Journal of Environmental Psychology 43 (2015) 136–144

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

Factors related to sex differences in navigating a computerized maze

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ARTICLE INFO

Article history:
Received 29 September 2014
Received in revised form
12 June 2015
Accepted 17 June 2015
Available online 20 June 2015

Keywords:
Sex difference
Navigation
Spatial anxiety
Map drawing
Heading direction estimation

ABSTRACT

The aim of this study was to compare computerized maze navigation performance and strategy by sex, and to investigate the relationships between navigation variables and self-reported experiential or personality dimensions. Participants used a joystick to explore a maze and were told to learn the layout of the maze as well as the locations of six objects within the maze. Men outperformed women, but some of the sex differences decreased in magnitude when we accounted for video game experience. Men were more likely than women to report strategies consistent with using an allocentric perspective to solve the maze, whereas women were more likely than men to report strategies consistent with an egocentric approach. We report several factors associated with successful navigation in a computerized maze, some of which relate to real life navigation and may contribute to the sex differences often reported for measures of spatial cognition.

1. Introduction

Contributions to the variability in human spatial behavior are manifold. Evolutionary (e.g. for review, see Silverman & Choi, 2005; Silverman, Choi, & Peters, 2007), developmental (e.g., for reviews, see Bohbot et al., 2012; Moffat, 2009; Voyer, Voyer, & Bryden, 1995), physiologic (e.g., for review of hormonal effects, see Hampson, 2008), and experiential/social (e.g., for review, see Hyde, 2014) influences on spatial behavior have all been demonstrated. Here we present a comprehensive investigation of sex differences in computerized maze navigation performance, self-reported maze navigation strategy, and real-life navigation-related experiential factors, which have all been previously investigated in their own right but to the best of our knowledge not in the same study. Considering these factors within the same study will allow us to address the ongoing yet unresolved investigation into the factors contributing to the male advantage in spatial performance. Specifically, the present study will allow us to better understand the relationships between performance in a controlled, laboratory spatial task and compare it to how people report to think or behave in large-scale environments in their daily lives.

Men reliably outperform women on tests of navigation, whether in real-world or computerized environments (Coluccia & Louse, 2004). In a review of sex differences in wayfinding abilities that spanned 20 years of literature, Coluccia and Louse (2004) reported a male advantage in at least 57% of the published reports. Navigation tasks based on maps (e.g., map drawing, verbal description of a route, recall of landmarks or streets) produced a male advantage in 42% and a female advantage in 18%of the studies. A male advantage was observed in approximately 59% of studies requiring men and women to navigate real environments such as woods, buildings, and university campuses. Of the simulated navigation studies, which required participants to actively traverse computerized environments, a significant male advantage was reported in nearly 86% of the studies.

Common simulated environments include computerized analogs of mazes traditionally used in non-human research, such as the Morris water task (MWT; Morris, 1984) which requires rodents to swim to a platform submerged in an opaque pool of water based on the configuration of external cues, or the multiple T-maze (e.g., Tolman, 1948) which requires rodents to find their way from a start to a goal position using either a place or response strategy. Humans view a virtual MWT (vMWT) on a computer screen and use various cues in the maze to locate the hidden platform by maneuvering through the pool with a joystick or keyboard. Time and distance to locate the hidden platform across learning trials, time and distance spent in the platform quadrant during the probe trial, and platform area crossings during the probe trial have all been used to describe performance. A sex difference favoring men is often present in hidden platform and probe trials (Astur, Ortiz, & Sutherland, 1998; Burkitt, Widman, & Saucier, 2007; Driscoll, Hamilton, Yeo, Brooks,

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http://dx.doi.org/10.1016/j.jenvp.2015.06.007

& Sutherland, 2005; Mueller, Jackson, & Skelton, 2008; Nowak & Moffat, 2011; Nowak, Diamond, Land, & Moffat, 2014; Sandstrom, Kaufman, & Huettel, 1998). Men typically locate the hidden platform across trials using less distance and time than women, spend more time and travel a greater distance within the goal quadrant during the probe trial than women, and cross the platform area during the probe trial more frequently than women.

Virtual corridor mazes generally include a start location, interconnecting corridors with multiple decision points, and a goal area (e.g., Moffat, Hampson, & Hatzipantelis, 1998). Errors, time to navigate from start to goal, and number of trials to criterion are commonly use to assess performance. Similarly to performance on vMWT, men commit fewer errors and complete the corridor mazes faster than women (e.g., Grön, Wunderlich, Spitzer, Tomczak, & Riepe, 2000; Moffat et al., 1998; Moffat, Zonderman, & Resnick, 2001).

Sex differences in spatial performance may be partially attributable to differential use of navigation strategies. Research commonly distinguishes two navigation strategies: egocentric, in which the self is the reference point for navigating based on self-landmark relationships (e.g., left and right turns); and allocentric, a viewer-independent conceptualization of the environment which affords knowledge of the relationships between multiple distal landmarks (for reviews of navigation strategies, see, e.g., Burgess, 2008; Klatzky, 1998; O'Keefe & Nadel, 1978). A number of investigations have supported the argument that men prefer allocentric strategies while women prefer egocentric strategies (e.g., Choi & Silverman, 1997; Coluccia & Louse, 2004; Dabbs, Chang, Strong, & Milun, 1997; Galea & Kimura, 1993; Lawton, 1994; Levy, Astur, & Frick, 2005; MacFadden, Elias, & Saucier, 2003; Malinowski & Gillespie, 2001; Sandstrom et al., 1998; Saucier et al., 2002; Ward, Newcombe, & Overton, 1986), while others have presented evidence against this claim (Andersen, Dahmani, Konishi, & Bohbot, 2012; Bohbot et al., 2012; van Gerven, Schneider, Wuitchik, & Skelton, 2012; Goeke, König, & Gramann, 2013; Hund & Nazarczuk, 2009; Iaria, Petrides, Dagher, Pike, & Bohbot, 2003; Rodgers, Sindone, & Moffat, 2012). There is evidence that women perform best when using an egocentric strategy, whereas men are adept at using both strategies. For example, men used distal geometric cues to locate the hidden platform in a vMWT whereas women performed better when stable landmarks were available to aid relocation of the hidden platform (Sandstrom et al., 1998). Likewise, women given Euclidean-based instructions to navigate a university campus made more errors than men, and more errors than women who were given landmark-based navigation instructions (Saucier et al., 2002). Although a sex difference in strategy preference was not observed in a study by van Gerven et al. (2012), their findings support the notion that even when women choose an allocentric strategy they may not be as successful as men at using that strategy.

In addition to a reliable effect of sex on laboratory tests of spatial performance, sex differences also exist in everyday spatial behavior and cognition. Men report a preference for orientation-based (e.g., cardinal directions), whereas women report a preference for route-based (e.g., left-right turns) wayfinding strategies (e.g., Lawton, 1994). Men score lower than women on measures of environmental navigation-related anxiety (Bryant, 1982; Castelli, Corazzini, & Giuliano, 2008; Gabriel, Hong, Chandra, Lonborg, & Barkley, 2011; Lawton, 1994; Lawton & Kallai, 2002; Malinowski & Gillespie, 2001; and Schmitz, 1997). Higher scores by men indicate they have a greater self-reported environmental spatial ability (e.g., sense of direction) than women (e.g., Turano et al., 2009). Men also tend to have more video game experience than women (e.g., Astur et al., 1998; Lawton & Morrin, 1999; Moffat et al., 1998; Richardson & Collear, 2011; Schmitzer-Torbert, 2007; Terlecki et al., 2011; van Gerven et al., 2012; cf. Daugherty et al., 2014; Driscoll et al., 2005; Levy et al., 2005.

2. Present study

The general aim of this study was to compare navigation performance and self-reported navigation strategy by sex in a novel environment. Specifically, we hypothesized that better performance in our computerized maze would require allocentric encoding. Further, we predicted that men would outperform women and be more likely to report using strategies that could be classified as allocentric.

The secondary aim was to investigate the associations between virtual navigation and self-reported experiential (video game experience, spatial anxiety, wayfinding strategy, and sense of direction) or personality (competitiveness) dimensions. We hypothesized that navigation-related experiential variables, spatial anxiety, and competitiveness would differ by sex and relate to maze navigation outcomes. Specifically, we predicted that men would be more competitive and less anxious than women, and that men would score higher on measures of environmental spatial ability. We predicted that higher self-reported environmental spatial ability and competitiveness, and lower spatial anxiety, would correlate with better maze performance.

3. Method

3.1. Participants

Participants were 50 undergraduate college students (21 men; 29 women) who were compensated with extra credit for a course. The mean age of the sample was 22.06 ($SD = 3.99$) years. The average college educational attainment was commensurate with a junior level standing. 62.8% of the sample identified as White or Caucasian; 14% as Black or African American; 11.6% as Asian; 7% as Hispanic; and 4.7% as Native American.

3.2. Navigation tasks

All virtual environments were designed using Unreal Tournament 2003 and Unreal Editor software (Epic Games Inc., Rockville, MD, USA). Participants viewed all virtual assessments on a 27.5″ flat panel LCD monitor, and controlled their movement through the virtual environments with a joystick. Software automatically collected (x,y) path coordinates every 10 ms, which it used to calculate distance and create a diagram of the participants' movement paths.

The maze used in this study is similar but not identical to the one developed and used by Moffat, Elkins, and Resnick (2006) in a study of the functional neuroanatomical correlates of allocentric spatial navigation. Like the Moffat et al. (2006) study, our participants were instructed to actively explore a virtual maze and learn the location of six objects, the interconnections of the hallways, and the general layout of the maze such that they could draw a map of the environment if asked to do so. The recall test used in the present study is also similar to the recall test of Moffat et al. (2006). The present study added assessments of free-hand map drawing, object location memory, heading direction, and self-reported strategy.

Participants received training in a general practice environment to familiarize them with the interface and use of a joystick. During practice, participants were instructed to move from object to object in a large square room containing five objects, and to follow a long winding hallway until they reached a flag at the end.

The testing maze was a combination of interconnected hallways and small rooms, where there were six common objects placed throughout (Figs. 1 and 2): a tree, flag, wheel, fire extinguisher, column, and bowl. Five of the six objects are located at the distal ends of the hallways, and a sixth object, the column, is located in the top right corner of the central rectangular room. During the 5-min exploration phase participants were instructed to actively explore the virtual maze and learn the location of six objects, the interconnections of the hallways, and the general layout of the maze such that they could draw a map of the environment if asked to do so. The specificity of these instructions presumably encouraged allocentric encoding. Outcome variables included the number of times objects were encountered and speed of movement.

After completing the exploration phase participants were told to draw a map of the maze on a blank American standard 8.5″ by 11″ piece of paper and then rate the level of confidence they had in their map on a scale from 1 (not at all confident) to 5 (completely confident). A map score was calculated based on the accuracy of the hallways, rooms, connections, and object placement. A higher score indicates greater accuracy. Appendix A explains the map scoring procedure in more detail.

The 5-min recall phase required participants to remember and actively navigate to the locations of the six objects encountered during the encoding phase and to move from object to object as quickly and as accurately as possible using the shortest possible route. When the participant approached an object, a directive appeared noting the next object in sequence to which they were to navigate using the shortest possible route. Upon approaching the second object, another directive appeared and so on (Fig. 1). Outcomes included the number of correct hits and speed of movement. Correct hits were defined as the number of objects correctly located during the recall phase.

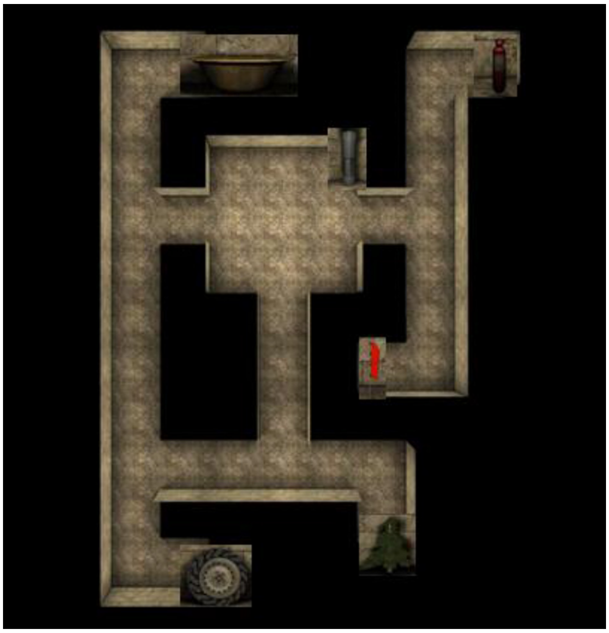

Fig. 2. Enlarged picture of the maze from an overhead perspective, with the six objects (wheel, tree, flag, fire extinguisher, column, and bowl) overlaid from a first-person perspective.

After the recall phase, the experimenter recorded participants' answers to two open-ended questions about their strategy: How did you learn the locations of the 6 objects in the maze? How did you learn the overall layout of the environment? Responses were later coded into dichotomous (yes/no) strategy variables by two raters: use of a mental map, learning the relationships between landmarks, using left-right turns, using the column as a central landmark, and focusing on the sections within the maze. These categories were created as a result of the self-reported strategy. Based on definitions of allocentric and egocentric, use of a mental map was interpreted as allocentric and use of left-right turns was interpreted as egocentric. Learning relationships between

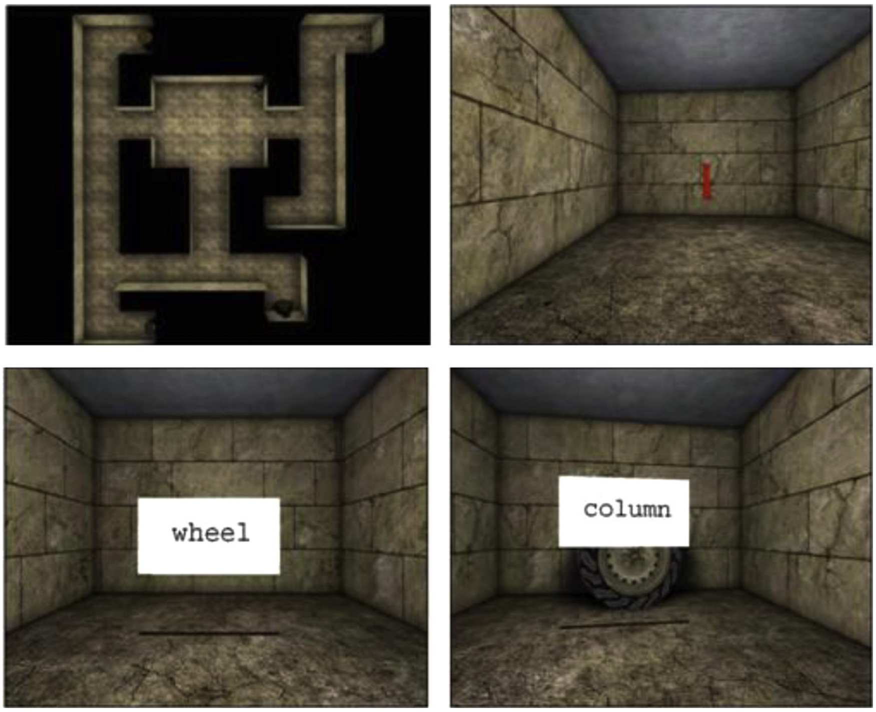

Fig. 1. Top Left: Overhead view of the virtual maze. Top Right: One of the six objects (flag) at the end of a hallway. Bottom: Sequence of directives that pop up during the recall trials. When wheel" appears, the participant knows they must travel to the wheel using the shortest route.

landmarks, and use of the column as a central landmark could also be classified as egocentric. Appendix B provides a sample of participants' responses and how they were coded by the experimenters.

Next, participants were given a 8.5″ by 11″ overhead map of the maze with all of the objects covered with the numbers 1 through 6 and told to match the numbers with the objects (e.g., 1 = tree, 2 = wheel). The dependent variable was the number of correct responses. They were asked to rate their level of confidence on a scale from 1 (not at all confident) to 5 (completely confident) in placing the objects correctly on the map.

Finally, a heading direction task required participants to estimate the heading from one object to another without the target object or any other objects in sight (Fig. 3). There were 12 heading direction trials in which each of the six objects was twice a starting point and twice a target. Participants began a trial at one object, rotated in the direction of a target object, and moved forward along that path in a straight line for 2 s to allow for creation of a ray. Heading error was measured from the movement paths automatically created by the navigation software. The outcome variable was mean heading error per trial.

3.3. Questionnaires

Participants completed five questionnaires.

The Computer Experience Questionnaire (CEQ; Moffat et al., 1998) assesses frequency of computer and video game use. Items are scored on a scale from 1 (never) to 7 (almost daily). Higher scores indicate frequent computer and video game experience.

The Spatial Anxiety Scale (SAS; Lawton, 1994) assesses environmental navigation-related anxiety on a 5-point scale from 1 (not at all anxious) to 5 (very much anxious). Sample items from the SAS include: “locating your car in a very large parking lot or parking garage” and “finding your way to an appointment in an area of a city or town with which you are not familiar”. Higher scores indicate greater anxiety.

The Way-Finding Strategy Scale (WFS; Lawton, 1994) assesses route and orientation based navigation strategies on two 5-point scales from 1 (not at all typical of me) to 5 (extremely typical of me). The WFS-orientation (WFS-O) scale includes items such as: “I kept track of the direction (north, south, east, west) in which I was going”. High scores on the WFS-O indicate preference for a navigation strategy that relies on maintaining one's position in relation to a number of points in the environment. The WFS-route (WFS-R) scale includes items such as: Before starting, I asked for directions telling me whether to turn right or left at particular streets or landmarks. High scores on the WFS-R indicate preference for a navigation strategy that relies on instructions from place to place from a first person perspective.

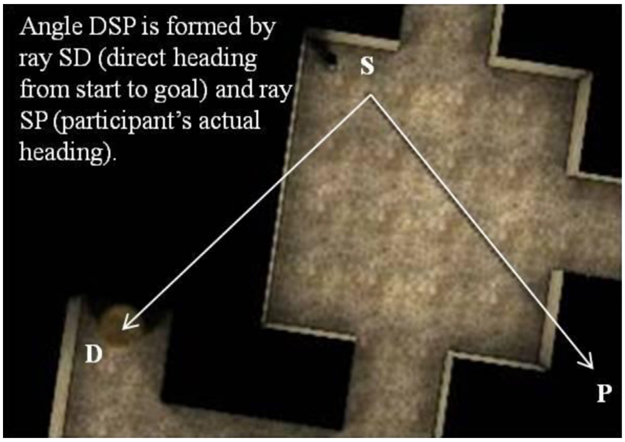

Fig. 3. Example of heading error calculation from the heading direction task. In this example the column was the starting point and the participant was told to rotate toward the bowl and step forward, which allowed the creation of ray SP. Heading error was operationally defined as angle DSP, where D was the direct heading, S was the starting point, and P was the heading response of the participant.

The Santa Barbara Sense of Direction questionnaire (SBSOD; Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002) assesses environmental spatial ability on a 7-point scale from 1 (strongly agree) to 7 (strongly disagree). Examples of items on the SBSOD include: I am very good at giving directions” and “I can usually remember a new route after I have traveled it just once”. Higher scores indicate a greater self-reported sense of direction.

The Competitiveness Inventory (CI; Gill, 1986) assesses competitiveness, goal orientation, and win orientation on a 5-point scale from 1 (strongly disagree) to 5 (strongly agree). CI items include: “I look forward to competing” and “I try my hardest to win”. Higher scores indicate greater self-reported competitiveness.

4. Results

4.1. Navigation tasks

Main effects of sex on navigation performance were tested using analysis of variance (ANOVA). Due to the video game-like interface of this task, video game experience was used as a covariate in statistical analyses. To determine whether main effects of sex were influenced by video game experience, CEQ was entered as a covariate in analysis of covariance (ANCOVA). Outliers on maze navigation variables (± 2.5 *SD* beyond the *M*) were excluded from analyses. Table 1 displays descriptive statistics for navigation performance by sex, and effect sizes (Cohen's *d*) of the sex differences.

In the practice environment, distance traveled did not differ by sex, $F(1, 40) = .16$, $p = .69$.

In the exploration phase, men encountered objects more frequently than women, ($F(1, 42) = 19.80$, $p < .001$); and traveled at a faster speed than women, ($F(1, 42) = 15.34$, $p < .001$). Neither CEQ ($F(1, 41) = 6.88$, $p = .01$) or the speed of movement through the exploration phase ($F(1, 41) = 7.78$, $p = .01$) decreased the effect of sex significantly.

In the recall phase, men had a greater number of correct hits than women, $F(1, 41) = 27.94$, $p < .001$; and traveled at a faster speed than women, ($F(1, 41) = 31.92$, $p < .001$). Neither CEQ ($F(1, 40) = 4.60$, $p = .04$) or the speed of movement through the recall condition ($F(1, 40) = 6.31$, $p = .02$) decreased the effect of sex significantly.

In the heading estimation task, men had lower heading error per trial compared to women, $F(1, 36) = 15.51$, $p < .001$, and the sex difference in heading error was no longer significant after CEQ was entered as a covariate, $F(1, 35) = .52$, $p = .47$.

At freehand map drawing of the maze, men were more accurate than women, $F(1, 35) = 27.38$, $p < .001$. CEQ decreased the effect of sex on map accuracy, $F(1, 34) = 2.52$, $p = .12$. Men were more confident than women in their map drawing, $F(1, 35) = 49.29$, $p = .001$. CEQ did not diminish the effect of sex on confidence, $F(1, 36) = 9.00$, $p = .01$. Regardless of map drawing accuracy, men were more confident than women, $F(1, 34) = 11.81$, $p = .002$.

At placing the six objects on an overhead map, men ($M = 6$, $SD = 0$) were more accurate than women ($M = 3.96$, $SD = 1.87$). A one-sample *t*-test determined the mean score for women was different than 6, $t(40) = 5.03$, $p < .001$. Men ($M = 5$, $SD = 0$) were more confident than women ($M = 3.58$, $SD = 1.02$) in their object placement. A one-sample *t*-test determined the mean score for women was different than 5, $t(40) = 5.53$, $p < .001$.

Table 1
Means and standard deviations (SD) for navigation tasks by sex.

	Explore – speed	Explore – number of objects encountered	Recall – speed	Recall – number of correct hits	Heading error per trial (degrees)	Map drawing	Object placement
Men							
Mean	332.99	21.65	368.63	10.41	21.35	35.54	6
SD	31.58	2.32	18.93	2.40	9.70	2.82	0
Women							
Mean	297.43	18.52	328.99	5.92	58.13	26.04	3.96
SD	33.65	2.24	29.47	2.91	24.53	6.94	1.87
Cohen's *d*	1.09	1.37	1.60	1.68	−1.97	1.79	1.54

4.2. Questionnaires

Sex differences on questionnaire scores were tested using independent samples *t*-tests. Men had higher scores on measures of video game experience (CEQ), t(43) = 5.10, $p < .001$, $d = 1.69$; competitiveness (CI), t(43) = 3.93, $p < .001$, $d = 1.25$; environmental spatial ability (SBSOD), t(43) = 2.83, $p = .01$, $d = .95$; and use of orientation-based wayfinding strategies (WFS–O), t(43) = 2.54, $p = .02$, $d = .83$; while women reported greater spatial anxiety (SAS), t(43) = −2.91, $p = .01$, $d = -.87$. The sexes did not differ on reports of route-based wayfinding strategies (WFS-R), t(42) = −.89, $p = .38$, $d = -.29$.

4.3. Self-reported strategy

The most commonly reported strategy factors for the sample as a whole were use of the column as a central landmark (57% of participants mentioned the column in their self-reported strategy), learning relationships between landmarks (41%), focusing on the sections within the maze (34%), use of a mental map (23%), and use of left-right turns (23%). Two raters independently categorized self-report strategies (Cohen's kappa = .95). A greater percentage of men (41%) than women (11%) reported using a mental map, X^2 (1, 44), = 5.37, $p = .02$, whereas a greater percentage of women (33%) than men (6%) reported using left-right turns, X^2 (1, 44), = 4.47, $p = .03$. The groups did not differ in their reports of trying to learn the relationships between objects, X^2 (1, 44), = 1.52, $p = .22$; use of the column as a central landmark, X^2 (1, 44), = .05, $p = .83$; or focusing on sections within the maze, X^2 (1, 44), = .48, $p = .49$.

4.4. Relationships between navigation performance, self-reported strategy and questionnaire scores

Relationships between navigation performance and questionnaire scores were tested using bivariate correlations (Table 2). Point biserial correlations were used to determine the relationships between self-reported strategy variables (dichotomous), navigation variables, and questionnaire scores (Tables 3 and 4). Correlations were assessed for the entire sample, as well as separately by sex given that men and women differed on many of the investigated measures.

Higher environmental navigation-related anxiety (SAS) was correlated with poorer performance. Video game experience (CEQ), competitiveness (CI), and environmental spatial ability (SBSOD) were positively related to navigation performance.

When men and women were considered separately, frequent video game experience (CEQ) was associated with less heading error ($r = -.57$) and greater number of recall hits in women ($r = .57$). Endorsement of an orientation-based wayfinding strategy (WFS-O) was correlated with number of correct objects placed on the map in the object placement test ($r = .42$). Also in women, lower environmental navigation-related anxiety (SAS) was related to better performance on five of the seven navigation outcomes: number of hits during recall ($r = -.46$), heading error ($r = .44$), map drawing ($r = -.42$), object placement ($r = -.53$), and confidence in object placement ($r = -.44$). In men, frequent video game experience (CEQ) was correlated with less heading error ($r = -.56$).

When the sample was considered as a whole, there were no consistent relationships between navigation strategy and questionnaire scores. The primary observation regarding questionnaire scores and self-reported strategy factors was the number of correlations that were significant only in women. Endorsement of the sections strategy was associated with more frequent video game experience (CEQ; $r = .38$), increased environmental spatial ability (SBSOD; $r = .61$), use of route-based wayfinding strategies (WFS-R; $r = .39$), and lower environmental navigation-related anxiety (SAS; $r = -.52$). Use of a mental map strategy was positively associated with competitiveness (CI; $r = .37$) in women. A maze navigation strategy that focused on relationships between landmarks was associated with orientation-based wayfinding in women (WFS–O; $r = .39$). In men only, a maze navigation strategy that focused on the column as a central landmark was correlated with orientation-based wayfinding (WFS-O; $r = .52$).

When correlations between navigation performance and strategy were assessed, the mental map strategy was associated with better navigation performance, whereas the use of left-right turns was related to relatively poor performance. Use of a mental map strategy was positively associated with number of recall hits in men

Table 2
Correlations between navigation tasks and questionnaire scores in the sample as a whole.

	CEQ (video game experience)	SAS (spatial anxiety)	WFS-O (orientation based wayfinding strategy)	WFS-R (route based wayfinding strategy)	SBSOD (sense of direction)	CI (competitiveness)
Objects Encountered Explore	.41**	−.32*	.18	.04	.33*	.32*
Correct Hits Recall	.62***	−.52***	.21	.02	.41**	.41**
Heading Error	−.69***	.50**	−.08	.04	−.11	−.13
Map Drawing	.69***	−.44**	.26	.09	.12	.39*
Confidence in Map Drawing	.71***	−.33*	.27	−.07	.32*	.35*
Object Placement	.55***	−.52**	.47**	.17	.32*	−.03
Confidence in Object Placement	.62***	−.47**	.41*	.13	.31	.30*

Note. $^{*}p \leq .05$, $^{**}p \leq .01$, $^{***}p \leq .001$.

Table 3
Correlations between self-reported strategy and questionnaire scores in the sample as a whole.

	CEQ (video game experience)	SAS (spatial anxiety)	WFS-O (orientation based wayfinding strategy)	WFS-R (route based wayfinding strategy)	SBSOD (sense of direction)	CI competitiveness)
Mental Map	.21	−.25	.15	−.11	.25	$.40^{**}$
Landmark Relation-ships	−.18	−.03	.07	.19	.02	−.15
Left-Right Turns	$-.32^{*}$	.26	−.11	−.06	−.21	−.07
Column	−.13	.14	.19	.18	.03	.11
Sections	.04	$-.29^{*}$	.17	$.35^{*}$	$.38^{*}$	.01

Note. $^{*}p \le .05$, $^{**}p \le .01$, $^{***}p \le .001$.

($r = .59$) and map drawing in women ($r = .47$). Use of a sections strategy was correlated with more recall hits in women ($r = .51$).

5. Discussion

The main aim of this study was to compare computerized maze navigation performance and self-reported strategy by sex in order to better understand which factors may account for differential performance between men and women when demand for allocentric processing is high. All effect sizes indicate that the distributions of navigation performance for men and women overlapped no more than 62%. Men traversed the exploration phase faster than women and encountered the objects in the maze more frequently even after speed was controlled statistically. The increased contact with objects in the maze may be interpreted as a relatively efficient exploration strategy. Men accumulated nearly twice the number of correct object hits than women in the recall phase even when we controlled for the speed of movement. Our results suggest that the difference in hits likely reflects the male advantage in knowledge of configuration of objects in relation to one another in the environment as well as the most efficient paths between objects, as opposed to being indicative of a comfort level with virtual environments.

In addition to standard measures of navigation success in maze environments, we added a novel heading estimation task as a direct assessment of a participant's allocentric “bird's eye view” knowledge of the maze. Participants estimated the direction of the most direct path from a starting point to another location within the maze that was not visible from the starting point, nor were the other objects visible as landmark cues. Given that much of the argument in the literature revolves around whether or not the sexes excel with different spatial strategies it was important to design a task which specifically assesses allocentric-based knowledge in this maze. Per trial, women had more than double the error in heading direction estimation than men. Moreover, video game experience was strongly related to heading estimation accuracy. The same viewer independent knowledge of the maze was arguably necessary to create an accurate freehand map, an outcome that showed a male advantage but was again strongly related to frequency of video game play.

Although the sex difference in map drawing and heading direction estimation persisted, the magnitude of the difference decreased when video game experience was used as a covariate in our statistical analyses. Our study is correlational and therefore we cannot draw causal inferences between video game experience and navigation performance, yet a major strength of our study is that we accounted for gaming experience as a potential contributing factor to variability in computer-based laboratory tests of wayfinding. It is possible that experience with video games contributes to better performance in virtual or even real life environments. It is also possible that men seek and enjoy activities such as playing video games because of their inherently better spatial skills.

On the object placement task, men performed with 100%accuracy placing all six objects correctly, while women correctly placed three to four of the six objects on the overhead map of the maze. This finding is interesting because a sex difference in object location memory usually favors women in traditional object location tasks (e.g., Eals & Silverman, 1994; McBurney, Gaulin, Devineni, & Adams, 1997). In traditional object location memory tasks, participants study an array of objects for some designated time (e.g., 60 s) and then identify in a new array the objects that have switched locations. In contrast, our object placement task required an accurate allocentric perspective of the maze that was established by actively traversing a maze environment in which only one object at a time was visible.

While our results are well placed within a long line of studies showing that men outperform women in navigating real-world (e.g., Coluccia & Louse, 2004; Dabbs, Chang, Strong, & Milun, 1998; Galea & Kimura, 1993; Lawton, 1994; MacFadden et al., 2003; Malinowski & Gillespie, 2001; Saucier et al., 2002; Ward et al., 1986) and virtual environments (e.g., Astur et al., 1998; Choi & Silverman, 1996; Coluccia & Louse, 2004; Dabbs et al., 1998; Driscoll et al., 2005; Levy et al. 2005; Moffat et al. 1998; Nowak & Moffat, 2011; Nowak et al., 2014; Sandstrom et al., 1998; cf. Livingston-Lee, Zeman, Gillingham, & Skelton, 2014), there is still much to be learned about the factors underlying sex differences in spatial performance.

Sex differences may be partially attributable to differential use of navigation strategies. In the present study, men were more likely than women to explain their navigation strategy in a manner consistent with allocentric encoding (i.e., mental map), whereas women were more likely than men to explain a strategy more consistent with egocentric processing (i.e., left-right turns). Moreover, allocentric strategy classification was associated with better

Table 4
Correlations between navigation tasks and strategy for the sample as a whole.

	Objects Encountered explore	Correct hits recall	Heading error	Map drawing	Confidence in map drawing	Object placement	Confidence in object placement
Mental Map	$.32^{*}$	$.57^{***}$	−.28	$.50^{**}$	$.54^{***}$	$.36^{*}$	$.43^{**}$
Landmark Relationships	−.27	−.02	.26	.05	.04	−.03	−.07
Left-Right Turns	−.05	$-.42^{**}$	$.47^{**}$	$-.48^{**}$	$-.44^{**}$	−.20	$-.43^{**}$
Column	.08	−.22	.34	−.25	−.03	−.03	−.00
Sections	.11	.23	.12	.16	.18	.11	.09

Note. $^{*}p \le .05$, $^{**}p \le .01$, $^{***}p \le .001$.

performance while egocentric strategy was associated with poorer performance for nearly all maze navigation variables. Reported use of a mental map strategy was positively associated with number of recall hits and map drawing accuracy in women but not men. In men, the mental map strategy was positively associated with number of recall hits. These findings are consistent with (a) a male preference for orientation based (see WFS-O) and a female preference for route based (WFS-R) navigation strategies in everyday behavior (Lawton, 1994); (b) at least three reports that men use cardinal directions and distance more frequently than women when giving directions, and that women more frequently mention landmarks or left-right turns when giving directions (Dabbs et al., 1998; MacFadden et al., 2003; & Ward et al., 1986); and (c) that when experimental conditions are manipulated, the male advantage is most pronounced when allocentric demands are high (Sandstrom et al., 1998; Saucier et al., 2002).

Strategy preference in virtual mazes that can be solved by multiple different strategies does not appear to differ by sex (e.g., Andersen et al., 2012; Bohbot et al., 2012; van Gerven et al., 2012; Iaria et al., 2003; Rodgers et al., 2012). For example, in the ambiguous version of a vMWT (i.e., the hidden platform could be located using multiple different strategies) used by van Gerven et al. (2012), a single object cue always served as an indicator of hidden platform position. Other combinations of proximal and distal cues allowed participants to use an allocentric strategy to locate the platform. Men were no more likely to prefer an allocentric strategy than women, though men outperformed women. These results support the notion that even when women choose an allocentric strategy they may not be as successful as men at using that strategy.

The maze used in the present study was not ambiguous. Developing an allocentric perspective of the maze was the most accurate approach, yet only three women described their strategy in a way that is consistent with a mental map/allocentric strategy, while only one man described a strategy consistent with left-right turns/egocentric strategy. These results may be interpreted as a sex difference in the likelihood of selecting the most appropriate strategy for the task. One would predict that if men and women use an allocentric strategy with approximately equal frequency in an ambiguous task (van Gerven et al., 2012), that the approach would shift to allocentric for both sexes in a task that requires it for successful completion. Ongoing research with this maze task will further investigate strategy use.

The second aim of our study was to investigate the correlations between computerized maze navigation and self-reported experiential and personality dimensions. We observed that men and women differ significantly on all experiential and personality factors included in this study except for self-reported use of route-based navigation (WFS-R). Men play video games more frequently than women, are more competitive in thought and behavior (CI), possess a greater sense of environmental spatial ability (SBSOD), and prefer to use orientation-based wayfinding strategies (WFS-O) in daily life. Video game experience, competitiveness, and environmental spatial ability were positively related to navigation performance for the whole sample. When men and women were considered separately, frequent video game experience was associated with less heading error and a greater number of recall hits in women but not men. In men only, a maze navigation strategy that focused on the column as a central landmark was correlated with orientation-based wayfinding (WFS-O).

Of the experiential factors we assessed in the present study, the key findings were the consistent correlations between maze performance and real-life experiences such as spatial anxiety and video game play in women but not men. Women reported experiencing a higher level of environmental navigation-related anxiety than men. Lower anxiety was correlated with better performance on five of the seven navigation tests: number of hits during recall, heading direction estimation, freehand map drawing, placement of the six objects on an overhead map, and confidence in object placement. Number of objects encountered during exploration, and confidence in map drawing were not significantly related to spatial anxiety.

Others have previously reported higher spatial anxiety, as measured by the SAS or questionnaires specific to the individual study, in women compared to men (Bryant, 1982; Castelli et al., 2008; Gabriel et al., 2011; Lawton, 1994; Lawton & Kallai, 2002; Malinowski & Gillespie, 2001; and Schmitz, 1997). Lower navigation-related anxiety has been correlated with frequent video game play (Tkacz & LaForce, 1998), accurate heading direction estimation in real-world (Lawton et al, 1996) and computerized navigation tasks (Mueller et al., 2009), faster completion and fewer errors in a model town navigation task (Hund & Minarik, 2009), faster completion of a real-world maze (Schmitz, 1997), and preference for route vs. landmark-based navigation (Schmitz, 1999). The relationship between SAS and navigation performance has not been demonstrated in all studies. Saucier et al. (2002) found that women reported higher spatial anxiety than men (Cohen's *d* effect size of .40), but the group difference was not significant. There were sex differences in spatial performance, however. SAS scores were not related to the number of errors made or time taken to complete the wayfinding task. Methodological differences between that study and the present study which may explain discrepancies related to spatial anxiety are numerous. One important factor is that an error in the Saucier et al. (2002) study was operationalized as five or more steps in the incorrect direction, whereas dependent measures in our laboratory task were more precise (e.g., the number of times an object was encountered across the exploration phase, degrees of heading error). We also included multiple tests of a participant's knowledge of the virtual environment, whereas Saucier et al. focused on time and errors. Another important difference is that we considered the relationships between SAS and our dependent variables separately for men and women because the two groups differed on SAS and most performance variables.

The big picture seems to suggest that high spatial anxiety is associated with poorer outcomes on our spatial performance measures; therefore, one might predict that reducing anxiety through navigation-related training would decrease the magnitude of the sex difference in spatial performance. A worthy endeavor may be to selectively recruit “high spatial anxiety” volunteers to participate in a navigation training intervention designed to improve navigation performance and confidence and decrease spatial anxiety. One approach to this intervention could be training participants to use an allocentric strategy in our computerized maze, then testing the transfer of that training in another maze or real life wayfinding scenario. Such interventions could have practical implication for individuals who may be experiencing a decline in daily wayfinding abilities, such as the elderly population who often report difficulties in wayfinding (e.g., Bryden, Charlton, Oxley, & Lowndes, 2013).

Although a topic of great debate, the underlying cause of sex differences in spatial ability remains unresolved. It is not surprising that experience (e.g., with technology such as video games) or emotional or personality traits (e.g., spatial anxiety) affect navigation performance. For example, if interest in and performance of spatially demanding activities differs by sex because of ancestral division of labor (hunter-gatherer hypothesis; Silverman & Eals, 1992), this does not imply that spatial behavior or the sex difference is immutable. Physiological influences on spatial behavior (e.g., sex hormones) likewise do not imply that evolutionary, social learning, or cultural factors do not work to reinforce or weaken the difference between men and women. Evolutionary, biological, developmental, and environmental sources of behavioral variability are not necessarily at loggerheads. The evolutionary explanations of *why* sex differences in spatial behavior exist are outside the scope of the present study; however, for a comprehensive review see Silverman and Choi (2005).

6. Conclusion

Here we present a comprehensive investigation of the factors contributing to sex differences in navigation performance within a computerized maze. The present study makes an important contribution to the understanding of how sex, strategy, and experiential factors such as environmental navigation-related anxiety relate to spatial performance. It also highlights the importance of considering relationships between experiential factors (or biological, experiential etc. factors in future studies) and navigation performance separately for men and women. Results will serve as background for future experiments, where we may manipulate factors such as competition or anxiety. The present study contributes at the behavioral level to a much larger literature dedicated to determining how factors such as sex, age, hormones, and anxiety for example, impact the structural and functional integrity of the neural substrates of spatial behavior.

Appendix A. Scoring of hand-drawn maps

Criteria related to objects and object placement:
    Were all 6 objects included in the map?
    How many objects were correctly placed in the map?
Criteria related to layout of the environment:
    Does the map include a central square or rectangular room?
    How many hallways are directly connected to this central room?
    Did the subject include 3 branches/sections of the maze that extend from the central room?
    How many connections does each branch make?
Criteria related to the relationships between objects and hallways:
    Is there a hallway connecting the tree and the wheel?
    Can the map be oriented in such a way that the bowl/wheel side is left of the column; the fire/flag side is right of the column; and the tree is below the column?
    How many hallways correctly turn at 90° angles to reach objects?

Appendix B. Coding self-report strategy

Examples of self-report strategy that were coded as a mental map strategy:
    Made a map in my head.
    Used an overhead mental picture.
    Placed objects on a grid.
Examples of self-report strategy that were coded as learning the relationships between landmarks:
    Tree and wheel go together.
    Flag and fire extinguisher are in the same hallway. Bowl is farther away from flag and fire.
    Think about all the objects and find the relationships between them.
Examples of self-report strategy that were coded as using left-right turns:
    Always turned right.
    Remembered left-right turns.
    Kept turning left; followed the wall and turned left.
Examples of self-report strategy that were coded as using the column as a central landmark:
    I based everything off the column.
    Column was the center piece and everything branched off from there; based off the column.
    Used column as center point.
Examples of self-report strategy that were coded as focusing on sections within the maze:
    Worked on each side passage.
    Tried to understand the extensions/sectors of hallways.
    “Chunked” the maze into sections.

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