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Two-Dimensional Representation of Movement Through Three-Dimensional Space: The Role of Video Game Expertise

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The anthropological study of games has demonstrated that a culture's games socialize children in accord with the needs and adaptational requirements of a particular society. The research presented here tested whether video games could contribute to the development of spatial representational skills required for humans to "interface" effectively with computer technology, an increasingly important part of the ecology of modern society. We studied university undergraduates in the U.S. to assess the relationship between expertise in a three-dimensional action arcade video game, The Empire Strikes Back, and the skills of dynamic three-dimensional spatial representation, as assessed in a mental paper-folding test. Study 1 established a correlation between video game expertise and skill in spatial representation. The goal of Study 2 was to establish a causal relationship between video game skill and spatial skill through an experimental paradigm. The predicted experimental effect did not occur—that is, *short-term* video game practice had no effect on mental paperfolding. However, structural equation modeling did provide strong evidence that video game expertise, developed over the *long-term,* had a beneficial effect on the spatial skill of mental paper folding. In this form, the hypothesis was confirmed.

Cognitive processes—the basic processes by which we take in, transform, remember, create, and communicate information—are universal. A culture has the power to selectively encourage some cognitive processes and let others stay in a relatively undeveloped state. As shared symbol systems, media are potent cultural tools for the selective sculpting of profiles of cognitive processes. A medium is

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not simply an information channel; as a particular mode of representation, it is also a potential influence on information processing.

The notion of symbol systems as cultural tools for cognitive development can be traced to Vygotsky (1962, 1978) and Bruner (1965, 1966). For Vygotsky, it was the internalization of a cultural tool or symbol system that constituted and produced cognitive development. For Bruner, it was the need for a match between external symbol systems and internal modes of representation that stimulated cognitive development. As applied to media, this notion was significantly expanded by Bruner and Olson (1973) and Salomon (1979). These researchers were the first to recognize communication media as distinct symbol systems.

Media of communication and representation tend to be embodied in various cultural artifacts. The role of cultural artifacts in developing representational and problem-solving skills has been extensively studied by Saxe (e.g., 1991) and reviewed by Guberman and Greenfield (1991). People engage with cultural artifacts not merely in the rarefied atmosphere of the psychology laboratory, but in their everyday lives. Hence, much of the cognitive activity that these artifacts engage falls under the rubric of "everyday cognition" (Rogoff & Lave, 1984).

A central aspect of human cognitive processes is representational competence. Sigel and Cocking (1977) saw the development of an understanding of various media of representation, such as pictures, verbalizations, and gestures, as part of representational competence. Nonetheless, each medium has its particular design features such that it presents certain kinds of information easily and well and other kinds poorly and with difficulty. Each medium, therefore, presents certain opportunities to construct particular kinds of representations. As a consequence, each medium stimulates different kinds of representational processes; it provides a particular kind of cognitive socialization.

The interactive television set we call a video game has entered our society on a mass scale. From the point of view of development and socialization, video games are particularly important because they affect children during the formative years of childhood, when socialization is taking place. For most children, the video game is one of the first opportunities they have to interact with computer technology.

Video games have risen from relative obscurity in the early 1970s to their assimilation in U.S. culture. In 1982, the video arcade business grossed about $8 billion; sales of home video games were worth less than half that amount (Condry & Keith, 1983). That same year, according to Condry and Keith (1983), the home video market reached 12 million homes, in contrast to the 75 million reached by television. Rushbrook (1986) showed that 94% of 10-year-old children in Southern California (Orange County) played video games. Still, the penetration of the home market continued; by the end of 1991, Nintendo game sets alone had entered 45 million homes. Such mass penetration led Provenzo (1991) to carry out a social and cultural analysis of the "Nintendo phenomenon." Although the overwhelming mass of research on children and computers has involved studies of children either programming or using "educational" software, video games are, in fact, much more pervasive elements in children's *everyday* cognition (Greenfield, 1983, 1984, 1993).

If the video game is indeed an interactive television, then it is not surprising that as a means of representation, it shares design features with television itself. Compared with pictorial representation, the video screen, possessed by both television and video games, adds two new interrelated dimensions—time and motion—to the iconic imagery of pictorial representation. These two new dimensions have implications for the representation of three-dimensional space. One would expect television and video games to require common representational skills.

The central thesis is that video technology, especially video games, augments skill in reading visual images as representations of three-dimensional space. The presence of print (and later photographic) technology is historically associated with the development of conventions of perspective. Such conventions both allow and require the three-dimensional representations. Video games and television go beyond print and photography in their presentation of two-dimensional representations of three-dimensional space. The consumer must demonstrate not only an ability to interpret static two-dimensional images in the third dimension, but also dynamic images. Video games go farther still; the player must not only interpret, but also mentally transform, manipulate, and relate dynamic and changing images. It is the transfer of this skill to spatial contexts outside the game that is the focus of the present research. The question is: Can video game practice develop transferable skills in manipulating three-dimensional spatial representations?

Other studies have shown that spatial skills are developed both through informal activities and formal training (Baenninger & Newcombe, 1989). Indeed, Salomon (1974) showed an effect of dynamic televised representations of mental paper folding on performance with the static stimuli of the mental paper-folding test. Following a suggestion by Lowery and Knirk (1982–1983), many studies indicated that video games are among the training experiences that develop spatial skills (Dorval & Pepin, 1986; Gagnon, 1985; Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994; McClurg & Chaillé, 1987; Okagaki & Frensch, 1994; Subrahmanyam & Greenfield, 1994), as well as spatial knowledge (Forsyth & Lancy, 1987). Of these, only McClurg and Chaillé used a task that involved mentally manipulating an object in three-dimensionally represented space. Their study used a mental rotations test (mentally turning a three-dimensional object represented in two-dimensional space) and involved fifth, seventh, and ninth graders; our test used a mental paper-folding test (mentally folding a two-dimensional object represented in two-dimensional space to form a three-dimensional object; based on Shepard & Feng, 1972) and involved college students.

Whereas all other previous studies of cognitive effects of video games (Greenfield, Camaioni, et al., 1994; Greenfield, Dewinstanley, et al., 1994; Subrahmanyam & Greenfield, 1994) were carried out in laboratory or classroom settings, the studies presented here were unique in utilizing the ecology of a video arcade. Study 1 was also unique in harnessing naturally occurring play for a systematic study. Unlike other studies, this one utilized subjects who actually play the "experimental" video game in real life. Study 1, therefore, had an unusual degree of ecological validity and complemented the experimental control of Study 2.

The importance of spatial skills as a form of representational competence goes beyond video games to the computer medium more generally. Greenfield (1984, 1993) summarized evidence that spatial skills were crucial to computer activities as diverse as word processing (Gomez, Egan, & Bowers, 1986) and programming (Roberts, 1984; Webb, 1984) in adults, adolescents, and children. Skills of spatial representation involved in word processing include understanding the sequential nature of text and how deleting and inserting text affects this sequence. Spatial representation is also required to understand the relation between the visible and invisible portions of the text. (In relation to programming, it should be noted that both Roberts, 1984, and Webb, 1984, did their respective research with LOGO, an iconically represented programming language; the role of spatial skills in learning more verbal or symbolic programming languages remains to be seen.)

The anthropological study of games has demonstrated that a culture's games socialize children in accord with the needs and adaptational requirements of a particular society (Roberts & Sutton-Smith, 1962; Werner, 1979). Video games provide many children with their first introduction to computers (Kiesler, Sproull, & Eccles, 1983). By promoting the spatial skills required for humans to interface effectively with computer technology (e.g., understanding how objects on the screen can be manipulated by input devices), video games can socialize children to adapt to a society in which computers have become central.

STUDY 1

Materials

The video game chosen for this experiment was The Empire Strikes Back. The game was selected for its graphic representation of three-dimensional space on a two-dimensional screen. The game gives the player the perspective of a starship pilot flying through space. The player's task is to shoot enemy ships while avoiding asteroids and enemy fire so as to accumulate points and advance in difficulty level.

For this experiment, spatial ability was defined by a subject's ability to correctly answer problems on an 8-item multiple-choice test of mental paper folding constructed by Brannon and Lohr for this study. The paper-and-pencil test required subjects to mentally refold drawings of unfolded cubes. This test is similar

Below are drawings each representing a cube that has been "unfolded." Your task is to mentally refold each cube and determine which one of the sides will be touching the side marked by an arrow.

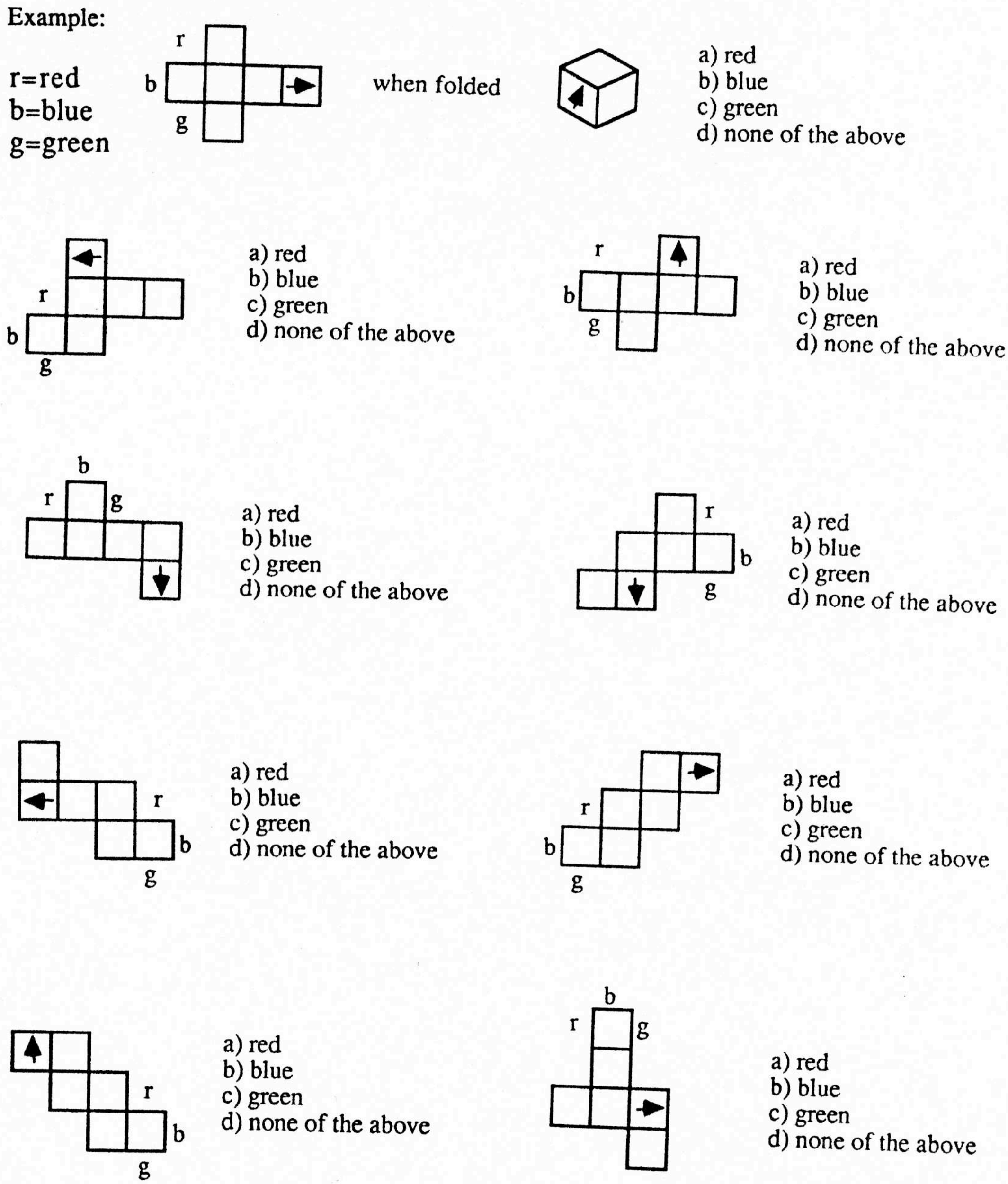

Figure 1. Mental paper-folding test used in Study 1.

to that used by Shepard and Feng (1972) in their study of mental paper folding. The test is shown in Figure 1.

Subjects and Procedure

The subjects for this study were 24 male UCLA undergraduates. To locate subjects, Brannon and Lohr watched The Empire Strikes Back machine in the UCLA video arcade and approached players as they finished playing a game, noting their scores. All of the players and therefore all of the subjects were made. In essence, the subjects were young men who played this particular game in their everyday life.

Potential subjects were asked to participate in a student research project and were informed that it would involve completing an 8-item test. Subjects took about 2 to 5 min to complete the test, with the average subject taking 3 min. Each subject was given as much time as needed to finish the test.

Analysis and Results

Game scores were used to divide the subjects into more and less skillful players; a score of 100,000 points was used as the criterion. In order to reach 100,000 points, a player had to complete a whole "round" and reach the next level, which seemed like a reasonable criterion to distinguish more and less skillful players. For the mental paper-folding test, a score of 6 out of 8 was considered to indicate good spatial skills; a score of below 6 was considered to show relatively weak spatial skills. The criterion score of 6 was used because it seemed reasonable that people with good spatial ability could fold all of the items, except for perhaps the two items that required the six folds (the maximum), to complete. Approximately half the subjects fell into each of the spatial skills groups.

There was a close relationship between scores on mental paper folding and video game scores. Seventeen out of 22 (or 77%) high video game scorers were also classified as high scorers on the spatial skills test. Conversely, 16 out of 18 (or 89%) low video game scorers also scored poorly on the spatial skills test. A chi-square test (corrected for continuity) showed this association between video game scores and spatial scores to be statistically significant on the .0001 level, $\chi^2 = 14.83$. Looking at the association the other way around, 89% of high spatial test scorers were also high video game scorers; only 24% of low spatial test scorers were high video game scorers.

Discussion

The Empire Strikes Back was notable for requiring players to navigate through three-dimensional space represented on a two-dimensional screen. The test of visual-spatial skills, mental paper folding, was also one that demanded visualizing three-dimensional movement from a two-dimensional display. At the same time there were differences between the requirements of the two situations. Probably the most important difference was that the video game was dynamic, whereas the spatial test was static. A second distinction was a difference in medium: the computer screen versus paper and pencil. Despite such differences in the stimuli and, consequently, the representational requirements of the two situations, the results strongly indicated that there was a unitary spatial skill that was evoked both in the video game and in the spatial test situation. One aspect of this common element was expressed by Loftus and Loftus (1983, p. 60) who wrote: "The visually represented objects on the screen are constantly changing, and the person who is able to mentally track these changes, and who can imagine what the configuration of objects will be in several seconds hence, is in a better position than the person who doesn't have these abilities." Similarly, mental paper folding requires the subject not merely to understand a pattern as it is now, but to imagine how it will look under a future transformation.

A major thesis concerning spatial skills and video games is that this medium is building on the everyday cognitive skills stimulated by television viewing. A study by Pezdek, Simon, Stoecert, and Kiely (1987) confirmed this relationship. Parallel to our findings concerning video game play, they found that skill in comprehending television (but not skill in comprehending radio or written material) was strongly correlated with performance on mental paper folding.

What we did not know from the results of Study 1 was anything about the causal relations between spatial skill and mental paper folding. Our hypothesis was that video game expertise could function as informal education for the development of skill in manipulating two-dimensional representations of three-dimensional space. Study 2 was designed to test this hypothesis.

STUDY 2

Design and Hypothesis

Before the experiment began, subjects were randomly assigned to an experimental or control group. Both groups were given a pretest and posttest of mental paper folding. The experimental group, but not the control group, played The Empire Strikes Back as a treatment condition; the number of games played and time spent playing were determined by the rate of progress to criterion. The control group did not have any experimental treatment; they merely took the pretest and posttest at the same time as the experimental group. At the end of the posttest, the control group played 10 games of The Empire Strikes Back as a way of assessing their level of video game expertise.

The experimental hypothesis was that the experimental group would make greater pretest–posttest improvement in mental paper folding than would the control group, as a function of their mastery of the "three-dimensional" video game The Empire Strikes Back.

Materials

The video game was the same as in Study 1. New paper-folding tests were constructed with similar items, but the number of items was doubled from 8 to 16 and the test was timed in order to create a greater range of scores. The additional items for the test were rotated and transformed versions of items from Study 1. Two forms, A and B, matched for the number of "mental folds" required by each item, were constructed. The same array of basic cube configurations was used on both forms; what varied from form to form were the questions asked and the orientation of the configurations. Subjects who received Form A in the pretest were to receive Form B in the posttest, and vice versa.

Subjects

Subjects for Study 2 were UCLA undergraduates, mostly 18- to 20-year-olds, recruited from the introductory psychology subject pool. Because of the absence of female video players in the first sample, we were interested in exploring gender differences in Study 2. We therefore did not mention video games in our recruitment material; we indicated only that the experiment involved "play." Our sample ended up with 18 men and 40 women—58 subjects in all. The greater number of women than men in Study 2 simply reflected the greater number of women in introductory psychology classes.

Procedure

Groups of subjects (approximately 7 to 10 per group) met to take the pretest and receive their random assignment to the experimental or control group. Alternating subjects received Form A or Form B and were asked to read instructions on the cover page of the test; these involved working a sample item. The experimenter directed the students: "You'll have 4 minutes to solve as many of the 16 problems as you can. If you get stuck on one, you may skip it and go to another. Don't guess because there is a penalty for wrong answers." Following the pretest, the control and experimental groups were separated; each met with an experimenter to hear the rest of the instructions.

Experimental Procedure. The experimental subjects were told to play the video game The Empire Strikes Back at the UCLA arcade at their own convenience, and were given $10 worth of marked quarters with which to do so. The quarters were painted purple and each set of 40 quarters were marked with an identification number associated with a particular subject. The experimenter explained the location of the game and the difficulty level at which they were to play. Subjects were given the task of practicing The Empire Strikes Back until they reached a score of 265,000 three times in a row; they were provided with sheets on which to record their scores. When they reached criterion, they were to call an experimenter who would verify their performance. They were also to call if they had not reached the criterion and needed more quarters.

The time frame for the experiment was the 10-week academic quarter. Subjects were pretested over the first 3 weeks of the quarter. At the end of Week 5, the experimenters began to call experimental subjects to encourage them to play more, in cases where a subject's quarters had shown up rarely or not at all in the machine. Most subjects were called two or three times during Weeks 6, 7, and 8. By the end of Week 8, fewer than one quarter of the experimental subjects had called for verification of the criterion. At that point, all of the experimental subjects were called and told to finish using their quarters, at which point the experimenters would watch them play one game regardless of their scores. As soon as subjects reached criterion (or during Weeks 9 and 10 if the criterion had not been reached), they were given the posttest. Following the posttest, each subject was given a questionnaire, which mostly inquired about previous video game experience.

Control Procedure. After the control subjects finished their pretests, they were told that they were finished with the first part of the experiment and that they would be called in about 2 weeks concerning the second part. We planned to give them the posttest with the experimental subjects; as seen in the previous description of the experimental procedure, 2 weeks turned out to be too short a period of time for the experimental subjects to reach the point of taking the posttest, so the control subjects had to wait longer.

Experimental and control subjects were posttested together, as they had been in the pretest. Subjects who had Form A on the pretest were given Form B, and vice versa. (In the case of two subjects, the wrong form was administered on the posttest because of experimenter error.) Following the posttest, control subjects were given the same questionnaire as the experimental subjects. Control subjects were then given marked quarters to play The Empire Strikes Back for 10 games. All agreed to do so by the next day and to put their score sheets in an envelope that was taped to the side of the machine. These 10 games were meant to assess the control group's initial level of video game expertise. The scores would be comparable to those for the experimental subjects' first 10 games during the experimental treatment. We assumed subjects were generally honest in reporting their scores, as they were told it did not matter how they performed on the game; therefore there was no situational source of a motivation to lie.

Analyses and Results

First, there was a large and statistically significant gender difference in the proportion of men and women reaching criterion. Whereas 75% of the men reached criterion on The Empire Strikes Back when tested by the experimenter, only 24% of the women did so. (A two-tailed chi-square test showed this difference to be significant at the .02 level.) It was not a question of the women practicing the game less than the men did. In fact, the reverse was true. On average, the women played 67 games and the men 49 games in the course of our experiment. A t test indicated that this difference was significant at the .05 level of probability, $t(29.2) = 2.30$.

In their normal lives, however, men already had more video game experience. Most men reported playing video games monthly, whereas most women reported playing only once per year. A chi-square test indicated that this association between gender and video game experience was significant at the .0001 level, $\chi^2(2, N = 54) = 26.01$. A correlational analysis showed that there was also a significant positive relationship between reported video game experience and initial performance on The Empire Strikes Back, $r(49) = .30$, $p < .025$.

Confirming the results of Study 1, we demonstrated an association between initial video game performance and spatial skill performance. There was a significant positive correlation between the highest of each subject's first 10 scores on The Empire Strikes Back and pretest performance on mental paper folding, $r(52) = .29, p < .025$. However, we were unable to demonstrate the predicted experimental effect: According to a 2 (Video Game Practice vs. No Practice) × 2 (Pretest vs. Posttest) repeated-measure analysis of variance (ANOVA), there was significant pretest–posttest improvement in mental paper folding, $F(1, 50) = 28.18, p < .001$. Practice in playing The Empire Strikes Back, however, did not improve mental paper-folding test scores more than the opportunity to practice this spatial skill during the pretest itself.

One possible reason for the lack of experimental effect was that the amount of practice in our treatment condition was not enough to produce far transfer to a static pencil-and-paper test. Perhaps far transfer might occur as a result of video game expertise built up over a longer period of time. The highest of the first 10 scores seemed a good measure of initial video game skill level and, therefore, also a measure of accumulated video game expertise. Knowing that there was a significant positive correlation between this measure and initial spatial test performance, we decided to use path analysis or, more precisely, structural equation modeling (Bentler, 1989) to ascertain the dominant direction of effects: from spatial skill to video game performance or from video game performance to spatial skill.

At the same time, we knew that males play video games more and, therefore, have more opportunities to build up expertise. In addition, males have been shown to have stronger spatial skills in a number of different tests (see Okagaki & Frensch, 1994; Subrahmanyam & Greenfield, 1994, for reviews of this literature). Our own repeated-measures ANOVA indicated that gender had a significant effect on mental paper-folding performance, $F(1, 50) = 5.82, p < .025$. We therefore constructed and tested different structural models that included gender, reported frequency of video game play, video game experience within the experimental (experimental vs. control group status), initial video game performance, and mental paper-folding performance (both pretest and posttest).

The most comprehensive causal model is shown in Figure 2. This model was derived by the application of Bentler's (1989) EQS program. The paths were tested as a single model derived from the major hypothesis of the study—that video game expertise would develop spatial skills. This model turned out to fit the data quite well, $\chi^2(10, N = 49) = 10.22, p = .42$ (Comparative Fit Index = .996; Bentler, 1990). In structural equation modeling, a large, nonsignificant probability level indicates a good fit with the model; a small, significant probability level indicates the absence of a fit (Bentler, 1989). According to this model, gender influences initial video game performance, a measure of accumulated expertise (i.e., boys perform better than girls), which, in turn, influences mental paper folding (pretest score).

The model also shows that the experience of receiving experimental video game practice does not affect posttest score (see nonsignificant path in Figure 2

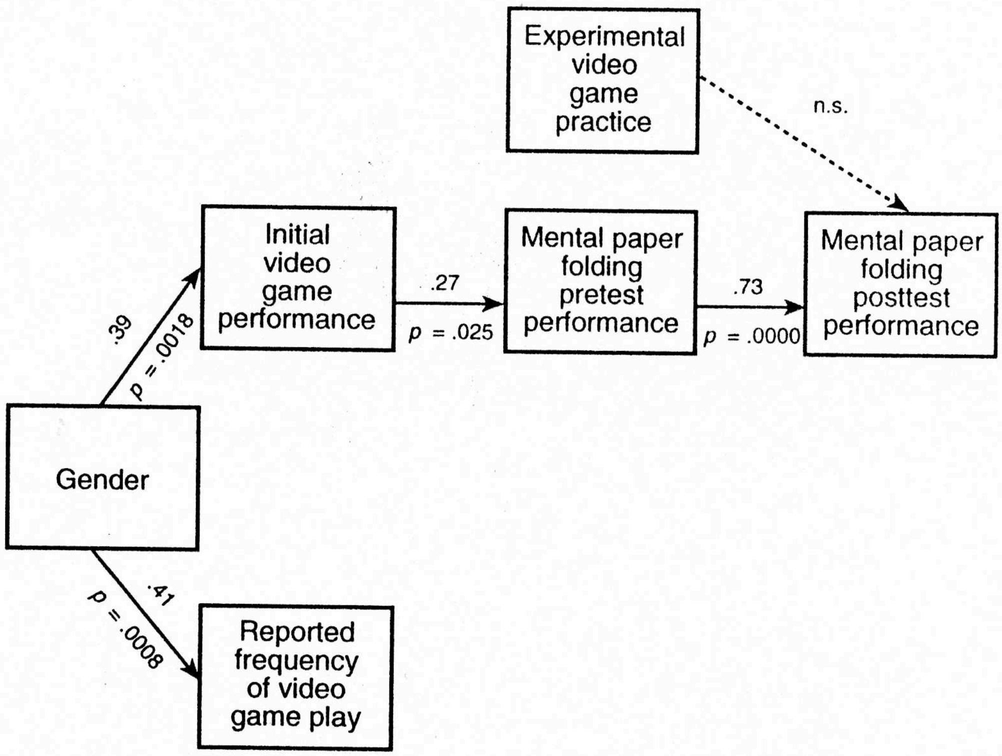

Figure 2. Structural equation model (Bentler, 1989) of causal relations among gender, video game expertise, video game experience, experimental video game practice, and mental paper folding. The depicted model is based on the subset of subjects (N = 49) that had no missing data in any of the six variables used in the model.

from experimental video game practice to mental paper-folding posttest performance). That is, the structural equation model confirms the absence of an experimental effect revealed in the repeated-measures ANOVA.

Because of findings in this and previous research concerning gender differences in spatial skills, we wondered whether gender was also having a direct effect on spatial skills. We therefore carried out a Lagrange Multiplier test for the path from gender to pretest paper-folding; the results, $\chi^2(1, N = 49) = .999$, $p = .32$, indicate that this causal path is not statistically significant. Therefore, gender does not influence this particular spatial skill directly, but through its influence on video game expertise.

Alternative models were also tested. An important alternative was the same model with an opposite direction of influence: from initial spatial skill to video game expertise, rather than vice versa. The causal link from mental paper-folding pretest performance to initial video game performance was statistically nonsignificant.

A Lagrange Multiplier test (Bentler, 1990) for additional parameters showed a statistically nonsignificant link between reported frequency of video game play and initial video game performance. Given the significant positive correlation between these two variables reported earlier, it seemed likely that reported experience was simply overwhelmed by the gender factor as a predictor of video game expertise. The fact that the significant relationship between reported experience and initial video game expertise was removed in a partial correlation in which gender was controlled substantiates this interpretation. Gender may mediate the relationship between practice and skill, as the differential success of men and women in reaching the experimental criterion in our study suggests.

Another Lagrange Multiplier test (Bentler, 1990) indicated that whereas initial video game expertise had a direct influence on initial spatial test performance (pretest), it did not directly influence posttest spatial performance. As shown in Figure 2, posttest performance, not surprisingly, was directly influenced by pretest skill level and the opportunity to practice mental paper folding during the pretest.

In order to obtain a more precise understanding regarding the appropriateness of the model in Figure 2 for both experimental and control groups, a two-group structural model was run. This model was identical to that shown in Figure 2, except that each of the parameters was estimated separately in each of the two groups, subject to the constraint that the estimates in one group would be identical to those in the other group, $\chi^2(21) = 32.07$, $p = .058$, Comparative Fit = .760. That is, the model fit statistically, but the fit index was somewhat on the low side. The Lagrange Multiplier test on the model showed that all but one of the parameters could be statistically considered to be equal across groups, but that the error or residual variance of reported frequency of video game play could not be considered statistically equal, LM $\chi^2(1) = 11.8$, $p = .001$. The variance of reported video game play was higher for the experimental groups. However, a nonsignificant Lagrange Multiplier test for the path from experimental video game practice to reported frequency of video game play in the Figure 2 model indicated that this difference in variance was a random phenomenon rather than one caused by the experimental treatment itself.

Because of the variance difference between experimental and control groups in reported frequency of video game play, a final model was run in which all parameters except this residual variance were forced to be estimated equally. This model fit exceedingly well, $\chi^2(20) = 12.73$, $p = .89$, Comparative Fit = 1.000.

DISCUSSION

Although we were not able to demonstrate the predicted experimental effect of *short-term* practice and mastery of The Empire Strikes Back on mental paper folding, we were able to use structural equation modeling to show a causal relationship between video game expertise, acquired over the *long-term*, and mental paper folding. There are a number of reasons why the experimental treatment may have failed, even though the theoretical analysis was correct.

First of all, the distance between the transfer test and the video game treatment was greater than in other studies (Greenfield, Camaioni, et al., 1994; Greenfield, deWinstanley, et al., 1994; Subrahmanyam & Greenfield, 1994). In all of those studies, the medium of the test stimuli matched the video medium of the game practice; in the research presented here, test stimuli were printed on paper, whereas game stimuli were presented on a video screen. Indeed, Okagaki and Frensch (1994) found that practice in mastering the game Tetris transferred to both computer screen and paper-and-pencil tests for male subjects, but to only screen-based tests for females. Hence, transfer distance for spatial skills may be narrower for females than it is for males—an interesting possibility. However, transfer distance (measured in terms of the similarity of the medium of test to the video game medium) may not be the whole story. Gagnon (1985), Dorval and Pepin (1986), and McClurg and Chaillé (1987) all found transfer from video game practice to spatial skills assessed through paper-and-pencil tests in female, as well as male, subjects.

A more important clue as to the absence of an experimental effect may lie in the fact that 76% of the female subjects failed to attain a criterion level of mastery of the video game itself, despite significantly greater practice in the course of the experiment. Because most of our subjects were women, it might be fair to state that the treatment itself failed, rather than the treatment effect.

Why the treatment itself failed is an interesting question. To the extent that there is a reciprocal influence of spatial skill on video game mastery, it might be because some women did not have the spatial skills to benefit from game practice and so failed to reach criterion, even with additional practice. Given the results of other studies of spatial skills in which female spatial skill benefited equally (Dorval & Pepin, 1986; McClurg & Chaillé, 1987; Subrahmanyam & Greenfield, 1994) or more (Gagnon, 1985) from video game practice, in comparison with male spatial skill, this does not seem to be a likely explanation.

One possible factor is the violence of The Empire Strikes Back. Malone (1981) found that the addition of thematic violence to a video game was a turn-on for boys but a turn-off for girls. The female preference for less aggressive themes was confirmed in a study of men and women by Morlock, Yando, and Nigolean (1985). Neither Okagaki and Frensch (1994) nor Subrahmanyam and Greenfield (1994) used a violent video game (for this very reason, in the case of Subrahmanyan & Greenfield). By contrast, the violence of The Empire Strikes Back may, on the average, have been a motivational turn-off for the women in our study.

On the other hand, this factor cannot be the total answer either: Gagnon (1985) used only violent games (one two-dimensional, one three-dimensional), and McClurg and Chaillé (1987) used one violent and one nonviolent game as experimental treatments in their studies. Yet female spatial skills and, in the case of Gagnon's (1985) study, female video game skills benefited as much or more than male skills did. Nonetheless, although the mental rotation performance of both boys and girls benefited from video game practice in McClurg and Chaillé's (1987) study, the benefit was considerably greater for boys than for girls following the violent game, but slightly better for girls than for boys following the nonviolent game. Dorval and Pepin (1986) used a three-dimensional violent game, Zaxxon, in their study; yet they found that males and females improved equally on their spatial task, the space relations test of the Differential Aptitude Tests.

One factor that might explain the different results with respect to gender in our study is that the subjects did not know that they were going to be in a video game experiment. Although the write-ups did not say so explicitly, it is likely that both Dorval and Pepin's (1986) and Gagnon's (1985) volunteer subjects were so informed. Hence, through self-selection, female motivation to play video games in those studies could have been greater than it was in the study presented here. In conclusion, it may be that violence made The Empire Strike Back unmotivating (cf. Malone, 1981) and, therefore, difficult for novice female players who lacked positive motivation to play video games.

Both studies confirmed a linkage between video game expertise, as demonstrated on a dynamic video game that requires navigation through three-dimensional space represented on a flat screen, and performance on a static spatial test that requires three-dimensional mental manipulation of a two-dimensional stimulus. Thus, this relationship between video game expertise and spatial skill performance had generality across two different kinds of populations: (1) arcade video players and (2) a student sample unselected for their video game interests. Although gender was a factor in the spatial test results, the structural modeling indicated that it operated by influencing video game expertise, which, in turn, developed spatial test performance; gender did not have a direct effect on the spatial test results.

By themselves, these studies suggested that practice over an extended period of time was necessary for the cultivation of spatial skills. However, motivational factors were confounded with short-term practice effects (or noneffects) in the research presented in this article. However, two other lines of investigation presented in this issue (Okagaki & Frensch, 1994; Subrahmanyam & Greenfield, 1994) found strong effects of short-term video game interventions on the cultivation of skills in manipulating spatial representations. Hence, the negative motivational effect of a violent video game on females who had not chosen to be in a video game experiment would seem to account for the failure of the treatment itself (i.e., lack of mastery of the video game by most of the women in the experimental condition). The failure of the treatment itself in turn could well account for the lack of an experimental effect in a sample that was predominately female.

As a cultural tool or artifact, these studies join others in this issue and elsewhere in demonstrating that video games are potent tools for cognitive socialization on a mass level for a variety of representational skills. In the case of spatial skills such as the dynamic representation of three-dimensional space on a two-dimensional screen, video games build on expertise utilized in an even more popular medium, the artifact of television (Pezdek et al., 1987). By showing that a video game can develop spatial skills similar to those utilized in other computer applications such as word processing (Gomez et al., 1986) and programming (Roberts, 1984; Webb, 1984), the results of these two studies confirm the anthropological emphasis on games as a socializer for adult roles in a particular society (Roberts & Sutton-Smith, 1962; Werner, 1979). They are a potent example of cognitive development resulting jointly from individual factors and processes of cultural appropriation (Saxe, 1991).

However, the cultural artifacts appropriated by subjects in Saxe's (1991) studies were not interactive. The metaphor for cultural learning through interactive processes is cognitive apprenticeship (Rogoff, 1991). In this model, the interaction is with another human model. Computer technology in general and video games in particular provide for the first time an opportunity for interactive apprenticeship by inanimate objects (although it is certainly significant that video games and other computer objects are created by human beings). The results of these studies and others are such that we have identified a form of cognitive apprenticeship that has the potential to be mediated entirely by an inanimate cultural artifact.

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