Archived at the Flinders Academic Commons:

http://dspace.flinders.edu.au/dspace/

This is the publisher’s copyrighted version of this article.

The original can be found at: http://www.bpsjournals.co.uk/journals/bjp/

© 2008 British Journal of Psychology

Published version of the paper reproduced here in accordance with the copyright policy of the publisher. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the publisher.
Spatial ability in secondary school students: Intra-sex differences based on self-selection for physical education

Michael Tlauka*, Jennifer Williams and Paul Williamson
School of Psychology, Flinders University, South Australia, Australia

Past research has demonstrated consistent sex differences with men typically outperforming women on tests of spatial ability. However, less is known about intra-sex effects. In the present study, two groups of female students (physical education and non-physical education secondary students) and two corresponding groups of male students explored a large-scale virtual shopping centre. In a battery of tasks, spatial knowledge of the shopping centre as well as mental rotation ability were tested. Additional variables considered were circulating testosterone levels, the ratio of 2D:4D digit length, and computer experience. The results revealed both sex and intra-sex differences in spatial ability. Variables related to virtual navigation and computer ability and experience were found to be the most powerful predictors of group membership. Our results suggest that in female and male secondary students, participation in physical education and spatial skill are related.

Sex differences in spatial ability are a widely reported phenomenon in the literature on human spatial cognition (Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995), with men typically outperforming women. The evolutionary development of sex differences has been accounted for in different ways. For example, Gaulin and Fitzgerald (1986, 1989) have suggested that in human evolutionary history, males tended to travel long distances in order to increase their chances of fathering offspring. In contrast, females are assumed to have inhabited relatively small home ranges. Other accounts focus on the division of labour between the sexes, with males being more likely to be involved in hunting and fighting (skills that rely on spatial awareness) and women being involved in the gathering of edible plants (Silverman, Choi, & Peters, 2007; see also Sherry & Hamson, 1997).

Although sex effects favouring men have received a great deal of empirical and theoretical attention, only a small number of investigations have examined intra-sex differences. Interestingly, recent findings have revealed variations in performance both within men (e.g. Manning & Taylor, 2001) and within women (e.g. Csatho et al., 2003),

*Correspondence should be addressed to Dr Michael Tlauka, School of Psychology, Flinders University, Adelaide, SA 5001, Australia (e-mail: michael.tlauka@flinders.edu.au).

DOI:10.1348/000712608X282806
suggesting that intra-sex effects are important to our understanding of visuospatial cognition. The aim of the current study was to further our knowledge of intra-sex effects, in particular the relation between spatial ability and participation in physical education (PE). Four groups of Australian secondary students were compared: girls who selected PE in either years 11 or 12 (henceforth referred to as PE girls); girls who decided not to pursue PE in school (non-PE girls); boys who selected PE (PE boys) and boys who did not (non-PE boys).

Tlauka, Brolese, Pomeroy, and Hobbs (2005) reported consistent sex differences on several tasks that tested spatial knowledge of a large-scale virtual shopping centre. In the current study, the students navigated through the same virtual environment employed by Tlauka et al. The participants' knowledge of the environment was subsequently assessed in a battery of spatial tests including route-learning and way finding. Given the large sex effects on tests of mental rotation (Voyer et al., 1995), a mental rotation task was also included. In addition, 2D:4D ratios were calculated and saliva samples were collected.

There is evidence that participation in sports activities may be related to spatial skill. For example, Manning and Taylor (2001) found that male professional footballers had lower second-to-fourth digit (2D:4D) ratios and scored higher on mental rotation tests by comparison with male non-footballers. Note that the term digit ratio is used for the proportion in length between the second and fourth digits of the human hand (the index and ring fingers, respectively). In women, the two digits tend to be of similar length resulting in a higher 2D:4D ratio, but in men, the second digit tends to be shorter than the fourth resulting in a lower ratio (e.g. Williams et al., 2000).

2D:4D ratios have been found to be negatively associated with prenatal testosterone (Manning, 2002) such that lower 2D:4D ratios are associated with increased prenatal testosterone levels. Prenatal testosterone levels may influence brain development thereby leading to sex-related differences in visuospatial abilities (Sanders, Bereczki, Csatho, & Manning, 2005). Csatho et al. (2003) investigated the relation between navigational abilities and 2D:4D ratios. These researchers observed that women with lower 2D:4D ratios excelled at spatial navigation through a Morris-type water maze by comparison with women with higher 2D:4D ratios (see also Kempel et al., 2005). In the present study, the assumption was made that prenatal testosterone exposure was related to spatial ability (Csatho et al., 2003) and sporting achievement (Manning & Taylor, 2001). More specifically, we assumed that high levels of prenatal testosterone (as indicated by low 2D:4D ratios) influenced brain development in the PE girls and PE boys enhancing visuospatial abilities and related skills such as sporting ability.

The results from several studies suggest that circulating testosterone levels are associated with spatial ability (e.g. Gouchie & Kimura, 1991; Kempel et al., 2005; Moffat & Hampson, 1996, Neave, Menaged, & Weightman, 1999), with low-androgen women displaying superior spatial performance than high-androgen women. As androgens (in particular, testosterone) have been related to performance on spatial tasks, saliva tests were sampled to provide a measure of circulating levels of free testosterone. Finally, a brief questionnaire required participants to provide information on computer experience and ability, a variable that has been shown to be related to spatial skill (e.g. De Lisi & Wolford, 2002; Quaiser-Pohl & Lehmann, 2002).

Our investigation differs from earlier work in several ways. Studies of spatial ability have principally focused on sex effects, with fewer investigations being concerned with intra-sex effects. With respect to within-sex effects little is known about the relation between participation in PE and spatial ability: while some earlier work
suggests that sports attainment and spatial ability are related in men (e.g. Manning & Taylor, 2001), to our knowledge, there are no comparable studies of both within-male and within-female differences. In order to examine intra-sex effects, we examined not only performance on a mental rotation task, but also on tests of knowledge derived from navigation through large-scale (virtual) environments. Navigation through computer-simulated environments has been shown to be comparable to real-world navigation (Waller, Hunt, & Knapp, 1998; Wilson, Foreman, & Tlauka, 1997). Finally, a comparison of teenagers will inform us as to whether intra-sex differences in spatial ability occur in amateur sportspersons (none of the students in our sample were involved in professional sports) rather than elite sportspersons (as shown in men by Manning & Taylor, 2001).

The aim of the present study was to examine intra-sex differences in spatial ability based on self-selection for PE. We expected sex and intra-sex differences in self-rated computer ability, in terms of hours spent on computer games, and in the tests of participants' spatial knowledge of the virtual environment (as well as in the mental rotation test). Our hypothesis was that on the majority of tasks, the boys would display the highest level of performance (Voyer et al., 1995). The question of primary interest was whether participation in PE would facilitate performance resulting in intra-sex effects based on self-selection for PE. A consideration of the 2D:4D scores and the analysis of the saliva samples allowed an investigation of the relation between inferred prenatal and circulating levels of testosterone and spatial skill.

Method

Participants
Seventy-eight secondary students (26 female PE students, 26 female non-PE students, 14 male PE students, 12 male non-PE students) participated in the study (range: 15–18 years). The volunteers were recruited from an Adelaide secondary school where they attended either year 11 or 12. At the school all students are required to undertake PE as a year 10 subject. However, in years 11 and 12, students are free to discontinue PE. Fewer female than male students tend to carry on with PE, and according to anecdotal reports from teachers in the school those students who continue commonly have a higher degree of sporting ability by comparison with students not choosing PE.

Virtual environments
The participants were presented with virtual environments that were run on a Dell personal computer with 768 SD-RAM (at 1,600 Mhz). The simulated environments (a pre-training environment and two versions of a shopping centre) were the same as those employed by Tlauka et al. (2005), and they were displayed on a 17-inch monitor with a resolution of 1,400 × 1,050 pixels. The pre-training environment consisted of a single room, which provided participants the opportunity to practice manoeuvring around objects. Movement throughout each virtual environment was continuous when participants pressed a specified key on a QWERTY keyboard (O = forward movement, K = backward movement, Q = left rotation, W = right rotation). Movement immediately stopped as soon as the key was released.

Each of the two simulated shopping centres consisted of 14 shops of different sizes and shapes that were linked by corridors (see for example Figure 1). There were 6
objects, which were placed in 6 of the 14 shops (see Figure 2 for a screenshot of one of the virtual shops). The targets differed in colour and shape (e.g. a purple cube, a black star, a yellow sphere), with different sets of objects being presented in the two shopping centres. A black star was the only target located within both environments. The environments also contained fourteen virtual people (one in each shop). The participants were also presented with a digital map of the virtual shopping centre (approximately 6.5 × 9 cm in size) that was presented in the top left corner of the computer screen. The participants navigated through the simulated environment using the digital map. An unbroken blue line specified the initial route of travel, and a beacon (red dot) continually displayed and updated the participant’s location within the environment. The size of the window on the VE (excluding the digital map) was always approximately 15.5 × 26 cm.
Introduction

Figure 2. A screenshot showing a target object, the cone, in one of the simulated shops. The digital map is shown in the top left corner. The beacon indicating the current position is also shown.

Procedure

All participants were asked to indicate (to the nearest hour) the numbers of hours per week they spent on organized sporting activities, and the number of hours spent playing computer games. Further, using a 7-point Likert-type scale, they were asked to assess their computer ability.

2D:4D ratios

The length of the index and ring fingers was measured in millimetres for each hand (from the basal crease to the top of the finger). Measurements were taken directly from the hands of the participants employing a ruler with millimetre markings. Measurements were taken by the experimenter, with the school doctor observing the measurements to ensure accuracy.

Saliva sample collection

Saliva collection was carried out by the school doctor. The students were asked to report to the school centre between 8.30 am and 10.30 am. The morning time slot was selected in order to control for circadian variation in testosterone (Diver, Intizaz, Ahmad, Vora, & Fraser, 2003). The first day of the female participants’ last menstrual cycle was determined. The students were instructed not to clean their teeth 30 minutes prior to collection and to avoid lip gloss and lip stick. To increase saliva production, all students rinsed their mouth with water and chewed a small square of paraffin. The students were asked to fill a sterile test tube (5 ml), and the saliva sample (at least 1.5 ml) was frozen before being stored for assay (using a commercially available ‘Salimetrics’ testosterone kit that is designed for the quantitative measurement of free salivary testosterone).
Testing was conducted by the Obstetrics and Gynaecology Department at the University of Adelaide.

Pre-training
All four groups of students familiarized themselves with the keyboard in the training environment. The pre-training session was timed, and the students were allowed as much time as they considered necessary to acquire the skills essential for virtual navigation. Each participant was tested individually.

Initial navigation
Participants were instructed to navigate as quickly as possible through one of the two simulated shopping centres following the designated route that was indicated on the digital map (Figure 2). The students navigated through the environment on one occasion only. For each group, half of the students were presented with one of the shopping centres and the remaining students with the other. Further, for each shopping centre, two start locations (A, B) were used, with half of the participants starting at the former and half at the latter location. During initial navigation, participants who veered off the route were stopped by the researcher before being directed back on course. The exploration session was timed, and the number of incorrect navigational decisions was recorded. The students were informed that whilst navigating, they would encounter six objects. It was their task to remember the location of each object. When participants saw the black star (see Figure 1), it was emphasized that the star was the location from which their spatial knowledge would be tested at a later stage of the experiment.

Tests of spatial knowledge
Initial navigation was followed by three tests of spatial knowledge (presented in a counterbalanced order in each group): a direction estimate task; a way finding task; and a map placement task:

(1) Direction Estimates. Participants were placed where the black star was located in the virtual shopping centre (hereafter referred to as the test location), and their viewpoint was rotated 360°. Note that at this stage of the experiment the star was removed from the simulated environment. Participants were then asked to indicate the direction of the five remaining objects (other than the black star). This was done by marking the appropriate location on a drawing of a circle (radius: 5 cm). The facing direction (shown on the computer screen) was marked on the circle by a line at the 12 o’clock position. The task was to indicate the direction towards the target objects on the circle. Separate recording sheets were employed for the individual judgments, and the time taken by participants to indicate the direction of an object was unobtrusively recorded using a hand-held stopwatch. Each direction estimate was timed from the moment the experimenter named the object to the response. The order in which the objects were tested was random across participants. Each direction estimate was to be performed as quickly and accurately as possible. For a similar directional task see Tlauka and Nairn (2004).

(2) Way Finding. The participants were instructed to navigate back from the test location to their start location (A or B) as quickly as possible, but without the assistance of the digital map. The time taken to do so was measured.
(3) **Map Placement.** A map of the virtual shopping centre was presented. The map showed the walls of the 14 shops, but did not contain any information regarding the target locations. The task was to indicate the location of the target objects.

**Mental rotation test**

In each group, for half of the students the mental rotation test was performed prior to the presentation of the tests of spatial knowledge described above, while for the remaining students it was performed immediately thereafter. In this computer-based mental rotation test (see Kemps & Newson, 2005), two shapes were shown next to each other on the computer screen. The shape on the left was always displayed upright. The shape on the right was identical to the one on the left or a mirror-reversed version, and the shape on the right was rotated relative to the orientation of the shape on the left (the rotations were 0°, 45°, 90°, 135°, or 180° clockwise). The students indicated whether the shape displayed on the right could be mentally rotated to match the shape shown on the left. Four practice trials (allowing participants to familiarize themselves with the test) were followed by 40 experimental trials. The ‘Z’ key on the keyboard was labelled ‘Y’ for ‘Yes’ and the ‘?’ key was labelled ‘N’ for ‘No’. Task instructions emphasized both speed and accuracy.

**Results**

In a study of spatial learning in virtual environments, Waller (2000) found that sex mainly affected spatial task performance through its relation with interface proficiency. In this study, the pre-training session (in an unrelated environment) was timed (for a similar procedure see Tlauka et al., 2005) with the students being allowed as much time as they considered necessary to acquire the skills essential for virtual navigation. The potential influence of individual differences in keyboard skills on performance was controlled by including training time (the time it took participants to familiarize themselves with the keyboard in the pre-training environment) as a covariate in analyses of covariance (ANCOVAs). Training was found not to be a significant covariate in any of the analyses, and preliminary analyses of the data indicated that the results of the ANCOVAs were similar to standard analyses of variance (ANOVAs) that did not consider training time. For all analyses an alpha-level of .05 was adopted, and the independent variables were gender (girls, boys) and PE status (PE, non-PE). The magnitude of the significant and marginally significant effects is indicated by partial eta squared (\(\eta_p^2\)). Table 1 presents a summary of the results.

**Sporting hours**

The results revealed significant differences in hours of organized sport between girls (\(M = 4.83, SD = 2.03\)) and boys (\(M = 6.35, SD = 2.88\)), \(F(1, 73) = 6.63, p < .05, \eta_p^2 = .08\), and between those engaged in PE (\(M = 7.43, SD = 2.56\)) and those not enrolled in PE (\(M = 3.13, SD = 2.66\)), \(F(1, 73) = 38.51, p < .001, \eta_p^2 = .35\). However, there was also a significant gender by PE interaction, \(F(1, 73) = 13.50, p < .001, \eta_p^2 = .16\). Bonferroni \(t\) tests (\(p < .05\) here and in all following comparisons) revealed a significant difference only for girls with non-PE girls engaged in fewer organized sporting hours than the PE girls (see Table 1). There was no significance difference between the PE and non-PE boys. Inspection of the means in Table 1 reveals a broader pattern that it was the non-PE girls who engaged in fewer organized sporting hours than either the PE girls or the boys.
Table 1. Unadjusted mean scores as a function of sex and PE status. Standard deviations are shown in parentheses.

<table>
<thead>
<tr>
<th>Task</th>
<th>Female</th>
<th></th>
<th>Male</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PE</td>
<td></td>
<td>Non-PE</td>
<td></td>
<td>Non-PE</td>
<td></td>
</tr>
<tr>
<td>Sporting hours</td>
<td>7.65 (2.39)</td>
<td>2.00 (1.67)</td>
<td>5.58 (2.81)</td>
<td>7.00 (2.88)</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Computer ability</td>
<td>5.15 (0.78)</td>
<td>4.46 (1.07)</td>
<td>4.83 (0.72)</td>
<td>4.71 (0.61)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Computer gamehours (per week)</td>
<td>0.58 (1.17)</td>
<td>0.35 (0.98)</td>
<td>3.00 (3.62)</td>
<td>1.64 (2.50)</td>
<td>**</td>
<td>NS</td>
</tr>
<tr>
<td>Initial navigation (seconds)</td>
<td>614.12 (114.56)</td>
<td>638.92 (89.28)</td>
<td>498.00 (53.39)</td>
<td>507.21 (81.22)</td>
<td>**</td>
<td>NS</td>
</tr>
<tr>
<td>Initial navigation (number of errors)</td>
<td>1.62 (1.55)</td>
<td>2.35 (1.47)</td>
<td>1.17 (1.34)</td>
<td>1.14 (1.23)</td>
<td>**</td>
<td>NS</td>
</tr>
<tr>
<td>Way finding (seconds)</td>
<td>313.42 (191.41)</td>
<td>418.69 (260.86)</td>
<td>236.67 (97.43)</td>
<td>242.79 (208.44)</td>
<td>**</td>
<td>NS</td>
</tr>
<tr>
<td>Direction estimates (seconds)</td>
<td>7.77 (3.61)</td>
<td>8.75 (3.97)</td>
<td>7.63 (3.08)</td>
<td>7.72 (4.74)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Direction estimates (error scores)</td>
<td>63.38 (27.59)</td>
<td>64.01 (36.41)</td>
<td>52.17 (26.38)</td>
<td>61.93 (31.59)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Map placement (error scores)</td>
<td>21.16 (17.98)</td>
<td>27.75 (17.38)</td>
<td>25.48 (16.95)</td>
<td>22.55 (17.69)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Mental rotation (number correct)</td>
<td>34.73 (6.48)</td>
<td>29.00 (9.36)</td>
<td>34.42 (5.47)</td>
<td>31.71 (8.44)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Mental rotation (seconds)</td>
<td>3.55 (1.33)</td>
<td>3.17 (1.69)</td>
<td>2.99 (0.76)</td>
<td>2.93 (1.36)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Digit ratios (right hand)</td>
<td>0.97 (0.04)</td>
<td>1.00 (0.03)</td>
<td>0.98 (0.05)</td>
<td>0.96 (0.03)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Digit ratios (left hand)</td>
<td>0.97 (0.04)</td>
<td>0.99 (0.05)</td>
<td>0.98 (0.05)</td>
<td>0.96 (0.03)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Digit ratios (both hands)</td>
<td>0.97 (0.03)</td>
<td>1.00 (0.04)</td>
<td>0.98 (0.04)</td>
<td>0.96 (0.03)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Testosterone levels (pg/ml)</td>
<td>94.37 (51.15)</td>
<td>106.44 (79.69)</td>
<td>98.13 (37.39)</td>
<td>74.31 (35.55)</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note. PE, physical education; NS, not significant; *trend; **p < .05.
**Computer ability and game hours**

The results revealed significant differences in computer game hours between girls ($M = 0.46$, $SD = 1.08$) and boys ($M = 2.27$, $SD = 3.08$), $F(1, 73) = 16.80$, $p < .001$, $\eta_p^2 = .19$. The interaction approached significance ($F(1, 73) = 3.73$, $p = .057$, $\eta_p^2 = .05$). Computer games hours were similar for PE girls and non-PE girls while the trend for boys reflected greater time spent playing computer games by non-PE boys (see Table 1). There were no significant effects for self-rated computer ability.

**Tests of spatial knowledge**

There were significant gender main effects for initial navigation time ($F(1, 73) = 24.48$, $p < .001$, $\eta_p^2 = .28$), navigational errors ($F(1, 73) = 6.18$, $p < .05$, $\eta_p^2 = .08$), and way finding time ($F(1, 73) = 5.84$, $p < .05$, $\eta_p^2 = .07$). The boys, relative to the girls, completed the initial navigation task more quickly (boys - $M = 502.96$, $SD = 68.60$; girls - $M = 626.52$, $SD = 102.46$), made fewer errors (boys - $M = 1.15$, $SD = 1.26$; girls - $M = 1.98$, $SD = 1.54$), and were faster on the way-finding task (boys - $M = 239.96$, $SD = 163.64$; girls - $M = 366.06$, $SD = 232.68$). No other effects approached significance. Furthermore, there were no significant effects for direction accuracy, direction latency scores, or the map placement task.

There were no main effects of gender or PE status for mental rotation accuracy, but there was a significant interaction ($F(1, 73) = 5.87$, $p < .05$, $\eta_p^2 = .07$). Bonferroni $t$ tests revealed a significant difference only for girls with PE girls being more accurate than non-PE girls (see Table 1). There was no significance difference between the PE and non-PE boys. In contrast, no significant effects were found for mental rotation time.

**Digit ratios and testosterone levels**

Significant PE main effects were found for both right hand 2D:4D ratio scores ($F(1, 73) = 5.75$, $p < .05$, $\eta_p^2 = .07$) and the combined (left and right) hand 2D:4D ratio scores ($F(1, 73) = 6.16$, $p < .05$, $\eta_p^2 = .08$). A marginal PE main effect was found for left-hand 2D:4D ratio scores ($F(1, 73) = 3.74$, $p = .057$, $\eta_p^2 = .05$). For all analyses, those enrolled in PE (right hand - $M = 0.97$, $SD = 0.03$; left hand - $M = 0.97$, $SD = 0.03$; combined hand - $M = 0.97$, $SD = 0.03$) had lower 2D:4D ratios by comparison with those not enrolled in PE (right hand - $M = 0.99$, $SD = 0.04$; left hand - $M = 0.99$, $SD = 0.05$; combined hand - $M = 0.99$, $SD = 0.04$). There were no significant gender main effects or interaction effects for 2D:4D ratio scores although the gender main effect for right-hand digit ratio scores approached significance ($F(1, 73) = 2.94$, $p = .09$, $\eta_p^2 = .04$). There was a trend towards higher right hand 2D:4D ratio scores for girls ($M = 0.99$, $SD = 0.04$) in comparison to boys ($M = 0.97$, $SD = 0.04$). There were no significant effects for testosterone levels.

**Discriminant function analysis**

The previous ANCOVA results revealed several intra-sex and sex differences. These analyses showed that a number of the variables were good discriminators between the groups. However, many of these variables were correlated indicating that the discrimination power of some of these variables may be spurious due to sharing common variance with another discriminating variable. To take this possibility into account, a direct discriminant function analysis (DFA) was undertaken using all of
the dependent variables identified as showing significant group differences in the preceding ANCOVAs. Training time was also included as a covariate. Note that organized sporting hours was not entered into the discriminant function analyses because this variable represented a proxy for the way the two groups were defined (particularly in relation to PE status for girls).

Two discriminant functions were identified in the DFA, combined \( \chi^2(24) = 71.29, p < .001 \). After removal of the first function, the association between predictors and groups was still significant, \( \chi^2(14) = 29.64, p < .01 \), but was not significant after the further removal of the second function, \( \chi^2(6) = 5.16, p > .05 \). Function 1 accounted for 62.1% of the variance in scores whilst function 2 explained an additional 32.0% of the variance.

As shown in Figure 3, the first discriminant function maximally discriminates the non-PE girls (group centroid at 1.09 on function 1) from the boys (PE: group centroid at -.87; non-PE: group centroid at -1.21), with the PE girls (group centroid at -.07) lying between these two groups. The loading matrix of correlations between predictors and functions showed that the best predictor for distinguishing between non-PE girls and boys was initial navigation time (.67). Computer game hours (-.47), way finding time (.40), navigational errors (.39), and right hand 2D:4D ratio (.38) were marginal discriminators. The second discriminant function discriminates the PE girls (group centroid at .88 on function 2) from the other three groups (non-PE girls: group centroid at -.40; PE boys: group centroid at -.39; non-PE boys: group centroid at -.58). Self-rated computer ability (.46) was the predictor that best distinguished the PE girls from

![Figure 3. Group centroids and cases as a function of two canonical discriminant functions derived from spatial ability performance, computer skills, and gender-related variables.](image-url)
the other three groups, although initial navigation time (40) and mental rotation accuracy (33) were marginal discriminators.

The classification results showed that all groups were classified at an accuracy rate greater than chance. Given the unequal sample sizes, chance classification rates were 33%, 33.3%, 17.9%, and 15.4% for the PE girls, non-PE girls, PE boys, and non-PE boys, respectively. For all four groups, the classification rate exceeded chance levels although classification relative to chance was better for the girls than the boys: PE girls (65.4% using jack-knifed classification); non-PE girls (57.7%); PE boys (21.4%); and non-PE boys (25.0%). Overall, 48.7% of cases were classified correctly using jack-knifed classification analysis, which compares favourably with chance (25%). In general, misclassification rates were relatively low except for non-PE boys misclassified as PE boys (33.3%) suggesting a greater difficulty in differentiating the boys on the basis of PE status. In fact, the third function differentiated the boys on the basis of PE status but was not statistically significant.

Discussion
Visuospatial ability in female and male secondary students was compared. The students differed in terms of whether they had enrolled in PE as a school subject. Figure 3 illustrates the results of the DFA: differences in the initial navigation task and computer game hours (function 1) mainly discriminated between the boys and the non-PE girls, while self-rated computer ability and initial navigation time (function 2) was found to discriminate between the PE girls and the other groups. The findings indicate that the groups were distinguishable on the basis of their performance in the tests.

The purpose of the study was to investigate the relation between participation in PE and spatial ability. The observed intra-sex effects were of primary interest. Employing a relatively small sample size, the effect sizes relating to differences between PE students and non-PE students explained between 5% and 35% of the variance. The PE girls were found to be more accurate on the mental rotation test by comparison with the non-PE girls (the difference between PE boys and non-PE boys did not reach significance). Relative to the non-PE groups, the PE groups had lower right (and combined) hand 2D:4D ratios. Overall, the 2D:4D ratios obtained were similar to those reported in earlier studies (e.g. Kempel et al., 2005), and our results are in agreement with some prior investigations showing that right hand 2D:4D ratios can be a more sensitive measure than left hand 2D:4D ratios (Williams et al., 2000; but for conflicting results see Kempel et al., 2005).

Prenatal levels of hormones are assumed to affect spatial abilities in adulthood (Csatho et al., 2003). Within the present sample of secondary students some individuals (the PE girls and PE boys) had relatively low 2D:4D ratios. Assuming that 2D:4D ratios are an indirect measure of prenatal testosterone (Manning, 2002), the superior visuospatial cognition performance of the PE groups may have been the result of unusually high prenatal levels of testosterone in utero. Note that high testosterone levels support the growth of the right hemisphere thereby enhancing visuospatial skills (Geschwind & Galaburda, 1985; for a similar argument see also Manning & Taylor, 2001). Thus, one account consistent with the present findings is that high levels of prenatal testosterone, expressed in low 2D:4D ratios, promoted the growth of the right hemisphere in the PE girls and PE boys resulting in superior visuospatial abilities and related skills such as sporting ability.
Manning and Taylor (2001) argue that spatial ability in men is related to physical competitiveness and sports achievement. Our results are consistent with the assumption that sports participation and spatial ability are related in both men and women. The finding that intra-sex effects were found in adolescent girls and boys rather than professional sportsmen is worthy of note. Presumably, the professional footballers tested in Manning and Taylor's study had a higher level of sporting skill by comparison with our PE students. To date the available evidence suggests that sports attainment and spatial skill are related. More specifically, (1) intra-sex differences in spatial ability occur in elite as well as (adolescent) amateur sportspersons and (2) sports-related sex differences arise in both women and men. Note that the conclusion assumes that in the present study, the source of the intra-sex differences is related to sporting ability, with PE students having a higher level of sporting ability than non-PE students. While not providing direct evidence, the finding that the PE girls spent more time on organized sporting activities relative to the non-PE girls (and the PE boys tended to report more time than the non-PE boys) is consistent with this assumption (Table 1).

In agreement with earlier work (Linn & Petersen, 1985; Voyer et al., 1995), sex effects in spatial ability were found, with the boys outperforming the girls in the initial navigation task as well as in the wayfinding test. Further, relative to the female groups, the male students reported spending more time per week on computer games. However, on some of the tasks in which significant differences were observed (mental rotation errors, 2D:4D ratios), the PE girls and the PE boys did not differ. In other words, had we examined only the PE girls and the PE boys, in a number of comparisons we would have obtained a lack of significant sex differences. Clearly, sex effects can be influenced by the composition of the female sample with which male samples are compared (and vice versa).

Computer ability and experience were significant predictors in the DFA, a finding that is consistent with prior investigations showing that computer experience and spatial ability are related (e.g. De Lisi & Wolford, 2002; Quaiser-Pohl & Lehmann, 2002). Contrary to expectations, circulating levels of testosterone did not affect performance. It is possible that the type of test used to examine testosterone levels lacks reliability (Hagen, Gott, & Miller, 2003; Zitzmann & Nieschlag, 2001). Note that in this study, mental rotation accuracy was associated with intra-sex effects (differences between PE girls and non-PE girls), while, typically, mental rotation tests are associated with sex effects only (e.g. Collins & Kimura, 1997).

Sex effects were apparent in the students' knowledge of the large-scale virtual environment. Initial navigation time in the simulated environment was found to discriminate between the non-PE girls and the boys suggesting that in investigations of spatial ability, spatial tasks examining allocentric knowledge acquired in large-scale environments need to be considered as well as abstract tests such as mental rotation (see also Csatho et al., 2003).

To conclude, the present findings are consistent with the notion that participation in PE and visuospatial ability are related: intra-sex differences in female and male secondary school students were found to arise on the basis of self-selection for PE. The findings demonstrate that sports-related within-sex effects can occur in amateur sportspersons. Our results have implications for sex effects suggesting that sex effects can be influenced by the composition of the female/male samples. Overall, our results along with those from previous investigations highlight the importance of a consideration of both sex and intra-sex effects in studies of spatial ability.
References


Received 23 May 2007; revised version received 14 January 2008