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Effect of Video Game Practice on Spatial Skills in Girls and Boys

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A study of the effect of video game practice on spatial abilities in girls and boys was carried out. Spatial performance, measured using two subtests of a computerized spatial skills battery, was significantly better in boys than in girls during pretest assessment. Subjects then practiced on an action video game, Marble Madness, or a computerized word game, Conjecture. Video game practice was significantly more effective than the word game in improving spatial performance on the posttest assessment; there was no significant interaction of gender with experimental treatment. However, video game practice was more effective for children who started out with relatively poor spatial skills. The pattern of results suggests that video games may be useful in equalizing individual differences in spatial skill performance, including those associated with gender.

In recent years there has been increasing recognition that, on the one hand, education is not limited to formal schooling and, on the other hand, cognitive processes are broader than those taught and tested in school (Greenfield & Childs, 1991; Greenfield & Lave, 1982; Guberman & Greenfield, 1991; Rogoff & Lave, 1984; Saxe, 1991; Scribner, 1986; Scribner & Cole, 1981). This has led to the study of both informal education and everyday cognition.

Informal education takes place by means of a host of cultural tools (Vygotsky, 1978), among which the electronic media have become increasingly important. The computer is the newest such medium. Whereas the impact of explicitly educational computer formats has been amply studied (e.g., Pea, 1985; Salomon, Perkins, & Globerson, 1988), recreational forms of computer use have been relatively ignored as a means of informal education. Chief among these is the action video game.

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The pervasive nature of these games is evident from a 1982 Gallup poll, which indicated that more than 93% of the nation's youth have at least played video games at some time or another (Alperowicz, 1983). Furthermore, in a random sample of 748 of the 1,274 respondents in a high school survey near Stanford University, it was found that students reported playing an average of 1.25 hours per week in a video arcade and 0.93 hours per week at home (Rogers, Vale, & Sood, 1984). Thus, the action video game has the potential to be a significant tool of cognitive socialization.

Whereas there has been considerable public concern about the possible deleterious effects of video games (e.g., Mayfield, 1982), there are relatively few data regarding their impact. A number of studies have investigated the social and personality correlates of video game play (Dominick, 1984; Gibb, Bailey, Lambirth, & Wilson, 1983; Morlock, Yando, & Nigolean, 1985). There has also been a lot of speculation about whether computer and video technology requires and develops various cognitive skills. Ball (1978) speculated that video games could teach eye-hand coordination, decision making, the following of directions, numerical concepts, and word recognition skills. Lowery and Knirk (1982–1983) proposed that video game playing might play a role in enhancing eye–hand coordination.

Greenfield (1983, 1984, 1990, 1993) suggested that there might be a set of literacy skills associated with computers and the video screen that are distinct from the traditional literacy skills required for print media (Greenfield, 1972). This idea has stimulated research as to whether video games might have beneficial effects on various cognitive processes (Greenfield, Brannon, & Lohr, 1994; Greenfield, Camaioni, et al., 1994; Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994; Okagaki & Frensch, 1994). Possibly, video games are also a means of informal education that develop computer and video literacy skills that are distinct from the traditional print literacy skills taught at school (Greenfield, 1972, 1990, 1993).

These speculations about the effect of video game training fit Vygotsky's (1978) view that cultural tools and artifacts are related to cognitive developmental processes. Given the growing importance of computers and video games as modern tools, their effect on cognitive skills is of interest from both a theoretical and practical perspective.

Skill in spatial representation is one example of everyday cognitive skills utilized and developed by video games and other computer applications (Greenfield, 1993). These skills build on the foundation laid down by television (Greenfield, 1984; Salomon, 1979). Spatial representation is better thought of as a domain of skills rather than as a single ability or skill (Pellegrino & Kail, 1982). Multivariate studies (Lohman, 1979) have identified three important factors in the domain of spatial abilities: (1) spatial relations ability, which refers to the capacity to rapidly transform objects in the mind, as is required when one "mentally rotates" an object about its center; (2) spatial visualization, which is the ability to deal with complex visual problems that require imagining the

relative movements of internal parts of a visual image, as in the folding and unfolding of flat patterns; and (3) perceptual speed, a visual-spatial factor, which involves rapid encoding and comparison of visual forms.

Although this is not commonly acknowledged in the literature on spatial skills, it is important to recognize that spatial tests assess skill in dealing with two-dimensional images of hypothetical two- or three-dimensional space, and not skill in navigating, comprehending, or representing real world, three-dimensional spaces. In this respect, spatial tests contrast with the spatial skill development studied by researchers such as Acredolo, Pick, and Olsen (1975), Hart and Berzok (1982), and DeLoache (1993).

Skills in utilizing two-dimensional representations of hypothetical space are important in a variety of computer applications, including word processing (Gomez, Egan, & Bowers, 1986; Gomez, Egan, Wheeler, Sharma, & Gruchacz, 1983) and programming (Roberts, 1984), as well as the recreational medium of action video games. These skills may be one component of the ability to "read" and utilize the information on computer screens.

Task analyses of video games led to early speculation that they could be a tool for the development of spatial skills (Ball, 1978; Greenfield, 1983, 1984; Lowery & Knirk, 1982–1983). This was of particular interest because of repeated findings revealing male superiority in this area. After a review of over 1,000 research reports on gender differences, Maccoby and Jacklin (1974) concluded that gender differences were "fairly well established" in the cognitive area of spatial skills. More recent work has confirmed that gender differences in spatial skills may indeed exist (Halpern, 1986; Hyde, 1981; Kerns & Berenbaum, 1991; Linn & Petersen, 1985; McGee, 1979; Peterson & Crockett, 1985). Even when male and female performance is equal on a spatial task, there is sometimes a gender difference in strategy: Males generally show preference for a more visual solution strategy whereas most females show preference for a more verbal strategy (Pezaris & Casey, 1991).

Lowery and Knirk (1982–1983) reasoned that if spatial skills are indeed built up over a period of time and repeated interactions, as suggested by research, then microcomputer video games should be an excellent mechanism for training these skills. In one of the first experimental studies utilizing video game training, Gagnon (1985) studied the effect of 5 hr video game practice on undergraduate and graduate students. Subjects in the experimental group played two games (Targ and Battlezone) for $2\frac{1}{2}$ hr each whereas subjects in the control group received no video game practice. The pattern of correlations indicated that the two different video games utilized different although overlapping skills.

Gagnon (1985) reported that at the start of the study, men scored higher than women on spatial orientation, spatial visualization, and the game Targ, whereas women scored higher on eye-hand coordination. Following 5 hr of video game practice, there were no significant differences between men and women on the final scores on Targ and spatial visualization. However, the gender differences found at the start continued to be present on spatial orientation (in favor of men) and eye-hand coordination (in favor of women). In addition, subjects with less video game experience at the outset improved in spatial skills as a result of video game practice, whereas more experienced players did not. There was also a large overlap between the less experienced and women. Finally, it was found that subjects who reported they had played more video games in the past tended to score higher on both the video games and the spatial tests. Thus, both gender and amount of past video game practice were related to subjects' scores on video games and spatial skills. Although we cannot say with certainty that gender differences cause differences in exposure to video games, it does seem to be the case that females, on average, seek out video games less than males do (Lockheed, 1985).

In another set of practice studies, Pepin and Dorval (1986) and Dorval and Pepin (1986) provided eight sessions of training on the video game Zaxxon (each session included five games of Zaxxon) to 70 undergraduate students in Quebec city. Training was also provided to 101 seventh-grade students in Quebec city, although the children received fewer practice sessions because of time constraints. A control group was given only the pretest and posttest and received no training. Scores on the Space Relations Test of the Differential Aptitude Test (DAT), Forms A and B, were used as measures of spatial ability.

In the adult experiment, there were no significant gender-related differences in visual-spatial skills, although there was a tendency toward a difference in favor of men. Furthermore, both men and women gained significantly and equally on the spatial measures from playing Zaxxon. In the experiment with adolescents, there was no initial gender difference in visual-spatial skills and no significant improvement in spatial skills following training on Zaxxon. One possible reason that adults but not adolescents improved is that the adult sample had no prior experience with video games, whereas the adolescent sample had some experience (although very limited).

McClurg and Chaillé (1987) also reported that playing computer games enhanced the development of the spatial skill of three-dimensional mental rotation in fifth-, seventh-, and ninth-grade students, with the treatment benefiting both boys and girls at all three grade levels equally. It is interesting to note that in their study there was an initial gender difference in spatial skill, with boys performing better than the girls; it is not clear from their article whether this difference continued to be present at the end of the study. Miller and Kapel (1985) found a positive effect of similar computer games on two-dimensional mental rotation in seventh and eighth graders.

A thesis by Chatters (1984) found a significant positive effect of $3^3/_4$ hr of practice with Space Invaders on the Wechsler Intelligence Scale for Children (WISC) Block Design subtest for sixth-grade children. No gender differences were observed.

Thus, there is evidence that in some age groups, with some games, video games are a tool of cognitive socialization for some skills of spatial representation. There is also evidence that these games can reduce some gender differences

in the spatial skills of adults. Our question was whether this effect could be obtained in a stronger form if we gave video game practice to children at the point in development when gender differences in spatial skills are first consistently detectable (Johnson & Meade, 1987).

According to Halpern (1986), there is "still some confusion about the youngest age at which gender differences in spatial abilities are found" (p. 51). Petersen and Crockett (1985) obtained gender differences in mental rotation tests for children in elementary school. In a large study of over 1,800 public school students, Johnson and Meade (1987) used a battery of seven spatial tests tailored to the developmental levels of the children and concluded that a reliable male advantage in spatial performance appeared by age 10. This means that gender differences in spatial skills are consistently detectable by the time children are about 10 years old. Although Johnson and Meade did not speculate about the theoretical rationale for these differences, there is evidence to indicate that they are the cumulative effect of the nature and nurture interaction (Pezaris & Casey, 1991).

The issue of gender differences in video game playing is also of relevance here. In a survey of video game use among fourth through sixth graders in the San Francisco Bay area, it was found that boys played video games more often both in arcades and at home (Linn & Lepper, 1987). In another survey of 10th and 11th graders in three high schools in northeast Georgia, Dominick (1984) reported that the average playing time per week was about $1^1/_2$ hr for boys compared to less than 1 hr for girls. Among college students, the relationship between gender and frequency of video game playing was similar (Morlock et al., 1985). Finally, video arcades were found to be basically male preserves (Kiesler, Sproull, & Eccles, 1985). The greater popularity of video games with males is not surprising, given the fact that in most games the player controls a male character (Provenzo, 1991; Rushbrook, 1986) who is carrying out activities that are perceived as being male oriented (Hess & Miura, 1985). In view of the male bias in video game design and video game play, Lepper (1982), Loftus and Loftus (1983), Greenfield (1984), and Kiesler et al. (1985) all expressed the concern that females might be at a disadvantage where computer usage is concerned, because computer and video games might provide an easy lead-in to computer literacy.

If we consider the research that shows a relationship between video game playing and spatial skill, it is reasonable to suppose that gender differences in spatial skills may be related to differences in video game play. Other research has implicated both training and practice in related activities as being relevant to the development of spatial skills (Baenninger & Newcombe, 1989; Brinkmann, 1966; Embretson, 1987; Gilger & Ho, 1989; Kyllonen, Lohman, & Snow, 1984; Newcombe, Bandura, & Taylor, 1983). Indeed, one study showed that brief training could eliminate gender differences favoring males on standard tests of visual-spatial skills (Stericker & LeVesconte, 1982), although another study found that initial gender differences remained after training (Embretson, 1987).

The purpose of the study presented here was to examine the relationship among gender, video game experience, and spatial skills. Based on earlier research, it was hypothesized that there would be gender differences favoring boys in both spatial skills and past video game experience. Also, we expected to find that gender and past experience would contribute to spatial scores prior to the experimental practice. We did not know whether video game practice would improve spatial skills equally in boys and girls (as in McClurg & Chaillé, 1987), improve them more in boys because of a possible biological component (Hier & Crowley, 1982), or improve them more in girls because of their lack of relevant previous experience (as in Gagnon, 1985). Because we wanted to maximize the possibility of reducing gender differences in spatial skills, we selected the age—10 years old—at which gender differences in spatial skills first become reliably evident (Johnson & Meade, 1987).

Our decision to work with 10-year-olds was driven more by empirical facts than theory. We wanted to be able to detect effects of video game training; thus we selected 10-year-olds because past research shows that gender differences in spatial skill are reliably detected by this age. We also thought that gender differences in spatial skills might be more easily eradicated when they first appeared, rather than at a later point in development.

Our study used a computerized spatial battery developed by Pellegrino, Hunt, Abate, and Farr (1987). This battery was chosen because it uses the same medium (the computer) as the video game. Also, it has been suggested that the ability to deal with objects in motion is separate from the ability to deal with the stationary displays used in conventional tests (Hunt et al., 1987). The dynamic-skill subtests of the computerized battery involve movement and are interactive in nature; because these features are present in video games, it was felt that the computerized battery would be most effective in measuring changes in spatial skill following training on video games. In other words, it was considered prudent to establish near transfer before testing for far transfer effects. In addition, these dynamic tests assess spatial skills in the context of spatial activity, an important influence on real-world spatial knowledge (Gauvain, 1993).

METHOD

Subjects

The sample included 61 subjects (28 boys, 33 girls) divided randomly into an experimental and a control group. The experimental group was made up of 15 boys and 15 girls, whereas the control group consisted of 13 boys and 18 girls. The subjects were in the fifth grade and were between 10½ and 11½ years of age (M = 11 years, 1 month; SD = 3.5 months).

All participants attended a private school in West Hollywood, Los Angeles. Five subjects did not complete the study: Two girls and two boys were not present on the final day of testing and one boy did not wish to take the posttest. These subjects were eliminated in all analyses of pre- and posttest change.

Materials

A questionnaire was used to record the subjects' past experiences with video games and was adapted from Rushbrook (1986). Items in the questionnaire concerned information about the number of days a subject played a video game (home or arcade) and the average time played at each sitting. Questions were also asked about a subject's favorite games, the setting in which the games were played, and who accompanied the subject while he or she played the games.

The video game Marble Madness (Harvey, 1986) was used as the experimental treatment in our study. This game, available in video arcades and on Nintendo game sets, was run on Apple II computers. The game involves guiding a marble along a three-dimensional grid using a joystick. Players have to be careful to keep the marble on the path and try and prevent it from falling off the grid. They also have to fight a black ball that tries to push the marble off and avoid small wormlike creatures that cause the marble to disappear temporarily on contact.

The game has increasing levels of difficulty. At lower levels, players have to simply trace a given path, taking care to prevent the marble from falling off and to avoid the black ball and the wormlike creatures. At higher levels, the grid becomes more complex and even involves a maze in the final level. At all levels, the players have to reach the end point of one level within the time allotted before they can move on to the next higher level. If players are unsuccessful at a given level, they have to start again at the first level and work their way up.

The video game Marble Madness was selected because it involves the use of: the spatial skills of guiding objects, judging speeds and distances of moving objects, and intercepting objects. In addition, preliminary use indicated that it is a challenging and motivating game that children enjoy playing. The game has very little violence and aggression. The purpose of the study being the examination of gender differences, this feature was a major factor in the selection of Marble Madness because it has been found that boys are especially likely to play games requiring aggressive competition (Heller, 1982, cited in Morlock et al., 1985; Kiesler et al., 1985; Linn & Lepper, 1987), whereas girls are turned off by violent themes (Malone, 1981). The paths in the different levels were charted out on graph paper to keep track of the point where a player failed on a particular trial.

Another computer game, Conjecture (1986), was used as a control condition in the study. This is a word game and does not involve any spatial skills. It involves solving puzzles in which, using some initial cues, the player has to fill in blanks in words that stand for phrases, capitals, and things. It is similar in structure and content to the television show "Wheel of Fortune."

Spatial abilities were measured using a computer-based test battery (Pellegrino et al., 1987). The test was run on Apple II+ and IIe computers using monochrome monitors. The test had 10 subtests: 5 of which measured static and 5 measured dynamic spatial skills. Three of the subtests measuring dynamic spatial skills were used; it should be recalled that dynamic spatial skills are the skills involved in dealing with objects in motion. The test developers reported no information about any gender differences in performance on the subtests.

The three subtests used were Memory Lane, Extrapolation, and Intercept; they were chosen because they appeared to measure the dynamic spatial skills that were relevant to performance on Marble Madness. In Memory Lane, each subject was presented with three sequential displays consisting of three small squares moving across the screen. Of these three paths, either the first or the third was different from the second. The subject had to judge which of the paths (either the first or the third) was different from the second one. In Extrapolation, the subject had to extrapolate mentally the location of a trajectory (straight, sine, or parabola) and then use a joystick to move an arrow to the point where he or she estimated the line would end. In Intercept, the subject had to press the space bar of the keyboard to trigger a missile in order to intercept a UFO that was released. The UFO would trace a path that was either a straight line, a sine curve, or a parabola. The reliability coefficients of the three tests ranged from .50 to .74, and the intercorrelations between them ranged from .12 to .22.

The subtests involved random presentation of stimuli, and the subjects had to respond by pressing the appropriate keys on the keyboard for Memory Lane and Intercept; however, for Extrapolation the subject had to use a joystick. The computer recorded the responses for each subject on a separate disk. The test also had software that analyzed and printed the results.

Design and Procedure

The study used a $2 \times 2 \times 2$ design where gender and experimental condition were between-subject independent variables, time of testing (pre- and posttest) was a within-subject independent variable, and spatial skill was the dependent variable. The study involved a pretest, a training period, and a posttest. Testing and practice required five sessions for each subject.

At the start of the experiment, all the subjects were given the questionnaire to fill out; subjects took an average of 5 min to answer all the questions. At this point subjects were asked whether they had played Marble Madness before. Following Rushbrook (1986), the questionnaires were given at the start of the study to get an index of video game experience prior to the playing of Marble Madness.

Next, all subjects were administered the spatial skill pretest on the computer; instructions were provided on the screen and subjects had to proceed only after indicating that they had been understood. Also, three practice trials were given before the test stimuli were presented. For the pretest, three subtests—Memory Lane, Extrapolation, and Intercept—were used; the total time taken was 45 min. The order of presentation of the subtests was counterbalanced to remove order effects; within each subtest, the computer presented the stimuli in a random order that varied from subject to subject. Testing took place individually at computers in a computer lab or in the library.

After the pretest, boys and girls were randomly divided into the experimental and control groups. Subjects in the experimental group were asked to play the game Marble Madness for a total of 2 hr and 15 min. This period was broken down into three sessions of 45 min each, which took place on different days; the sessions were from 1 day to 1 week apart.

Subjects in the control group were asked to play the game Conjecture, also on the computer, for the same time period. This period was again broken down into three sessions of 45 min each. Subjects in the control group were told that they would be given an opportunity to play Marble Madness at the end of the study, and vice versa for the experimental group.

Following the training sessions, all the subjects were given the posttest. The posttest took about 30 min to administer and was similar to the pretest except that only two of the subtests, Extrapolation and Intercept, were used. This was done because many of the children found Memory Lane boring; it was observed that children were often not attending to the stimuli and were simply guessing their responses. We therefore felt that it would not be advisable to run it a second time. The order of administration of the subtests was again counterbalanced.

Analysis

The software for the computerized test performed the analysis for the pre- and posttests. Scores on the subtests Extrapolation and Intercept were in terms of absolute error (in pixels) whereas scores on the subtest Memory Lane stood for average difficulty level of correct responses. Pearson product-moment correlations revealed a significant positive relation between each subject's pretest scores on the Extrapolation and Intercept subtests, r (48) $= .55$, $p < .01$. It was therefore decided to form a composite spatial ability score by combining them. The scores on the Extrapolation and Intercept subtests were transformed into z scores to make them comparable with each other. These scores were then averaged for each subject to obtain the composite score for spatial ability. This score was computed for both the pre- and posttest. In cases where data from one of the two tests were lost because of random software failures, the single available score was used. (Four subjects were missing two pretest scores and one different subject was missing two posttest scores because of random software failure; these subjects were eliminated from the relevant analyses.[1]) Due to the fact that Memory Lane could not be administered on the posttest and because the children's behavior while taking the pretest cast doubts on its accuracy, it was decided not to use Memory Lane scores in reporting results.

The information obtained from the questionnaire was used to calculate an index of the subjects' past experiences with video games in terms of the number

[1]For a given subject, software failure on the pretest was theoretically independent of software failure on the posttest.

of hours played per week. The children were also asked whether they had ever played Marble Madness. For the experimental group, initial and final levels of performance on Marble Madness on each trial were also noted.[2]

RESULTS

To analyze whether there were gender differences in spatial ability and past experience with video games at the start of the study, mean scores on these variables were analyzed using *t* tests. As predicted, there were gender differences in baseline spatial performance scores, with boys having significantly lower error scores ($M = -0.27$) than the girls ($M = 0.29$), $t\ (56) = -2.50$; $p = .01$). It was also found that, as predicted, there was a significant difference between boys ($M = 4.16$) and girls ($M = 1.80$) in the estimated number of hours spent weekly playing video games, $t\ (58) = 2.06$, $p < .05$ (see Footnote 2 and Table 1).

To determine whether variables other than gender, specifically those related to past experience, would help to predict spatial ability at the start of the study, a stepwise multiple regression was performed. The dependent variable was the composite spatial ability score obtained from the pretest; the independent variables were gender of the subject, past video game experience, and past experience with the video game Marble Madness. Gender and past experience with Marble Madness were coded as dichotomous variables whereas past video game experience was coded as a continuous variable.

Only gender contributed significantly to the overall adjusted R^2 of .073, $F\ (1, 54) = 5.36$, $p < .05$, accounting for about 7% of the total variance in spatial ability at the start of the study.

To determine the effect of video game practice on error scores, a 2 × 2 × 2 (Time of Test × Training × Gender) repeated-measures analysis of variance (ANOVA) was performed, with the composite spatial ability score as a repeated measure and gender and experimental conditions as the between-subjects variables. This analysis would also provide information about any differential effect of video game practice for boys versus girls.

Analysis indicated a significant two-way interaction of experimental condition and time of test, $F\ (1, 47) = 5.00$, $p = .03$. The two-way interaction, shown in Figure 1, indicates that video game practice (video game group) resulted in improved relative performance on the spatial tests whereas the computerized word game (control group) did not. No main effect or interaction effect involving gender was obtained.

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[2]Because of experimenter error, two subjects lacked information on past video game experience, one subject lacked an initial score on Marble Madness, and two subjects lacked a final score on Marble Madness. These subjects were dropped from the relevant analyses. No subject was missing data on more than one variable, including pretest and posttest scores.

TABLE 1
Means and Standard Deviations of Spatial Error *Z* Scores and Video Game Experience as a Function of Gender

	Boys			Girls		
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*
Spatial Score						
Pretest**	28	−0.27	0.67	29	0.29	0.99
Posttest	26	−0.12	0.70	29	0.16	0.89
Video Game Experience*	28	4.16	4.98	31	1.86	3.89

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

T tests indicated that there was no significant difference between the video game and control group on pretest scores; however, the video game group showed significantly smaller spatial error on the posttest $t\ (54) = -2.26$, $p = .02$. (Note that in this and all other *t* tests, each datum point entered into only one test and so a normal unprotected *t* test was considered appropriate.)

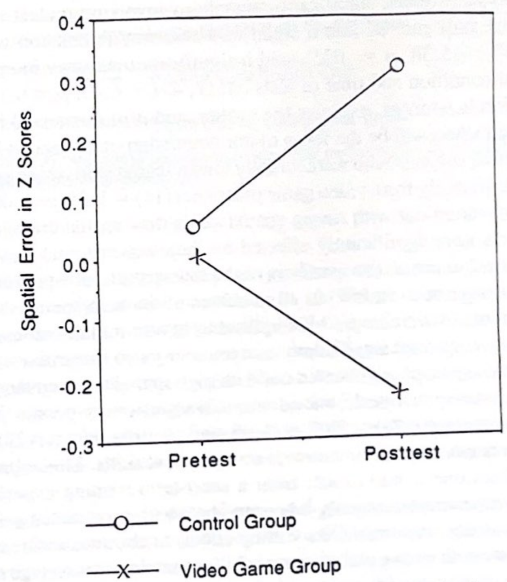

Figure 1. Effect of video game practice on error reduction in spatial task performance. The video game group played Marble Madness. The control group played a computer word game, Conjecture.

In the absence of an interaction involving gender, it was thought that the critical variable determining effectiveness of training might be pretest spatial skill. Although girls had significantly poorer spatial scores on the pretest than did boys, there was considerable overlap between the two groups. (The range of absolute error scores for boys was 13.82–34.02; for girls, it was 15.48–55.78.)

A Pearson product-moment correlation was computed between initial spatial ability and change scores (difference between the pre- and posttest scores) for the experimental group. It was found that there was a significant negative correlation between initial spatial scores and change scores, $r\ (24) = -.69$, $p < .001$, indicating that subjects who initially did poorly on the pretest showed the greatest improvement in spatial skills after training.

A new repeated-measures ANOVA was therefore run with pretest spatial skill replacing gender. The group with relatively strong preexisting spatial skills had error scores in which z equaled zero or less. The group considered to have relatively weak spatial skills had z scores above zero. The other two variables (experimental treatment as the between-subjects variable and pre- vs. posttest as the repeated-measures variable) remained the same as in the first ANOVA. In addition to replicating the experimental effect demonstrated from the first analysis, this analysis revealed significant interactions involving pretest spatial skill. Pretest spatial skill entered into a significant two-way interaction with time of test, $F\ (1, 47) = 5.38$, $p = .025$), and a significant three-way interaction with experimental condition and time of tests, ($F\ (1, 47) = 6.13$, $p = 0.17$. Because the latter effect is stronger, explains the former, and is of theoretical interest, the three-way interaction will be the focus of our description; it is graphed in Figure 2.

As predicted, subjects who were initially low in spatial skills (high spatial error) benefited significantly from video game practice, $t(11) = 3.65$, $p = .004$. Neither subjects who started out with strong spatial skills (low spatial error) nor control group subjects were significantly affected by their experimental treatments. As expected, most but not all the members of the low spatial skills pretest group (21 out of 30) were girls; most but not all members of the high spatial skills pretest group (17 out of 26) were boys. Although subjects who initially scored poorly on the spatial tests improved significantly as a result of video game play, they did not catch up with the groups who started out with high spatial skills on the pretest. At the posttest, their spatial performance was still significantly poorer than that of both the experimental, $t\ (24) = 2.07$, $p < .05$, and control subjects $t\ (27) = 3.81$, $p < .001$, who began the experiment with strong spatial skills. This is precisely the pattern of effect one would expect from a short-term training experience. The failure of the experimental subjects, who started out with good spatial performance, to improve was not attributable to a ceiling effect. In absolute terms, the experimental subjects with strong pretest spatial skills committed an average error of 18 pixels on the pretest. Their absolute error scores stayed constant at the posttest, whereas the group of subjects who started out with poorer spatial performance reduced the mean error from 26 to 22 pixels as a result of video game practice.

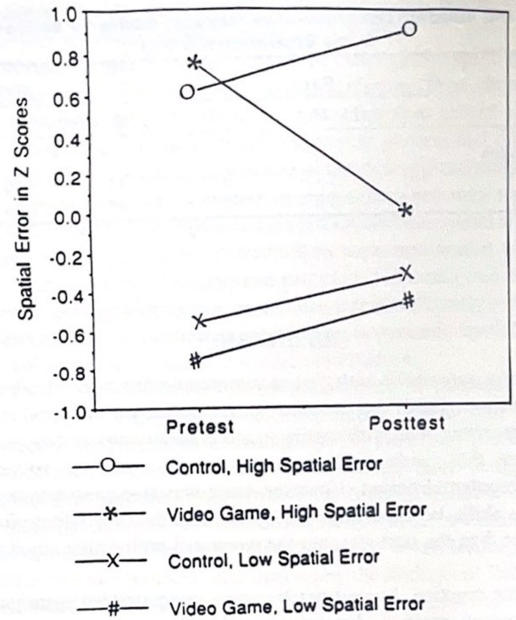

Figure 2. Effect of video game practice on spatial test performance as a function of experimental condition and pretest spatial skill.

Having demonstrated that video game practice can improve spatial skills, we wondered whether the reverse would also hold: Would better spatial skills enhance the acquisition of video game skill? Pearson product-moment correlations indicated that there was no significant relation between initial spatial scores and initial performance on the video game Marble Madness; however, initial spatial scores were significantly correlated with the final levels of video game performance, $r\ (26) = -.33$, $p < .056$. The results indicate that spatial skill enhances video game learning, just as video game practice enhances the acquisition of spatial skills.

To check whether practice helped boys and girls gain equally on video game performance, t tests were carried out to compare their mean performance scores at the beginning and end of the study. It was found that there were no significant gender differences in video game performance at the beginning; however, a significant gender difference favoring boys was found after repeated game practice, $t\ (27) = 6.18$, $p < .001$ (see Table 2).

TABLE 2
Means and Standard Deviations of Performance Scores for Boys and Girls in the Experimental Group

	Boys			Girls		
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*
Marble Madness						
Initial Score	15	1.40	0.51	14	1.28	0.47
Final Score*	15	3.53	0.64	13	2.23	0.44

*$p < .001$.

DISCUSSION

The data are in agreement with earlier research (Johnson & Meade, 1987; Petersen & Crockett, 1985) that found a gender difference in spatial ability; boys made smaller errors than girls while judging speeds and distances. Also, the results confirm that gender differences may appear as early as 10 years of age, during the prepubertal period. However, there was also considerable overlap in initial spatial skills between boys and girls, with the best boy performing just slightly better than the best girl, but the worst girl performing much worse than the worst boy.

Video game practice, but not practice on a computerized word game, led to significant improvement in dynamic spatial skills, an improvement that was concentrated in those subjects who started out with relatively poor spatial performance. The results showed strongly that, irrespective of gender, video game practice could serve as compensatory education for relatively weak spatial skills. The results confirm the thesis that video games are cultural artifacts that provide informal education for spatial skills. As the meta-analysis of Baenninger and Newcombe (1989) shows, the effects of training on spatial skills do not differ for males and females. Therefore, video games can provide a cultural push that sends both boys and girls down the developmental path of spatial skill development.

However, girls take this path less frequently. In line with earlier findings (e.g., Dominick, 1984), boys estimated that they spent significantly more time per week playing video games. Although estimates of past video game experience did not predict initial spatial performance, video game practice in our experiment did produce improved spatial performance on the posttest. Nevertheless, this study did not address the issue of the stability of transfer following short training on a video game.

The connection between spatial skills and video game expertise was further strengthened by the finding that initial spatial skills predicted ultimate video game performance in the experiment. This pattern of results indicates that strong dynamic spatial skills enhance the mastery of a video game, whereas video game practice improves relatively weak dynamic spatial skills.

The lack of relation between estimates of past video game experience and error scores on the spatial tests may be because of various factors. First, there could have been a bias in the subjects' self-reports as to how often they played video games. Second, the questionnaire dealt with video games in general and did not distinguish between games on the basis of whether or not they utilized particular spatial skills. It is possible then that our index of past experience may have included exposure to games that both involved and did not involve the spatial skills tested in our study and, therefore, did not contribute to measured spatial performance. Indeed, after our data were collected and analyzed, Kuhlman and Beitel (1991) found that more reported video game experience was significantly associated with better performance on anticipation of coincidence (a dynamic spatial task related to our test of Extrapolation) in 7- to 9-year-old children.

The ability to learn a video game (as represented in personal best performance) was strongly related to spatial skill: Initial spatial skill significantly predicted ultimate attainment on Marble Madness. However, it did not predict initial levels of performance. One possible reason for there being no relation between spatial skill and initial performance on Marble Madness could be that the index of game performance was not very sensitive to differences at the beginning, when almost all subjects failed on the first level, leading to a nonsignificant result. This interpretation is supported by the findings of Bliss, Kennedy, Turnage, and Dunlap (1991), who found that correlations between spatial tracking tests and video game performance steadily increased with increasing practice on both the tests and the video games.

Video game practice tended to equalize spatial performance among groups, but it had the opposite effect on video game performance. In the experimental group, there were no gender differences in initial scores on Marble Madness; but after several hours of practice, boys showed significantly better performance than girls did. Thus, the same amount of video game practice led to lesser improvement in game skill for girls. One factor may be that because of boys' greater previous video game experience, they "learned how to learn" a new video game better than girls.

A second factor may be revealed in our informal observation that boys were much more enthusiastic about participating in our experiment than girls were. Indeed, in a coeducational sports camp where we tried to recruit additional volunteer subjects, not one girl returned a permission slip. (Because we needed to have both boys and girls in our sample, we therefore were unable to use this setting to recruit volunteer subjects.) Clearly, girls lacked motivation to do the computer-related activities that were part of our experiment.

This research leaves questions regarding breadth of transfer unanswered. In this study, care was taken to choose a video game that involved skills similar to those measured in the spatial ability subtests. It is possible that practice on

Marble Madness was effective because of this similarity in skills. However, McClurg and Chaillé (1987) found a transfer effect from practice on a dynamic video game to a static paper-and-pencil spatial test. Nonetheless, in general we do not expect very broad transfer as a result of training on video games.

It is clear that this study involved low-road transfer through extensive practice, not high-road transfer through intentional mindful abstraction of a concept, followed by its application in a new context (Salomon & Perkins, 1989). Low-road transfer is generally narrower than high-road transfer in which an abstract schema is formulated. However, the more automatic nature of the spatial skills developed through extensive and varied practice (part of the nature of a video game) in low-road transfer may be particularly useful as foundational visual literacy skills upon which more conceptual applications of computer technology may depend.

Other studies of video game training that obtained mild, mixed, or no effects of training (Dorval & Pepin, 1986; Gagnon, 1985; Greenfield, Brannon, et al., 1994; Greenfield, Camaioni, et al., 1994) used older subjects: junior high, high school, undergraduate, and graduate students. In contrast, this study focused on fifth graders or 10-year-olds and found strong effects. It seemed possible that this was the age when spatial abilities were emerging and developing and were therefore more susceptible to the effects of training—a kind of sensitive period. However, a study by McClurg and Chaillé (1987) obtained a training effect for seventh- and ninth-grade children, as well as for fifth graders. Our sensitive period hypothesis was subsequently tested and refuted by Okagaki and Frensch (1994), who showed training effects of video game practice on the spatial skills of late adolescents.

As mentioned earlier, there is evidence that individual and gender differences in spatial skills are a product of both nature and nurture (Pezaris & Casey, 1991). The study reported in this article exemplified the effect of nurture (in our case, repeated practice with a video game) on spatial skill development. Yet research has also shown that participation in spatial activities, of which video games could be considered an example, is affected by age of pubertal maturation (nature; Newcombe & Bandura, 1983). The influences of nature and nurture on spatial skill development are thus complementary and inseparable.

In conclusion, we can say that if the right game is selected and practice is given, video games may serve as important tools in programs designed to improve spatial abilities. Such programs are especially useful for training personnel on jobs that require a high level of spatial skills, such as mechanical tasks, machinery operation tasks, and jobs using radars for tracking purposes (Hunt et al., 1987). Performance on video games can also be used in place of traditional paper-and-pencil tests to identify personnel best suited for jobs requiring high levels of spatial skill, specifically dynamic skills.

Finally, nonviolent video games may be very useful to narrow the gender gap in both spatial skills and computer usage. With computers fast becoming the

dominant technology of the day, video games may serve as an informal technique for equipping girls and women with the skills and motivation they need to ensure that they are not left behind in the future.

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