Are Sex Differences in Navigation Caused by Sexually Dimorphic Strategies or by Differences in the Ability to Use the Strategies?

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When navigating, women typically focus on landmarks within the environment, whereas men tend to focus on the Euclidean properties of the environment. However, it is unclear whether these observed differences in navigational skill result from disparate strategies or disparate ability. To remove this confound, the present study required participants to follow either landmark- or Euclidean-based instructions during a navigation task (either in the real-world or on paper). Men performed best when using Euclidean information, whereas women performed best when using landmark information, suggesting a dimorphic capacity to use these 2 types of spatial information. Further, a significant correlation was observed between the mental rotation task and the ability to use Euclidean information, but not the ability to use landmark information.

Humans use a number of skills in navigation, such as monitoring their position and orientation with respect to both local and distant landmarks, as well as distance or time constraints (Loomis et al., 1993). However, humans must also have some type of internal representation of space when they travel, which presumably would be a function of the type of information that is attended to during navigation. Montello and Pick (1993) observed individual differences in the ability to maintain orientation while navigating, suggesting individual differences in the type of information that an individual focused on in their environment.

Wayfinding is goal-directed navigation in which people must adopt a strategy to find a target location (Gerber & Kwan, 1994). Lawton (1994) describes two major approaches to wayfinding activity based on self-reports of navigation strategy. Landmark strategies use environmental information, such as where to turn right or left, in addition to details about major landmarks. A spatial representation based on landmarks is therefore relatively rigid and sequential: Point 3 follows from Point 2, which follows from Point 1. In self-report, females are more likely to indicate use of a landmark strategy while navigating (Dabbs, Chang, Strong, & Milun, 1998; Lawton, 1994). In contrast, males tend to report use

of an orientation strategy (Lawton, 1994), which involves a more Euclidean representation of space, including descriptors such as cardinal directions and exact distances (Dabbs et al., 1998). This Euclidean strategy imparts greater flexibility in navigation, allowing Point 3 to be reached either indirectly via Point 2, or directly from Point 1.

Euclidean strategies may also confer an advantage in situations where the navigator has left a specified route, such as when a wrong turn has been made. In these situations, navigators using Euclidean strategies can rely on cardinal directions to assess their position, whereas navigators using landmark strategies may become disoriented in the absence of familiar cues. Such disorientation can lead to anxiety, which may persist through subsequent navigation activities. In fact, women report significantly higher levels of environmental confusion and anxiety when navigating than do men (Lawton, 1994). Anxiety itself may have a negative impact on navigational ability by reducing attention to features in the environment or impairing the ability to encode these features.

Sex differences in navigation or wayfinding ability have often been examined by using pencil-and-paper route-learning tests (Galea & Kimura, 1993), route-learning tasks using photographs (Holding & Holding, 1989), or tasks requiring navigation in a virtual environment (Moffat, Hampson, & Hatzipantelis, 1998; Sandstrom, Kaufman, & Huettel, 1998). In all of these instances, males have outperformed females, performing the tasks more quickly and/or making fewer errors. In addition, females demonstrate an enhanced knowledge of landmarks, both on- and off-route, whereas males tend to have enhanced knowledge of the Euclidean properties of the environment (Galea & Kimura, 1993; Sandstrom et al., 1998). Participants in all of these studies were allowed to use the navigation strategy of their choice. Thus, it is unclear whether the male advantage exists because of superior skill or because males tend to use superior strategies for navigating. To

address this concern, two studies were undertaken in which participants were required to follow either landmark or Euclidean directions to locate a destination. These studies examine whether males and females can apply Euclidean and landmark strategies equally well. In Study 1, the degree to which participants can use either Euclidean or landmark strategies in the real-world is examined. The second experiment (Study 2) examines the degree to which participants can use either Euclidean or landmark strategies in a novel two-dimensional (2-D) pencil-and-paper task.

Study 1: Real-World Navigation Task

Rationale

We investigated whether males and females are equally adept at using either Euclidean or landmark instructions when navigating in the real world. We looked for sex differences in the number of errors made and the time required to navigate to these destinations. We hypothesized that overall, males would make fewer errors than females while navigating. However, we also predicted that females who were navigating with the landmark-type instructions would make fewer errors than females navigating with the Euclidean instructions. As well, we had participants complete a landmark recognition task, in which they were required to name the location depicted in a photograph. As we predicted that females would be more likely to use landmark strategies when navigating, it was anticipated that females would also have superior landmark recognition.

The Mental Rotations Test (Vandenberg & Kuse, 1978) was administered to ensure a representative sample, which demonstrates the typical male advantage on this task. Performance on this spatial test has been shown to be related to human navigation on maps (Galea & Kimura, 1993). As anxiety may adversely affect navigation performance, Lawton's (1994) Spatial Anxiety Questionnaire was also administered. If, as Lawton suggests, females report greater anxiety while navigating, anxiety may play a significant role in the reported sex difference in navigation skill.

Method

Participants

A total of 42 participants (20 men, 22 women) from an introductory psychology class at the University of Regina completed the real-world navigation task. Participants were randomly assigned to conditions. A total of 20 participants (10 men and 10 women) followed Euclidean-type instructions while navigating, and 22 participants (10 men and 12 women) navigated using landmark-type instructions. All participants were right-handed, spoke English as their first language, and were between 18 and 31 years of age ($M = 20.27 \pm 3.97$). The participants received course credit in exchange for participation.

Tasks

Navigation task. For this task, participants had to navigate to four unknown destinations within the University of Regina campus. The location of each destination was determined by following the instructions on five laminated sheets of paper, which were presented sequentially. Although the task required mostly indoor navigation, participants were required to navigate outside for short distances between buildings. The choice points were chosen so as to have three or more discrete alternatives

(e.g., hallway intersections) to choose from, thus requiring the participants to make their response on the basis of the instructions given rather than allowing the environment to guide their responses.

Euclidean-based instructions indicated the directions (e.g., north or east) and metric distances (e.g., 100 m) to be followed, whereas landmark instructions indicated the salient landmarks (e.g., the purple doors) and egocentric turn directions (right or left) to be followed. The same four destinations were indicated by the two sets of instructions, and each required a total of 30 turns. For both types of instructions, participants were shown the direction of true north before the start of the first trial. Participants were accompanied by an experimenter who followed them while they were navigating. This allowed the experimenter to time the activity and record the number of errors made and ensured that the same rate of walking occurred among participants. An error was scored when the participant took five or more strides in the wrong direction. The experimenter then told the participant that an error had been made, and they then returned to the last choice point and were allowed to proceed again.

Spatial Anxiety Questionnaire (SAQ). The SAQ measures the degree to which an individual experiences anxiety while navigating (Lawton, 1994). The questionnaire consists of eight hypothetical scenarios, in which the participant is asked to rate how anxious each scenario would make them on a 5-point scale. A score of 40 indicates the highest level of anxiety, and a score of 8 indicates the lowest level of anxiety.

Spatial ability. The Mental Rotations Test is a task requiring spatial ability (Vandenberg & Kuse, 1978), in which participants are required to match a target item to two of four rotated alternatives. There were 12 items, and participants were given 4 min to complete the task. The maximum score was 24, and the minimum score was 0. The task was scored to correct for guessing.

Landmark Recognition Test. Participants were presented with 13 photographs of locations in and around the University of Regina (within 5 km of the campus). Of these photographs, 3 depicted locations that were directly on-route, and 4 depicted locations close (within 50 m) to the route. However, none of the photographs depicted locations that the participants were required to attend to directly in the navigation task. Participants were asked to name the location depicted by each photograph. The maximum score was 13, and the minimum score was 0.

Procedure

Once participants provided informed consent, they were tested individually on the navigation task. On arrival at the final destination, the participant and the experimenter returned to the lab. The participant then completed the SAQ, the Mental Rotations Test, and the Landmark Recognition Test. The order of these three tasks was randomly assigned among participants.

Results

Navigation Task: Total Number of Errors

A 2 × 2 analysis of variance (ANOVA) was performed, with the total number of errors made in the navigation task as the dependent variable and the type of instructions (Euclidean, landmark) and sex as the independent variables. There was a significant interaction between sex and the type of instructions, $F(1, 38) = 16.52$, $p < .05$. Post hoc analysis (Tukey's) indicated that females following the Euclidean-type instructions made significantly more errors than the females following landmark-type instructions ($p < .05$), males following Euclidean-type instructions ($p < .05$), or males following landmark-type instructions ($p < .05$; see Figure 1a). There were no other significant effects observed among the four groups ($ps > .10$).
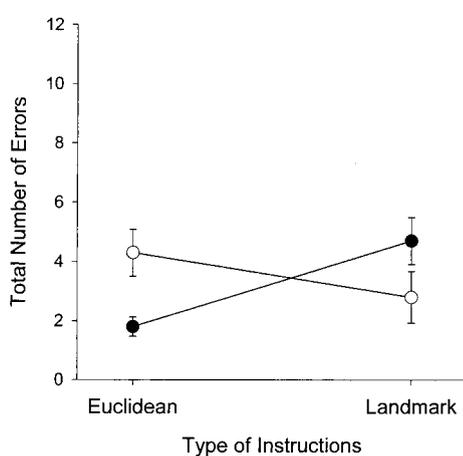
a Real-World Navigation
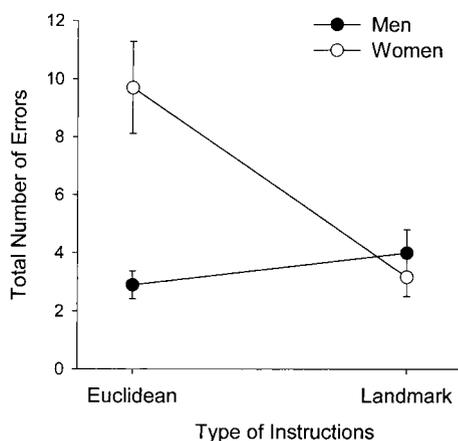
b 2-D Matrix Navigation

Figure 1. Mean (± *SEM*) total number of errors in (a) the real-world navigation task and (b) the two-dimensional (2-D) matrix navigation task.

Navigation Task: Average Time Required to Locate Each Destination

A 2 × 2 ANOVA was performed, with the average time required to arrive at each of the four destinations as the dependent variable and the type of instructions (Euclidean or landmark) and sex of the participant as the independent variables. There was a significant interaction between sex and the type of instructions, $F(1, 38) = 4.58$, $p < .05$. Post hoc analysis (Tukey's) indicated that the females following the Euclidean instructions were significantly slower to arrive at the destinations than either the females following landmark-type instructions ($p < .05$), males following Euclidean-type instructions ($p < .05$), or males following landmark-type instructions ($p < .05$; see Figure 2a). There were no other significant effects observed among the four groups ($ps > .10$).

Landmark Recognition Test

A 2 × 2 ANOVA was performed, with the number of landmarks correctly identified as the dependent variable and the type of

instructions (Euclidean or landmark) and sex as independent measures. There was a significant main effect of sex, $F(1, 38) = 6.65$, $p < .05$. There was no significant effect of the type of instructions, $F(1, 38) = 0.001$, nor was there a significant interaction between sex and the type of instructions given while navigating, $F(1, 38) = 0.16$. However, contrary to predictions, men outperformed women on this task, identifying significantly more landmarks (men = 11.60 ± 1.70, women = 10.23 ± 1.69).

Spatial Ability

The first 6 people (2 men and 4 women) who participated in the study did not receive the correct version of the Mental Rotations Test (the second page was missing). Thus, their data were not included in this analysis. These participants were equally distributed among the four groups (1 man in the landmark-type instruction group, 2 women in the landmark-type instruction group). A 2 × 2 ANOVA was performed, with the scores on the Mental Rotations Test as the dependent variable and the type of instructions (Euclidean or landmark) and the sex of the participant (male,

a Real-World Navigation
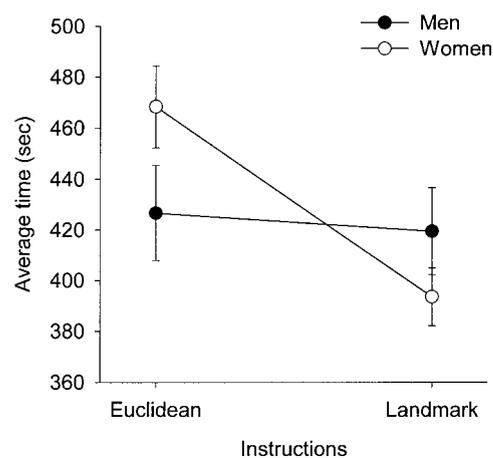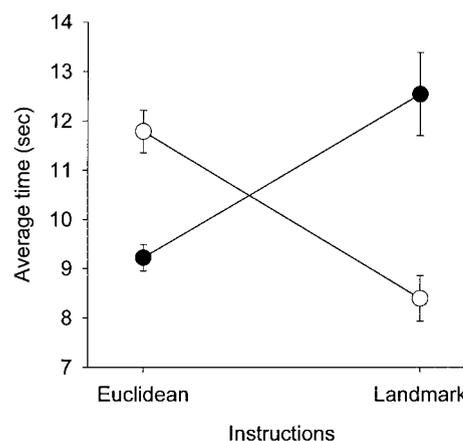

b 2-D Matrix Navigation

Figure 2. Mean (± *SEM*) average time (in seconds) required to navigate per trial in (a) the real-world navigation task and (b) the two-dimensional (2-D) matrix navigation task.

female) as the independent variables. The only significant effect observed was a main effect of sex, $F(1, 32) = 7.55$, $p < .05$, and as predicted, men outperformed women on this task (men $= 10.22 \pm 4.83$, women $= 6.00 \pm 4.75$).

SAQ

A 2×2 ANOVA was performed, with the total level of anxiety indicated on the SAQ as the dependent variable and the sex of the participant and the type of instructions used (Euclidean or landmark) as independent variables. Although the means suggest that women endorsed higher levels of navigational anxiety ($M = 22.77 \pm 5.13$) than did men ($M = 20.60 \pm 5.72$), this difference did not reach significance, $F(1, 38) = 1.77$, nor were any other significant differences observed.

Correlations Among the Tests

Pearson product–moment correlations were performed among the four measures. A significant negative correlation was observed between performance on the Mental Rotations Test and the total number of errors made while navigating, $r(36) = -.354$, $p < .05$, indicating that better spatial ability as measured by mental rotation was associated with fewer errors (better performance) in the navigation task. No other significant correlations were observed. To explore the relationship between mental rotations and navigation ability, two separate correlations were performed. These correlations were split by condition; that is, separate correlations were performed for participants who followed Euclidean-type instructions and for participants who followed landmark-type instructions. For participants who followed Euclidean-type instructions, a significant negative correlation was observed between performance on the Mental Rotations Test and the total number of errors made while navigating, $r(18) = -.760$, $p < .05$, indicating that as errors in the navigation task increased, performance on Mental Rotations decreased. Moreover, this relationship held even when the two sexes were considered independently: males, $r(9) = -.611$, $p < .05$; females, $r(9) = -.621$, $p < .05$. The relationship between performance on Mental Rotations and total number of errors made while navigating was not observed for participants who followed landmark-type instructions, $r(18) = -.071$, ns.

Discussion

As predicted, men made significantly fewer errors than women in our real-world navigation task. This difference can be attributed to the large number of errors made by women following Euclidean instructions, as men and women did not differ in the number of errors made during the landmark condition. Although there was a significant sex difference in performance on the Mental Rotations Test, these differences did not appear between the groups who followed Euclidean or landmark instructions while navigating. Thus, the high rate of errors among women using Euclidean instructions did not simply result from reduced spatial ability in these women. Rather, our data suggest that, overall, women were less able to use the Euclidean instructions accurately (based on errors) and efficiently (based on time).

Spatial ability (as measured by the Mental Rotations Test) was significantly correlated with the number of errors made while navigating using the Euclidean instructions. This correlation accounted for over 50% of the variance and suggests that performance on these tasks may result from similar facets of spatial ability. Scores on the Mental Rotations Test were not related to the performance of participants who followed landmark instructions, who could reach their destination by following the directions directly, whereas participants using Euclidean instructions had to monitor their spatial orientation to get to the target location.

Research in both humans and nonhuman animals suggests that the hippocampus is involved in spatial navigation (e.g., Maguire et al., 2000; Morris, Garrud, Rawlins & O'Keefe, 1982). Although the animal studies have made much progress in understanding the neural mechanisms of navigation, less progress has been made in studies of human navigation, which must rely either on correlational models (e.g., Maguire et al., 2000) or by imaging the brain while participants are performing related spatial navigation tasks (e.g., recall of routes, map exploration, or exploration of virtual environments). Although a number of these studies have suggested a role for the right hippocampus (Gron, Wunderlich, Spitzer, Tomczak, & Riepe, 2000; Maguire, Burgess, Donnett, Frackowiak, & Frith, 1998; Maguire, Frackowiak, & Frith, 1996, 1997; Mellet et al., 2000), others have failed to observe significant hippocampal activation (Aguirre & D'Esposito, 1997; Aguirre, Dettre, Alsop, & D'Esposito, 1996; Maguire, Frith, Burgess, Donnett, & O'Keefe, 1998). These inconsistencies may reflect subtle differences among the studies, as some studies used tasks that measured acquisition of spatial information, whereas others required retrieval of spatial knowledge. Moreover, Mellet et al. (2000) present data that suggest that the right hippocampus is active when Euclidean features of the environment are recalled, and that parahippocampal and entorhinal activation is observed when landmark representations of the environment are recalled.

A wide variety of neural structures have been implicated as involved in the performance of mental rotations. These regions include the motor cortex (e.g., Richter et al., 2000; Vingerhoets et al., 2001), basal ganglia (e.g., Alivisatos & Petrides, 1997), right parietal cortex (e.g., Thomsen et al., 2000), left parietal cortex (e.g., Alivisatos & Petrides, 1997) or both parietal cortices (e.g., Jordan, Heinze, Lutz, Kanowski, & Jancke, 2001). However, Mellet et al. (2000) report that mental imagery, especially visual imagery, is associated with activation in occipital–parietal regions and frontal areas, including secondary motor regions. Thus, Mellet et al. suggest that a parietofrontal network is activated whenever visuospatial imagery or visuospatial working memory is required for task performance.

Our results suggest that the solution of both mental rotations and human navigation rely on similar abilities, presumably mediated by similar brain areas. It is noteworthy that none of the studies that have examined neural activation associated with the performance of mental rotations have reported significant activation of the hippocampus or parahippocampal regions (e.g., Alvisatos & Petrides, 1997; Cohen et al., 1996; Just, Carpenter, Maguire, Diwadkar, & McMains, 2001; Kosslyn, DiGirolamo, Thompson, & Alpert, 1998; Richter et al., 2000). Instead, these studies report activation in the parietofrontal network, which presumably is related to the mental imagery and working memory components of the task. However, given our results, it is unclear why mental rotation has not resulted in hippocampal or parahippocampal activation in these studies.

Significant sex differences on the SAQ were not observed in this sample, indicating that men and women did not differ in reported navigational anxiety. As well, navigational anxiety, as measured by the SAQ, was not correlated with performance on the navigation task. Lawton (1994) related prenavigation SAQ scores to navigation performance; in the present study, the SAQ was administered after navigation. Thus, it is evident that the number of errors made did not result in increased navigational anxiety, suggesting that in this experiment, sex differences in navigational anxiety cannot account for dimorphic navigational skill. An alternative explanation is that the failure to observe a relationship between anxiety and navigation ability may result from the rather benign testing situation, including the accompaniment of an experimenter, and the artificial condition in which participants had to follow one of two types of instruction (as the participants may attribute their performance to the type of instructions they were required to follow, rather than innate navigational ability).

The male advantage observed on the Landmark Recognition Test was not anticipated. This result may indicate that, although men were better able to recognize landmarks in their environment, they may not use landmarks while navigating. Or, it may suggest that the male participants in our task had greater familiarity with the larger university environment that they were required to navigate through. Although performance on the Landmark Recognition Test did not significantly correlate with performance on the navigational task, greater familiarity with the larger university environment may have exerted subtle effects that allowed men to excel at this task. Thus, a second experiment was performed in which participants navigated in an entirely novel environment, following either Euclidean or landmark instructions. Comparisons between these two experiments will also give some preliminary insight into spatial cognition in general and navigation strategies specifically, at different scales of space (i.e., 2-D small space vs. 3-D real-world space).

Study 2: 2-D Matrix Navigation Task

Rationale

A 2-D pencil and paper navigation task was developed to ensure that the navigational environment would be equally novel to all participants. The task required participants to follow directional instructions (either Euclidean or landmark) in a 10×10 matrix, with each cell containing one of 10 repeated, nameable symbols (see Figure 3). It was hypothesized that if women are less able to use Euclidean strategies to navigate, then an increase in time and errors should result when they must follow Euclidean instructions. It was similarly predicted that if men are less able to use landmarks to navigate, then an increase in errors and time should result when they are forced to use a landmark strategy.

Method

Participants

A total of 40 students at the University of Saskatchewan (20 men, 20 women) completed the matrix navigation task. Participants were randomly assigned to conditions. A total of 20 participants navigated in the matrix while following the Euclidean-type instructions (10 men and 10 women), and 20 participants navigated in the matrix while following the landmark-
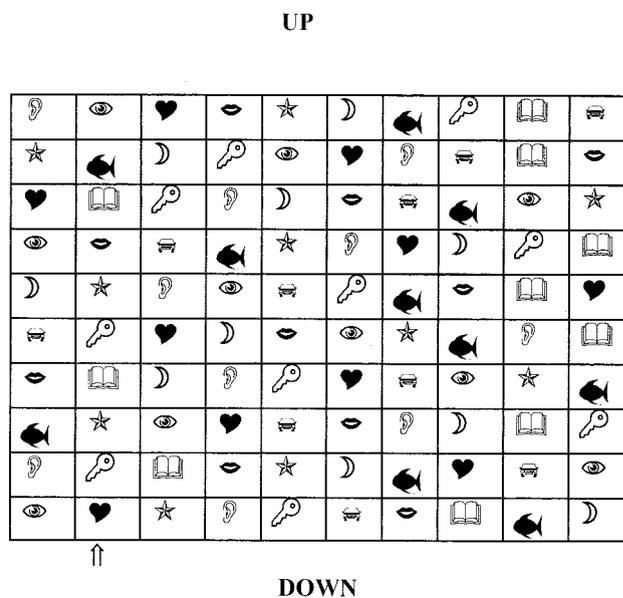
UP

DOWN

Figure 3. The two-dimensional (2-D) matrix required for the matrix navigation task. A sample landmark question would be, "Starting at the ♥ (indicated by the ⇨), go right until the 🚗 , go up to the ☽, turn right, and go until you see the 🗝 . Which symbol is to your immediate left?" (The correct answer is ☽.)

type instructions (10 men and 10 women). All participants were right-handed, spoke English as their first language, and were between 18 and 31 years of age ($M = 22.05 \pm 5.05$). The participants received either remuneration or course credit in exchange for participation.

Tasks

2-D matrix navigation task. The navigation environment consisted of a laminated 10×10 grid (25 cm $\times$ 23 cm), with each cell containing a symbol (see Figure 3). Ten unique symbols, which were iconic representations of 10 highly frequent English nouns, appeared 10 times within the matrix. The placement of each symbol was random, with the exception that a symbol could not appear more than once per row, nor could it appear adjacent to itself in bordering rows. When participants were required to use Euclidean instructions, north and south were marked prominently at the top and bottom of the matrix. Thus, unlike Study 1, participants could always correctly orient themselves to north in this task. To ensure comparability between the two types of environments, when participants were required to follow landmark instructions, *up* (replacing north) and *down* (replacing south) were marked prominently at the top and bottom of the matrix. To eliminate the opportunity to use an unintended strategy (e.g., marks made by others on the matrix), participants were not allowed to touch or point at the page. During testing, the matrix was placed directly in front of the participant, with an answer sheet to the right of the matrix.

Each participant completed a set of 30 instructions, all of which were either in a Euclidean (cardinal directions and distances in "blocks") or landmark format (landmarks and relative positions such as up, down, left, or right). Each question consisted of three directional statements. A sample Euclidean question would be, "Starting at the symbol next to the arrow, go North 3 blocks, then go East 7 blocks, then go North 5 blocks. What symbol is to your immediate West?" A sample landmark question would be, "Starting at the ☽ (located next to the arrow), go up to the ◉ , go right until the ♥, turn right and go until you see the 👄 . Which symbol is to your immediate left?"

Before starting the test trials, participants completed a practice trial to familiarize themselves with the procedure. The procedure for both the practice and test trials was the same, with the exception that feedback was only provided for the practice trial. An arrow indicating the starting position for each question was placed on the matrix (30 unique locations on the exterior boundary of the matrix). Participants were instructed, "Starting at the arrow, complete the series of three instructions without touching or pointing at the matrix. Once you complete these instructions, you will be asked to circle your answer on the sheet provided." Participants were told that when answering, they were to assume that they were facing the top of the array (either north or up, depending on the array). Participants were encouraged to complete the task as quickly and accurately as possible. Timing began when the question was revealed to the participant and stopped when the participant indicated his or her answer. The time to answer each question and the number of errors made was recorded for each trial. An error score was calculated on the basis of total number of errors made over the 30 trials.

Recognition task.   After the matrix navigation task, participants were presented with an array of 40 symbols (10 symbols that appeared in the matrix and 30 distractors). Participants were asked to circle all the symbols that had appeared in the matrix and to cross out all the symbols that had not appeared in the matrix. An error was scored when a participant failed to indicate a symbol that occurred in the matrix and when a participant mistakenly indicated that a symbol had occurred in the matrix.

Results

Matrix Navigation Task

Number of errors.   A 2 × 2 ANOVA, with sex and type of instructions (Euclidean or landmark) as between-subjects factors, was performed on the total number of errors. There was a significant interaction between sex and the type of instruction, $F(1, 36) = 5.15$, $p < .05$ (see Figure 1b). Post hoc analyses (Tukey's) indicated that the women following the Euclidean instructions made significantly more errors than did the men following the Euclidean instructions ($p < .05$). As well, men following the landmark instructions made significantly more errors than did the men following the Euclidean instructions ($p < .05$). No other significant differences were observed. There was no significant main effect of sex observed, $F(1, 36) = 0.41$, nor was there a significant main effect of instruction type, $F(1, 36) = 1.22$.

Reaction time (RT).   A 2 × 2 ANOVA, with sex and type of instructions (Euclidean or landmark) as between-subjects factors, was performed on the mean RT score for the 30 matrix navigation trials. There was a significant interaction between sex and the type of instruction, $F(1, 36) = 38.04$, $p < .05$ (see Figure 2b). Post hoc analyses (Tukey's) found that men who followed Euclidean instructions outperformed men who followed landmark instructions ($p < .05$) and women who followed Euclidean instructions ($p < .05$). As well, women who followed landmark instructions outperformed women who followed Euclidean instructions ($p < .05$) and men who followed landmark instructions ($p < .05$). No other significant differences were observed.

Recognition Task

A 2 × 2 ANOVA, with sex and type of instructions (Euclidean or landmark) as between-subjects factors, was performed on the total number of errors that occurred in the recognition task. The ANOVA failed to reveal any significant effects: interaction between sex and type of instructions, $F(1, 36) = 0.43$; main effect of sex, $F(1, 36) = 1.19$; or main effect of the type of instructions, $F(1, 36) = 0.43$. Thus, we failed to find a difference among the groups in the ability to recognize symbols that were viewed during their navigation task.

Discussion

In the 2-D matrix task, men were significantly better than women at using Euclidean instructions (making fewer errors and taking less time), and the men using Euclidean instructions were significantly better than the men who used landmark instructions (making fewer errors and taking less time). Navigation among women who used landmark instructions was significantly faster than in women who used Euclidean instructions, although there was no significant difference in accuracy between these two groups. Further, there were no significant differences in symbol recognition, suggesting that symbols were equally attended to by all groups in the matrix navigation task.

This experiment was intended to control for greater environmental experience in men, as suggested by the recognition task in Study 1. By presenting participants with a novel environment, the ability of participants to use landmark and Euclidean instructions was assessed independent of previous experience with the navigational environment. Unlike Experiment 1, it was determined that men using landmark instructions made significantly more errors and took more time than either women using landmark instructions or men using cardinal instructions. Although women using Euclidean instructions made more errors than did men using Euclidean instructions or women using landmark instructions, the only significant differences among these groups was between the men and the women.

General Discussion

This investigation extends previous research that has examined sex differences in navigation or wayfinding ability, as it required participants to both physically navigate through a real environment and mentally navigate through a symbolic environment. Unlike previous studies (Galea & Kimura, 1993; Holding & Holding, 1989; Moffat et al., 1998; Sandstrom et al., 1998), this investigation did not allow participants to use personally selected strategies for navigation. Instead, the ability of participants to use Euclidean or landmark information during navigation was examined.

Study 1 demonstrated that men and women differ in their ability to use Euclidean and landmark directional information in a real-world task. That is, men proved more adept at using Euclidean information, whereas women proved more adept at using landmark information. Study 2 also demonstrated that men were advantaged at using Euclidean information and women were advantaged at using landmark directional information. However, unlike Study 1, there was no difference between men and women in the ability to recognize landmarks from the novel navigation environment. The convergence of results suggests that the type of instruction given, not experience, was responsible for observed differences in error rate among men and women. Further, as the directional information was always present in the 2-D matrix navigation task, it is unlikely that these differences can easily be attributed to some inability to maintain Euclidean representations by women.

These results also suggest that, although there are obvious qualitative differences between these two spaces (scale, dimensionality, and environmental vs. nonenvironmental landmarks), the use of different navigational strategies by men and women in this controlled setting is consistent across these two scales. Patterns of performance in large- and small-scale navigation with Euclidean directions indicated that men could use these strategies/directions equally well in both spaces. This was also the case for women when using landmark-based strategies/directions. Although numerous accounts of the qualitative differences between spaces of varying scale have been offered, very little has been settled with respect to the information processing differences between spaces of different size or scale (Freundschuh & Egenhofer, 1997; Montello, 1993; Tversky, Morrison, Franklin, & Bryant, 1999). The majority of evidence for cognitive and behavioral differences in spaces of qualitatively different sizes has come from studies that were not primarily examining effects of scale on spatial information processing (Freundschuh & Egenhofer, 1997; Montello, 1993; Tversky et al., 1999). Our results also do not provide an unbiased examination of scale as we not only manipulated the size of the experimental spaces, but also their dimensionality and the types of landmarks present. These manipulations were necessary, and the trade-offs deemed reasonable. With this in mind, we offer the consistency of performance in large and small spaces for the reader to consider and will not overstate the importance of this interpretation of our results.

There appeared to be differences between the 3-D real-world task and the 2-D matrix navigation task. That is, performance in the 2-D matrix task suggests that men are less able to use landmark information while navigating, whereas performance in the real-world task suggests that men are equal to women in their ability to use landmark information. Further, it is striking that, for women, the use of Euclidean information appears also to be related to the navigational environment. There are two possible reasons why the 2-D matrix task resulted in fewer errors for women: The 2-D matrix provided constant reference to north, and the participants did not have to move through space; thus, spatial orientation of self was simplified in this environment.

Future studies could explore instances of disorientation in navigation. For example, it would be informative to track the ability of men and women to maintain orientation to north in the real-world task by allowing them to ask for north when necessary. Consistent with the correlation between the Mental Rotations Test and Euclidean performance, women may commit more errors in Euclidean navigation because of a reduced ability to maintain orientation with respect to north. Moreover, because the two major approaches to navigation are linked to sex, it should be noted that one approach is decidedly more spatially descriptive, whereas the other employs verbal, or at least language-based, descriptions. Other researchers have demonstrated that the type of strategy used to solve spatial problems can affect the neural structures that are activated during problem solving and that these tasks have complex demands beyond just the simple spatial parameters of the task (e.g., Carpenter, Just, Keller, Eddy, & Thulborn, 1999; Cohen et al., 1996; Kosslyn et al., 1998).

Taken together with the observations of men excelling in a number of spatial domains and women excelling at a number of more verbal tasks (for review see Kimura, 1999), it may be that our observations of real-world human navigation illustrate how such abstract abilities are manifested in the real world. Furthermore, this study provides evidence that tasks such as mental rotations may adequately test abilities similar to those manifested in real-world spatial navigation. As such, future studies may investigate why human imaging studies of mental rotations do not typically report activation of the hippocampus (or parahippocampal regions), when studies of human navigation (albeit in artificial situations) clearly demonstrate the importance of the hippocampus in solving tasks of spatial navigation. Furthermore, the neural correlates of both of these sexually dimorphic abilities also remain unexplained.

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