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Effects of Video Game Playing on Measures of Spatial Performance: Gender Effects in Late Adolescence

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Older adolescents played the video game Tetris for a total of 6 hr each in two separate experiments. None of the subjects had had any prior experience with Tetris, a video game requiring the rapid rotation and placement of seven different-shaped blocks. In Experiment 1, subjects were pre- and posttested on paper-and-pencil measures of spatial ability. In Experiment 2, computerized measures of mental rotation and visualization skills were administered. In both studies, experimental subjects' pre-post scores were compared to pre-post scores obtained from a control sample of subjects. Results indicated that playing Tetris improves mental rotation time and spatial visualization time. Consistent with earlier research, reliable and consistent differences between males and females were only obtained on complex mental rotation tasks.

Educators and behavioral scientists have long recognized the value of play in children's development (e.g., Almy, 1967; Athey, 1984). In particular, games have been identified as an important facilitator of children's cognitive, social, and moral development (e.g., Kamii & DeVries, 1980; Piaget, 1965; Selman, 1980). Currently, one of the most popular varieties of games for both children and adolescents is the video game. The meteoric rise of video games over the last decade has led to a corresponding rise in the emotional debate regarding the consequences of video game playing. Do video games, like other games, provide a context that encourages positive development?

The research presented here is guided by the belief that, partly because of their enormously and intrinsically motivating qualities (Malone, 1981), video

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games do indeed have great potential as educational tools. Empirical research on the impact of video game playing is scarce, however. Most of the existing research has dealt with social and emotional factors. For those interested in cognitive domains, researchers have proposed that spatial skills are the cognitive skills that are most likely to benefit from video game practice (e.g., Greenfield, 1984; Loftus & Loftus, 1983; Lowery & Knirk, 1982–1983). Indeed, spatial skills are the focus of two of the empirical articles in this special issue (Greenfield, Brannon, & Lohr, 1994; Subrahmanyam & Greenfield, 1994). Improvement of spatial skills could be particularly beneficial for females, who reportedly do not do as well as males on some spatial performance tasks (for reviews, see Halpern, 1986; Maccoby & Jacklin, 1974; McGee, 1979).

EFFECTS OF VIDEO GAME PRACTICE ON MEASURES OF COGNITIVE AND PERCEPTUAL PERFORMANCE

The few existing studies examining the impact of video game practice on cognitive and perceptual variables have obtained mixed results. Some studies have obtained limited effects of video game practice on performance of spatial tasks (e.g., Gagnon, 1985; Pepin & Dorval, 1986 [cited by Subrahmanyam & Greenfield, 1994]; Strein, 1987). In contrast, however, some studies have found that positive benefits can be obtained from video game playing (e.g., Dorval & Pepin, 1986; Forsyth & Lancy, 1987; Subrahmanyam & Greenfield, 1994). Reasons for the discrepancies in the findings may lie in the variety of spatial skills that were tapped by the video games and by the spatial performance tests, the degree of transfer required between the video game and spatial performance test, and differences in the ages of the participants.

With respect to variation in spatial skills, Linn and Petersen (1985) suggested that spatial tasks may in fact require three different types of spatial skills: (1) spatial perception, (2) mental rotation, and (3) spatial visualization. Spatial perception is the ability to infer the orientation of an object with respect to one's own orientation. Mental rotation is the ability to imagine the rotation of a visual stimulus. Spatial visualization is the most difficult ability to describe precisely. According to Linn and Petersen, spatial visualization tasks "involve complicated, multistep manipulations of spatially presented information. These tasks may involve the processes required for spatial perception and mental rotations but are distinguished by the possibility of multiple solution strategies" (p. 1,484). That is, spatial visualization requires multiple mental manipulations of spatially represented objects. In addition, spatial visualization tasks can be accomplished using analytic strategies. It is also important to note that the spatial tasks that are referred to are tasks that require the individual to manipulate mental representations of objects and not to manipulate actual physical objects in real space. Whether or not studies obtain differences on spatial tasks after video game practice may depend on the type of spatial skills that are utilized and on the match between the spatial skills involved in the video game and the skills that are tested on the transfer task.

In a study with an undergraduate and graduate student sample, Gagnon (1985) had the experimental group play two video games for a total of 5 hr over a 1-week period. The two video games were: (1) Targ, in which a spaceship is manipulated through a two-dimensional grid while shooting enemy spaceships; and (2) Battlezone, in which the participant drives a tank through a battleground while shooting enemy tanks. In Battlezone, the participant views a three-dimensional representation of the battlefield (as if looking out of the tank's window) and has a two-dimensional aerial view (the view generated by a radar screen) of the field. Both games require spatial visualization and spatial perception skills. Three paper-and-pencil measures were used as pre- and posttests of spatial performance. In the Guilford-Zimmerman Spatial Orientation Test, the participant compares pairs of pictures to determine how a figure (the prow of a boat) must have moved to get from its position in Picture 1 to its position in Picture 2. In the Guilford-Zimmerman Spatial Visualization Test, an alarm clock is shown in an initial orientation, with arrows showing how it will be rotated, and the subject must determine which picture depicts the clock after it has been rotated. The third test was the Visual Pursuit Test (not part of Linn & Petersen's, 1985, taxonomy), in which the subject traces a line from beginning to end on a circuit board as it crosses several other lines on the circuit board.

Initial scores on Targ were correlated with pretest scores on the Visual Pursuit Test, but not with pretest scores on the other two spatial performance tests. It appeared that players were relying on visual tracking skills during their initial playing of the video game. In contrast, it seemed that playing Targ did not utilize spatial orientation and spatial visualization skills to the same degree. Initial scores on Battlezone were not significantly correlated with any of the paper-and-pencil tests. However, final scores on Battlezone were correlated with the Visual Pursuit and Spatial Visualization pretests. Gagnon (1985) suggested that because Battlezone was more complex than Targ, it might simply have taken longer for subjects to figure out how to play the game. In addition, final scores on Battlezone were correlated with posttest Visual Pursuit scores, which suggests that playing Battlezone may have influenced participants' Visual Pursuit performance.

Although Gagnon (1985) did not obtain overall differences between experimental subjects and control subjects on paper-and-pencil Spatial Visualization, Spatial Orientation, and Visual Pursuit tests, post hoc analyses indicated that women in the experimental group showed more improvement on the Spatial Visualization posttest than women in the control group. There were no differences among the men on any test. Gagnon suggested that because the women did not perform as well as the men initially on all of the pretests, they might have been able to benefit from playing the video games whereas men did not do so.

Because the 5 hr of video game practice all occurred within a 1-week period and 5 hr were equally split between two different games, it is possible that subjects did not have enough time to gain much expertise in these video games. Alternatively, Gagnon may have found limited gains in spatial skill performance after playing Targ and Battlezone because the measures of spatial skill were static, paper-and-pencil measures of the skills and consequently different from the utilization of those skills during video game play.

Dorval and Pepin (1986; Pepin & Dorval, 1986 [cited by Subrahmanyam & Greenfield, 1994]) also had limited success in obtaining improvement in spatial skill performance after video game practice. In a study of 70 French Canadian undergraduates who had no prior experience playing video games, Dorval and Pepin (1986) found that after eight sessions of practice, pretest-to-posttest improvement on a paper-and-pencil spatial visualization test was greater for experimental subjects than for control subjects. In this experiment, each practice session included five games of Zaxxon, and the subjects could play no more than two sessions within each week. In Zaxxon, the player manipulates a spaceship through three-dimensional space while shooting down enemy ships. However, using the same materials, Pepin and Dorval (1986 [cited by Subrahmanyam & Greenfield, 1994]) did not obtain similar improvement of experimental subjects over control subjects with a sample of 101 seventh-grade students.

Others have found stronger support for the hypothesis that video game playing can improve spatial skill performance (e.g., Forsyth & Lancy, 1987; McClurg & Chaillé, 1987; Subrahmanyam & Greenfield, 1994). For example, McClurg and Chaillé (1987) found that fifth, seventh, and ninth graders' mental rotation performance as measured by a paper-and-pencil test improved after video game practice. In their experiment, participants in the experimental conditions played either the video game Factory or the video game Stellar 7 for 45 min twice a week for 6 weeks. In Factory, participants must visualize what will happen to a sheet of metal as it goes through an assembly line of punch, stripe, and rotate machines in order to create a particular product. Because players initially see an overhead view of the metal sheet and then see side views of the machines, they must be able to mentally rotate the image and imagine the effect of the punch, stripe, and rotate machines on the metal sheet. In Stellar, a spaceship is manipulated through three-dimensional space while avoiding objects and shooting enemy targets. The players see objects at different distances and in different orientations and must learn to recognize the enemy targets in their various orientations. Both games rely on mental rotation and spatial visualization skills. The transfer task was a paper-and-pencil mental rotation test in which subjects saw a three-dimensional target shape in one orientation and had to determine whether another shape was the same as the target shape but in a different orientation, or whether it was a different shape.

Also using tests that closely matched the skills used in the practice sessions, Subrahmanyam and Greenfield (1994) found that after only three 45-min sessions, children 10 years, 5 months–11 years, 5 months who had played the video game Marble Madness showed more improvement on the spatial skill tests than did control subjects who had played a computerized word game. They suggested that their success in obtaining training effects might have been due to the age of the subjects. That is, late childhood to early adolescence may be a time when spatial abilities are developing and are more easily affected by training. They also observed that both the spatial skill tests and the video game utilized dynamic spatial skills involving judging speeds and distances of moving objects and intercepting moving targets. Hence, transfer from the video game to the spatial skills was a close transfer of skills between relatively similar contexts.

GENDER DIFFERENCES IN THE EFFECTS OF VIDEO GAME PLAYING ON MEASURES OF COGNITIVE AND PERCEPTUAL PERFORMANCE

In video game research, gender differences on spatial performance tests have not been consistently obtained. For example, in the previously cited studies by Dorval and Pepin (1986; Pepin & Dorval, 1986 [cited by Subrahmanyam & Greenfield, 1994]), there were no gender differences on pre- and posttest scores for either the undergraduates or the seventh graders. In contrast, Gagnon (1985) found that men outperformed women on spatial orientation pre- and posttests, and on the spatial visualization pretest. However, there was no difference between the men and women on the spatial visualization posttest. As mentioned earlier, Gagnon found that women improved their spatial visualization scores after practice on the video games, but there was no improvement for the men. She argued that the lack of difference between men and women on the spatial visualization posttest was most likely due to the practice on the video games.

Although there appears to be some evidence for a gender difference on tests of spatial skills (e.g., Halpern, 1986; Maccoby & Jacklin, 1974; McGee, 1979), the magnitude of the gender difference, the specificity of the difference with respect to type of spatial skills, and the ages when gender differences emerge have been questioned (e.g., Caplan, MacPherson, & Tobin, 1985; Hyde, 1981). For example, Hyde (1981) argued, on the basis of a meta-analysis of visual-spatial ability studies, that the magnitude of the difference between males and females is very small. Others (e.g., Caplan, et al., 1985) have argued that the data are very inconsistent and reflect the lack of consensus about the specific skills that comprise visual-spatial abilities and their operationalization.

Basing their observations on the results of their meta-analysis of spatial ability studies, Linn and Petersen (1985) suggested that: (a) on spatial orientation tasks, reliable effect sizes indicating gender differences different from zero occurred only for subjects over 18 years old, (b) on mental rotation tasks, gender differences were found at all ages, with the largest effect sizes occurring on more complex mental rotation tasks (e.g., those using three-dimensional figures); and

(c) on spatial visualization tasks, the average effect size for gender differences did not differ from zero. Hence, whether gender differences on spatial ability tasks are obtained appears to be a function of both the type of spatial ability task used and the ages of the participants.

In their frequently cited review, Maccoby and Jacklin (1974) concluded that from early adolescence on, males typically outperform females on visual spatial tasks (e.g., spatial orientation, spatial relationships, spatial visualization tasks). Subrahmanyam and Greenfield (1994) suggested that one reason Maccoby and Jacklin might have obtained gender differences in both performance and training effects, was that late childhood and early adolescence might be a particularly sensitive period in the development of spatial abilities.

The main goal of the research presented here was to examine three specific aspects of the relation between video game play and spatial skills among older adolescents. First, we examined whether gender differences can be obtained in initial visual spatial performance and in video game play in a sample of older adolescents. Second, we examined the impact of video game play on spatial performance in the same sample. In essence, a replication of Subrahmanyam and Greenfield's (1994) findings with an older sample is provided. Third, we studied the effect of video game play on the specific component of spatial skills utilized in the game. That is, if a video game relies heavily on two spatial skills, is the impact on those skills predictable? We present two experiments in which measures of spatial performance were obtained from subjects both before and after they practiced the video game Tetris. In Experiment 1, paper-and-pencil measures of spatial performance were used, and in Experiment 2, computerized measures of spatial performance were used.

EXPERIMENT 1

Tetris is a game that requires the rapid rotation and placement of two-dimensional stimuli. In Experiment 1, subjects were given four paper-and-pencil tests assessing mental rotation, spatial visualization, and perceptual speed. We examined whether performance on spatial performance tests, game playing performance, and the impact of playing Tetris on spatial performance differed for males and females. In general, we anticipated that scores on measures that assess rotation and spatial visualization should have increased as a result of playing Tetris because playing this game requires the participant to practice mental rotation and spatial visualization. Conversely, scores on the measure of perceptual speed should have been affected to a much lesser degree, if at all. The perceptual speed test consisted of encoding and differentiating letters, functions that are highly overlearned and likely to be at ceiling for most subjects. Hence, practicing Tetris for 6 hr was not likely to affect performance on the perceptual speed task.

METHOD

Subjects

Fifty-seven undergraduate students (28 males, 29 females, *M* age = 19.93 years, *SD* = 4.33) were recruited from introductory psychology classes at the University of Missouri-Columbia and either participated in the study for course credit or for payment ($10). At their first session, all subjects completed the questionnaire about their previous video game experience. None of the subjects reported any prior experience with Tetris.

Materials

Participants in the experimental group played the video game Tetris on a Nintendo game set. In Tetris, seven different two-dimensional shapes, each consisting of four squares, must be placed into openings in a wall so that there are no holes in the wall. The target shapes appear at the top of the screen and fall at a set rate toward the wall at the bottom of the screen (see Figure 1). The wall is 10 squares wide and the target shapes initially appear over the center of the wall. The shapes may be placed in the wall in their original orientation or they may be rotated to obtain a better fit. In addition, the shapes may be moved left or right to fall into more suitable openings. The object of the game is to prevent the wall from

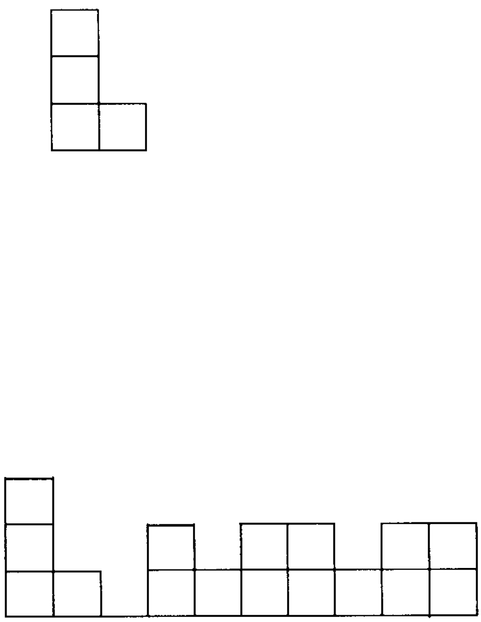

Figure 1. Example of Tetris shape and wall.

building up to the top of the screen and thereby ending the game. Whenever a row is completely filled (i.e., there are no holes or gaps in it), the row disappears, the height of the wall drops down, and players score one "line." The speed at which the target shapes fall increases as the level of difficulty increases. Successful play requires players to compare the presented shapes in their original and rotated orientations with the various openings (or spaces) in the wall to determine their best possible fit. That is, players must not only mentally represent the shapes in different orientations (mental rotation skill), but must also mentally visualize what would happen if the shapes were dropped into a particular opening in the wall (spatial visualization skill).

Subjects in both the experimental and control groups completed four paper-and-pencil tests taken from the French Kit (French, Ekstrom, & Price, 1963): (1) Finding A's, a perceptual speed measure; (2) the card rotations test, a two-dimensional mental rotation task; (3) the cube comparisons test, a three-dimensional mental rotation task; and (4) the form board test, a spatial visualization measure. For the perceptual speed task, subjects are presented with several lists of words and must cross out words that contain the letter A. For the card rotations test, subjects must determine whether a two-dimensional figure is the same as the target figure (i.e., the figure can be rotated to match the target) or whether it is different from the target (see Figure 2A). In the cube comparisons

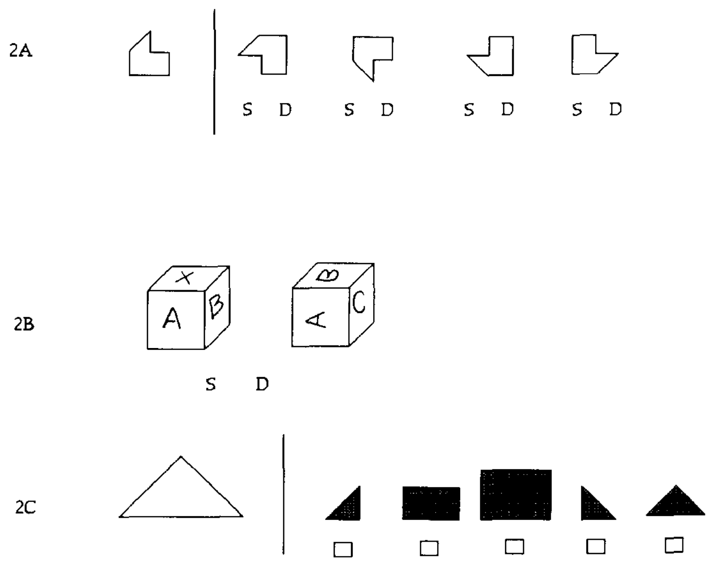

Figure 2. Figure 2A is an example of a card rotation item. Figure 2B is an example of a cube comparisons item. Figure 2C is an example of a form board item. Used by permission of the Educational Testing Service, the copyright owner.

task, subjects see two cubes lying side by side (see Figure 2B). Three sides of each cube are visible and on each side there is a letter. Subjects must decide whether the cubes are the same (i.e., one cube can be rotated so that the three visible sides will match those of the other cube) or different. For the form board test, Subjects see a target shape and must determine which of the shapes from a set of five could be combined to form the target shape (see Figure 2C). All four tests are timed tests. There were two versions of each test, one for the pretest (Time 1) and one for the posttest (Time 2). Half of all subjects received Version 1 at Time 1 and Version 2 at Time 2; the other half received Version 2 at Time 1 and Version 1 at Time 2.

Procedure

Participants were randomly assigned either to the experimental or the control group. During the first and last sessions, both experimental and control participants completed the four paper-and-pencil tasks as the Time 1 and Time 2 measures of their spatial and perceptual speed performance. Tests were administered to groups of 3 to 8 subjects at a time. The time between testing was 14 days, on average, for the experimental and control groups. In addition to the paper-and-pencil tests, both groups completed a brief questionnaire about their prior video game playing experience during the first session.

At the end of the Time 1 assessment session, practice sessions for playing Tetris were scheduled for the experimental group participants. Individual practice sessions for each subject were scheduled 1 day apart, except for weekends. At the first practice session, subjects were given instructions in booklet form for playing Tetris. Each of the 30 experimental subjects (15 males, 15 females) played Tetris for twelve 30-min sessions for a total of 6 hr of playing time. The subjects' first and last practice sessions were videotaped, and they usually took the posttests the day after the last practice session.

The 27 control group participants (13 males, 14 females) completed the Time 1 measures and returned 2 weeks later to do the Time 2 assessment. During that time, they reportedly refrained from playing any video games.

Design

The dependent variables of interest were subjects' scores on the paper-and-pencil spatial performance measures as well as measures representing the quality of game-playing performance for subjects in the experimental condition. The independent variables were *group* (between-subjects; experimental vs. control), *gender* (between-subjects; male vs. female), and *time of testing* (within-subjects; Time 1 vs. Time 2).

RESULTS AND DISCUSSION

For clarity of presentation, the results have been organized into two main sections. In the first section, we present analyses testing for gender differences on paper-and-pencil spatial and perceptual speed tests and game performance at the beginning of the experiment. The second section contains the results pertaining to the effects of video game playing on improving performance on spatial performance tests.

Initial Effects of Gender

Spatial Performance Tests. Table 1 contains the mean pretest scores on the four spatial performance tests as a function of gender. To test whether males and females differed on their initial performances on the spatial performance tests, we performed a one-way multivariate analysis of variance (MANOVA) with gender as a between-subjects variable on the scores from the four spatial skill and perceptual speed tests. In this analysis, the gender effect was reliable, Wilks' $\Lambda = 0.81$, $F(4, 52) = 2.98$, $p < .05$. Separate follow-up analyses of variance (ANOVAs) on the scores from the four spatial skill and perceptual speed tests yielded reliable effects of gender for the card rotations test, $F(1, 55) = 5.61$, $p < .05$, the cube comparisons test, $F(1, 55) = 3.98$, $p < .05$, and the form board test, $F(1, 55) = 5.04$, $p < .05$, but no reliable effect of gender for the perceptual speed test, $F(1, 55) = 1.03$, $p > .31$. As can be seen in Table 1, the Time 1 spatial performance test scores favored males.

Game-Playing Performance. For subjects in the experimental group, we tested whether males and females differed on their initial game-playing performances. The videotapes of the first and last video game playing sessions were coded for two variables that captured the quality of performance: (1) the mean number of points achieved per game and (2) the mean number of lines created per game. (In Tetris, each line represents a row of blocks in which there are no holes or gaps in it.) Table 2 contains the average scores for the number of lines and points at Time 1 (first video game playing session) separately for males and females. A one-way MANOVA with gender as between-subjects variable on the two dependent variables number of lines and number of points at Time 1 yielded

TABLE 1
Initial (Time 1) Scores on Spatial Performance Measures for Men and Women (Experiment 1)

	Males		Females	
Perceptual Speed	32.32	(7.97)	34.28	(6.02)
Card Rotation	68.33	(7.97)	62.26	(11.40)
Cube Comparison	14.53	(2.71)	13.14	(2.47)
Form Board	74.44	(21.46)	62.33	(18.03)

Note. Standard deviations are given in parentheses. Scores on each test represent number of correct responses.

TABLE 2

Time 1 and Time 2 Scores on Spatial Performance Measures and Game Playing Indices for Men and Women (Experiment 1)

	Experimental Condition							
	Males				Females			
	Pretest		Posttest		Pretest		Posttest	
Perceptual Speed	32.00	(9.19)	36.01	(6.59)	31.17	(4.37)	37.01	(4.75)
Card Rotation	67.99	(8.73)	72.22	(6.30)	65.45	(12.66)	67.53	(13.13)
Cube Comparison	14.21	(2.99)	17.88	(1.53)	13.66	(2.17)	13.73	(3.64)
Form Board	66.43	(25.71)	83.30	(20.51)	61.86	(21.33)	65.82	(18.74)
No. of Lines	18.6	(6.7)	58.4	(24.8)	7.7	(5.8)	52.9	(17.0)
No. of Points	2,716.9	(1,759.9)	16,964.0	(9,915.0)	808.3	(667.0)	13,271.00	(6,230.0)
	Control Condition							
	Males				Females			
	Pretest		Posttest		Pretest		Posttest	
Perceptual Speed	32.63	(6.89)	37.06	(11.33)	38.64	(5.39)	38.60	(8.57)
Card Rotation	68.66	(7.43)	71.56	(5.14)	57.80	(7.94)	62.61	(13.00)
Cube Comparison	14.83	(2.47)	15.38	(3.20)	12.40	(2.80)	13.00	(2.91)
Form Board	71.99	(13.29)	71.09	(9.75)	63.00	(13.16)	68.60	(22.34)

Note. Standard deviations are given in parentheses. Scores on each test represent number of correct responses. Number of lines and points are explained in the text.

a reliable gender effect, Wilks' $\Lambda = 0.55$, $F(2, 27) = 11.18$, $p < .001$. Separate ANOVAs yielded reliable effects of gender, with males outperforming females on both variables, $F(1, 28) = 22.53$, $p < .001$, and $F(1, 28) = 14.58$, $p < .001$, for the number of lines and the number of points, respectively. To determine whether the effects of gender on initial game-playing performance were due to initial gender differences in spatial performance, we repeated the analyses as analyses of covariance (ANCOVA), partialing gender differences on the Time 1 spatial performance scores. Even after partialing the gender differences in spatial performance, the gender differences on initial game-playing performance remained reliable, suggesting that these differences were not solely due to differences in spatial performance, but might have been due to the effects of other variables as well (e.g., overall experience with video games).

Effects of Game Playing on Spatial Performance Scores

Table 2 also contains the mean scores of the four spatial performance measures for both the experimental and the control conditions at Times 1 and 2, again separately for males and females. To determine whether subjects' game-playing performance did, in fact, improve as a result of practice, we performed a two-factorial MANOVA with gender (between-subjects) and time (within-subjects) as independent variables on the dependent variables number of lines and number of points. (Note that Time 2 scores for numbers of lines and points represent the quality of subjects' performance during the last video game session.) In this analysis, only the main effect of time was reliable, Wilks' $\Lambda = 0.18$, $F(2, 26) = 57.85$, $p < .001$. Separate ANOVAs on the two dependent variables with gender as between-subjects variable and time as within-subjects variable yielded a reliable main effect for time for both the number of lines and the number of points, $F(1, 27) = 118.13$, $p < .001$, and $F(1, 27) = 69.37$, $p < .001$, respectively. Thus, the quality of game playing improved reliably over the 12 practice sessions. Because the interaction between time and gender was not reliable in any of the analyses, we concluded that males and females did not differ in how much their game-playing performance improved over the 6 hr of practice.

To test whether game playing improved subjects' scores on the spatial performance measures, we ran four separate ANOVAs with group (experimental vs. control) and gender as between-subjects variables. The dependent variables were subjects' change scores (Time 2 minus Time 1) on the four spatial performance measures. The only reliable effects obtained with these analyses were a main effect of gender, $F(1, 53) = 5.28$, $p < .05$, with males improving more than females did and an interaction between gender and group, $F(1, 53) = 5.62$, $p < .05$, on the cube comparisons test. Because the general pattern of scores shown in Table 2 appears to indicate that males tend to show greater improvements in spatial performance than females as a result of game playing, we performed one-way ANOVAs, with group as the between-subjects variable on card rotations, cube comparisons, and form board tests, separately for males and females. For males, the main effect of group was reliable for both the cube comparisons and form boards tests, $F(1, 31) = 14.07, p < .001$, and $F(1, 31) = 4.56, p < .05$, respectively. In contrast, none of the effects were reliable for females (all p's $> .70$). These results indicate reliable improvements for males as a result of video game practice on the cube comparisons and form board tests, but no reliable change for females.

To test whether the amount of improvement on the spatial performance scores could be reliably predicted by amount of improvement in game-playing skill, we computed the correlations between the changes, from Time 1 to Time 2, in the four spatial performance measures and the change in the number of lines and points. None of the resulting eight correlations was reliable (all p's $> .05$), indicating that the amount of improvement in spatial performance was not predicted by amount of improvement in game-playing performance.

Furthermore, final game-playing performance did not reliably predict final spatial performance on any of the four measures, nor did initial spatial performance reliably predict either initial or final game-playing performance (all p's $> .40$).

In sum, Experiment 1 demonstrated that video game playing has the potential to improve performance on spatial performance measures. However, it appeared that improvements were generally greater for males than they were for females. In fact, none of the spatial performance measures we employed demonstrated reliable change after practice for females. In contrast, scores on two of the three measures that we had predicted would improve as a result of game playing did indeed improve for males.

Theoretically, the lack of an effect for females could be explained by assuming that more practice on video game playing was needed for such an effect to appear (notice that our results demonstrated a male superiority in initial game-playing performance that was not entirely due to the male subjects' advantage in spatial performance), and/or that females' spatial performance did, in fact, improve but our dependent measures were not sensitive enough to pick up the improvement. Experiment 2 dealt with the second possibility. In lieu of the paper-and-pencil measures of spatial performance employed in Experiment 1, Experiment 2 utilized computerized tests that were specifically constructed to measure mental rotation and spatial visualization performance as they are practiced in the video game Tetris. We hoped that the use of the reaction time measure instead of number correct, as in paper-and-pencil measures, would increase the sensitivity of the dependent measures. In addition, because the computerized tasks were much more similar to the Tetris game than the paper-and-pencil measures were, they constituted a closer transfer task from the video game; for this reason, greater effects from the video game practice might be observed.

As reported in Experiment 1, males and females already differed in their game-playing performances at the first time of testing. Although gender differences no longer existed at the end of the 6 hr of practice, Wilks' $\Lambda = 0.94$, $F(2,$

26) < 1, it is possible that the initial gender differences may have affected our results. Therefore, we included in Experiment 2 only subjects who had not played *any* video game during the past year, thus hoping to eliminate the initial gender difference in game-playing performance.

EXPERIMENT 2

Experiment 2 was essentially a replication of the first experiment. The main goals of Experiment 2 were to examine whether spatial performance scores, game-playing performances, and the impact of playing Tetris on spatial performance scores differed for males and females; and whether playing the video game Tetris would improve spatial performance scores.

METHOD

Subjects

A total of 53 undergraduate students (27 males, 26 females), *M* age = 19.85, *SD* = 3.52) recruited from an introductory psychology class participated in the experiment either for credit or for a small payment ($10). At their first session, all subjects completed the questionnaire about their previous video game experience. None of the subjects reported any prior experience with Tetris. In addition, none of the subjects reportedly had played any video game during the past year.

Materials

Visualization Task. For this experiment, two computerized spatial performance tests were designed. Both tasks were presented on Macintosh SE computers. The first task was a spatial visualization task in which the subjects saw a shape at the top of the screen and had to decide whether the shape would fit into the hole or gap in the wall at the bottom of the screen by imagining what would happen if the shape was moved into the hole. To qualify as fitting into the hole, the shape had to completely "disappear" into the wall, such that no part of the shape was left above the wall and there were no enclosed or completely surrounded empty spaces or gaps in the wall. In addition, the shape had to fit the hole in its presented orientation—that is, subjects could not mentally rotate the shape to make it fit into the wall (see Figure 3).

A total of 10 shapes were used, each consisting of four basic squares. Five shapes were the same as the shapes used in the Tetris game (Tetris shapes). For these five shapes, the four squares were arranged such that at least one side of each square was connected to the side of another square (see Figure 1). The remaining five shapes were different from the Tetris game shapes (non-Tetris shapes). For these non-Tetris shapes, the four squares were arranged such that each square was connected either to the side of another square or to the corner of

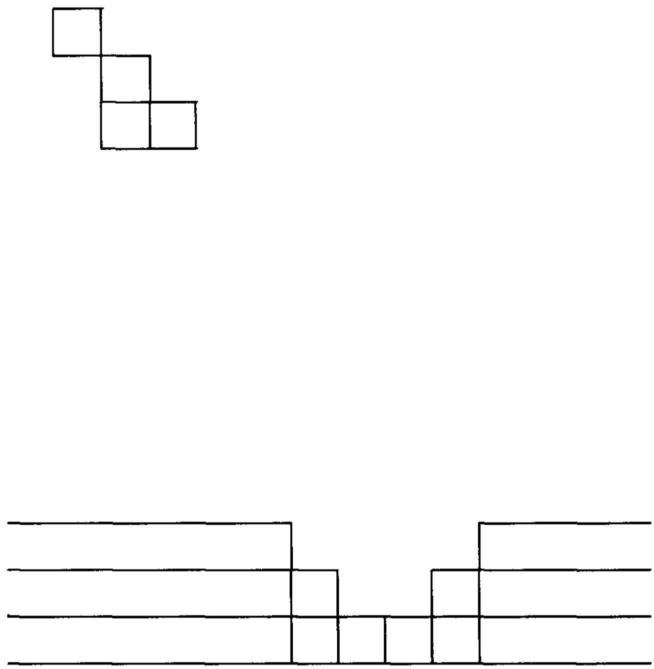

Figure 3. Example of a non-Tetris shape and wall as they would appear in the computerized spatial visualization task.

another square (see Figure 3). Notice that because all possible shapes consisting of four squares with connected sides were utilized in Tetris, our non-Tetris shapes necessarily differed from the Tetris shapes in terms of complexity. In 50% of the trials, the correct response was that the shape fit into the hole (fit); for 50% of the instances, the correct response was that the shape did not fit the hole (no-fit).

Instructions for the task were presented on the computer screen at a subject-controlled pace. After reading the instructions, subjects pressed the space bar to begin 10 practice trials. After each practice trial, subjects received feedback as to whether the response was correct or not. At the end of the practice trials, subjects could either stop and ask the experimenter for clarification of the task, reread the instructions, or begin the actual test.

Mental Rotation Task. The second computerized task was a mental rotation task in which a reference shape was presented to subjects along with a second shape. Subjects had to decide whether the second shape was the same as the reference shape—that is, whether or not it could be mentally rotated within the plane to look exactly like the reference shape, or whether the second shape was different from the reference shape, in which case it was the mirror image of the reference shape. The exact same shapes used in the visualization task were used again in the mental rotation task. In exactly 60% of the trials, the correct response was that the shapes were the same; in the remaining 40% of the trials, the correct response was that the shapes were different.

As in the spatial visualization task, instructions for the task were presented on the computer screen at a subject-controlled pace. After reading the instructions, subjects completed 10 practice trials and received feedback after each response. At the end of the practice trials, subjects could either stop and ask the experimenter for clarification of the task, reread the instructions, or begin the actual test.

At the first time of testing, half of the subjects in the experimental and control conditions received the visualization task first and the mental rotation task second; for the remaining subjects the order was the reverse. At the second time of testing, subjects received the two tasks in the reverse order that they received them at Time 1.

Subjects in the experimental group practiced the video game Tetris according to the exact specifications provided for Experiment 1. As in the first experiment, the first and last game-playing sessions were videotaped.

Procedure

Subjects were randomly assigned either to the experimental or the control group. At their first session, all subjects were individually tested on the two computerized measures of spatial performance, and they completed the questionnaire about their previous video game experience.

At the end of the initial testing session, individual practice sessions for each experimental subject were scheduled one day apart, except for weekends. At the first practice session, subjects were given instructions in booklet form for playing Tetris. Each of the 25 experimental subjects (13 males, 12 females) played Tetris for twelve 30-min sessions. The control group was comprised of 28 undergraduate students (14 males, 14 females) who reportedly refrained from playing any video games during the pre- to posttest periods. The time between testing was 14 days, on average, for each of the two groups.

Design

The dependent variables of interest were subjects' reaction times on the mental rotation task and the visualization task as well as measures representing the quality of game-playing performances for subjects in the experimental condition. The independent variables were group (between-subjects; experimental vs. control), gender (between-subjects; males vs. females), and time of testing (within-subjects; Time 1 vs. Time 2).

RESULTS AND DISCUSSION

For clarity of presentation, the results have again been organized into two main sections. In the first section, we present analyses testing whether males and females differed on our new measures of spatial performance and on game performance at the beginning of Experiment 2. The second section contains the results pertaining to the effects of video game play on the improvement of spatial performance. Because there were no systematic differences in error rates, we will present the results for reaction times only.

Initial Effects of Gender

Mental Rotation Task. For each subject, the median reaction time (RT) of correct "yes" responses in the mental rotation task was determined separately for Tetris and non-Tetris shapes at each of the seven different angles used in the experiment (i.e., 45°, 90°, 135°, 180°, 225°, 270°, 315°). Initial analyses indicated a nonlinear, inverted U-shaped relation between degree of angle and RT. That is, shapes that were presented at angles between 180° and 315° were mentally rotated in the opposite direction to that of shapes that were presented at angles between 45° and 180°. Therefore, the average time needed to rotate a shape by 1° of angle was determined separately using RTs from angles varying from 45° to 180°, and angles varying from 180° to 315°. The estimates for the time taken to rotate a shape by 1° of angle were computed separately for each subject and each type of shape (Tetris vs. non-Tetris) by performing a series of multiple regressions using degree of angle as predictor of RT. The numerical estimates for rotation time correspond to the B values in the best-fitting multiple regression equations. Because the results obtained with the two ranges of angles (i.e., 45°–180° vs. 180°–315°) were qualitatively identical, we averaged the two estimates obtained for each subject and each type of shape. All results described in the following are therefore based on the average of the two estimates of mental rotation time.

Table 3 contains the mean Time 1 (pretest) scores on the measure of mental

TABLE 3
Initial (Time 1) Scores on Spatial Performance Measures for Males and Females (Experiment 2)

	Males		Females	
Mental Rotation Time				
Tetris Shapes	4.04	(1.30)	3.90	(1.03)
Non-Tetris Shapes	4.11	(0.84)	5.36	(0.93)
Visualization Time				
Tetris-Fit	1,914	(725)	1,987	(742)
Tetris-No-Fit	2,183	(645)	2,078	(717)
Non-Tetris-Fit	2,589	(953)	2,566	(913)
Non-Tetris-No-Fit	2,637	(893)	2,610	(749)

Note. Means and standard deviations (in parentheses) for mental rotation time are in milliseconds per degree of rotation; for visualization time, means and standard deviations are in milliseconds.

rotation time for both Tetris and non-Tetris shapes as a function of gender. The means represent mental rotation time as the number of milliseconds needed to rotate a Tetris or non-Tetris shape by 1° of angle. To test whether males and females differed on their initial mental rotation times, we performed a one-way ANOVA with gender as a between-subjects variable and type of shape (Tetris vs. non-Tetris) as a within-subjects variable. In this analysis, reliable main effects of gender and type of shape were obtained, $F(1, 51) = 7.71, p < .01$, $F(1, 51) = 13.47, p < .001$, respectively. In addition, there was a reliable interaction between gender and type of shape, $F(1, 51) = 11.24, p <. .001$. Follow-up ANOVAs indicated that the gender effect was reliable for non-Tetris shapes, $F(1, 51) = 24.93, p < .001$, but was not reliable for Tetris shapes, $F(1, 51) < 1$. This finding suggests that gender differences in mental rotation time vary with the degree of complexity and is consistent with Linn and Petersen's (1985) observations that effect sizes for gender differences on mental rotation tasks vary with task complexity and that large effect sizes are obtained on more complex mental rotation tasks. Notice that our interpretation emphasizes complexity rather than familiarity because for the initial spatial tests, neither the simpler Tetris shapes nor the more complex non-Tetris shapes had been previously seen by the subjects. The familiarity dimension only entered into the situation after the subjects had practiced Tetris.

Visualization Task. For each subject, the median RT of correct responses was determined separately for Tetris and non-Tetris shapes that either fit or did not fit into the wall pattern displayed on the screen. Table 3 contains the means in milliseconds for Tetris-fit, non-Tetris-fit, Tetris-no-fit, and non-Tetris-no-fit shapes computed for Time 1, separately for males and females. A three-way ANOVA with gender as a between-subjects variable, and type of shape (Tetris vs. non-Tetris) and fit (fit vs. no-fit) as within-subjects variables on subjects' RTs for Time 1, yielded a reliable main effect of type of shape, $F(1, 51) = 199.83$, $p < .001$, a marginally reliable main effect of fit, $F(1, 51) = 3.12, p < .08$, and a reliable interaction between type of shape and fit, $F(1, 51) = 5.38, p < .05$. Non-Tetris shapes were processed more slowly, on average, than the less complex Tetris shapes. In addition, subjects were faster when a given shape fit the wall pattern than when it did not fit the wall pattern. The interaction between type of shape and fit indicated that the difference between shapes that fit and did not fit the wall pattern was larger for Tetris than for non-Tetris shapes. Most important, neither the main effect of gender nor any of the interactions involving gender were reliable, all *ps* $> .05$. Thus, males and females did not differ initially in terms of visualization time.

Game-Playing Performance. To test whether males and females differed on their initial game-playing performances, we coded, for subjects in the experimental group only, the videotapes of the first video game playing session for two variables that captured the quality of performance: (1) the mean number of points per game achieved and (2) the mean number of lines created per game. Table 4 contains the average scores on the number of lines and points for the experimental condition at Time 1 and Time 2, again separately for males and females. On the Time 1 scores for number of lines and points, we performed a one-way MANOVA with gender as between-subjects variable. In this analysis, the main effect of gender was not reliable, $p > .39$. However, as can be seen in Table 4, the average scores for males were again slightly higher than the average scores for females as was found in Experiment 1.

Effects of Game Playing on Spatial Performance Measures

To test whether subjects' game-playing performance did in fact improve as a result of video game practice, we performed a MANOVA with gender as between-subjects variable and time (Time 1 vs. Time 2) as within-subjects variable on the number of lines and points on the dependent variables. In this analysis, only the main effect of time was reliable, Wilks' $\Lambda = 0.31$, $F(2, 20) = 22.92$, $p < .001$. Separate ANOVAs on the two dependent variables indicated that the main effect of time was reliable with both the number of lines, $F(1, 21) = 32.97$, $p < .001$, and number of points, $F(1, 21) = 36.73$, $p < .001$, indicating that subjects' quality of game playing improved reliably over the course of the practice sessions. Neither the main effect of gender nor the interaction between time and gender was reliable in any of the analyses, all Fs < 1. Thus, males and females did not differ in the amount of improvement, with practice, that they demonstrated in game-playing performance.

Mental Rotation Time. Table 4 also contains the mean scores on the measure of mental rotation time for both the Tetris and non-Tetris shapes and the experimental and control conditions at Times 1 and 2, again separately for males and females. To test whether game practice improved subjects' scores on the mental rotation time measure, we performed an ANOVA with group (experimental vs. control) and gender as between-subjects variables and type of shape (Tetris vs. non-Tetris) as within-subjects variable. Subjects' change scores (Time 1 minus Time 2) on the time-of-rotation measures were the dependent variables. In this analysis, only the main effect of group was reliable, $F(1, 49) = 19.20, p < .001$; for all other effects, $p > .30$. The average change score was 1.19 ms per degree of rotation, $SD = 1.01$, for the experimental group, and 0.01 ms per degree of rotation, $SD = 0.95$, for the control group.

Neither the main effect of gender nor any of the interactions involving gender were reliable in this analysis, indicating that males and females did not differ in the amount of improvement in mental rotation time resulting from video game practice.

Separate follow-up analyses indicated that the decrease in mental rotation time was reliable for the experimental group, $F(1, 24) = 34.49$, $p < .001$.

TABLE 4

Time 1 and Time 2 Scores on Mental Rotation Task and Game-Playing Indices for Men and Women (Experiment 2)

	Males				Females			
	Pretest		Posttest		Pretest		Posttest	
Experimental Condition								
Tetris Shapes	4.01	(1.35)	2.80	(1.65)	3.80	(0.86)	2.83	(1.01)
Non-Tetris Shapes	4.16	(0.62)	2.63	(1.19)	5.39	(0.91)	4.24	(1.21)
No. of Lines	14.4	(20.5)	60.0	(27.8)	9.8	(14.6)	57.6	(19.7)
No. of Points	1,603.4	(1,789.9)	17,746.6	(12,769.5)	1,391.5	(1020.3)	16,615.3	(12,022.0)
Control Condition								
Tetris Shapes	4.06	(1.32)	4.02	(0.71)	3.99	(1.19)	4.10	(0.98)
Non-Tetris Shapes	4.06	(1.02)	4.26	(1.25)	5.32	(0.98)	5.05	(1.17)

Note. Means and standard deviations (in parentheses) for Tetris and non-Tetris shapes are in milliseconds per degree of rotation. Number of lines and points are explained in the text.

The change in mental rotation time was not reliable for the control group, $F(1, 27) < 1$.

Visualization Time. Table 5 contains the mean scores on various measures of visualization time for the experimental and control conditions at Times 1 and 2, again separately for males and females. To test whether game practice improved subjects' scores on the visualization time measure, we performed an ANOVA with group (experimental vs. control) and gender as between-subjects variables, and type of shape (Tetris vs. non-Tetris) and fit (fit vs. no-fit) as within-subjects variables. Subjects' change scores (Time 1 minus Time 2) on the visualization time measures were the dependent variables. In this analysis, only the main effect of group was reliable, $F(1, 49) = 9.12, p < .01$; however, the main effect of type of shape approached significance, $F(1, 49) = 3.49, p < .07$. The average improvement for the experimental group was larger than the average improvement for the control group, and the improvement for non-Tetris shapes was larger than the improvement for Tetris shapes.

Again, neither the main effect of gender nor any of the interactions involving gender were reliable in this analysis, indicating that males and females did not differ in the amount of improvement in visualization time resulting from video game practice.

Separate follow-up analyses indicated that the decrease in visualization time from Time 1 to Time 2 was reliable for all four measures in the experimental group, all $ps < .05$, but was not reliable in the control group, all $ps > .05$. In addition, the advantage of the experimental group over the control group was reliable for all four measures, all $ps < .05$.

TABLE 5
Time 1 and Time 2 Scores on Spatial Visualization Task for Men and Women (Experiment 2)

	Males				Females			
	Pretest		Posttest		Pretest		Posttest	
Experimental Condition								
Tetris-Fit	1,983	(670)	1,448	(542)	2,072	(789)	1,294	(395)
Tetris-No-Fit	2,176	(674)	1,612	(726)	2,211	(573)	1,570	(791)
Non-Tetris-Fit	2,684	(820)	2,121	(804)	2,759	(976)	1,879	(608)
Non-Tetris-No-Fit	2,743	(1,039)	1,940	(823)	2,688	(778)	1,910	(622)
Control Condition								
Tetris-Fit	1,857	(790)	1,899	(867)	1,906	(711)	2,088	(844)
Tetris-No-Fit	2,189	(650)	2,164	(1,087)	1,953	(829)	1,992	(787)
Non-Tetris-Fit	2,510	(1,081)	2,361	(899)	2,386	(839)	2,453	(832)
Non-Tetris-No-Fit	2,549	(786)	2,583	(1,325)	2,537	(738)	2,520	(1,143)

Note. Means and standard deviations (in parentheses) are in milliseconds.

Game Playing and Spatial Performance Measures. To test whether the amount of improvement on the spatial performance measures could be directly predicted by amount of improvement in game-playing skill, we computed the correlations between changes in all six spatial performance measures and changes in the number of lines and points. Of the resulting 12 correlations, 4 were reliable—namely, the correlations between the change in number of lines and two measures of visualization performance, Tetris-fit, $r(23) = -.43$, and non-Tetris-fit, $r(23) = -.46$, and the correlations between the change in points and the same two measures of visualization performance, Tetris-fit, $r\ (23) = -.41$, and non-Tetris-fit, $r(23) = -.44$. The negative sign indicates that the amount of improvement in game playing was related to the amount of decrease in RT on the two measures of visualization performance. In contrast, the changes in the two measures of mental rotation performance were not related to amount of improvement in game playing.

To summarize the main results of Experiment 2, practicing Tetris for a total of 6 hr did reliably improve both mental rotation time and spatial visualization skill for both Tetris and non-Tetris shapes. The improvement in spatial skill did not differ for men and women.

GENERAL DISCUSSION

The playing of video games and their counterparts, arcade and computer games, is a ubiquitous feature of the culture of today's children and youth. Yet very little is known about the impact of playing video games on cognitive skills. Taken together, our two experiments, like earlier research, obtained mixed results in finding a relation between video game playing and improvements in spatial skills, and in finding gender differences in performances on spatial performance tasks. We begin our discussion by focusing on the effects of gender on spatial skills performance and then examine the impact playing Tetris had on spatial skills.

Effects of Gender on Spatial Skills Performance

Consistent with Linn and Petersen's (1985) meta-analysis of spatial-ability research, we found reliable and consistent differences favoring males on complex mental rotation tasks (i.e., the cube comparison and the mental rotation of non-Tetris shapes) and obtained mixed results for simple rotation tasks. On the paper-and-pencil card rotation task, males did better than females. However, for the RT measure of mental rotation on the relatively simple Tetris shapes, there was no difference between males and females. If large effect sizes for gender differences are only obtained on complex mental rotation tasks, then on simple tasks one would not expect to consistently obtain reliable gender differences.

On the spatial visualization tasks, males did better than females on the form board test, but not on the computerized visualization task. In both Linn and Petersen's review (1985) and in Maccoby and Jacklin's (1974) review, the authors concluded that for spatial visualization tasks there are no consistent gender differences.

Effects of Playing Tetris on Mental Rotation and Spatial Visualization Performance

In the first experiment, we found that males' scores on the cube rotation and the form board tests did improve, but females' scores did not improve on any measures. In light of Baenninger and Newcombe's (1989) meta-analysis of spatial-skill training studies, in which they found that the impact of training on males and females did *not* differ, we replicated our experiment using more sensitive (i.e., RT) measures of spatial skills. It was possible that the females might have improved, but the measures were not sensitive enough to detect that improvement. Experiment 2 also used tests presented in the same (computer) medium as that of the video game training. In contrast to Experiment 1, therefore, Experiment 2 required relatively near transfer.

In the second experiment, we found that mental rotation time and visualization time decreased reliably for both males and females and that the amount of improvement on these two measures of spatial performance did not differ for males and females. Thus, the findings presented here replicate Subrahmanyam and Greenfield's (1994) finding that practice on a spatially oriented video game positively affects closely related spatial skills. Because our replication used an older sample than did Subrahmanyam and Greenfield's the data suggest that the effectiveness of video game practice for improvement of spatial skills may have more to do with the similarity between the video game and the transfer task than with a particularly sensitive period for the development of spatial skills. The video game and the transfer tasks shared a common medium (i.e., the computer), at least some common shapes for manipulations (i.e., the Tetris shapes), and common skills (e.g., mental rotation of shapes, visualizing whether a shape would fit into a hole in a wall). This explanation is also consistent with Baenninger and Newcombe's (1989) observation that the effectiveness of spatial training is a function of the similarity between the training task and the testing task. The greater sensitivity of the reaction time measures in Experiment 2 may also have contributed to the demonstration of transfer for females in Experiment 2, but not in Experiment 1.

Numerous training studies (e.g., Connor, Schackman, & Serbin, 1978; Embretson, 1987; McGee, 1978; see also Baenninger & Newcombe, 1989, for meta-analysis of training studies) have found that spatial performance can be improved through practice. The importance of this study is that the gains in spatial performance occurred as a by-product of playing a popular video game for only 6 hr. The implication is that adolescent video game players can accrue some specific cognitive benefits from the time they spend playing video games.

Transfer of Skills Gained in Video Game Context to Other Tasks

The second study demonstrated that skills acquired through playing Tetris can be generalized to different shapes. On the visualization task, improvement of Tetris scores was correlated with both placement of the Tetris shapes and with placement of the non-Tetris, complex shapes. Thus, visualization skill developed in Tetris could be transferred to the visualization and mental manipulation of different (non-Tetris) stimuli. It is also important to note that even though the visualization task was designed to be similar to the placement of shapes within the Tetris game context, the requirements for shapes "fitting" in the wall in the visualization task were somewhat different than the requirements for placing shapes in the Tetris game. Effective strategies for placing shapes in the Tetris game do no necessarily require players to make sure there are no empty spaces enclosed by the shape and the wall. There are times in the Tetris game in which the best placement of a shape will leave some empty spaces, and knowing which kinds of spaces are easier to fix than others is important for successful game playing. Consequently, there were some differences in the rules that governed effective Tetris placement and correct placement decisions in the placement task. Although the transfer of spatial visualization skill from Tetris to the visualization task may on the surface appear trivial, studies have shown that transfer of skill when stimuli are changed is not always obtained (e.g., Lantz, 1979; Scribner, 1984).

In summary, spatially oriented video games do have potential to improve late adolescents' mental rotation and spatial visualization skills. However, without a formal test of the variety of contexts to which spatial skills developed within a particular video game can be successfully transferred, it is difficult to say how generalizable these skills might be. Although there were differences between the Tetris game and the transfer task, the tasks shared many similar features. Thus, along with other research our studies suggest that spatial skills developed through video game practice or practice on other spatial skills training tasks may be contextualized or tied to contexts closely linked to the practice setting. Development of spatial skills within the video game context may be another example of what Brown, Collins, and Duguid (1989) called "situated cognition." If this is the case, those wishing to capitalize on the motivational aspect of video games for spatial skills training will need to find or develop games that are similar to the actual contexts in which the spatial skills will eventually be used.

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