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ORIGINAL ARTICLE

Mom, Let Me Play More Computer Games: They Improve My Mental Rotation Skills

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Abstract This study investigated how 3-D and 2-D computer game practice and delivery as well as individual differences affect performance on two tests of mental rotation (Vandenberg Mental Rotation Test and Card Rotation Test). Sixty-one US undergraduates from the Midwest completed 4 h of either massed or distributed practice. While computer game practice improved mental rotation scores in general, women's gains were significantly greater than men's, and the most significant gains were accomplished when practice was massed. High mathematical ability, gender, and type of practice significantly predicted improvement scores. The findings suggest that even very minimal computer game practice may improve performance on mental rotation tasks.

Keywords Spatial experience · Gender · Mental rotation · Computer games · Visuospatial practice

Introduction

Visuospatial ability generally refers to skills in representing, transforming, generating, and recalling symbolic, nonlinguistic information (Halpern 2000; Linn and Petersen 1985). Visuospatial and mathematical skills are thought to be related in that visuospatial skills may serve as mediators of gender-based mathematics differences (Casey 2001). Both these skills are critical for mastering material in the physical sciences, architecture, medicine, dentistry, chemistry, and engineering and may thus play an important role in the underrepresentation of women in Science, Technology, Engineering, and Mathematics careers (STEM fields; see Ceci and Williams 2007; Halpern et al. 2007 for reviews). Despite increased attention paid to ways to narrow the gender gap in visuospatial ability through spatial practice and training (e.g., Newcombe 2007; Terlecki et al. 2007) it is unclear whether massed or distributed practice can achieve significant improvements that could be effective for educational intervention. It is also unclear how individual differences affect practice outcomes. Thus, the purpose of the present study was to examine how massed and distributed practice of a three-dimensional (3-D) or two-dimensional (2-D) computer game as well as individual differences would affect performance on mental rotation.

Cognitive Gender Differences

Despite the equivalent overall intellectual capacity of men and women, researchers have identified a number of cognitive gender differences. On average, women perform better on verbal tests, whereas men demonstrate greater visuospatial capabilities, and these differences are more striking at both the lower and upper extremes of intellectual ability (Halpern 2000). Males typically outperform females on certain tests of mental rotation (Cherney and Collaer 2005; Linn and Petersen 1985; Voyer et al. 1995) and spatial perception (Liben and Golbeck 1980; Linn and Petersen 1985). Like many other broad cognitive categories, visuospatial ability is not a unitary concept and gender differences depend on the type of test used. The largest

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effect sizes and most reliable gender difference in performance of all spatial tests have been found with mental rotation (e.g., Halpern 2000; Linn and Petersen 1985; Voyer et al. 1995). One of the most widely used instruments to assess mental rotation ability is Vandenberg and Kuse's (1978) Mental Rotation Test (VMRT). Other gender differences favoring males are found on tasks involving judgments of movements (Law et al. 1993), judgments of horizontality and verticality (e.g., Liben and Golbeck 1980, 1986; Linn and Petersen 1985) and judgments of line angle and position (e.g., Cherney and Collaer 2005; Cherney et al. 2006; Collaer and Nelson 2002).

The causes of these cognitive gender differences are unclear. Many researchers contend that visuospatial skills develop over time and that certain real-life experiences foster the development of these abilities. For example, being in school is associated with an increase in elementary school children's spatial skills (Huttenlocher et al. 1998). Toys, sports, computer play, and course choices (see Cherney and London 2006) have also been shown to contribute to spatial experiences. Boys are typically given more toys that require manipulation in space (Etaugh 1983) and engage in more sports activities. They also play with video/computer games more frequently than girls (Cherney and London 2006; Subrahmanyam and Greenfield 1994). Males tend to take more mathematics courses and potentially experience more spatially relevant material such as geometry (Cherney and Collaer 2005; Sherman 1982). Because girls have been shown to have fewer out-of-school spatial experiences than boys (Baenninger and Newcombe 1995), many girls may never tap their potential to think spatially unless spatial experiences are introduced within the school curriculum (Hyde 2007). In general, females perceive spatial tasks as masculine and are more intimidated by them than are males (Meyer and Koehler 1990).

Ultimately, determining the causes of gender differences in spatial abilities may not be as important as determining whether individual performance can be enhanced (Newcombe et al. 2002). If spatial ability is the result of an environment rich in spatial experience, then a relationship between the two should exist. As previously mentioned, studies seem to suggest that there is a relationship between early spatial experiences and performance on spatial tests. Thus, the direction of this association may be established using training studies.

Training and Practice Effects

In general, training studies involve formal instruction of a skill, whereas practice studies involve the repeated "use of" the skill. Several training studies have been shown to be beneficial for both men and women (e.g., Baenninger and Newcombe 1989; Terlecki et al. 2007) depending on the tasks and duration of the training. Baenninger and Newcombe (1989) performed a meta-analysis on the role of spatial activities and spatial training in spatial test performance showing that both men's and women's performances benefit from spatial activities such as play with manipulative toys, geometry and mathematics, and from medium-duration spatial training. Other studies have shown that even a brief spatial exposure can produce significant changes. For example, when men and women were exposed for 2 min to another pencil-and-paper rotation task (cube rotation test) the gender differences on the VMRT disappeared (Cherney et al. 2003). Furthermore, individuals who had previously completed a mental rotation test scored significantly higher than those who had never completed one (Cherney and Neff 2004) demonstrating significant practice effects. In addition, several studies (Kenyon 1984; Liben and Golbeck 1986; Parameswaran and De Lisi 1996; Vasta et al. 1996) have reported on several different training procedures that erased the gender differences in performance on Piaget's water-level task. These studies indicate that environmental factors may play an important role in the development of visuospatial gender differences.

Training in visuospatial skills is often accomplished with video/computer game play. Although research indicates that video/computer games are played mostly by males (e.g., Cherney and London 2006; Terlecki and Newcombe 2005), studies have also shown that both females and males can improve their performance on spatial tasks by playing video games (Dorval and Pepin 1986; McClurg and Chaillé 1987; Subrahmanyam and Greenfield 1994). Terlecki and Newcombe (2005) gave undergraduate students extended training on mental rotation and found that, after a semester of work, the participants were still improving their mental rotation ability with no sign of leveling off. They found that playing the computer game Tetris led to greater improvement than simple practice, and that these training effects lasted for months and generalized to other spatial tasks, such as the Surface Development Test (Ekstrom et al. 1976). Interestingly, training effects were large—far larger than the typical gender difference (Terlecki and Newcombe 2005). Terlecki et al. (2007) further found that individuals who experienced the greatest spatial experience through videogame practice demonstrated transfer effects (a generality of improvements) that were maintained over several months. Their participants played with computer games for 12 weeks for a total of 12 h.

Although males and females seem to benefit from spatial training and experience, some studies have shown that training may benefit females more than males. Because females generally spend less time engaging in spatial activities, and have lower levels of computer or videogame experience, they may have more room for improvement, and thus may improve more on spatial tasks as a result of computer use (Subrahmanyam and Greenfield 1994). In a recent study, Feng et al. (2007) reported that after 10 h of training, females realized greater gains than males on a computerized version of the VMRT and on the spatial attention task. There was no improvement in spatial attention or VMRT performance after training with a non-action game. Taken together, these studies suggest that depending on the type of video/computer games they may play an important role in equalizing individual differences in spatial skill performance. However, it is unclear whether a more intensive practice (massed) would create similar improvements, and if computer game practices lasting for more than 1 h a week would have larger effects on spatial performance than practice distributed across weeks.

Massed vs. Distributed Practice

Massed practice conditions are those in which individuals practice a task continuously with minimal rest or time lag, while spaced or distributed practice conditions are those in which individuals are given rest intervals across the practice session. The majority of research conducted within this area has focused on the learning and performance of simple motor tasks. This research has demonstrated that spaced practice conditions are superior to massed practice conditions, but it is unclear if this finding generalizes to other more complex, cognitive tasks (Donovan and Radesovich 1999). Recent studies have suggested that a benefit from distributed practice is generally found for verbal memory tasks (Janiszewski et al. 2003), and for skill learning (Donovan and Radosevich 1999). In spite of evidence for distributed practice benefits, a recent review of the literature concluded that longer spacing and/or lag intervals sometimes failed to benefit retention. Donovan and Radosevich's (1999) research suggested that increasingly distributed practice may impair learning and retention, seemingly counter to Janiszewski et al.'s (2003) research, which concluded that increasingly distributed practice improves retention. Research suggests that the nature of the task, the intertrial time interval, and the interaction between these two variables significantly moderate the relationship between practice conditions and performance (Donovan and Radosevich 1999). Given the inconsistent findings, it is important to further examine this issue in the context of visuospatial skills.

Researchers have used varying practice times and video games to test gender differences in mental rotation in children and adults. McClurg and Chaillé (1987) studied the effects of video game practice on fifth, seventh, and ninth graders' mental rotation performance. The students played either "The Factory" or "Stellar 7," which both require mental rotation skills, for two 45-min sessions per week over 6 weeks. Both computer groups outperformed a control group on the posttest, and improvements in mental rotation performance were evident across grades and for boys and girls alike in both computer groups. Similarly, Subrahmanyam and Greenfield (1994) asked fifth graders to play "Marble Madness" (which involves spatial skills) or "Conjecture" (a word game that does not involve spatial skills), in three separate 45-min sessions. The researchers found that the students who made the greatest gains on the posttest were those whose pretest spatial skills were the weakest. Okagaki and Frensch (1994) found that 6 h of playing the game "Tetris" improved mental rotation speed and spatial visualization performance in both female and male college students. Although these studies demonstrate improvement in posttest mental rotation performance, it is not possible to ascertain whether playing the videogames in a massed practice situation would show similar benefits for females and males.

Individual Differences

Few studies have examined how individual differences may affect computer game training and visuospatial performance. For example, high levels of anxiety have been shown to negatively influence performance on various tests, with females, on average, having higher levels of test and/or mathematics anxiety than males (e.g., Eccles and Jacobs 1986). Anxiety has been linked to poor performance on simple memory tests such as the digit span (e.g., Paulman and Kennelly 1984), and free recall of word lists (e.g., Eysenck and Byrne 1994). Highly anxious people have also been found to perform relatively poorly on tasks assessing more complex cognitive processes, such as analogical reasoning (Tohill and Holyoak 2000), mathematics problem solving (e.g., Hopko et al. 1998), and other reasoning tasks (e.g., Derakshan and Eysenck 1998; MacLeod and Donnellan 1993). It is therefore reasonable to assume that high levels of anxiety might negatively influence performance on mental rotation tasks as well.

Individual differences in quantitative abilities have also been suggested to influence gender differences in visuospatial abilities (Casey et al. 1997). For example, Casey et al. (1995) found that gender differences on the SAT-M were eliminated in several samples when the effects of mental rotation ability were statistically removed. Similarly, Cherney and Collaer (2005) showed that prior mathematics experience accounted for unique variance on spatial perception tasks, suggesting that these two abilities tend to covary. Furthermore, Voyer and Sullivan (2003) showed that partialling out performance in mathematics courses increased the magnitude of gender differences in spatial performance.

In addition, previous spatial experiences such as sports ability and computer game play have been shown to affect visuospatial ability. Ozel et al. (2004) showed that athletes performed better than non-athletes on mental rotation tests.

Males' greater experience with physical play and activities that involve eye–hand coordination, such as estimating trajectories of moving objects and/or moving about within a complex spatial configuration may promote the development of spatial cognition to a higher level than that generally seen in females (Bjorklund and Brown 1998). Furthermore, activities such as computer and video game play that develop hand–eye coordination (e.g., Okagaki and Frensch 1994; Subrahmanyam and Greenfield 1994) are associated with increased visuospatial abilities.

Present Study

This study was designed to examine whether the type (3-D vs. 2-D) and delivery (massed vs. distributed practice) affect the degree of improvement of males' and females' mental rotation performance and how individual differences such as anxiety, prior spatial experiences such as computer game play, and mathematical performance might affect performance. Two existing visuospatial tests, Vandenberg and Kuse's (1978) mental rotation test and the card rotation test (CRT; Educational Testing Services Sanders et al. 1982) that have shown gender differences and that are of different levels of difficulty, were used. Generally, tests that are more difficult show larger gender differences and may be particularly susceptible to individual differences. Furthermore, tasks with large gender differences are important in trying to understand the origins of gender differences because they are likely to show the most robust findings across many different types of studies and experimental manipulations. In addition, these two tests were chosen because they both involve mental rotation: one requires 3-D mental rotation (VMRT) whereas the other one requires 2-D mental rotation (CRT).

The largest effect size and most reliable gender difference in visuospatial performance has been found with the VMRT (Vandenberg and Kuse 1978; Halpern 2000; Linn and Petersen 1985; Voyer et al. 1995). Males consistently outperform females on this difficult task with effect sizes as high as $d=1.10$ (Cherney and Collaer 2005). The second spatial task, the CRT (Educational Testing Services) also shows a male advantage with an average effect size of $d=.29$ (Sanders et al. 1982).

Cognitive Gender Difference Hypotheses

The two mental rotation tests (VMRT and CRT) were expected to correlate significantly with each other. Additional correlational analyses were hypothesized to show negative relationships between anxiety levels and performance on the mental rotation tests. Consistent with previous studies (Collaer and Nelson 2002; Cherney and Neff 2004; Halpern 2000; Linn and Petersen 1985; Sanders et al. 1982), men were hypothesized to outperform women in the pretest of both mental rotation tests. Because the tests varied in difficulty, it was hypothesized that the effect sizes would differ among the tests, with the more difficult test (VMRT) showing the larger effect size.

Practice Hypotheses

Based on previous studies showing gains for both genders (e.g., Baenninger and Newcombe 1989), computer game practice was expected to be beneficial for both genders. That is, 3-D and 2-D computer practice was hypothesized to increase VMRT scores significantly, whereas individuals in the control group were not expected to increase their mental rotation performance. Based on Feng et al.'s (2007) findings that females may benefit from some practice more than males and because of ceiling effects, it was expected that women would display a larger gain than men when using prior visuospatial experiences as a covariance.

Massed vs. Distributed Practice Hypothesis

Based on previous findings showing that distributed practice tends to be beneficial for skill learning, a main effect of delivery was expected with higher gains in the distributed practice condition than in the massed practice condition.

Individual Differences Hypotheses

Women were hypothesized to have significantly lower prior computer game and sports experience, but higher anxiety levels. Lower levels of anxiety, higher levels of computer game experience, and higher levels of mathematical performance were expected to be predictive of overall positive performance gains. Mathematics performance was hypothesized to moderate mental rotation performance.

Method

Participants

A total of 64 (32 men and 32 women) from a US Midwestern private university participated. Their ages ranged between 17 and 23 years (mean age 19.1, $SD=1.4$) and the majority of participants were European–Americans. Significant outliers (one male and one female scored less than 5% correct on the tests) and one male who did not complete the training were eliminated from the data set. The final sample was composed of 30 men and 31 women. Participants were randomly assigned to each of the 3-D ($n=20$), 2-D ($n=21$), and control conditions ($n=20$). Thirty-six completed the training over 2 weeks (distributed learning), whereas 25 completed it within 1 week (massed learning). Introductory psychology students volunteered for the study by signing up for a study entitled "examining visuospatial skills using computer games." They received course points for participating.

Materials

The pre-and posttest measures consisted of the 2-D Card Rotation Test (CRT by ETS) and the 3-D VMRT (Vandenberg and Kuse 1978). In the CRT participants must indicate whether a 2-D abstract target figure has been rotated (same) or is a representation of a mirror image (different) of that target. There are eight examples for each target drawing for a total of 20 target drawings, ten per page. Participants have 6 min to complete the two pages of 80 item drawings each (maximum score of 160).

The Vandenberg and Kuse (1978) VMRT consists of two ten-items sections. Each item contains one target image and four alternative images. Two alternatives are identical to the target and two are mirror images. Within the allotted 7 min, participants must mentally rotate each item and match the two alternatives to the target. Scores on the VMRT can be calculated with 20 possible points. One point is allocated when both items have been correctly identified. Alternatively, one point can be given for each correct item for a total of 40 points (Casey et al. 1992). Voyer et al. (1995) showed that both scoring methods reveal significant gender differences. In the present study, the first scoring method (20 points) was used.

Consistent with the findings showing a relationship between previous spatial experiences, affective variables, and visuospatial performance, it is important to quantify these factors to some extent. Unfortunately, it is impossible to measure the degree to which each person has been exposed to spatial experiences directly. Therefore, only indirect measurements are possible. Thus, participants were instructed to complete a background questionnaire that included questions on computer game expertise, handedness, number of courses taken in mathematics and science, and sports activities. Participants also completed a brief mathematics test that consisted of six questions varying in difficulty (two easy questions, two questions of middle difficulty, and two difficult questions as judged by two mathematics professors) that were specifically created for this study. They were given 15 min to complete the mathematics test. In addition, participants completed the State- and Trait-Anxiety Inventory (STAI, Spielberger et al. 1970). The STAI inventory has been used extensively in research. It comprises separate self-report scales that measure state and trait anxiety. The S-Anxiety scale consists of 20 statements that evaluate how respondents feel "right now, at this moment." The T-Anxiety scale consists of 20 statements that assess how people generally feel. Cronbach alpha for the anxiety scales was .86.

During the training period, participants were exposed to training sessions of either the 3-D *Antz© Extreme Racing* computer game, the 2-D *Tetrus©* computer game or several paper-and-pencil logic games. The 3-D *Antz©* racing computer game was chosen to allow novices to easily learn, manipulate a joystick, and navigate within a 3-D space. It was important to use a novel game to eliminate expertise and minimize confounding. The 3-D game, *Antz©*, is a racing game based on the *Antz©* film about a colony of ants. Initially, players must race as one of two characters from the movie, but more characters can be unlocked later on. After selecting a character, the player chooses from two short racecourses; further game-play unlocks increasingly challenging courses. During the race, players control their character's movements and speed using a joystick (e.g., the character turns right when players move the joystick to the right). While racing, the participant can gain special bonuses by driving over "power-ups" along the track. The course environment varies between levels, but it generally involves a track along the ground, with grass towering above the bugs. Racing type also varies level to level; racers fly, run, drive, or surf (over grass, not water) along the track.

Tetrus© was chosen because of its ease of use and two dimensionality. *Tetrus©*, is a personal computer version of the puzzle-type game Tetris. In *Tetrus©*, players try to prevent the cubes from touching the top of the game area while more cubes, arranged in various shapes and colors, drop down from the top. When an unbroken horizontal line of cubes spans the game area, it disappears. Thus, the goal of the game is to arrange the cube-based shapes in order to eliminate as many cubes as possible. Players can move and rotate the shapes using the left, right, down, and up arrows, and drop them into place using the spacebar. The shapes fall faster as the game progresses, making it increasingly difficult to position the shapes strategically. The control condition consisted of paper-and-pencil cross-word puzzles and logic games. The paper-and-pencil games were copied from a Games World of Puzzles magazine (ISSN 1074-4355. Games Publications, Ambler, PA: Kappa Publishing Group) and consisted of cross-word puzzles, sudoku, and other mind games.

A "computer game index" was established summing the weekly hours participants reported spending time with video games and computer games. The "sports index" referred to the total number of hours of sports played in high-school and college. The "mathematics index" consisted of the score on the math test (range 0–6). The indices with significant gender differences were later used as individual difference covariates.

Procedures

Participants scheduled individual practice sessions with trained research assistants. On their first appointment, the participants completed the two visuospatial tests (counterbalanced), followed by the background questionnaire. An equal number of men and women were then randomly assigned to the 3-D training condition (Antz© racing computer game), the 2-D training condition (Tetrus©), or the control condition (paper-and-pencil puzzles) for a half hour. Participants returned to the laboratory for another three times for 1 h of practice each. About half of the participants in each practice condition were randomly exposed to either: (a) distributed practice sessions (they completed the three 1-h practice sessions over more than 2 weeks) or (b) massed practice sessions (they completed the three 1-h practice sessions within 3 days). During the final session, after a half hour of practice, participants completed the two mental rotation tests as a posttest. Participants were exposed to a total of four training hours. They were asked to abstain to play any computer games between the practice sessions.

Results

Preliminary analyses about the regular use of the present computer games showed no gender differences. Nobody knew the Antz© game and an equal number of males and females had previously played Tetris.

Cognitive Gender Difference Analyses

It was hypothesized that the two mental rotation tests (VMRT and CRT) would correlate significantly with each other. Correlational analyses between the dependent variables pretest scores revealed a significant positive relationship between VMRT and CRT scores, $r(61)=.5$, $p<.001$. Additional correlational analyses were hypothesized to show negative relationships between anxiety levels and performance on the mental rotation tests. VMRT pretest scores were negatively correlated with trait anxiety, $r(61)=-.3$, $p=.027$, and state anxiety, $r(61)=-.3$, $p=.043$. Consistent with previous studies (Collaer and Nelson 2002; Cherney and Neff 2004; Halpern 2000; Linn and Petersen 1985; Sanders et al. 1982), men were hypothesized to outperform women in the pretest of both mental rotation tests. Because the tests varied in difficulty, it was also hypothesized that the effect sizes would differ significantly among the tests, with the more difficult test (VMRT) showing the larger effect size. The univariate analysis of variance (ANOVA) on the total VMRT pretest scores showed a significant main effect of gender, $F(2, 55)=16.5$, $p<.001$. On average, men ($M=12.6$, SD=3.7) scored significantly higher than women ($M=8.5$, SD=4.2). Surprisingly, there were no gender differences on the CRT pretest scores. As hypothesized, the effect size for the VMRT pretest was stronger ($d=1.03$) than that for the CRT ($d=.46$).

To examine whether there were a priori differences, a 3 (type of training) × 2 (sex) analysis of variance of covariance (ANCOVA) on the pretest test scores with mathematics and computer game indices as covariates was performed. The ANCOVA on the VMRT and CRT pretest scores showed a significant main effect of gender, $F(2, 56)=4.9$, $p=.011$. Men ($M=12.3$, SD=3.7) outperformed women ($M=8.7$, SD=4.2) on the VMRT, $F(1, 53)=9.9$, $p=.003$, but there were no significant gender differences on the CRT, $F(1, 53)=1.3$, ns.

Practice Effect Analyses

Based on previous studies showing gains for both genders (e.g., Baenninger and Newcombe 1989), computer game practice was expected to be beneficial for both genders. 3-D and 2-D computer practice was hypothesized to increase VMRT scores significantly, whereas individuals in the control group were not expected to increase their mental rotation performance. However, because females may benefit from some practice more than males and because of ceiling effects, it was expected that women would display a larger gain than men when using prior visuospatial experiences as a covariance. A mixed repeated-measures ANCOVA on the pre- and posttest scores across the three conditions with computer game index as the covariate and gender as the between-subject variable showed a significant main effect of improvement scores, $F(1, 58)=56.1$, $p<.001$, and a significant interaction, $F(1, 58)=3.8$, $p=.05$. Figure 1 illustrates the significant interaction that showed, partially in line with the hypothesis, that when prior computer game experience is controlled for,

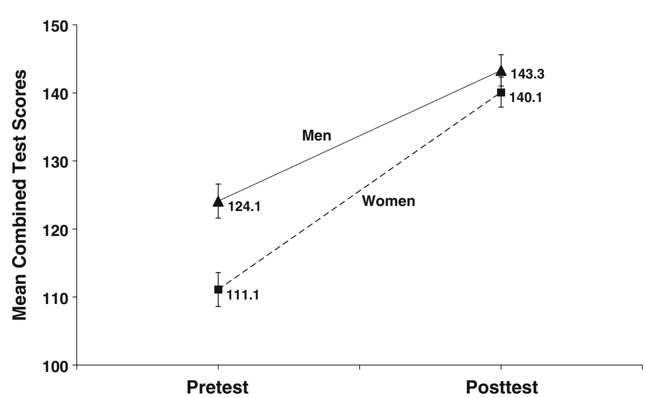
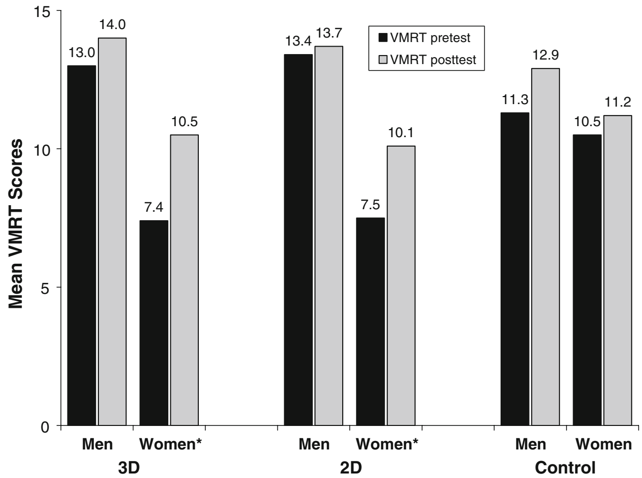


Fig. 1 Means and standard errors for the combined pre-and posttest scores on VMRT and CRT by gender with prior computer game experience as covariance.



Note: * $p < .05$

Fig. 2 Mean VMRT test scores by gender and training condition.

women show greater gains than men. Bonferroni adjusted paired sample *t*-tests on both mental rotation pre-and posttest scores showed that, for the VMRT there were significant improvements for women, $t(30)=-3.6$, $p=.001$, but not for men, and for the CRT, there were significant improvements for both men and women, $t(29)=-6.5$, $p<.001$. On average, female scores improved from a mean of 8.5 (SD=4.3) to 10.6 (SD=4.9) on the VMRT. On the CRT, men improved from a mean of 111.9 (SD=24.1) to a mean of 131.9 (SD=24.8), and women from a mean of 102.3 (SD=24.2) to a mean of 127.4 (SD=21.4). Figures 2 and 3 depict the changes for each practice condition and gender for the VMRT (Fig. 2) and the CRT (Fig. 3). Interestingly, in the control condition, men's and women's CRT scores improved significantly, whereas there were no significant differences on the VMRT pre- and posttest scores.

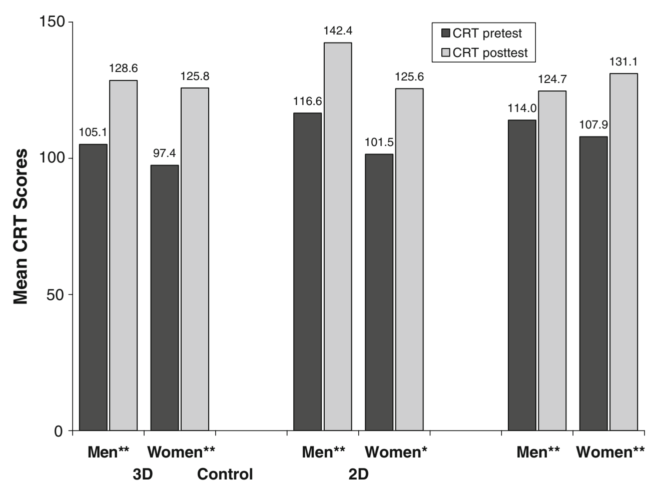
Overall, CRT improvement scores showed large effect sizes (Cohen 1988; range .35 to 1.54), whereas VMRT improvement scores showed moderate (for females .56 to .64) to small (for males .06 to .26) effect sizes. Similar to the pretest, correlational analyses between the posttest scores revealed a significant positive relationship between VMRT and CRT scores, $r(61)=.4$, $p=.001$. However, no other correlations among the dependent variables were significant. Effect sizes for each posttest decreased from a pretest $d=1.03$ to $d=.66$ (VMRT), and from a pretest $d=.46$ to $d=.16$ (CRT). Unlike the ANCOVA on the pretest scores, the ANCOVA on the posttest scores with computer game index and mathematics index as covariates showed no significant main effects or interaction.

Massed vs. Distributed Practice Analysis

It was expected that performance gains under distributed practice would be greater than those under massed practice. The 2 (gender) × 2 (delivery of practice) ANOVA on the total change scores showed a main effect of gender, $F(1, 57)=4.4$, $p=.04$, and a main effect of delivery, $F(1, 57)=5.1$, $p=.028$. The gender effect showed that on average, women ($M=30.6$, $SD=3.4$) improved significantly more than men ($M=20.8$, SD=3.2). The main effect of delivery of training showed that participants on average had significantly higher gains under the massed training ($M=31.0$, SD=3.6) than the distributed training ($M=20.5$, SD=3.0). There was no significant interaction.

Individual Differences

Women were hypothesized to have significantly lower prior computer game and sports experience, but higher anxiety levels. Lower levels of anxiety, higher levels of computer game experience, and higher levels of mathematical performance were expected to be predictive of overall positive performance gains. A multivariate analysis of variance on the individual difference variables and gender as the between-subject variable showed significant differences. Table 1 describes the a priori gender differences. Mathematical performance was hypothesized to moderate mental rotation performance. A regression analysis failed to show any significant moderating effect of mathematics performance on visuospatial skills. However, separate regression analyses on the low and high mathematics achievement groups (median split Mdn=3.0) with the total change scores serving as the criterion and gender and practice conditions (dummy coded) as the predictors showed that for the high mathematics performing individuals, gender and type of practice condition together predicted 33% of the variance in the total change scores ($F(3, 26)=4.3$, $p=.014$; $R^2=.33$). Both gender and 3-D training condition were significant contributors to the



Note: ** $p < .001$; * $p < .01$

Fig. 3 Mean CRT test scores by gender and training condition.

Table 1 Means, standard deviations, range, and *F*-tests for dependent variables by gender.

Variable	Gender	*M*	Number	SD	Range	*F*	*p*	*d*
State anxiety	Men	34.8	30	9.6	21–54	4.1	.48	−.51
	Women	39.8	31	9.8				
Trait anxiety	Men	36.5	30	8.1	23–55	7.0	.010	−.68
	Women	42.8	31	10.0				
Math test	Men	3.8	30	1.4	0–6	3.7	.060	.49
	Women	3.1	31	1.3				
Video and computer game index	Men	6.8	30	7.6	0–21	10.6	.001	.96
	Women	1.5	31	1.8				
High school and college sports index	Men	16.5	30	7.8	0–47	1.1	.304	.27
	Women	14.1	31	9.9				

State and trait anxiety inventory (0–60; Spielberger et al. 1970); mathematics test (0–6)

variance in the total change scores (t_{gender}=2.4, p=.024; $t_{3d\ condition}$=2.9, p=.008). However, gender and type of practice were not predictive of the performance for low mathematics scoring individuals, ($F(3, 26)<1$, ns). The multiple regression analyses for anxiety and computer game experience did not account for any significant variance in the total change scores.

Discussion

The purpose of the present study was to examine the effects of different practice methods and delivery, as well as individual differences on two mental rotation tasks of varying difficulty. The results suggest that even a very brief practice (4 h) in computer game play does improve performance on mental rotation measures. In general, practice with computer games improved both men's and women's performance, but women's gains were significantly greater than men's. Interestingly, massed training improved mental rotation performance more significantly than distributed learning. The results suggest that computer games might be particularly beneficial for the improvement of women's VMRT scores. Finally, for individuals with high mathematics ability, gender and type of training condition accounted for a significant proportion of variance in the total change scores.

Consistent with previous findings (Cherney and Collaer 2005; Cherney and Neff 2004; Halpern 2000; Linn and Petersen 1985; Sanders et al. 1982) men outperformed women on the VMRT. This 3-D mental rotation test has consistently shown robust gender differences and large effect sizes. The pretest effect size of d=1.03 was very similar to that found in previous studies (e.g., Cherney and Collaer 2005; Linn and Petersen 1985; Voyer et al. 1995). However, contrary to previous findings, there was no significant gender difference on the CRT (Sanders et al. 1982), although the CRT correlated moderately with the VMRT. It is reasonable to assume that, because the CRT involves the rotation of 2-D stimuli compared to 3-D stimuli for the VMRT, the task may have been easy enough to complete accurately in the allotted time. Linn and Petersen's (1985) meta-analysis showed that the magnitude of the gender difference depended on the complexity of the test used, with easier (2-D) tasks having a smaller effect size than more difficult (3-D) tasks. Similarly, Collins and Kimura (1997) who manipulated the difficulty of a 2-D test showed that the gender effect was highest for the more difficult task. Thus, consistent with the hypothesis the more difficult VMRT test showed the larger effect size and the less difficult CRT test the smaller effect size (d=.46).

Computer game practice was expected to be beneficial for both genders (Baenninger and Newcombe 1989; Terlecki and Newcombe 2005). Several studies have shown that both men and women can benefit from computer game play (McClurg and Chaillé 1987; Okagaki and Frensch 1994; Subrahmanyam and Greenfield 1994). However, it has also been suggested that those individuals with lower levels of computer or videogame experience, such as women, may have more room for improvement, and thus may improve more on spatial tasks as a result of computer use (Subrahmanyam and Greenfield 1994). The results tended to support this hypothesis. Improvement in VMRT performance as a function of practice is not a new finding (e.g., McClurg and Chaillé 1987), but what is noteworthy is that women's gains were significantly larger than men's only after 4 h of practice. Generally, practice studies have shown significant effects after extended intervention. It is also remarkable that the improvement was greater in the massed practice condition than in the distributed practice condition. Although women's gains were larger than men's, their posttest scores did not reach the level of men's scores. Thus, men benefited from practice as well. Individuals in the control condition also improved their mental rotation scores, but only for the CRT. This finding may be due to the fact that the CRT is easier and has a larger variance. It is also interesting to note that VMRT pretest scores of women in the control condition were unusually high when compared to the other two practice conditions. It is unclear why that group scored higher and may also account for the lack of improvement on the VMRT in the control condition.

Practice with the Antz© game, a 3-D computer game, seemed particularly beneficial for women's VMRT scores (pairwise comparisons showed a significant difference between the 3-D training condition and the control) perhaps because the Antz© game and the VMRT illustrate 3-D representations. The Antz© game is a navigational game that necessitates individuals to orient themselves in a 3-D space. Navigation, map reading, and driving skills that utilize similar skills have been shown to be significant predictors of spatial perception (Cherney et al. in press) and mental rotation (Kozhevnikov et al. 2006). Perspective-taking required to play the Antz© game probably involves spatial transformation ability similar to mental rotation representation. Feng and colleagues (2007) showed that spatial attentional capacity is an important component of higher-level spatial cognition. Playing an action video game for 10 h eliminated gender differences in spatial attention and also decreased the gender difference in mental rotation ability whereas playing a non-action game did not eliminate the gender difference. Thus, it is possible that playing with a 3-D game promotes lower-level capacities in spatial attention that then leads to improved higher-level spatial cognition (mental rotation). This general practice can perhaps be considered like an intensified spatial experience that can benefit both males and females. Alternatively, merely retaking a spatial test can improve mental rotation scores (Cherney and Neff 2004) and elevated performance on spatial tasks has even been elicited by simply facilitating familiarity with computers (Roberts and Bell 2000). Such effects are presumably more likely with easier spatial tests, such as the CRT. In the present study, participants tended to improve on the CRT in all practice conditions. Terlecki et al. (2007) showed that there was greater initial growth in mental rotation performance during training than in repeated testing alone, suggesting that training can be an effective intervention.

Besides the type of practice, the duration of practice and its transferability are important aspects to consider. The current results suggest that massed practice (4 h in 3 days) may be enough to show short-term improvement in mental rotation ability. It is likely that this effect is short-lived. Several studies have shown that for gains to be long-lasting, training or practice has to be sustained over a long time period (e.g., Feng et al. 2007; Terlecki and Newcombe 2005; Terlecki et al. 2007). It is also unclear whether this short-term gain may be transferable or generalizable to another visuospatial task. Future studies should examine the transferability of short-term gains to other tasks.

Another purpose of this study was to explore whether individual differences in anxiety, mathematics ability, and prior computer game experiences would influence mental rotation performance. Similar to previous studies, the current findings confirmed that men had more prior computer game experience, and women higher trait and state anxiety. Although men had a higher computer game experience, it did not account for any variance in the total change scores. However, women's gains were significantly different from men's when computer expertise was statistically controlled. These findings are consistent with other studies (e.g., Casey 1997; Cherney et al. 2006) that have shown a link between spatial experience and performance on spatial measures. A problem with any spatial activity index or scale when used with adults is that it is by necessity a retrospective measure and one that changes drastically over the lifetime. This study cannot rule out self-selection of videogame and computer use by high spatial-ability individuals. It is also noteworthy that high mathematics performance (as measured by the score on a mathematics test) predicted 33% to the variance in change scores, suggesting that this individual difference variable should be considered when assessing outcomes of spatial training.

This study has several limitations. The sample size was very limited. The Antz© game, although three-dimensional in its graphic and settings, may require only minimal navigational skills (there is only one path to follow) and the effort is directed into keeping an object on track. Using a 3-D game that requires actual spatial navigation and that has been researched regarding cognitive and neural models may show clearer results. It is also difficult to ascertain whether self-reported spatial experiences were accurate, whether the gains would transfer to other spatial skills, and for how long they would last. Furthermore, it is unclear whether longer-duration massed practice would still be superior to distributed practice. Because there was no control group that only received the pre- and posttest, one cannot rule out that the gains were due to merely retaking the test. Future studies should consider examining long-term transfer of skills in different age groups as to ascertain whether children would show similar gains with massed training.

The present study confirms that computer game practice may differentially improve the scores of males and females in mental rotation. The findings show that women had overall larger gains than men and that men, as well as women, still have substantial room for improvement. What is particularly noteworthy is that only 4 h of computer game practice can produce an improvement in VMRT performance, and that massed practice can produce higher gains than distributed practice. Although visuospatial gender differences may be one of many reasons for the underrepresentation of women in STEM careers (e.g., Ceci and Williams 2007; Newcombe 2007), there is an increasing need to identify how various forms of training could enhance growth in spatial ability. This study confirms that spatial ability is malleable regardless of gender and that specific interventions should be considered to increase the level of spatial functioning in the population.

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