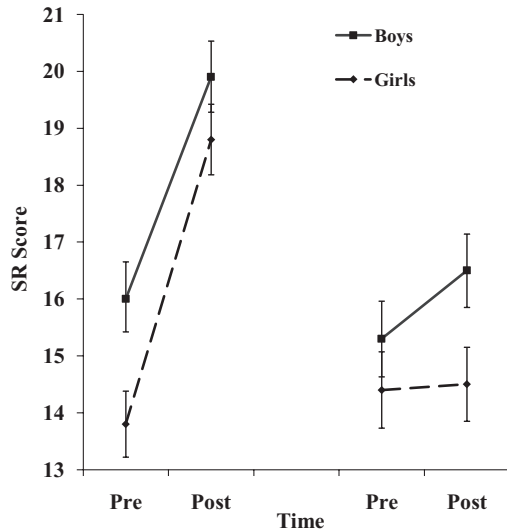


Figure 7. Pre- and postintervention Spatial Relations (SR) scores by treatment group and gender.

group, on the other hand, boys performed better than girls in both pre-, $t(1, 54) = 2.44, p < .01$, and postintervention, $t(1, 54) = 2.55, p < .01$, phases. Thus, the intervention moderated and even canceled out the initial gender differences. Furthermore, in the postintervention phase the experimental girls performed significantly higher than the control boys, $t(1, 56) = 2.68, p < .01$. The SR findings are very similar to those found for the WT and support out main hypothesis.

Effect-Size Analyses

In order to compare our findings with previous studies, we calculated the effect size of gender differences in the preintervention phase using Cohen's d . The results for gender, yielded an effect size of $d = .45$ ($r = .22$), $d = .69$ ($r = .32$), and $d = .60$ ($r = .28$) for the SR, WT1, and WT2, respectively. These effect sizes are very similar to the effect sizes found with older children and adults using spatial tasks like the Shepard Metzler mental rotation test (Voyer et al., 1995). It should be noted that the initial gender differences in our study are not likely to be attributed to general cognitive ability, as there were no gender differences on the WISC-R95 subscales of Vocabulary, $t(1, 114) = .64, ns$, and Concept Formation, $t(1, 114) = .30, ns$. Additional effect-size analyses were calculated for gender differences in the experimental and control groups before and after the intervention, using a composite score of WT (WT1 + WT2). The findings indicate that although in the experimental group the effect

size decreased drastically from pre- (.71) to postintervention (.23), in the control group the effect size increased from pre- (.68) to postintervention (.73).

GLPS as a Moderating Factor Between Gender and Mental Rotation

The second objective of this study was to investigate whether the GLPS is a moderating factor that explains gender differences in mental rotation performance as well as the interactive effects of GLPS and task difficulty on mental rotation.

Prior to analyzing the effect of GLPS as a moderating factor of gender differences in mental rotation, we carried out two analyses to establish gender differences in GLPS. The first analysis was an ANOVA of Gender \times Treatment (2×2) on GLPS. The ANOVA revealed a significant main effect of gender, $F(1, 112) = 25.76, p < .001, \eta^2 = .19$, indicating that boys were more global than were girls in their perceptual judgments, across treatment groups. Out of a possible total score of 16, the mean global choices selected were 10.14 ($SD = 2.15$) and 5.03 ($SD = 2.05$), for boys and girls, respectively.

The effect of the GLPS as a moderating variable was analyzed in a repeated measures MANCOVA of Gender \times Treatment \times Test Level \times Degree of Rotation with GLPS as a covariate. The dependent variables were WT1 and WT2, which allowed the comparison of test levels and degrees of rotation. The findings revealed that (a) the gender main effect, which was significant in a previous MANOVA, $F(1, 112) = 12.80, p < .001, \eta_p^2 = .10$, was no longer significant in the current MANCOVA, $F(1, 111) = 1.75, ns$. Thus, once GLPS was included as a covariate, the gender main effect is not significant. (b) A significant interaction of GLPS \times Degree of Rotation, $F(1, 111) = 5.08, p < .05, \eta^2 = .08$, indicates that the higher the degree of rotation, the higher is the contribution of a global orientation to mental rotation performance. As expected, the main effects of (c) test level, $F(1, 111) = 125.18, p < .001, \eta^2 = .53$; (d) degree of rotation, $F(1, 111) = 227.28, p < .001, \eta^2 = .81$; and (e) GLPS (covariate), $F(1, 111) = 31.51, p < .001, \eta^2 = .22$, were significant. These findings indicate that the higher the degree of rotation, test level, and the GLPS scores, the higher is the mental rotation score.

Further support for the relation between GLPS and mental rotation was indicated by correlation analysis. Pearson correlations between a combined

preintervention WT score (WT1 + WT2) and GLPS score, showed positive significant correlations of .60 ($p < .001$) and .50 ($p < .001$) for the experimental and control groups, respectively. Similarly, the correlations between the GLPS and the initial SR scores were .30 ($p < .01$) and .28 ($p < .05$) for the experimental and control groups, respectively. These findings indicate that a global strategy was more efficient than a local strategy for solving mental rotation tasks.

Discussion

Data analysis of the pre- to postintervention scores showed clearly that the training program, focused on teaching of representation and transformation of spatial information, brought about a significant improvement in the spatial performance of young children, as well as a significant mitigation of the initial gap between boys and girls. The experimental group improved significantly more than the control group on both WT (Figure 4) and SR (Figure 7) tests. As the experimental and control groups showed high initial similarity on mental rotation scores, the observed improvement of the experimental group can be attributed mainly to the intervention effects. The slight improvement of the control group may indicate a self-practice effect caused by a repeated administration of the tasks. These findings differ from previous training studies, which indicate that the performance levels of males and females rise in parallel and maintain the gender gap (e.g., Baenninger & Newcombe, 1989; Levine et al., 1999).

Comparison of the pre- to postintervention improvement of boys and girls showed that girls' improvement in the experimental group was greater than that of boys and that the girls closed the initial gap. This finding was repeated in both the WT (Figure 4) and the SR (Figure 7) tests. Similar comparisons in the control group showed that the initial gender gap differences were not reduced from pre- to postintervention; on the WT, there were minor equal improvements among both boys and girls, and on the SR test, boys showed a slight improvement whereas girls showed no improvement. Moreover, in the postintervention phase, *girls in the experimental group showed higher performance than did boys in the control group; this improvement occurred on both tests*. Further support for the effectiveness of the intervention in reducing gender differences was evident in the effect-size findings. The effect size decreased sharply from pre- to postinter-

vention in the experimental group but increased in the control group. A possible explanation for the uniqueness of our findings relates to the type of training given as well as to its intensity. It appears that self-training caused by repeated administration of the tasks, characterizing previous studies, was not alone sufficient to narrow the gap between boys and girls. As shown in previous studies (e.g., Marulis et al., 2007), males and females benefit equally from this type of self-training on spatial tasks. The findings of our experimental group revealed, on the other hand, that a relatively long-term *deliberated/instructive* training program based on teaching strategies for the transformation of visuospatial stimuli brought about substantial improvement in mental rotation of young children, particularly of girls who reached the same performance level as boys. The strategies focus on expanding working memory, perceiving spatial information in a global rather than analytic way, and flexibly conceptualizing spatial stimuli from different points of view. These findings are consistent with recent adult studies showing that females benefited more than males from active and guided training programs such as training with computer and video games, and that prior gender disparities in spatial ability, as measured by mental rotation tasks, were significantly reduced (Coluccia & Louse, 2004; Feng et al., 2007).

Support for our findings is found in Linn and Petersen's (1985) analysis of the processes that underlie the solution of mental rotation tasks. They suggested that a global-holistic or a Gestalt-like strategy is more effective than a part-by-part analytic approach. As the mental rotation tasks yield the largest and most robust gender differences, they raised the possibility that gender differences on these tasks are associated with the selection or efficient application of solution strategies. This argument is also supported by recent studies showing that boys tend more often than girls to adopt global-holistic strategy in processing visuospatial information since the early childhood years (e.g., Kramer et al., 1996; Lawton, Charleston, & Zieles, 1996; O'Laughlin & Brubaker, 1998).

Because mental rotation is considered to represent a high level of spatial cognition (Gardner, 1983) as well as the skill found to be most related to gender differences (Linn & Petersen, 1985; Voyer et al., 1995), our findings are of most importance. They suggest that early *deliberate/instructive* training programs might help to bridge the gender gap in spatial ability, whether the differences in ability are attributed to biological mechanisms or

to environmental inputs. Moreover, our findings indicate that girls in the experimental group outperformed boys in the control group on both the SR and the WT tasks. These findings strengthen our claim that strategy-oriented intervention can overcome gender differences considered by many researchers to be biologically determined. Newcombe et al. (2002) noted that although the question of the origins that lead to the observed gender differences in spatial competence may be of scientific interest, *it is more important to determine whether intervention can reduce or eliminate them.* We would add that adequate intervention could reverse gender differences causing girls to perform higher than boys!

In the current research, first-grade boys showed higher initial performance than girls on a standardized SR test and even more on the WT, which was specifically developed to tap spatial skills involving mental rotation of young children. These initial gender differences are not likely due to intellectual ability, as boys and girls performed similarly on Vocabulary and Concept Formation subtests of the WISC-R or by SES level.

One of our main hypotheses was that processing strategies moderate and help to explain initial gender differences in mental rotation. By using Kimchi and Palmer's (1982) GLPS tasks, we first found that children who used a global-holistic strategy in their perceptual judgments were more likely to succeed in solving the mental rotation tasks, than children who used a local strategy: The GLPS scores were significantly and positively correlated with the SR and WT scores. The hypothesis is also strongly supported by two interrelated findings. The first is that once we introduced the GLPS variable as a covariate into the MANOVA (see previously mentioned MANOVA of Treatment \times Gender \times Time \times Test Level \times Degree of Rotation), the significant main effect of gender disappeared. The second is the finding showing that the GLPS score (introduced as a covariate) was significantly and positively related to the mental rotation scores. These findings support our assertion that a global-holistic strategy is more efficient than a local strategy in solving spatial tasks involving mental rotation.

Clinical observations of strategies used by boys and girls clearly show that boys used significantly more perceptual global judgments than girls did. Analysis of the GLPS scores indicated that boys tended to focus on the global shapes with more attention to the outer configurations, whereas girls tended to focus on the local elements in a more details-oriented fashion. This finding is consistent

with Kramer et al. (1996), who used the same global-local paradigm with children between the ages of 4 and 12 years, and reported large gender differences with greater global bias in boys at all ages. These findings support our hypothesis that early gender differences in strategies used to process visuospatial information account for at least a portion of the gender differences in spatial performance as measured by mental rotation tasks. We would like to note that more evidence should be provided concerning the change in strategy usage from pre- to postintervention as well as the change in correlation patterns between mental rotation and processing strategies. Unfortunately, we did not gather information on the strategies used *during* testing; neither did we administer the GLPS test at the end of the intervention. In future research, we suggest use of the GLPS both before and after the intervention so that simultaneous comparisons can be carried out on mental rotation performance and processing strategies. We expect the intervention not only to affect both domains but also to observe a correlation between pre and postchanges in both domains. The findings showing that gender differences in mental rotation are moderated by differences in global-local strategies used to complement our expectations that a training program aimed at improving mental representation and transformation of visuospatial information would provide girls with opportunities to select and apply more efficient strategies for solving mental rotation tasks, leading to a reduction in gender differences.

In congruence with findings of meta-analytic studies (Linn & Petersen, 1985; Voyer et al., 1995), the magnitude of gender differences in the current study was influenced by task demands. Analysis of the interactive effects of treatment and task demands in WT revealed significant interactions of treatment with the degree of rotation (Figure 5) and test level (Figure 6). These interactions indicate that the higher the task difficulty, the higher was the impact of the intervention. On both variables, the experimental children showed significantly higher pre- to postintervention improvement on the difficult tasks than on easy tasks whereas the control group children showed consistent, slight and insignificant improvement.

Similar to the intervention effects on different levels of task difficulty, our findings indicate that the global strategy is more efficient in coping with tasks of high level than with low level of mental rotation. This was shown by the significant interaction of GLPS \times Degree of Rotation and by the correlation analysis indicating higher correlations

between WT and GLPS with increase in levels of rotation.

The origins that lead to the observed gender differences in strategies used for processing visuospatial information have not been clarified yet. On the one hand, evidence for biological mechanisms may derive from differences emerging by early childhood and remain relatively constant over the course of development (e.g., Kramer et al., 1996). On the other hand, these differences might be attributed to different experiences that are relevant to acquisition, selection, and application of solution strategies (Halpern, 2004; Linn & Petersen, 1985). Longitudinal and cross-sectional research showing parallel developmental trajectories of mental rotation and global-local strategies might help to establish the relation between the two domains.

In conclusion, given the fact that superior spatial skills are important in mathematical and scientific thinking (e.g., Clements & Battista, 1992; Gardner, 1983; Wheatley, 1990, 1991, 1996, 1997; Wheatley & Reynolds, 1999), it is crucial to implement intervention programs aimed at improving spatial skills and help to bridge the gap between males and females in these areas. In our study, mental rotation was found as a malleable domain that can be acquired through training. The findings indicate also that mental rotation is intimately related to global-local perception and that holistic strategies can help the individual in representing and transforming perceptual stimuli and directly affect mental rotation skills.

In view of the importance of spatial ability in many scientific domains and in view of the current results in supporting intervention for developing spatial skills, we recommend, together with others (e.g., Vasta et al., 1996; Webb et al., 2007), that more emphasis is needed to nurture such skills within the school curriculum. Training should include enhancing the processing strategies of visuospatial stimuli using computer technology (e.g., virtual reality) and targeted instructional approaches. Training should start as early as possible to prevent gender differences and to provide equal opportunities for girls to excel in spatial abilities that are required for success in scientific domains. Because girls have been shown to have fewer out-of-school spatial experiences than boys, many girls may never tap their potential to think spatially, unless spatial thinking is specifically introduced into the school curriculum. Nevertheless, further research is necessary to identify specific experiences that promote the development of spatial skills of young children.

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Appendix A

Matrix of Correlations of the Study's Variables for Boys and Girls

	WT Pre	WT Post	SR Pre	SR Post	GLPS
WT Pre	—	.72**	.34**	.45**	.46**
WT Post	.70**	—	.32*	.57**	.39**
SR Pre	.46**	.28*	—	.71**	.39**
SR Post	.40**	.56**	.54**	—	.38**
GLPS	.50**	.40**	.28*	.16	—

Note. Plain font = boys; italic font = girls. WT = Windows Test, general score; SR = Spatial Relations test; GLPS = Global-Local Processing Strategies.

* $p < .05$. ** $p < .01$.

Appendix B

Matrix of Correlations of the Study's Variables for Experimental and Control Groups

	WT Pre	WT Pre	SR Pre	SR Post	GLPS
WT Pre	—	.72**	.48**	.46**	.60**
WT Post	.86**	—	.40*	.50**	.43**
SR Pre	.41**	.34*	—	.75**	.30**
SR Post	.44**	.37**	.76**	—	.34**
GLPS	.50**	.52**	.28*	.34*	—

Note. Plain font = experimental; italic font = control. WT = Windows Test, general score; SR = Spatial Relations test; GLPS = Global-Local Processing Strategies.

* $p < .05$. ** $p < .01$.