Research Report

Playing an Action Video Game Reduces Gender Differences in Spatial Cognition

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ABSTRACT—***We demonstrate a previously unknown gender difference in the distribution of spatial attention, a basic capacity that supports higher-level spatial cognition. More remarkably, we found that playing an action video game can virtually eliminate this gender difference in spatial attention and simultaneously decrease the gender disparity in mental rotation ability, a higher-level process in spatial cognition. After only 10 hr of training with an action video game, subjects realized substantial gains in both spatial attention and mental rotation, with women benefiting more than men. Control subjects who played a nonaction game showed no improvement. Given that superior spatial skills are important in the mathematical and engineering sciences, these findings have practical implications for attracting men and women to these fields.***

It is generally accepted that gender differences in spatial cognition exist (e.g., Kimura, 1999; Terlecki & Newcombe, 2005; Voyer, Voyer, & Bryden, 1995). Surprisingly, however, few studies have investigated possible gender differences in the basic capacities that support spatial cognition. Recently, using structural equation modeling, Kaufman (2007) explored the role of working memory in gender differences in spatial cognition, but there are no comparable experimental studies that have specifically examined attentional processes, which also likely contribute to the disparities between males and females in spatial cognition. Establishing whether or not there are gender differences in spatial attention—and determining whether or not such differences may be modified—is therefore of scientific interest and potential practical importance.

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There is ample evidence that attentional processes are intimately involved in higher-level tasks in spatial cognition. Functional neuroimaging has linked mental rotation tasks to selective attention and the spatial distribution of attention; the right posterior parietal cortex (PPC) is strongly activated during tasks involving attention (e.g., Behrmann, Geng, & Shomstein, 2004) and mental rotation (e.g., Cohen et al., 1996). Indeed, Coull and Frith (1998) have hypothesized that the right posterior parietal lobe (particularly the inferior parietal lobule) is involved in fundamental low-level attentional processes that "act as the lowest common denominator for many types of cognitive processes" (p. 185). Studies of visual neglect (Halligan, Fink, Marshall, & Vallar, 2003) also indicate that there is a close connection between selective spatial attention and the parietal lobes. Furthermore, the right PPC is important for selective spatial attention (Desimone & Duncan, 1995; Yantis & Serences, 2003), and it seems that an essential function of PPC is to shift attention among items in memory in order to keep them active (LaBar, Gitelman, Parrish, & Mesulam, 1999; Lepsien & Nobre, 2006). This shifting of attention is likely critical for superior performance in mental rotation tasks.

Boys have always played different games than girls, and early recreational activities have often been cited as a major cause of gender differences in adult spatial cognition (e.g., Baenninger & Newcombe, 1989). In recent years, improvements in performance on a variety of high-level spatial tasks have been associated with playing video games (e.g., Law, Pellegrino, & Hunt, 1993; McClurg & Chaillé, 1987). Because spatial attentional capacity is an important component of visual cognition, players who develop enhanced spatial attentional ability as a result of playing first-person shooter action games (Castel, Pratt, & Drummond, 2005; Green & Bavelier, 2003, 2006, 2007) may also realize benefits in higher-level spatial cognition.

The first-person shooter action games that are appealing to boys, however, are not so attractive to girls (Quaiser-Pohl, Geiser, & Lehmann, 2006; Terlecki & Newcombe, 2005). Thus, boys may realize benefits in spatial attention that are largely denied to their female counterparts, who participate in such action games in much smaller numbers. The present study is the first to systematically investigate possible gender differences in low-level spatial attentional processes and their likely effects on higher-level spatial cognition.

Our first experiment investigated group differences—including gender differences—in spatial attention. In our second experiment, we explored the possibility that group differences in both low-level and higher-level spatial cognition might be modified. As Newcombe, Mathason, and Terlecki (2002, p. 184) have observed, documenting a gender difference may be of scientific interest, but it is more important to determine whether the difference may be reduced or eliminated.

EXPERIMENT 1

In Experiment 1, we examined group differences in spatial attention for groups defined by gender, video-game-playing experience, and chosen field of study. We used the useful-field-of-view (UFOV) task to measure spatial attention. This well-established paradigm assesses the ability to detect, localize, and identify a target, and assesses the spatial distribution of attentional resources over a wide field of view (Edwards et al., 2005).

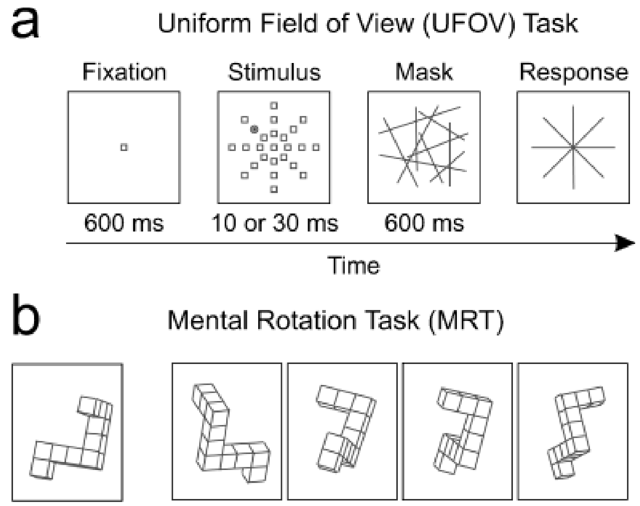

Fig. 1. The display sequence for a single useful-field-of-view (UFOV) trial (a) and a sample mental rotation task (MRT) item (b). In the UFOV task, subjects had to indicate the direction in which the target had appeared. In the MRT, subjects had to choose which two of four pictures shown on the right portrayed objects identical to the one shown on the left.

Method

Subjects

Undergraduates at the University of Toronto, Canada (N = 48; age range: 19–30 years), participated for course credit or compensation of $10/hr. The basic design was a between-subjects 2 × 2 × 2 balanced factorial with 6 replications per cell. The factors were gender (male vs. female), video-game-playing experience (players vs. nonplayers), and field of study (arts vs. science). The players reported playing action video games for more than 4 hr per week, and the nonplayers reported no video-game play within the past 3 or more years. The science students were majoring in mathematics, physics, chemistry, biology, computer science, neuroscience, psychology (cognitive and neuroscience area), and cognitive science. The arts students were majoring in English literature, French, art history, fine arts, sociology, political science, economics, psychology (social area), and history. Subjects were recruited by an advertisement that described the desired subject characteristics, and when each of the eight cells of the design had been filled, no more recruits for that cell were accepted.

Stimuli

The stimuli were presented in an invisible circular area (63° in diameter) centered on a uniform light-gray screen (see Fig. 1a for the display sequence). Each trial began with a centered, unfilled fixation square with a dark-gray border (3° × 3°). The fixation square was presented for 600 ms and then augmented by the stimulus display, which consisted of 24 similar distractor squares, each uniquely localized at an eccentricity of 10°, 20°, or 30° in one of eight equally spaced directions. On each trial, one randomly selected distractor square was replaced by the target, a dark-gray filled square (1.5° × 1.5°) surrounded by an unfilled circle with a dark-gray circumference (3° × 3°). The distractors were unfilled squares with dark-gray borders (3° × 3°), identical to the fixation square. When the target was located at an eccentricity of 10°, the stimulus display was presented for 10 ms; this duration was increased to 30 ms for eccentricities of 20° and 30°, to maintain a reasonable level of difficulty. After presentation of a mask and then a response cue, subjects indicated in which of the eight possible directions the target had appeared.

Results and Discussion

Players were much superior (77% vs. 58%) to nonplayers, on average, $F(1, 40) = 34.38$, $p_{rep} > .99$, $\eta^2 = .46$. There was also an effect of eccentricity, but no interactions involving eccentricity were significant. These findings replicate Green and Bavelier's (2003) UFOV results, and we have displayed our means in a fashion similar to theirs to facilitate comparison (Fig. 2). The science students outperformed the arts students (72% vs. 63%), $F(1, 40) = 6.99$, $p_{rep} = .95$, $\eta^2 = .15$, which suggests that students with superior attentional capacities may be drawn to careers in science. On average, males made more correct responses than females (71% vs. 64%), $F(1, 40) = 5.03$, $p_{rep} = .91$, $\eta^2 = .11$; most of this effect was due to the gender

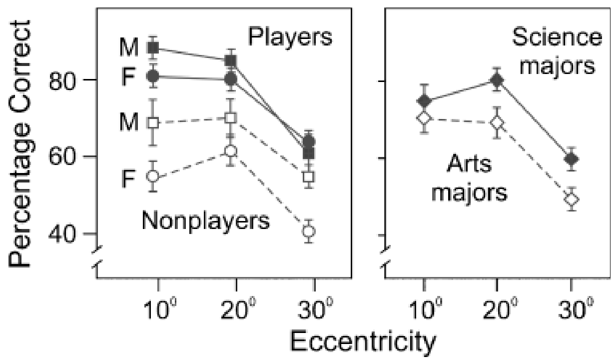

Fig. 2. Percentage of correct responses in Experiment 1. The left panel shows the means for male (M) and female (F) video-game players and non-video-game players, and the right panel shows the means for science and arts majors. Error bars represent ±1 *SE*.

difference (64% vs. 52%) in the nonplayers, least significant difference in the means = 12% (*SE* = 5%), p_{rep} = .94. This experiment demonstrates—for the first time—a gender difference in spatial selective attention. Because the gender difference was much smaller in the players group than in the nonplayers group (and was not statistically significant in the players group), our second experiment was designed to determine whether or not the gender difference in spatial selective attention could be modified by training with a video game.

EXPERIMENT 2

In Experiment 2, we compared spatial attention and cognition in men and women before and after 10 hr of action-video-game training. A control group trained for 10 hr with a non-action game. Spatial attention was measured with the UFOV task used in Experiment 1. In addition, we assessed higher-level spatial abilities using a mental rotation test (MRT; see Fig. 1b). We expected to find enhanced MRT performance as a by-product of improvements in spatial attentional capacity after training. Moreover, we expected that if the gender difference in selective attention was reduced after action-game training, the gender difference in MRT performance would also be reduced.

Method

Subjects

Twenty undergraduates (none of whom had participated in Experiment 1) were recruited. Six males and 14 females (age range: 18–32 years) participated and received $50 in compensation. All subjects reported no video-gaming experience during the preceding 4 years. Ten same-gender pairs were formed by matching individuals as closely as possible on their pretest scores in the UFOV task and MRT. One member of each pair was allocated at random to the experimental (action game) group, and the other member of the pair was assigned to the control (non-action game) group.

Tests

The UFOV task was as described in Experiment 1. The MRT used an AutoCAD-redrawn version of the Vandenberg and Kuse (1978) items (Fig. 1b). The 24 MRT items were presented in the normal order during the pretest. At posttest, the sequence was randomly reordered to make it difficult for subjects to recall their previous answers. Subjects had 3 min to complete as many items as possible.

Training

The experimental group was trained using *Medal of Honor: Pacific Assault*, which was chosen because it is similar to the games typically played by players in Experiment 1 and because it has been used before in attention training studies (Green & Bavelier, 2003). This game is a 3-D first-person shooter game that requires intense visual monitoring and attentional resources. The control group played *Ballance*, a 3-D puzzle game that involves steering a ball through a hovering maze of paths and rails with obstacles such as seesaws, suspension bridges, and pendulums.

Procedure

Subjects completed a pretest (UFOV task and MRT), 10 hr of individually supervised training with a video game (conducted in sessions of 1 to 2 hr in our laboratory within a maximum period of 4 weeks), and then a posttest (UFOV task and MRT). We had not originally planned a follow-up testing session; however, we were able to contact and retest all 20 subjects after an average interval of about 5 months (16–24 weeks).

Results and Discussion

After training, all subjects in the experimental group reported better shooting accuracy than when they started. Two subjects in the control group reached the maximum possible level of performance, and the others were very close to the maximum. Thus, both groups achieved substantial mastery of the games on which they were trained.

UFOV Task

Performance on the UFOV task showed no significant interactions involving eccentricity, so we collapsed the means over that factor. Because the follow-up data were collected 5 months (on average) after the main experiment was completed, these data were not included in the formal statistical analyses (analyses of variance); however, the means and standard errors from the follow-up testing are shown in Figure 3.

An improvement in UFOV was observed in the experimental group, but not in the control group (see Fig. 3, upper panels). Performance of subjects who had trained with the action game improved substantially (from 61% to 74%), whereas there was no significant difference between pretest and posttest in the control group (from 61% to 63%). This finding replicates Green and

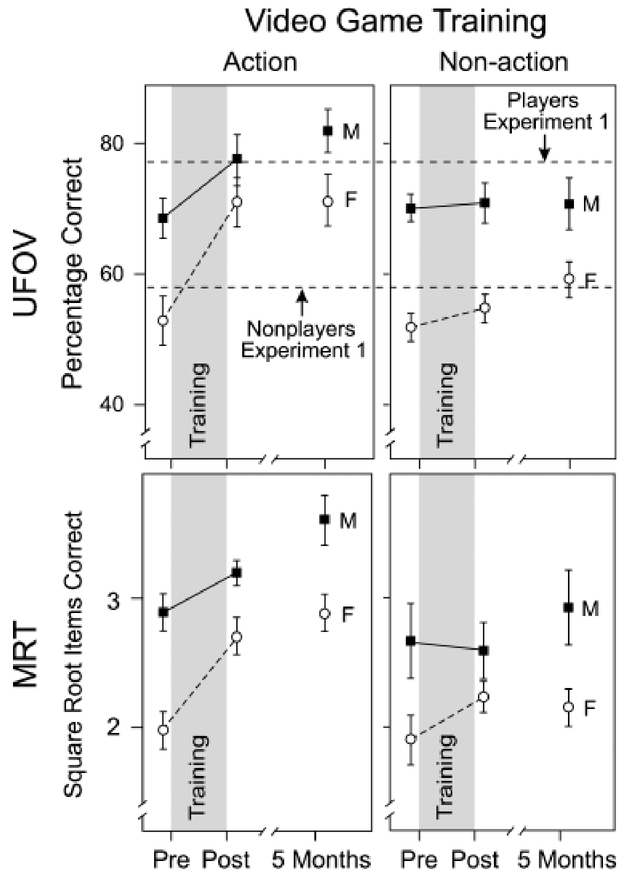

Fig. 3. Results from Experiment 2: percentage of correct responses in the useful-field-of-view (UFOV) task (upper panels) and performance (presented as square root of the number of correct items, to stabilize variance) on the mental rotation task (MRT; lower panels). Results are shown separately for males (M) and females (F). The left panels show the means for the experimental (action-video-game-training) group, and the right panels show the means for the control (non-action-video-game training) group. Means are shown for before (''Pre'') and immediately after (''Post'') training, and at follow-up, an average of 5 months after training. For comparison, the average levels of players and nonplayers in Experiment 1 are indicated. Error bars represent ±1 *SE*.

Bavelier's (2003) finding that playing an action video game enhances spatial attention. However, the females benefited more (from 55% to 72%) than the males (from 68% to 78%), $F(1, 8) = 14.79$, $p_{rep} = .97$, $\eta^2 = .65$, and although the females did not quite reach the same level as the males, the posttest means were not statistically distinguishable (least significant difference, $p = .14$).

The 5-month follow-up means differed by gender. In the experimental group, the females maintained their level of performance, and the males increased their level by a small amount. However, 2 males in the experimental group had continued to play action video games in the interim (no other subjects had continued to play); this anomaly likely contributed to the improvement in the follow-up mean for males.

MRT

A square-root transformation of the number of correct items on the MRT was used to stabilize variance. Both males and females in the experimental group improved, but there was no significant change from pretest to posttest in the control group (see the lower panels of Fig. 3), $F(1, 16) = 7.33$, $p_{rep} = .94$, $\eta^2 = .31$; furthermore, the improvement in the experimental group was larger for females (2.0 to 2.7) than for males (2.9 to 3.2), $F(1, 8) = 5.193$, $p_{rep} = .87$, $\eta^2 = .39$, and the performance of the females on the posttest was indistinguishable from that of the males in the control group. Although the gender difference on the MRT was not eliminated, its size was much reduced (see Fig. 3, lower left panel).

GENERAL DISCUSSION

Playing an action video game can differentially enhance males' and females' performance on spatial tasks: Females showed larger improvements than males, such that prior gender differences were virtually eliminated (UFOV task) or reduced (MRT). Both males and females (with no prior video-gaming experience) in Experiment 2 either reached or closely approached the average UFOV performance of players in Experiment 1, and follow-up testing suggests that these gains were persistent. This finding is remarkable and implies that the underlying processes in the brain are qualitatively different from those in more typical cases of skill acquisition through practice—generally these show decay if there is no continued practice to maintain the level of skill.

Improvement in MRT performance as a function of training is not a novel finding (e.g., McClurg & Chaillé, 1987). What is new here is that the improvement in MRT performance paralleled the improvement in UFOV and that the females realized greater gains in both tasks. This result supports our contention that MRT performance depends, at least in part, on lower-level capacities in spatial attention. Our study differs from previous training studies in another respect: Because our control group received a treatment (training on a non-action game), our results clarify the training effects of particular video games on MRT performance. Some previous studies found that video-game practice had little or no effect (e.g., Peters et al., 1995), implying that improved performance on spatial tasks after video-game practice may depend on the kinds of spatial abilities that are needed in the game and in the spatial task (Ogakaki & Frensch, 1994). Our data support this contention: We found no improvement in either UFOV or the MRT after training with a non-action game. Non-action games may be less likely to have a beneficial effect because they do not sufficiently exercise spatial attentional capacities.

Spatial abilities—including mental rotation ability—have been associated with success in mathematics and science courses (Delgado & Prieto, 2004), performance on standardized tests (e.g., the SAT; Casey, Nuttall, Pezaris, & Benbow, 1995), and the choice of mathematics and science as majors in college (Casey et al., 1995). Although superior performance on tasks of spatial ability, such as the MRT, is strongly associated with success in the mathematical and engineering sciences, one does not *cause* the other. Rather, both are supported by lower-level cognitive capacities, and our data suggest that selective attention and the ability to distribute attention spatially are critically important building blocks of spatial cognition. Our second experiment has shown that spatial attentional capacity and a higher-level spatial function may be improved simultaneously by appropriate training.

Superior spatial ability is related to employment in engineering and science (McGee, 1979), and females, who typically score lower than males on tests of spatial skills, are underrepresented in these fields, with worldwide participation rates as low as one in five. Given that our first experiment and others (e.g., Greenfield & Cocking, 1996; McGillicuddy-De Lisi & De Lisi, 2002) have shown that particular cognitive capacities are associated with educational and career choices, training with appropriately designed action video games could play a significant role as part of a larger strategy designed to interest women in science and engineering careers (Quaiser-Pohl et al., 2006). Non-video-game players in our study realized large gains after only 10 hr of training; we can only imagine the benefits that might be realized after weeks, months, or even years of action-video-gaming experience.

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