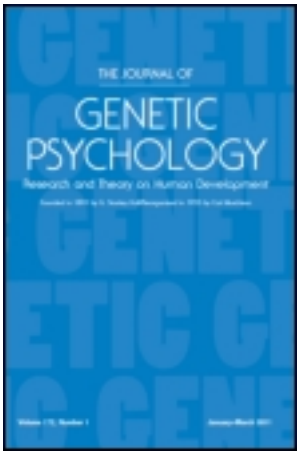

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Improving Children's Mental Rotation Accuracy With Computer Game Playing

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ABSTRACT. The authors investigated the relation between mental rotation (MR) and computer game-playing experience. Third grade boys ($n = 24$) and girls ($n = 23$) completed a 2-dimensional MR test before and after playing computer games (during 11 separate 30-min sessions), which either involved the use of MR skills (the experimental group) or did not involve the use of MR skills (the control group). The experimental group outperformed the control group on the MR posttest but not on the pretest. Boys outperformed girls on the pretest but not on the posttest. Children whose initial MR performance was low improved after playing computer games that entailed MR skills. The findings imply that computer-based instructional activities can be used in schools to enhance children's spatial abilities.

Key words: computer games, gender differences, mental rotation, sex differences, training study

MENTAL ROTATION (MR) is a type of spatial ability in which a person imagines how a two- or three-dimensional object or array would appear after it has been turned around a specified axis a given number of degrees. Researchers of children's MR abilities have focused on (a) normative developmental sequences and (b) individual differences in MR performance. The first approach was exemplified in the seminal work of Piaget and Inhelder (1956, 1971), who demonstrated that accuracy, anticipatory flexibility, and logical consistency in MR increase as 4- to 12-year-old children progress from preoperational to concrete operational thought. Researchers have used the second approach in studies of gender differences in MR performance (Maccoby & Jacklin, 1974) and have clearly established that boys and men are more adept at MR than are girls and women. Although gender differences with respect to speed of rotating three-dimensional objects are especial-

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ly pronounced in adolescence and adulthood, consistent gender differences in childhood, for both accuracy and speed, have also been found (Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995). In the present study, we also focused on individual differences and investigated whether differences in young children's MR performance could be reduced in a school setting.

In a recent review of gender differences in spatial abilities, Newcombe, Mathason, and Terlecki (2002) proposed that investigators direct their attention to the malleability of mean levels of performance. These authors asserted that determining the ultimate cause of gender differences in spatial abilities such as MR is not as important as determining whether individual performance can be enhanced. This perspective is especially relevant if participants are school-aged children. Although spatial abilities are not an explicit part of school curricula, they are important for some aspects of mathematical and scientific problem solving. Students who develop their spatial abilities are more apt to use alternative solution strategies, thereby improving their overall mathematical problem-solving skills (De Lisi & McGillicuddy-De Lisi, 2002; Newcombe et al., 2002).

In the United States, computer hardware and software are readily available resources that could be used to enhance children's MR abilities. Many schools, for example, have computer laboratories and allocate instructional time for student use. Word processing and information seeking on the Internet are two ubiquitous uses of school-based computer resources by students. Although these applications are important, they are not likely to significantly affect spatial skills. However, experiences with certain computer or video games, which are also readily available in schools (and in homes, without the necessity of an Internet connection), have been shown to enhance MR performance.

McClurg and Chaille (1987) studied the effects of video game practice on fifth, seventh, and ninth graders' MR performance. The students played either "The Factory" or "Stellar 7," which both require MR skills, for two 45-min sessions per week over 6 weeks. Students were pretested and posttested for MR performance. Both computer groups outperformed a control group on the posttest, and improvements in MR performance were evident across grades and for boys and girls alike in both computer groups. Subrahmanyam and Greenfield (1994) asked fifth graders to play one of two computer games, "Marble Madness" (which involves spatial skills) or "Conjecture" (a word game that does not involve spatial skills), in three separate 45-min sessions. A computerized spatial battery was used for pre- and posttests. The authors found that the students who made the greatest gains on the posttest were those whose pretest spatial skills were the weakest. However, those students with low spatial skills (many more girls than boys) did not ultimately achieve the posttest levels of the initially high spatial group (many more boys than girls). These two studies indicate that it is possible to improve children's spatial test performance via computer game playing.

The participants of most other studies on the effects of computer video games on subsequent spatial performance have been college students. Okagaki and Frensch

(1994) observed that 6 hr of playing the game "Tetris" (which requires quick rotation of two-dimensional objects) improved MR speed and spatial visualization performance in both female and male college students. Male students, however, were observed to make greater gains than female students on paper-and-pencil, but not computerized, MR posttests. De Lisi and Cammarano (1996) found that both male and female students who played "Blockout," a computer game that involves rotating three-dimensional figures, improved their paper-and-pencil MR performance. (See Saccuzzo, Craig, Johnson, & Larson, 1996, for additional evidence on the positive effects of computerized practice on the MR ability of female college students.)

In this study, we sought to investigate the effects of computer video game playing on third-grade students who were 8- to 9-years-old. Recent studies have indicated that individual differences in spatial performance may be observed in children of this age or even younger (Brosnan, 1998; Karadi, Szabo, & Szepesi, 1999; Levine, Huttenlocher, Taylor, & Langrock, 1999; but, see Pontius, 1997, for a counterexample). Because individual differences in MR performance are evident in such young children, it is important to see if school-based experiences can be designed to improve performance and minimize such differences. In the present study, we investigated this possibility, using the existing computer resources and curriculum time allotments of a given elementary school system. We examined individual differences in MR performance on a paper-and-pencil test that was administered before and after children had extensive experience playing (a) a computer video game that entailed MR and (b) a computer game that did not entail MR. We predicted that students' performance on the mental rotation test (MRT) would be significantly improved after they played a computer game that required MR. This study was unique, compared with other studies on children's spatial abilities, in that we attempted to improve MR performance in children as young as 8 years old using computer games in a typical school context.

Method

Participants

The participants were 47 third-grade students, aged 8 to 9 years, who attended a small public school in central New Jersey. A total of 24 boys and 23 girls participated. Informed parental consent was obtained for every third grader in the school, and each of these students completed all phases of the study. It was explained to parents that the computer games used in this study were educational in nature and approved by the professional staff of the school.

Materials

We devised a version of the French Kit Card Rotation Test (French, Ekstrom, & Price, 1963) for this study to measure children's MR accuracy. The original card rotation test displays figures in rows. A standard figure is at the left margin,

with a series of additional figures displayed to the right. Some of the figures are identical to the standard figure, but rotated; others are different figures, such as mirror images. The participant must judge whether each of these figures is the same as or different from the standard figure at the far left of the row. Participants indicate judgments by circling S (same) or D (different).

To make this measure more appropriate for young children and to eliminate scanning across a series of figures, we paired the standard figure with only one comparison figure. Each test page presented five figure pairs for comparison with the words "same" and "different" below each pair to lessen the possibility of confusion in recording. Figure 1 contains a sample page of the MRT used in this study. Of the 39 total test items, which filled eight pages, the correct answer was "same" for 18 items and "different" for 21 items. Written directions and 2 sample problems were contained on a cover page, and additional instructions were provided in a warm-up phase (to be described).

The computer games used in this study were "Tetris" and "Where in the USA Is Carmen Sandiego?" In having the children play "Tetris," we intended to provide them with MR experience. In playing "Carmen Sandiego," the children gained geography and social studies knowledge but not explicit MR practice.

Procedure

MRT. The MRT was administered to groups of 15 to 16 children in their school "homerooms." In a preliminary warm-up phase, intended to help the students understand the basis for making same or different judgments on sample pairs, the second author demonstrated MR using enlarged versions of the types of figures students would encounter on the MRT. Specifically, the experimenter tacked a standard figure on the left side and a comparison figure on the right side of a bulletin board in the front of the classroom, then spun the shape on the right and asked the students to compare it with the shape on the left as rotation proceeded. The students appeared to quickly understand the task requirements based on this demonstration, and the MRT was administered immediately after this warm-up phase. Students worked in a group format and were given 4 s per item (20 s per page) to answer. They completed the MRT twice: once as a pretest prior to playing computer games and once as a posttest after the month-long computer game-playing sessions ended. The students completed the posttest 1 to 3 days after their last computer game-playing session. The warm-up phase was not used for the posttest.

Computer games. The students went to a computer laboratory for 11 class sessions during 1 month of instruction. Computer laboratory work was considered a special subject, and normally 11 to 12 sessions per month were allotted in the curriculum for this activity. One group of students played "Tetris," and the other played "Carmen Sandiego" for an approximate total of 330 min during the 11 class sessions. Because playing "Carmen Sandiego" was a control condition for which performance was not recorded or analyzed, we do not describe the procedures of that game.

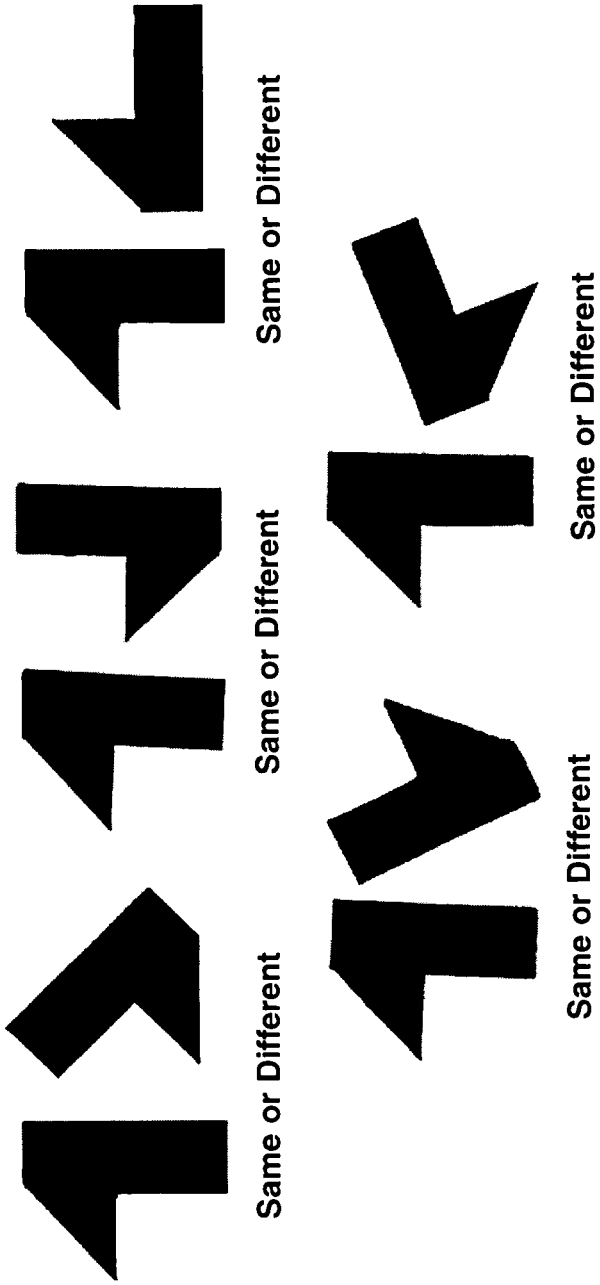

FIGURE 1. Five items on the mental rotation test.

"Tetris" can be played at 0–9 levels, as selected by the student. In play, a shape made up of four squares descends steadily from the center of the top of the screen toward a wall at the bottom. The shape might be in the form of a long, thin rectangle or various L-shaped figures. The player can rotate the shape as it is descending and also move the shape to the right or left for placement. As shapes land, they comprise a wall, which then grows in height. The object of the game is to keep the wall from reaching the top of the screen. Once the wall reaches the top of the screen, the game is over. The way to prolong play and thus earn a higher score is to efficiently place the figures to allow no unused spaces. When one row of squares, called a line, is completely filled, with no unused spaces, it vanishes, earning a player a higher overall score, a higher line score, and more game time. Students maintained their results for each game play on a scorecard. Level, score, and lines were displayed at the end of each game for easy recording. During the course of every class session, students completed multiple games. For each session, the computer instructor or the second author recorded each student's high score. The average of the students' high scores from the first three sessions was called the *beginning average score*, whereas the *ending average score* was the average of high scores from the last three sessions. We derived these measures to increase the reliability of the "Tetris" scores.

Design

The median score on the MR pretest was 31.00 correct. We used this score as the basis for dividing the children into one of two groups. Those above the median were considered to have high MR ability (n = 24); those below the median were considered to have low MR ability (n = 23). Although the students' assignment to an experimental group that played "Tetris" or to a control group that played "Carmen Sandiego" was random, the groups were balanced by initial MR ability classification and by student gender. The control group contained 12 boys and 12 girls; the experimental group contained 12 boys and 11 girls. Because of the small sample sizes, we were not able to analyze performance on the MRT in terms of Experimental Group × Gender × Ability Level in one (2 × 2 × 2) analysis. Separate Experimental Group × Gender (2 × 2) and Experimental Group × Ability Level (2 × 2) analyses were conducted on MR pre- and posttest scores.

Results

Nonexperimental Findings

Fifteen of 23 girls and 8 of 24 boys were classified as low ability on the MR pretest. Conversely, 8 girls and 16 boys were classified as high ability on the MR

pretest. The association between child gender and MR ability was significant, $\chi^2(1, N = 47) = 4.77, p < .05$. At the start of this study, boys had higher numbers of correct MRT responses than did girls. For the experimental group, we examined the correlation between performance on the MRT and on "Tetris" and found that the beginning average "Tetris" scores and the MR pretest scores were not significantly correlated, $r(21) = -.03, p > .05$. In contrast, for this same group of children, the final average "Tetris" scores and the posttest MR scores were significantly correlated, $r(21) = .51, p < .05$. Thus, after considerable experience with "Tetris," performance on this computer game was significantly and positively associated with performance on the paper-and-pencil MRT devised for this study. (A discussion of the impact of "Tetris" experience on MRT scores follows.)

Experimental Findings

The pre- and posttest MR scores (*M* and *SD*) for boys and girls in the control ("Carmen Sandiego") and experimental ("Tetris") groups are shown in Table 1. A Treatment Group × Gender × Time of Testing (2 × 2 × 2) analysis of variance (ANOVA) with a repeated measure on the last factor revealed significant main effects for treatment group, $F(1, 43) = 4.84, p < .05$, and for time of testing, $F(1, 43) = 11.14, p < .01$. The results of the analysis also revealed significant interactions involving treatment group and time of testing, $F(1, 43) = 11.55, p < .01$, and gender and time of testing, $F(1, 43) = 11.97, p < .01$. Means for the

TABLE 1
Mental Rotation Test (MRT) Scores by Treatment Group and Gender ($N = 47$)

	Pretest		Posttest	
Participant	*M*	*SD*	*M*	*SD*
	Control group			
Girls ($n = 12$)	27.25	7.72	29.58	7.63
Boys ($n = 12$)	33.00	3.66	30.58	5.50
Total	**30.13**	5.69	**30.08**	6.57
	Experimental group			
Girls ($n = 11$)	28.72	5.95	35.63	1.43
Boys ($n = 12$)	33.00	4.08	35.25	2.49
Total	**30.95**	4.97	**35.43**	1.98

Note. The maximum possible score on the MRT was 39. Bold-face type highlights the means for the Treatment Group × Time of Testing interaction.

Treatment Group × Time of Testing interaction are reported in bold face type in Table 1. The two groups did not differ on the MR pretest (standardized mean difference: $d = 0.15$), but the experimental group outperformed the control group on the MR posttest ($d = 1.23$). The control group mean did not change over time; however, the experimental group mean significantly increased. Experience with "Tetris" led to an increase in MRT scores.

Means for the Gender × Time of Testing interaction were as follows: On the pretest, boys averaged 33.00 correct and girls averaged 27.95 correct; on the posttest, boys averaged 32.92 correct and girls averaged 32.61 correct. Thus, boys outperformed girls on the MR pretest but not on the MR posttest. The standardized mean difference favoring boys over girls was large on the pretest ($d = 0.94$) but small on the posttest ($d = 0.10$). The students with the largest pretest to posttest increase in MR scores were the girls who played "Tetris." These girls performed as well on the MR posttest as did the boys who played "Tetris."

The pre- and posttest MR scores (M and SD) for low- and high-ability students in the control and experimental groups are shown in Table 2. A Treatment Group × Ability Level × Time of Testing (2 × 2 × 2) ANOVA with a repeated measure on the last factor revealed significant main effects for treatment group, $F(1, 43) = 9.64$, $p < .01$; ability level, $F(1, 43) = 50.14$, $p < .01$; and time of testing, $F(1, 43) = 13.84$, $p < .01$. The results of the analysis also revealed sig-

TABLE 2
Mental Rotation Test (MRT) Scores by Ability Level and Treatment Group ($N = 47$)

	Pretest		Posttest	
Treatment group	*M*	*SD*	*M*	*SD*
	Low-ability level			
Control	24.58	4.75	26.91	6.31
Experimental	26.54	3.98	34.72	2.28
Total	**25.52**	4.38	**30.64**	4.38
	High-ability level			
Control	35.66	1.23	33.25	5.22
Experimental	35.00	2.59	36.08	1.56
Total	**35.33**	1.91	**34.65**	3.39

Note. The maximum possible score on the MRT was 39. There were 4 boys and 8 girls in the low-ability control group, 4 boys and 7 girls in the low-ability experimental group, and 8 boys and 4 girls in each of the two high-ability groups. Bold-face type highlights the means for the Ability Level × Time of Testing interaction.

nificant interactions involving treatment group and time of testing, $F(1, 43) = 14.35$, $p < .01$, and ability level and time of testing, $F(1, 43) = 23.05$, $p < .01$. (The interaction for treatment group and time of testing was discussed previously.) Means for the Ability Level × Time of Testing interaction are reported in bold face type in Table 2. As expected, high-ability students outperformed low-ability students on the MR pretest and posttest. However, the standardized mean difference was $d = 3.15$ on the pretest and $d = 1.03$ on the posttest. Thus, the performance difference between the high- and low-ability groups was much smaller on the MR posttest due, for the most part, to the large gains made by the low-ability students who played "Tetris." On the posttest, for example, the students who had been classified as low ability performed at a level that was slightly above the children who had been classified as high ability in the control group. Individual differences in the children's MR performance were greatly reduced after experiences with "Tetris."

Discussion

This study yielded three main findings. First, individual differences in the third-grade children's two-dimensional MR accuracy were observed on the card rotation task designed for this investigation. Although there were some boys with low levels of MR performance and some girls with high levels, a significant gender difference favoring boys over girls was evident. The effect size for this gender difference on the MR pretest was large ($d = 0.94$). Thus, a significant gender difference in MR accuracy was found in children as young as third grade. Second, at the start of the study, performances on the MR pretest and on "Tetris" were not correlated, which suggests that children used different solution strategies for the two activities. However, after the children played "Tetris" for a number of weeks, a significant association between final "Tetris" scores and the MR posttest was evident, suggesting that the children used similar solution strategies for the two activities. It is probable that MR, considered as an analog cognitive process akin to actual physical rotation of objects through space, was the solution strategy used. Third, children's MR performance was enhanced after playing "Tetris" for a number of weeks. On the MR posttest, the children who played "Tetris" outperformed the children who played "Carmen Sandiego" (and these groups did not differ on the MR pretest). In addition, individual differences that were evident on the pretest were greatly reduced on the posttest. This study provides evidence of a successful training method that led to improved performance on a paper-and-pencil MR task in third graders, and, therefore, the study contributes to an important but understudied aspect of individual differences in spatial abilities (Newcombe et al., 2002).

The experimental intervention we used in this study was "seamless" as far as the children's normal school schedule was concerned. Thus, the study was ecologically valid. Note that the control group played a computer game that was

entertaining and educative in its own right. It is not difficult to envision a computer laboratory curriculum being designed to teach and enhance a variety of skills, one of which could be MR. An important benefit of using computer software programs in school-based settings is the flexibility that the programs give educators to tailor experiences for each individual student according to the student's need.

This study adds to a small but growing literature on the positive benefits of computer video games such as "Tetris" on MR abilities. Children with lower initial levels of performance, as compared with their peers, showed improvements after 11 game-playing sessions, which all participants seemed to find enjoyable. In future classroom studies, researchers might seek to specify (a) how much practice would be needed for elementary school students to reach asymptotic levels of performance, (b) the minimum number of hours or sessions needed to demonstrate positive effects with children this young or younger, and (c) the extent to which positive effects are maintained over time once computer practice ceases.

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