

Women Match Men When Learning a Spatial Skill

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Meta-analytic studies have concluded that although training improves spatial cognition in both sexes, the male advantage generally persists. However, because some studies run counter to this pattern, a closer examination of the anomaly is warranted. The authors investigated the acquisition of a basic skill (spatial selective attention) using a matched-pair two-wave longitudinal design. Participants were screened with the use of an attentional visual field task, with the objective of selecting and matching 10 male–female pairs, over a wide range (30% to 57% correct). Subsequently, 20 participants 17–23 years of age (selected from 43 screened) were trained for 10 hr (distributed over several sessions) by playing a first-person shooter video game. This genre is known to be highly effective in enhancing spatial skills. All 20 participants improved, with matched members of the male–female pairs achieving very similar gains, independent of starting level. This is consistent with the hypothesis that the learning trajectory of women is not inferior to that of men when acquiring a basic spatial skill. Training methods that develop basic spatial skills may be essential to achieve gender parity in both basic and complex spatial tasks.

Keywords: spatial cognition, attentional visual field, gender differences, video game training, learning trajectory

Gender differences in spatial abilities (Halpern, 2000; Kimura, 1999) cannot be attributed to inheritance alone; learning plays a major role, and activities that exercise and nurture spatial skills are essential to achieve superior performance. The quality and quantity of play in early childhood (Baenninger & Newcombe, 1989, 1995; Cherney & London, 2006; Terlecki & Newcombe, 2005) seem to be especially important. If the right kinds of early experiences are lacking, an individual's potential may remain unrealized. Recently, however, several studies designed to improve the spatial abilities of adolescents and young adults have reported significant gains, and individuals with poor initial skills often benefited most from the training (see Liu, Uttal, Marulis, & Newcombe, 2008, for a comprehensive review).

Because females, on average, do not perform as well as males on some spatial tasks—most notably mental rotation (Voyer, Voyer, & Bryden, 1995)—it is of interest to determine whether appropriate training can remove or reduce the disparity. In a survey of the literature, Baenninger and Newcombe (1989) found that the gender difference remained constant when men and women received training designed to improve performance on a variety of spatial tasks. A more recent meta-analysis of 113 research studies (Liu et al., 2008) also found that although training improved spatial skills in both sexes, the female participants failed to match the male participants. However, in contrast to this general finding,

a few studies using computer games as training tools showed that females can close, or at least reduce, the gap (e.g. Cherney, 2008; Feng, Spence, & Pratt, 2007; Gagnon, 1985; Subrahmanyam & Greenfield, 1994). These contradictory findings may be the result of differences in (a) methodology, (b) spatial tasks, (c) training methods, and/or (d) participants' prior experience with spatial activities, including video games. Any of these variables could have led to differences in the learning trajectories of male and female participants.

Learning Trajectories

Figure 1 shows four plausible models of how males and females might acquire a spatial skill (Newell & Rosenbloom, 1981). The superimposed rectangles summarize learning at particular levels: The bases of the rectangles are equal, corresponding to equivalent training, and the heights represent the corresponding improvements whose magnitudes depend on the starting levels and rates of learning. The slopes of the diagonals of the rectangles, if drawn, would reflect the rates of learning. The starting levels illustrated assume that individuals already have some level of skill on the task, presumably acquired as the result of prior relevant learning experiences.

In model m1, males and females learn at the same rate. Two different starting levels are shown to illustrate the effect of high versus low starts. If males and females start at the same low level, a greater gain is expected and the rate of learning decreases as experience is accumulated. Females perform as well as males, given the same starting level and the same training. Model m2 assumes that males and females start at the same level but that females learn more slowly. The rate of learning for females will always be lower than for males if both sexes start from the same level, regardless of whether that level is high or low. Models m3 and m4 assume an initial advantage for males that is presumably genetic—sex differences in mental rotation have been observed as

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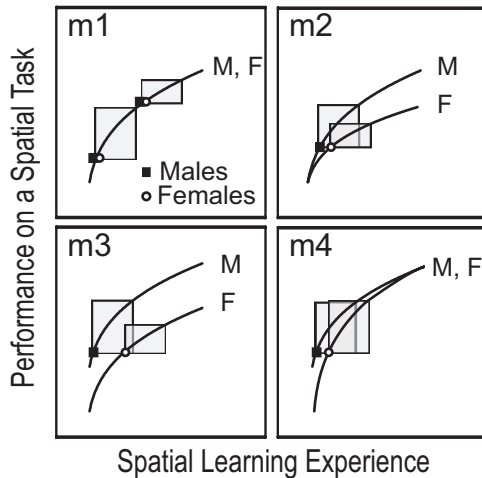


Figure 1. Percentage correct performance on the attentional visual field task as a function of prior relevant spatial learning experience; hypothetical learning trajectories are illustrated. The lower left corner of each rectangle indicates the starting level, and the (identical) width of each rectangle is proportional to the learning experience; the height denotes the gain in performance. The four models (m1–4) show male (M) and female (F) participants learning at the same or different rates, initial levels, and asymptotes.

early as 4 or 5 months (Moore & Johnson, 2008; Quinn & Liben, 2008). In model m3, the starting levels differ, but the trajectories are identical (the apparent widening of the gap with experience is an illusion). If either model m2 or m3 holds, the learning rates of females will be lower and will always be inferior to those of males. There is no possibility of catch up. If we were able to reject the hypothesis of equal learning rates for males and females that start from the same level, we would be forced to conclude that a model similar to either m2 or m3 must hold. Model m4 postulates a difference in initial levels, but unlike model m3, the females learn at a higher rate and eventually catch up. Models m1 and m4 both assume that the performance of males and females will eventually converge, even if they start from different levels. The learning rates of females are never inferior, for the same amount of training.

Spatial Cognition

The cognitive resources required to perform spatial tasks vary considerably. Some tasks place heavy loads on attention and working memory, whereas others are less demanding. Some call for symbolic problem-solving skills, whereas others require little in the way of conscious mental operations. Thus, we distinguish two different types of tasks on the basis of the skills that are required. We characterize some tasks as *basic* if they depend predominantly on basic capacities such as spatial selective attention, spatial working memory, or other fundamental perceptual and visuomotor skills. Other tasks are more *complex* and call for additional cognitive operations, which may involve searching, matching, mental imagery, number, language, gesture, symbolic problem-solving skills, and so forth.

Virtually all tasks in spatial cognition, whether basic or complex, depend on spatial selective attention and spatial working memory. Moreover, these critical supporting capacities are very

closely interrelated (Awh, Anlo-vento, & Hillyard, 2000; Awh & Jonides, 2001; Olivers, 2008; Zimmer, 2008). The ability to switch attention selectively among items in working memory in order to keep them active (Awh, Vogel, & Oh, 2006; LaBar, Gitelman, Parrish, & Mesulam, 1999; Lepsien & Nobre, 2006) is crucial for superior performance on complex spatial tasks—such as mental rotation—which require rapid allocation, disengagement, and re-allocation of attention to multiple components of the stimuli. Awh et al. (2006) hypothesized that spatial selective attention acts as a gatekeeper, deciding which components of the stimulus (e.g., vertices, faces, or cubes in the mental rotation task) will occupy the capacity-limited workspace in visual working memory. Awh et al. (2006) also argued that executive spatial attentional processes manipulate and update the contents of spatial working memory and are active in the coordination of other brain systems that maintain and select object representations. Selective attention is a core component of spatial cognition, and it is essential for the efficient operation of spatial working memory.

Most training studies in spatial cognition have examined relatively complex spatial skills, using tasks such as mental rotation, embedded figures, or paper folding. Although not as complex as real-world activities like navigation or learning geometry, these and other similar tasks call for multiple and varied cognitive abilities. Training methods also differ in the spatial skills required, and not all methods are equally effective. Thus the particular methods and tasks can have a substantial effect on the outcomes of training studies. If training does not improve basic spatial skills, transfer of learning will be limited to similar tasks, and any gain is likely to be the result of improvements in task specific skills. Unfortunately, not all training methods improve basic capacities. Many computer games provide only modest exercise for basic processes even though, on the face of it, they appear to engage a range of spatial skills.

Video Games as Training Tools

Different games offer different kinds of cognitive training, and they exercise different skills (Achtman, Green, & Bavelier, 2008). For example, first-person shooter games modify basic functions such as target detection, spatial selective attention, spatial resolution, and processing speed (Green & Bavelier, 2003, 2006, 2007). The player must detect the sudden appearance of potential threats at unpredictable locations in a complex visual environment, discriminate friend from foe, and take selective action, which is usually to shoot at threats. To avoid being killed in the game, these basic operations must be executed rapidly. Thus the first-person shooter game has many elements that exercise spatial selective attention and spatial working memory. The effects of training transfer to other tasks such as mental rotation, and the benefits persist for several months (Feng et al., 2007). This “far transfer” (Barnett & Ceci, 2002) is largely due to the fact that the complex activity—mental rotation—depends on basic supporting skills such as spatial selective attention and spatial working memory (Heil, 2002; Hyun & Luck, 2007; Suchan, Botko, Gizewski, Forsting, & Daum, 2006; Wolbers, Schoell, & Buchel, 2006).

Some training tools, such as *Tetris* (2009), do not improve basic capacities. *Tetris* does not require the player to attend to multiple objects whose features, presence, and positions change rapidly and continuously (Achtman et al., 2008; Green & Bavelier, 2006). The

focus of attention is predominantly on one object at a time, and the player is not required to detect, discriminate, select, or track objects over a wide field of view. However, fast visuomotor control is necessary and, after practice, a shift from controlled to automatic processing (Schneider & Chein, 2003) occurs, resulting in improved play. Proficiency in *Tetris* does transfer to similar tasks such as mental rotation (De Lisi & Wolford, 2002; Sims & Mayer, 2002; Terlecki Newcombe, & Little, 2008), but playing *Tetris* does not develop basic skills like spatial selective attention (Green & Bavelier, 2003) or dissimilar skills like multiple-object tracking (Green & Bavelier, 2006). Indeed, Sims and Mayer (2002) concluded that “*Tetris* is a game whose component skills are somewhat separate from other kinds of spatial skills.” *Tetris* may improve higher order task-specific processes such as the player’s strategy (Heil & Jansen-Osmann, 2008; Jordan, Wustenberg, Heinze, Peters, & Jancke, 2002; Wraga, Thompson, Alpert, & Kosslyn, 2003), but other than increasing processing speed (Jansen-Osmann & Heil 2007; Peters, 2005), *Tetris* does little to enhance basic spatial capacities.

Gender Differences in Basic Spatial Capacities

Although gender differences in complex spatial tasks are well documented, differences in basic skills have received less attention. Feng et al. (2007), reported a large and previously unknown difference in spatial selective attention. This study also showed that the gender difference was virtually erased after training with a first-person shooter game. In addition, an initial difference in mental rotation scores was greatly reduced, with female participants realizing the greater benefit. At first glance, mental rotation seems to have little in common with either the first-person shooter game or spatial selective attention; however, as we have argued, because virtually all spatial cognition is supported by basic capacities like spatial selective attention and spatial working memory, the improvement in mental rotation is largely a consequence of improvements in basic skills.

If females are inferior to males in the rate at which they acquire basic spatial skills, we should not expect to see convergence on either basic or complex spatial tasks. On the other hand, if their learning trajectories are similar to those shown in models m1 and m4 (Figure 1), females should achieve gains that are just as large as those of males after equivalent training. Our hypothesis, therefore, is that females are not inferior to males in the rate at which they acquire a basic skill, specifically, spatial selective attention.

Method

We used a matched-pair, two-wave longitudinal design, with male and female participants paired according to their starting levels of performance on a fundamental spatial skill, specifically, spatial selective attention. The use of matching in this context is novel. Matching avoids a costly comparison of rates of learning over multiple waves by concentrating instead on a direct comparison of gains, as illustrated in Figure 1. Without matching, the comparison would be problematic if there were a difference in starting levels. Our training intervention used a first-person shooter video game, *Medal of Honor: Pacific Assault*. Similar versions of this game were used by Green and Bavelier (2003) and Feng et al. (2007).

Participants

Students at the University of Toronto participated for \$50 compensation (plus \$15 for a follow-up session). They were recruited from an introductory psychology class and via posted notices. The advertisement solicited male and female students who had no action video game experience during the past 3 years (occasional play—not exceeding 4 hr/month—with other genres was acceptable). When participants arrived at the lab, they were tested with an attentional visual field task, which assessed their ability to detect a target among distractors over a wide field of view. If a close match in the spatial attentional score could be found with a previous participant of the opposite sex, the matched pair was invited to continue with the experiment. A total of 43 participants were tested before 10 matched male–female pairs (age = 17 to 23 years) were formed. The remaining 23 participants did not continue to the training phase. Because we wanted the starting scores (percentage correct detections of the target) to span a wide range, the matches were not as good near the lower (30%) and upper (57%) limits of the range as they were in the middle (~45%); 6 male–female pairs differed by 1% or less, and the remaining 4 male–female pairs differed by no more than 4%.

Procedure

We followed the procedure of Experiment 2 in Feng et al. (2007). We used the same measure of spatial selective attention (an attentional visual field task), which is similar to the useful field of view task described by Edwards et al. (2005).¹ A head/chin rest controlled the distance from the screen, thus ensuring accurate visual angles. On each of 240 trials, a fixation square appeared in the center of a computer monitor for 600 ms, followed by a briefly flashed display of 23 distractors (unfilled squares) plus a target (filled square surrounded by an unfilled circle). Each object was located at an eccentricity of 10° or 20° or 30° in eight equally spaced directions, like an eight-point compass rose. During the 240 trials, the target appeared randomly 10 times in all 24 possible locations. The exposure times at eccentricities of 10°, 20°, and 30°, respectively, were 10, 20, and 30 ms. After presentation of a mask and then a response cue, participants indicated the direction of the target by pressing the appropriate key on the number keypad (e.g. “8” for north, “1” for southwest).

Participants completed the spatial attentional task at pretest, then 10 hr of individually supervised training with the action video game—conducted in sessions of 1 to 2 hr in our laboratory within a maximum period of 4 weeks—and the spatial attentional task again at posttest. Testing sessions were never conducted on the same day as training sessions, and all participants were able to achieve reasonable mastery of the game (measured by game scores and level reached) during the training period.

Results

An overall improvement in mean spatial attentional accuracy (from 44% to 54%) was observed, $F(1, 18) = 77.26, p < .0001$,

¹ Our measure of the attentional visual field is similar to, but not identical to, a proprietary test called Useful Field of View (UFOV®), a registered trademark of Visual Awareness, Inc. and Posit Science, Inc.)

and performance at 20° eccentricity was higher (54%) than at 10° (47%) or 30° (45%), $F(2, 36) = 8.23, p = .0001$; Tukey’s honestly significant difference (HSD) = 5.4% for $\alpha = .05$. These results replicate Green and Bavelier (2003, 2006) and Feng et al. (2007). The effect of eccentricity is a function of exposure time; decreasing the exposure at 20° would reduce the mean percentage correct to the levels at 10° and 30°. There were no other significant effects (F ratios < 1) in an analysis of variance (ANOVA) with gender (male vs. female) as the between-participants variable and training (pre vs. post) and eccentricity (10°, 20°, and 30°) as within-participant variables. The improvement for female participants was 11%, compared with 10% for male participants, but this Gender \times Training effect was not significant, $F(1, 18) = 0.20, p = .66$; a post hoc estimate of power exceeded .70, for an effect size of 2% and an α of .05. A test for non-inferiority (Tamayo-Sarver, Albert, Tamayo-Sarver, & Cydulka, 2005), with a margin of 2%, yielded $p = .09$.

Figure 2 shows the average spatial attentional scores for male and female participants before and after training. Individual learning rates varied, but all participants showed improvements. The right panel shows the average performance of the top five pairs (from 51% to 59%), $F(1, 8) = 33.11, p = .0004$, and the bottom five pairs (from 38% to 50%), $F(1, 8) = 49.06, p < .0001$. The gains obtained were 8% and 12%, respectively, indicating a marginally greater improvement for the low starters, $F(1, 18) = 3.45, p = .08$. Regression to the mean may be ruled out as an explanation for the observed gains, as in a comparison of the first-person shooter game and a control game, Feng et al. (2007) showed that whereas the first-person shooter game produced large positive changes in performance, the control game produced no significant improvements, even in participants with low initial scores.

Visualizing the Learning Trajectory

A power function was fit by minimizing the least squares function, $S = \sum(y_{ijk} - \beta\xi_{ijk}^\gamma - \alpha)^2$, where y_{ijk} is the percentage

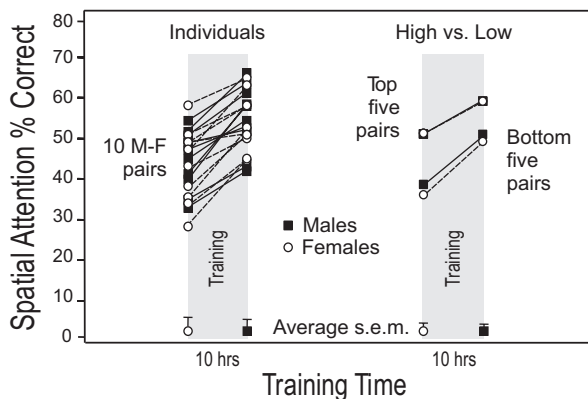


Figure 2. The left panel (Individuals) shows the spatial attention percentage correct scores before and after 10 hours of video game training for 10 males and 10 females matched on their initial scores. The right panel (High vs. Low) shows the mean spatial attention percentage correct scores before and after training for the top 5 male–female (M–F) pairs and for the bottom 5 M–F pairs. To avoid clutter, only the average standard error of the mean (s.e.m.) values are shown.

correct score of participant i , sex j , at training time k , and α, β, γ are the intercept, slope, and exponent of the function, respectively. The ξ_{ijk} value represents the spatial attentional ability levels of the participants before ($k = 1$) and after ($k = 2$) training. The nonlinear least squares loss function, S , was minimized by use of a grid search followed by a quasi-Newton algorithm (Fletcher, 1987) subject to the constraints that $\xi_{i1k} = \xi_{i2k}$ and $\xi_{ij2} = \xi_{ij1} + \delta$. The former constraint assumes that the male–female pairs possessed identical initial spatial attentional ability levels, and the latter constraint assumes that all participants received the same amount of training, δ , which was set arbitrarily—and without loss of generality—to the constant 10, the number of hours of video game training. The fit statistics were as follows: $R^2 = .90$ and $F(12, 27) = 23.26, p < .0001$, and $\hat{\alpha} = 8.7, \hat{\beta} = 4.9$, and $\hat{\gamma} = 0.66$. Figure 3 shows the fitted function. The parameter estimates should be interpreted cautiously; the fitted function is intended as a descriptive summary only.

Follow-Up Testing

We had intended to conduct follow-up sessions (at 3 and 6 months), but we were unable to contact all participants. We retested 14 of the 20 participants at varying intervals averaging 4.0 months. The participants had been asked not to play video games before being retested, and all 14 reported compliance. There was no loss in performance on the spatial attentional task (7 male participants, 56% to 57%; 7 female participants, 53% to 50%). The 3% decline in the female average (though nonsignificant) was caused by a single participant whose follow-up test score dropped by 14%. No explanation for this aberration was apparent. Although incomplete, the follow-up data support Feng et al. (2007): The training effect of playing an action video game persists for some time.

Discussion

Despite a large body of experimental evidence (see Baenninger & Newcombe, 1989, 1995; Liu et al., 2008), considerable uncertainty regarding the nature of the learning function in males and females remains. The general failure to demonstrate that females can close the gender gap appears to reinforce the belief that the acquisition of spatial skills may proceed differently in females than in males. However, as results of some studies run counter to the trend, a closer examination of the possible reasons for these apparently contradictory findings is appropriate.

Our approach to examining the learning trajectories differed significantly from most previous research in four respects:

- (a) Methodology: We compared the gains obtained by matched pairs of male and female participants across a range of initial performance levels in a two-wave longitudinal design. The use of matching in this context is novel and simplifies comparison of the trajectories of male and female participants (see Figure 1).
- (b) Spatial task: We concentrated on spatial selective attention rather than on a more complex spatial task, given that basic spatial capacities support virtually all tasks in spatial cognition. More complex tasks depend

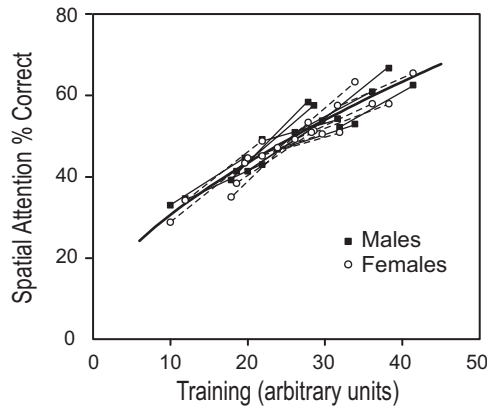


Figure 3. A power function fitted to the spatial attention percentage correct scores based on the assumption that the members of each male-female pair were at the same level of prior spatial learning experience.

on idiosyncratic task-specific skills in addition to basic skills.

- (c) Training method: We used a first-person shooter game that is known to produce large changes in basic skills rather than a game like *Tetris*, which does not boost spatial selective attention.
- (d) Prior action game experience: Our participants did not have any action video game experience, and they played games from other genres occasionally at most. Even so, our participants were not all low performers; their pretraining scores spanned a wide range on the spatial selective attentional task.

The average gains on the spatial selective attentional task were virtually identical for both sexes, regardless of whether the matched pairs started from a high or a low level of expertise. If the learning trajectory of the female participants had been inferior (as in models m2 and m3 in Figure 1), we should have observed differential gains favoring male participants. However, the female participants were slightly superior, although not significantly so. Thus, we conclude that the learning trajectories are more likely to resemble those in models m1 and m4, where convergence is possible, than models m2 and m3, where females are always inferior.

Our results strengthen the case for similar learning trajectories in male and female participants when acquiring a basic spatial skill. Previously, Feng et al. (2007) found that experienced male and female action video game players did not differ in spatial selective attentional capacity, suggesting that the asymptotes of the learning trajectories in male and female participants do not differ. However, interpretation of that result is complicated by a possible self-selection bias. In their second experiment, Feng et al. (2007) found that the gender disparity in spatial selective attention was virtually eliminated when nonplayers were trained using a first-person shooter game. Thus, both of these experiments support the case for a model similar to m1 or m4. The present study provides additional convergent evidence for identical trajectories by demonstrating that female participants are not inferior to male partic-

ipants. Furthermore, interpretation of this result is not compromised by a self-selection bias or unequal starting levels of performance.

Other studies that showed convergence, partial convergence, or equivalent gains starting from the same level (Cherney, 2008; Dorval & Pepin, 1986; Gagnon, 1985; Subrahmanyam & Greenfield, 1994) used games that probably boosted basic skills. In Cherney (2008), *ANTZ Racing*, an action kart-racing game, produced superior gains (over *Tetris*) in mental rotation. Participants in Gagnon (1985) played *Targ* and *3D Battlezone*, early third-person shooter games, with female participants improving their spatial skills more than male participants. Subrahmanyam and Greenfield (1994) used *Marble Madness*, where the player guides a marble through three-dimensional courses containing objects and enemies that obstruct the player. Dorval and Pepin (1986) found that nonplayers of both sexes improved equally after training with an early shooter game called *Zaxxon*. Dorval and Pepin's performance measure was an embedded figures task, which relies on the ability to perceive figures amidst distracting background information. It is highly likely that this task placed substantial demands on spatial selective attention and spatial working memory.

In a carefully controlled study, Terlecki et al. (2008) examined the mental rotation performance of males and females over 12 weeks using (a) repeated testing with the mental rotation task and (b) training with two-dimensional and three-dimensional versions of *Tetris*. The learning trajectories of the groups were roughly parallel, with the male participants starting and finishing at higher levels. However, encouraged by the result that the performance of female participants who had received video game training came close to that of male participants who had received no training, Terlecki et al. (2008) speculated that, given enough training, the performance of the female participants might converge to that of the male participants. However, as we have argued, training with games such as *Tetris* may not be able to achieve parity, as training methods that only modify task-specific skills may be incapable of closing the gender gap. Training methods that develop an individual's ability to maintain, select, and exchange items in spatial working memory may be essential to provide a basis for equalization on complex spatial tasks.

Our participants had never played action video games and had played other video games rarely, if at all, during the 3 years prior to the experiment. Thus, it could be argued that action video game players might follow a different learning trajectory. However, because both male and female action game players are probably already close to asymptote on the attentional task and because their performance does not differ (cf. Figure 2; Feng et al., 2007), detecting gender differences in learning rates as a function of further training would be difficult. Feng et al., 2007 (Figure 3) also found that action game training with both male and female nonplayers improved their performance on the spatial selective attentional task almost to the level of experienced action game players. Thus, it seems unlikely that players and nonplayers could differ substantially in their learning trajectories (as in models m2 and m3). Nonetheless, we cannot definitively rule out the possibility that individuals who self-select to play action video games follow different learning trajectories than do nonplayers.

Learning trajectories for the acquisition of spatial skills may also differ depending on age and maturational level; our findings are based on the performance of young adults. However, as Liu

et al. (2008) found that children and adults showed very similar gains after training, it is plausible that learning basic skills would proceed at similar rates at earlier stages of development. Further research with children, perhaps with specially constructed games that possess the critical training elements of first-person shooter games, but without the violence, would be valuable.

Educational Implications

Spatial abilities are associated with success in mathematics and science courses (Delgado & Prieto, 2004), performance on standardized tests (Casey, Nuttall, Pezaris, & Benbow, 1995), and the choice of mathematics and science in college (Casey et al., 1995). Early individual differences in abilities influence confidence, self-efficacy, and attitudes (Bandura, 1997), and thus inferior spatial skills lead to avoidance of learning situations that require spatial cognition. These lost opportunities for learning have an effect on subsequent participation in science, technology, engineering, and mathematics. Worldwide, women are underrepresented in these areas; no more than one in four workers is a woman (Arnold & Niederman, 2001). Changes in early education and play, geared toward improving individual levels of spatial cognition, could have a major impact on the choice of programs of study and, eventually, on career decisions. If the gender disparity in spatial cognition (Halpern, 2000; Kimura, 1999) can be diminished or eliminated by early intervention, the subsequent educational and career paths of girls might more closely resemble those of boys.

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