Sex-Related Differences and Similarities in Geographic and Environmental Spatial Abilities

Daniel R. Montello*, Kristin L. Lovelace**,
Reginald G. Golledge*, and Carole M. Self***

*Department of Geography,
**Department of Psychology,
***Department of Anthropology,
University of California, Santa Barbara

On average, males have reliably been found to outperform females on several traditional psychometric tests of spatial ability, especially those involving a component of mental rotation. The evidence is much less clear and complete with respect to performance on larger-scale and more ecologically valid tasks generally associated with geographic investigation, such as those involved in wayfinding, map use, and place learning. In this study, a community sample of 43 females and 36 males performed a large battery of spatial and geographic tasks. The battery included psychometric tests; tests of directly acquired spatial knowledge from a campus walk; map-learning tests; tests of extant geographic knowledge at local, regional, national, and international scales; tests of object-location memory; a verbal spatial task; and various self-report measures of spatial competence and style. Both univariate means tests and multivariate discriminant analyses largely agree on a comprehensive picture of the spatial abilities and styles of males and females. In particular, the study supports a "route-survey" distinction between the sexes, and replicates previously published evidence of female superiority at a static object-location memory task. Males were found to most clearly outperform females on tests of newly acquired spatial knowledge of places from direct experience rather than tests of extant knowledge or map-derived knowledge; the latter tests revealed no clear differences between the sexes. *Key Words: gender, geographic skills, sex, spatial abilities.*

Both common belief and a great deal of scientific literature claim that the sexes differ in their ability to perform certain spatial and geographic tasks. Some of these claims enjoy more empirical substantiation than others. Frequently such claims overgeneralize from patterns found on a single spatial task or on a limited range of tasks, effectively defining "spatial tasks" in an overly narrow way. In this paper, we briefly review the extensive multidisciplinary literature on sex-related differences in spatial abilities, emphasizing results that are most relevant to the development of geographic knowledge. We then present the results of a study designed to compare the sexes on a wide array of spatial and geographic tasks. Unlike most of the past research conducted in other disciplines, we do not restrict ourselves to pictorial and graphical spatial tasks, but include tasks involving environmental and geographic spaces. Our focus is on characterizing the pattern of performance across this broad array of tasks in a way that more accurately conveys both the differences and similarities between males and females in "spatial" ability.

We use the term "sex-related" to refer to statistical comparisons of performance between males and females (see Deaux 1993). By using this term, we do not imply a particular causal explanation for any differences that may actually exist, only a description of data patterns. "Sex-related" refers only to a correlation between the measured value of a variable and a person's status as a female or male (or, equivalently, a mean difference between females and males on a particular variable). Some causal explanation underlies such a correlation, but it is typically ambiguous as to what that explanation is. Of course, the question of why any sex-related differences exist

Annals of the Association of American Geographers, 89(3), 1999, p. 515–534

Published by Blackwell Publishers, 350 Main Street, Malden, MA 02148, and 108 Cowley Road, Oxford, OX4 1JF, UK.

is an important one, and one that has generated a great deal of theorizing and speculation. Explanations have run the gamut from biological theories of hormones, brain laterality, and evolutionary strategies of the sexes, to learning and socialization theories of toy play, activity spaces, and parental and societal feedback, to theories about bias and stereotyping in spatial testing and data interpretation (Serbin and Conner 1979; McGlone 1980; Shute et al. 1983; Signorella and Jamison 1986; Bowers and LaBarba 1988; Goldstein et al. 1990; Kimura 1992; Newcombe and Dubas 1992; Sharps et al. 1994; see reviews in Maccoby and Jacklin 1974; McGee 1979; Harris 1981; Self et al. 1992). We remain neutral however, in this paper on the issue of causality, though we recognize the likely interactive roles of genetics, neurophysiology, learning, and biased socialization. The research we present below was not designed to shed light on the causes of differences; the one-shot correlational design we use and the lack of child and adolescent research participants make causal conclusions quite ambiguous (the literature in fact contains many such dubious conclusions about causality). Instead, our research was designed simply to describe and characterize the nature and extent of differences and similarities in a comprehensive fashion. We believe this fulfills the necessary function of describing sex-related patterns of performance that is a prerequisite to causal research. It also serves the purpose of alerting geographers to some of the possible ways that a person's sex might influence teaching and research in geography, as well as to ways in which sex might not be influential.

Review of Literature

Hundreds of studies on patterns of spatial task performance as a function of sex have been conducted and reported during the last hundred years. The great majority of such studies have involved psychometric paper-and-pencil tests, of which there are over a hundred published examples (Eliot and Smith 1983; Eliot 1996). Even restricting ourselves to these psychometric tests, there are many different ways in which "spatial ability" has been conceptualized and operationalized. Tests have variously required individuals to find hidden shapes, match 2-D or 3-D figures, balance figures with respect to horizontal or vertical axes, solve mazes, imagine the results of rotations or manipulations of figures, and more. In many cases, data collected with these tests have been subjected to data reduction techniques like factor analysis in an attempt to identify a small number of basic underlying spatial abilities (summarized by Eliot and Smith 1983). Most often two or three primary factors have been identified, sometimes along with less important minor factors (Guilford's [1967] once-influential approach was an important exception in identifying a large number of spatial and other intellectual component "abilities"). The two most common primary factors have typically been labeled "spatial visualization," the ability to mentally manipulate or rotate 2-D or 3-D pictorially presented visual stimuli, and "spatial orientation," the comprehension of the components or elements within a visual stimulus pattern or the ability to imagine how a stimulus or configuration would appear from another perspective (McGee 1979; Eliot and Smith 1983). A "spatial relations" factor has also been identified, though its uniqueness relative to visualization and orientation has been unclear.

Statistically reliable sex-related differences favoring males in their performance of several psychometric tests of spatial ability have repeatedly been found, though the differences are typically modest in size (reviewed by Harris 1981; Maccoby and Jacklin 1974). Not all tests reveal differences of equal magnitude or robust significance, however, and there may exist a number of studies that did not find statistically reliable sex-related differences and thus were not published. Although not the only type of test that has revealed differences favoring males (for example, males outperform females on "dynamic spatial reasoning" tasks, such as judging the relative speeds of two moving symbols on a computer screen [Law et al. 1993]), those involving the mental rotation of 2-D and 3-D figures consistently show the largest differences (Linn and Peterson 1985; Masters and Sanders 1993; Voyer et al. 1995). The difference appears to reflect the fact that males perform mental rotation more quickly than do females (Kail et al. 1979; Goldstein et al. 1990).

In sum, the extensive psychometric literature has conclusively demonstrated that males on average perform better than females on some types of spatial tests, especially speeded tests involving a component of mental rotation. What is unclear is what role "spatial ability," as it has been defined in psychometric research, plays in the performance of such real-world and large-scale spatial tasks as using a map, navigating through an environment, and giving and interpreting verbal spatial descriptions. For example, commentators have noted that:

> Nearly all of this research [on sex differences], however, has used two-dimensional spatial tasks (paper-and-pencil tests) and has not investigated three-dimensional, spatial comprehension at real scale (Evans 1980:275).
>
> Few "spatial ability" studies have involved the requirement to perform such practical, everyday tasks as finding one's way around a locale (Caplan et al. 1985:795).
>
> To what extent [do] common processes and representations underlie skill in dealing with large-scale space and spatial ability as measured by standard aptitude tests? (Cooper and Mumaw 1985:91–92).

A few studies suggest that factors derived from paper-and-pencil tests account only very weakly for performance on large-scale spatial tasks (Pearson and Ialongo 1986; Bryant 1991; Allen et al. 1996). We believe it is unlikely that factors derived from paper-and-pencil tests could account for the entire spectrum of skills that might reasonably be thought to involve "spatial ability" in this more ecologically relevant sense. The restricted definition of spatial ability, as incorporated into many psychometric tests, contrasts with the richness of the general literature on spatial activities and spatial behavior, much of it from disciplines other than psychology. What is not at all obvious is how scores on spatial psychometric tests relate to the spatial skills necessary in many of these problem-solving situations.

Some research does exist comparing males and females on their performance of environmental and real-world spatial tasks, though it constitutes only a small portion of the research on sex-related differences in spatial abilities. For instance, several studies have examined the performance of spatial tasks involving extant knowledge of places acquired from previous experience. Evans (1980) summarized work of this type involving sketch map measures by concluding either that the sexes did not differ or that the male superiority sometimes found was due to differences in home range. Several studies since then have found only small differences between the sexes on their extant knowledge of distances and directions between places in local environments (Gärling et al. 1982; Kirasic et al. 1984; Kitchin 1996). Holding (1992) did find that males were significantly more accurate locating campus buildings on a grid placement task.

The evidence for sex-related differences is much stronger in studies that have examined environmental spatial knowledge acquired as part of the study, particularly when based on direct locomotor experience. Bryant (1982) reported that females made significantly higher errors pointing to target landmarks in the environment. Other studies have replicated this male superiority in indicating directions to places and features along routes in the environment to which they were exposed as part of the study (Holding and Holding 1989; Presson et al. 1989; Lawton 1996; Lawton et al. 1996). Pearson and Ferguson (1989) had female and male college students learn a city route by viewing a sequence of slides taken during a walk along the route (they did not actually locomote along the route). Males drew more accurate sketch maps of the route, though this difference was small and did not reach statistical significance.

A few studies have examined differences between the sexes in learning information from maps, finding quite mixed results. Gilmartin and Patton (1984) and Golledge et al. (1995) reported small and nonsignificant differences between the sexes on a variety of map use and map-learning tasks. Beatty and Tröster (1987) found that males located cities and other features more accurately on U.S. and state outline maps based on extant knowledge of geography, but no difference was found on such a task when based on new knowledge learned from fictitious maps. Henrie et al. (1997) found that male college students outperformed female college students on a multiple-choice test of map skills and map-based geographic knowledge. Galea and Kimura (1993) had participants learn a route from a fictitious city map. Males retraced the route faster and more accurately, and were more accurate estimating straight-line directions. It is clearly difficult to make any generalization about "map abilities," however, given the wide variety of map types and tasks employed in these studies.

A task that has revealed some of the most robust evidence for sex-related differences in environmental spatial tasks is self-report of spatial ability and anxiety. Kozlowski and Bryant (1977) provide one of the earliest reports of this trend, finding, in their first study, that 20 of 28 male participants, but only 8 of 17 females, self-classified themselves as having a "good sense-of-direction" (notwithstanding Evans's 1980 interpretation of this as no difference). Since then, several studies have reported higher self-reports of "sense-of-direction" or "spatial confidence" by males (Harris 1981; Bryant 1982; Foley and Cohen 1984; Lunneborg 1984; Devlin and Bernstein 1995) and higher reports of "spatial anxiety" by females (Lawton 1994, 1996; Lawton et al. 1996).

It has often been suggested in the literature that males and females differ stylistically in their environmental cognition along a dimension of "route versus survey" knowledge. Females are said to rely more on a "route strategy" that depends on a sequential knowledge of landmarks. Males, on the other hand, are thought to employ a "survey strategy" to a relatively greater extent. This would be reflected in greater reliance on metric knowledge of distances and directions (particularly cardinal directions), and better knowledge of straight-line relationships of places between which they had not directly traveled. This stylistic difference has been identified in sketch maps drawn by the two sexes (e.g., Spencer and Weetman 1981; McGuinness and Sparks 1983). Evidence reviewed above involving environmental knowledge acquired as part of the study is consistent with this difference as well. Furthermore, Galea and Kimura (1993) found that females did in fact recall more landmarks on a task involving route-learning from a fictitious city map. As reviewed above, however, males retraced the route faster and more accurately, and made more accurate estimates of straight-line directions. But Devlin and Bernstein (1995), using a task that exposed first-time campus visitors to a computer-simulated tour of the campus, found that females did not benefit from a condition in which landmarks were highlighted.

Probably the most common form of evidence that females and males differ stylistically along some type of route-survey knowledge dimension comes from studies of verbal descriptions of routes and places. Ward et al. (1986) had participants give verbal instructions for following routes from fictitious maps ("directions"). Whether done while viewing the maps or from memory, males used more cardinal-direction terms and more metric-distance terms than females. Miller and Santoni (1986), using a similar task, found that females referred more to landmarks in their route descriptions.

Self-report measures have also supported the existence of some type of route-survey distinction. Lawton (1994, 1996) reported that females were more likely to report using a route strategy (attending to feature cues and connections between places), while men were more likely to report using an "orientation" strategy (maintaining a sense of self-location relative to environmental reference points). Lawton et al. (1996) found no difference in the reported use of landmarks in a task that required participants to learn a route in a large building.

To this point, whatever the nature of the spatial task, nearly all evidence finds either that males are faster or more accurate at the task, or that the sexes do not differ. Recently, reasoning from ostensible evolved differences between the spatial skills of "hunters" and "gatherers," Silverman and Eals (1992) introduced a spatial task for which they predicted and found better performance by females. We call the task "object-location memory." In their first study, Silverman and Eals found that females recognized significantly more objects on a sheet of paper that they had seen on a study sheet shown earlier; they also recognized better whether objects were in different locations than on the study sheet. The second study was conducted in a small office with objects placed around the room. In an incidental learning task, females verbally recalled more of the names and approximate locations of the room objects after a short delay. Study 3 used the same office, but both incidental and intentional learning conditions. In both learning conditions, females placed more objects into their approximately correct locations on a schematic drawing of the room. This was true even when placed objects were divided by the number of remembered objects, an attempt to control for differences in object-identity memory. In follow-up research, Eals and Silverman (1994) drew a further explanatory analogy by reference to the supposed "landmark" style of females. They replicated the patterns of object memory with both common and uncommon objects; the latter would not easily be labeled verbally, and a female advantage with them could not readily be attributed to female verbal superiority. In fact, the patterns were less consistently replicated with uncommon objects; for example, female location memory was better only in an incidental learning condition.

In sum, existing research indicates that males and females do differ in their performance of some spatial and geographic tasks, but not others. Males have usually been shown to excel at knowledge of directions between places in the environment; this pattern is much clearer in studies involving knowledge directly acquired as part of the study, rather than extant knowledge of the environment brought into the study. The notion of a stylistic difference along the lines of a "route-survey" distinction receives support from several bodies of evidence. Also, males typically report a better "sense-of-direction" and lower anxiety about wayfinding and spatial learning. The evidence from studies of map abilities is quite mixed, but it is probably correct to conclude that males have no consistent superiority on map tasks in general. Finally, there is evidence that females excel at object-location memory, whether based on pictorial stimuli or environmental spaces. The suggestion of female superiority in a spatial task is quite novel and intriguing, but this finding needs to be replicated.

In the study reported below, we administered a wide variety of environmental and geographic spatial tasks to a single sample of research participants in order to assess the nature of sex-related differences and similarities. Attempts were made to evaluate a wide cross-section of measures of spatial abilities that have been reported in the literature. Traditional paper-and-pencil psychometric tests were included as a replication of past research. Spatial learning and acquired knowledge in larger-scale spaces was also investigated, including a room space, a campus route, city landmark locations, and national and world-city locations. The ability to learn information from maps was tested. We also included a task involving verbal spatial ability, specifically the verbal description of a route through campus. Finally, several self-report measures of spatial familiarity and ability were administered. In addition to traditional measures of psychometric dimensions of spatial ability, this array of tasks and measures included several that more closely resemble real-world spatial activities. They varied in the scale of the space, the contribution of static and dynamic abilities, and the type of spatial knowledge assessed.

Methods

Participants

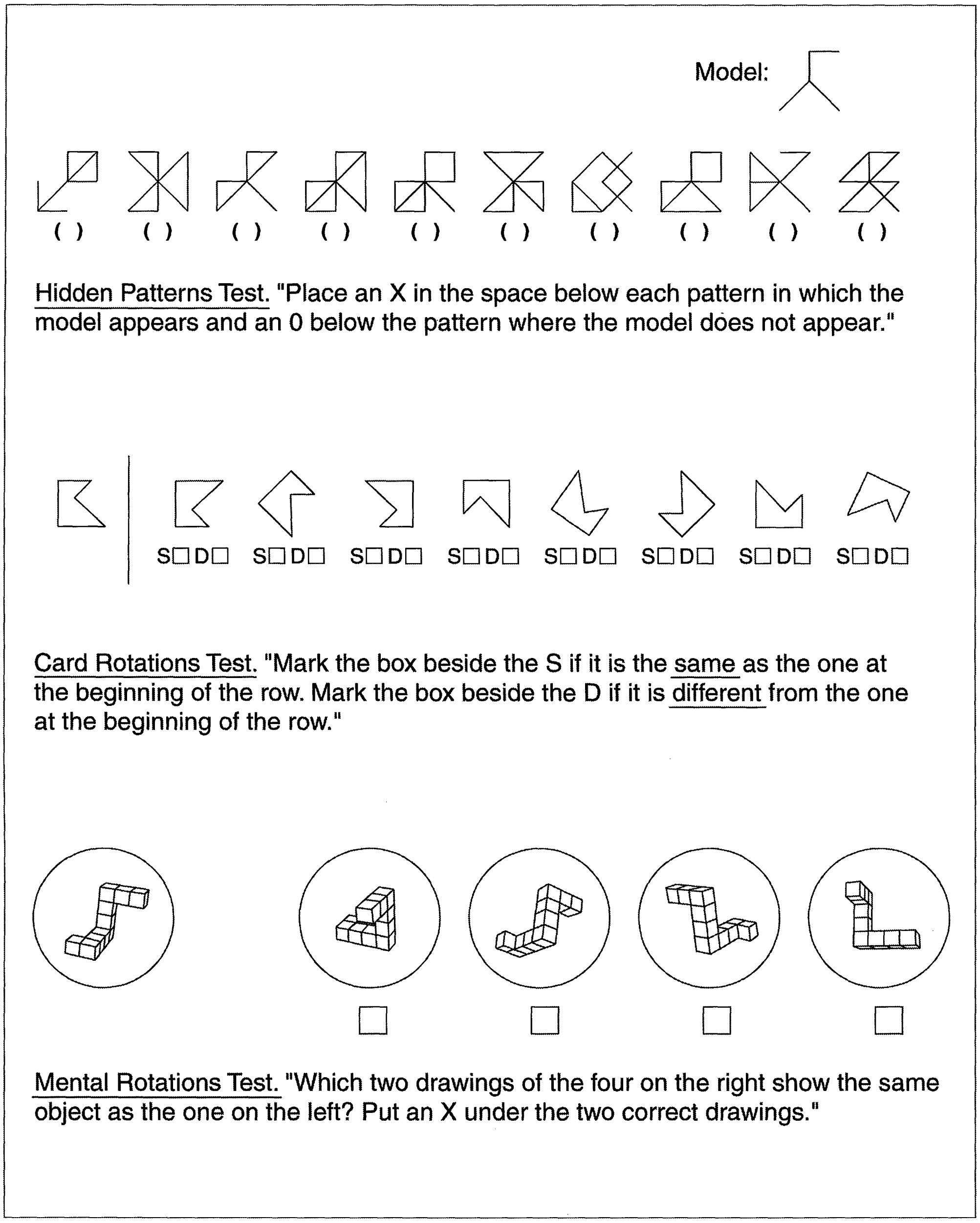
Participants were drawn from a pool of about 450 residents of the Santa Barbara area who had earlier responded to a mail survey about their spatial activities and experiences (described in a separate manuscript in preparation). Participation was solicited by phone; an attempt was made to balance the age composition of our sample between the two sexes. Eighty-one participants agreed to participate and began the study, but two participants were dropped because they did not complete both data-collection sessions. Participants completing both sessions were paid \$40. The final group of 79 participants consisted of 43 females and 36 males. They ranged in age from 19 to 76 years, with a mean age of 47. The socioeconomic status of our participants was quite high, with a median income level of \$40,000–60,000 per year and a median education of "four years of college" (none had less than a high-school diploma, and 23 had postgraduate degrees). In addition to their similarity in age, female and male participants were very similar and not significantly different on average with respect to income and education. Furthermore, the two sexes had lived in the Santa Barbara area for about the same number of years and had nearly equal amounts of self-reported contact with local landmarks, familiarity with the campus, and knowledge of U.S. and world cities.

Tasks and Measures

The battery of tasks administered to participants may be organized into seven groups:

Psychometric Tests. Three standard paper-and-pencil tests were administered: the Hidden Patterns (French et al. 1963), Card Rotations (French et al. 1963), and Vandenberg Mental Rotations (Vandenberg and Kuse 1978) tests. Sample items from each test are presented in Figure 1. These tests assess both "visualization" and "orientation" dimensions, static and dynamic spatial abilities, and 2-D and 3-D spaces. All of these tests are composed of small abstract shapes drawn on paper. Each test consists of 2 sections, each of which must be completed within 3 minutes.

Campus Route Learning. Participants were taken on a walk through an area of campus. This route was approximately 420 m in length and wound around various buildings and other structures (Figure 2); it required about 5 minutes to walk once. The first walk constituted an incidental learning trial, as no instructions were given to pay attention to landmarks or spatial properties of the route, only to follow the researcher. After completing this first walk, participants sat on a



Hidden Patterns Test. "Place an X in the space below each pattern in which the model appears and an 0 below the pattern where the model does not appear."

Card Rotations Test. "Mark the box beside the S if it is the same as the one at the beginning of the row. Mark the box beside the D if it is different from the one at the beginning of the row."

Mental Rotations Test. "Which two drawings of the four on the right show the same object as the one on the left? Put an X under the two correct drawings."

Figure 1. Sample items from the Hidden Patterns Test, Card Rotations Test, and Vandenberg Mental Rotations Tests.

bench next to the end of the route and were asked to draw a sketch map of the route. The sketch map was drawn on an 8.5" × 11" piece of paper that was blank except for the initial straight segment of the route, 55 m in length, which was included to provide scale for the maps. This scale segment was explained to participants, and they were told to show distances, directions, and other details as accurately as possible. No time limit was placed on the sketch mapping. After the sketch map was complete, participants were taken on two more walks along the route. These may be considered intentional learning trials, as participants knew they would be drawing sketch maps after each walk. Also, a series of eight landmarks were pointed out and named to participants on the second and third trials (see Figure 2). They were told to remember the names and locations of these landmarks because they would need to place them on their sketch maps. An alphabetically ordered list of landmark names was given to participants while they drew their maps on these two trials, so that all sketch maps would contain marked locations for all landmarks (a small number of participants omitted one or more nonetheless).

Map Learning. This set of measures consisted of two separate tasks in which participants learned information from novel maps.

(a) *Amusement Park Map*: This task was a map analogue to the campus route-learning task described above. Participants were shown a simple map of a fictitious amusement park (Figure 3). The route shape was exactly the same as the campus route and had 8 landmarks in the same locations as the target landmarks in the campus route (Lloyd [1989] inspired our use of analogue maps in this task and the Grand Forks task below). Participants were given a copy of the 8.5" × 11" map, which they looked at as the researcher highlighted a specific route through the environment on a copy of the map projected with an overhead projector (see Figure 3). Three learning trials were administered, as in the campus route task. The first trial again constituted incidental learning. After the route was shown, the projector was turned off, and participants were given a minute to study their maps. After that minute, they were given a piece of 8.5" × 11" paper, which included the initial segment of the route. They were asked to draw a sketch map of the route, just as in the campus route task, requiring up to five minutes to complete. After this drawing, two more intentional learning trials were administered (the participants knew they were going to draw sketch maps). The 8 target landmarks were pointed out on the projector and provided to participants in an alphabetically ordered list while they drew their sketch maps.

(b) *Grand Forks Map*. In this map-learning task, participants were shown a fictitious map of Grand Forks, North Dakota (Figure 4), constructed by rotating a simplified line map of the city of Santa Barbara and changing the names of the target landmarks used in the Santa Barbara distance-estimation task described below, allowing

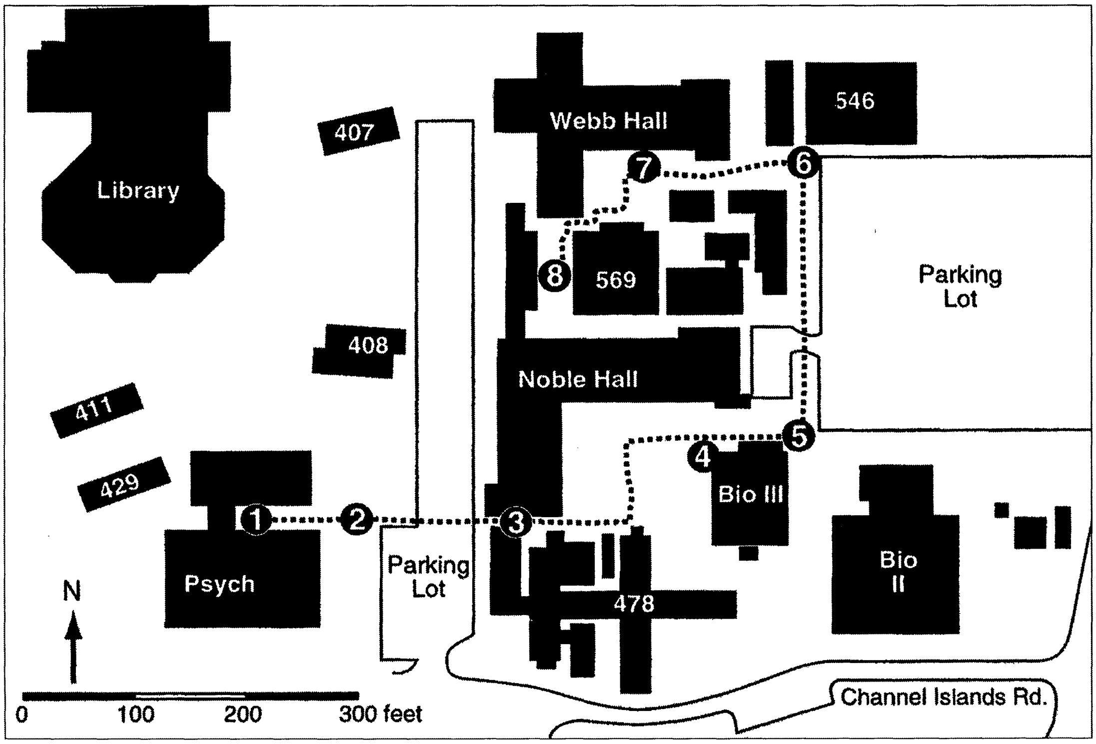


Figure 2. Campus route learned via walking, including locations of eight landmarks taught to participants.

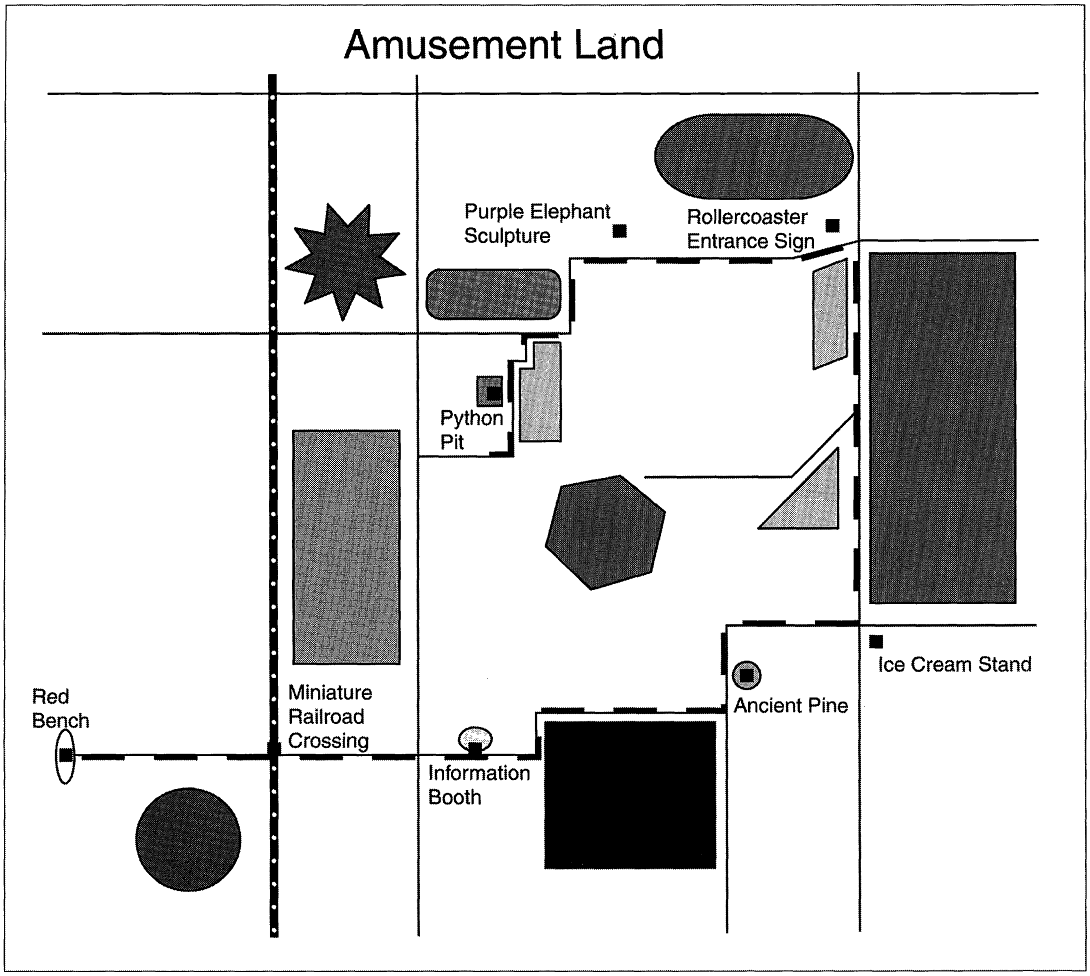


Figure 3. Fictitious amusement park learned via map, including eight landmarks taught to participants. Route followed in dashed line.

a direct comparison with the data from that task. Participants were given the 8.5" × 11" map and were given 2 minutes to study the map in order to learn the names of 8 target landmarks. After studying the map, they were asked to draw a sketch map of the city including as many of the landmarks with their names as they could remember. This map study and drawing cycle was repeated twice more. After each drawing was complete, the researcher checked the map for correctness of the names of the landmarks. If landmarks were missing or incorrect, the name was told to participants. No feedback was given on the correctness of the drawing or the locations of the landmarks. These 3 sketches served as learning trials only. After they were complete, participants performed straight-line distance estimates between pairs of the 8 landmarks. Magnitude estimates were of the form, "If it is 100 units from A to B, how many units is it from C to D?" Eight landmarks can be grouped into 28 possible pairs. One pair was always used as the reference distance (A to B), leaving 27 pairs to be estimated. Participants read a set of instructions and an example, and were given a chance to ask questions before performing these estimates. Up to 25 minutes were given to complete this task.

Extant Geographic Knowledge. This set of measures consisted of four separate tasks in which participants answered questions about local, national, and international place locations they knew from prior experience, either direct travel or indirect sources such as maps.

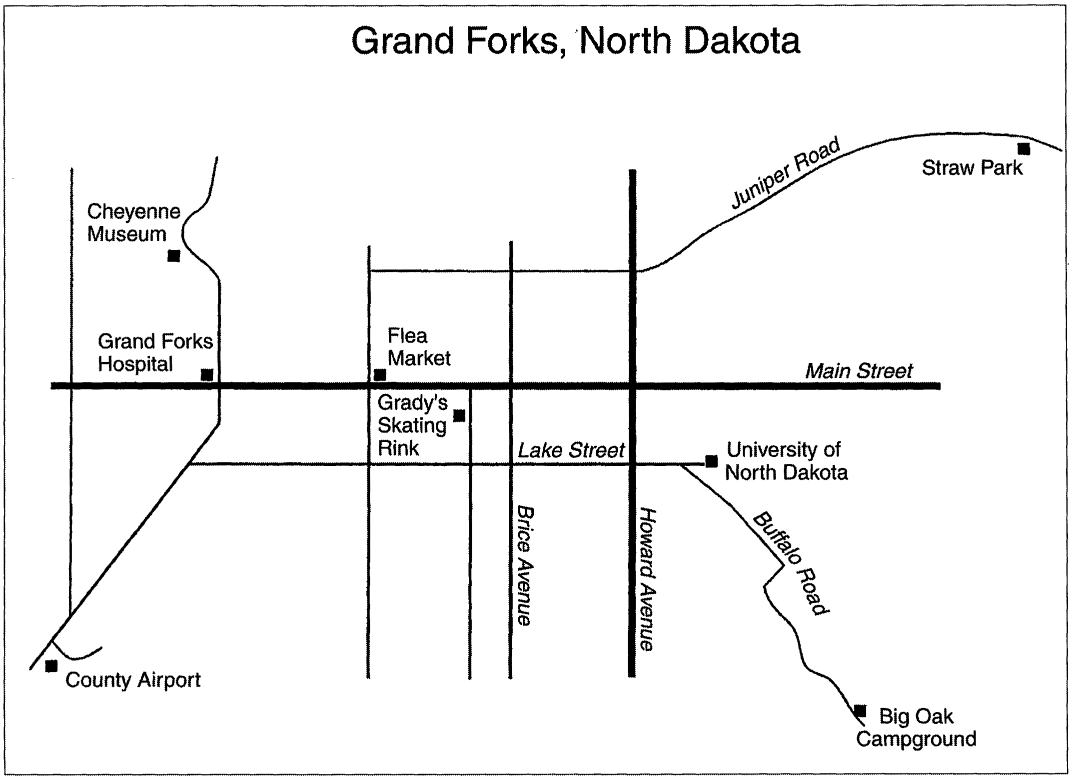


Figure 4. Fictitious map of Grand Forks.

(a) *Santa Barbara Distances*. Magnitude estimates of distances between 27 pairs of locations in the Santa Barbara area were collected as in the Grand Forks task above. As described there, these eight landmarks formed the same configuration as those depicted on the Grand Forks map, though rotated. It is important to note, however, that participants were never shown a map of the Santa Barbara landmarks, but had to estimate distances from prior knowledge. Up to 25 minutes were given to complete this task.

(b) *City Cardinal Locations*. In this task, participants judged which of a pair of cities was either farther north or farther east (e.g., "which is farther to the north, Washington, DC or Paris, France?"). Eight pairs of cities were used. Four minutes were given to complete this task.

(c) *City/State Ordinal Distances*. Participants answered 27 questions of the type, "Which city (or state) is closer to A: B or C?" (e.g., "which city is closer to Phoenix: Las Vegas or Los Angeles?"). Fifteen questions involved city locations, and 12 questions involved U.S. state locations. Up to 10 minutes were given to complete this task.

(d) *City Placements*. Participants were given an outline map of the world (Mercator projection) and a list of 15 cities (with their countries identified) to place on the map (e.g., Athens, Greece; Sydney, Australia). They placed a small dot on the map at their best guess of the location of each city and wrote its name. Participants were given up to 7 minutes to complete this task.

Object Location Memory. This task was a replication of the task introduced by Silverman and Eals (1992). Participants were taken to a curtained-off corner of a room that contained two tables. Thirty-five items (e.g., battery, chalk, shoes) were placed on the two table tops, the walls above the two tables, and on the floor beneath the tables. Participants were given 2 minutes to study the items, and told to try to memorize the identities of everything there, including items on the walls and floor. Object locations were learned incidentally. Participants were also asked not to touch anything. After 2 minutes, the participants were taken to a different table where they were given a perspective drawing of the corner of the room (Figure 5) and a list of the 35 items (in alphabetical order). The participants were asked to place the numerical label of each of the 35 items onto the drawing in the location where the item was. They were instructed to skip any item which they could not remember having seen. The recall of object locations required as long as 12 minutes to complete, about 5 minutes on average.

Verbal Spatial Descriptions. This task was performed as part of the campus route-learning task described above. After the third walk and sketch map of the route, participants verbally described the route into a tape recorder as if they were instructing someone how to follow the route. They were told to use whatever information they thought would be most useful.

Self-Report Measures. Demographic variables assessed included sex, age, years living in the area, income level, education level, and occupation (the latter three measures were taken from participants' earlier responses to our mail survey). Self-reports about prior familiarity with and exposure to the campus, the city, and U.S. and world cities were collected with 5- and 7-point scales. Participants also rated their environmental spatial "style." This consisted of 10 7-point scales asking about sense-of-direction, spatial ability, spatial preferences, and spatial anxiety (Table 1).

Design and Procedure

Tasks were administered in 2 sessions, a group session (1 to 6 participants), lasting approximately 2.5 hours, and an individual session, lasting approximately 1.5 hours. The sessions were scheduled about 2 weeks apart, in counterbalanced order. Participants were assigned to a session according to their sex and age group. The group session consisted of the psychometric tests, the map learning tasks, and the extant geographic-knowledge tasks. Within this session, the order of these 3 groups of tasks was counterbalanced. Two breaks of 10 and 5 minutes were taken in between these groups of tasks. The individual sessions consisted of the route learning and object-location tasks, also counterbalanced for order. The self-report questions dealing with spatial ability and familiarity were administered either at the beginning or at the end of the route learning task. All sessions were conducted by female research assistants.

Table 1. Self-Report Environmental Spatial-Style Questions[a]

(1) I am very good at giving directions.
(2) My "sense of direction" is very poor.
(3) I am very good at judging distances.
(4) I do not like to explore.
(5) I tend to think of my environment in terms of cardinal directions (N,S,E,W).
(6) I very easily get lost in a new city.
(7) I don't confuse right and left much.
(8) I am very good at reading maps.
(9) I don't remember routes very well while riding as a passenger in a car.
(10) It's not important to me to know where I am.

[a] Answers were made on 7-point Likert scales: 1 was "strongly agree," 7 was "strongly disagree."

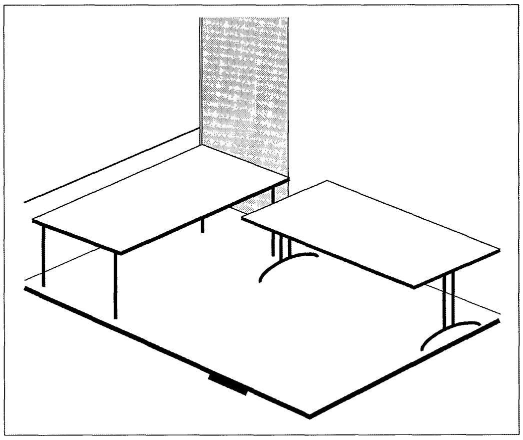


Figure 5. Perspective drawing of room used to collect data for Object Location Memory task.

Results

Separate univariate analyses are first presented for each of the spatial tasks, organized into groups as in the Methods Section. The results are then examined using multivariate discriminant analysis.

Univariate Results

Psychometric Tests. Mean scores for males and females on the Hidden Patterns Test (HPT), Card Rotations Test (CRT), and Vandenberg Mental Rotations Test (MRT) are shown in Table 2. Males scored significantly higher than females

Table 2. Mean Scores[a] by Males and Females on the Psychometric Paper-and-Pencil Tests

Test	Male	Female
Mental Rotation***	16.6 (6.4)	11.8 (5.0)
Hidden Patterns	191.4 (50.3)	177.3 (47.1)
Card Rotation	100.7 (28.4)	93.9 (31.1)

[a] Mean raw scores (standard deviations).
*** $p < .001$

on the MRT, $t(77) = -3.72$, $p < .001$, but not on the HPT, $t(77) = -1.28$, nor on the CRT, $t(77) = -1.01$.

Campus Route Learning. Several variables were scored from the sketch maps, based on the average performance after the second and third walks. Mean scores for males and females for the following variables are shown in Table 3: route-turn errors (Route-Turn), including extra turns, omitted turns, and turns in the wrong direction; route-landmark errors (Route-Landmark), including landmarks on the wrong route segment and skipped landmarks; route-distance error from correct (Route-Distance), in mm; straight-line distance error from the end to the beginning of the route (Survey-Distance); and straight-line direction error from the end to the beginning of the route (Survey-Direction). The first two may be thought of unambiguously as measures of "route knowledge," while the latter two are clearly measures of "survey knowledge"; Route-Distance is a measure of metric spatial knowledge along the route, arguably transitional between route and survey knowledge. Route-Distance error was significantly lower for males than for females, $t(77) = 2.55$, $p < .01$, as was Survey-Direction, $t(77) = 3.04$, $p < .01$. Females made marginally fewer Route-Landmark errors, $t(77) = -1.92$, $p < .06$. Neither Route-Turn errors, $t(77) = 1.00$, nor Survey-Distance errors, $t(77) = 0.20$, significantly differed for males and females.

Table 3. Mean Error Scores[a] by Males and Females on the Campus Route Learning Task

Task	Male	Female
Route-Turn	2.5 (1.4)	2.8 (1.6)
Route-Landmark	.3 (.6)	.2 (.3)
Route-Distance** (mm)	51.5 (34.0)	73.2 (40.3)
Survey-Distance (mm)	18.9 (14.6)	19.5 (14.7)
Survey-Direction** (°)	8.7 (7.3)	17.6 (16.3)

[a] Mean raw scores (standard deviations).
** $p < .01$

Table 4. Mean Error Scores[a] by Males and Females on the Amusement Park Map Learning Task

Task	Male	Female
Route-Turn	1.5 (1.1)	1.6 (1.2)
Route-Landmark	.9 (1.0)	.9 (.8)
Route-Distance (mm)	37.3 (29.6)	34.6 (28.8)
Survey-Distance (mm)	12.9 (7.8)	12.5 (9.9)
Survey-Direction (°)	9.1 (7.3)	10.9 (8.0)

[a] Mean raw scores (standard deviations).

Map Learning. Participants learned a route from a map of a fictitious amusement park. They were not informed that the route was shaped the same as the campus route described above that was learned through direct experience. The same variables were scored here, again based on the average performance after the second and third learning trials (Table 4). In the case of this map-acquired knowledge, unlike the directly acquired campus knowledge, males and females did not significantly differ on any of the variables (degrees of freedom are less because two respondents were accidentally given the wrong data sheets for this task): Route-Landmark errors, $t(75) = -0.27$; Route-Turn errors, $t(75) = 0.51$; Route-Distance error, $t(75) = -0.39$; Survey-Distance errors, $t(75) = -0.16$; and Survey-Direction errors, $t(75) = 1.05$.

In a second map task, participants learned a fictitious map of Grand Forks, North Dakota. The street layout was a rotated version of the street layout of Santa Barbara, which allows us to compare these results to the results from the Santa Barbara knowledge task presented below. One measure was scored here: mean error on a pairwise distance estimation task involving 8 landmarks on the map. Females ($M = 103.1$ units, $SD = 49.9$) and males ($M = 115.8$ units, $SD = 64.1$) did not significantly differ, $t(77) = -0.99$.

Extant Geographic Knowledge. This consisted of four tasks. The "Santa Barbara Distances" task required participants to make distance estimates between pairs of landmarks, as was done for the Grand Forks task. These were actual landmarks from the Santa Barbara area that participants had learned about through some combination of direct and indirect experience during the time they had lived in the area. They were not shown a map of the area as part of the study. Just as was true for errors estimating distances from the Grand Forks map, males and females performed very similarly on this task (Table 5) and did not significantly differ, t(77) = –0.27. The "City Cardinal Locations" task required participants to judge which of a pair of world cities was further north or east. This data consists of the proportion correct out of eight pairs. Males and females (Table 5) did not significantly differ on their performance of this task, t(77) = –1.53. The "City/State Ordinal Distances" task required participants to judge which of a pair of cities or states is closer to a third. Male and female proportion correct out of 23 was similar (Table 5) and did not significantly differ, t(77) = –1.28.

The final geographic-knowledge task, "City Placements," was the only one of the four that did result in significantly different performance by males and females. The task required participants to place 15 world cities on an outline map of the world. Mean error in miles (Table 5) was greater for females than for males, t(77) = 2.21.

Object Location Memory. This task required the placement of objects on an outline drawing of the corner of a room. Object-identity memory did not confound any variables scored from this task because participants were given the list of the objects and did not have to recall their identities, only their locations. The task was scored in several ways, all of which converge on the conclusion that females perform this spatial task better than males. A mean of only 2.4 out of 35 objects were not placed, 1.9 by females and 3.0 by males, which was not a significant difference. "Topological" errors were separated from "metric" errors. The former consisted of a count of objects that were located on an incorrect surface—for instance, a table object placed on the floor. Overall, an average of 1.6 objects were so misplaced. Males misplaced significantly more objects in this way (M = 2.2, SD = 2.1) than did females (M = 1.0, SD = 1.4), t(77) = –3.00, p < .01. Metric errors consisted of a measurement of the distances between the objects' recalled locations and their actual locations (in cm of room space after being scaled from the response sheet). First, all recalled objects were included; objects determined to be topological errors obviously contributed large metric errors. Calculated in this way, males in fact had significantly greater metric errors (M = 25.3cm, SD = 10.3) than did females (M = 20.0cm, SD = 8.6), t(77) = –2.49, p < .01. It is possible that including objects misplaced topologically, as has been done in all previous research, is misleading. Maybe the difference is entirely due to such topological misplacements. Because of this possibility, we carried out a second analysis of metric errors. This included only objects located topologically correctly. Errors were somewhat smaller of course, yet males (M = 21.9cm, SD = 9.3) and females (M = 18.3cm, SD = 7.6) still differed. The difference, however, did not quite reach significance when analyzed this way, t(77) = –1.85, p = .07.

Verbal Spatial Descriptions. This set of measures was derived from a verbal description of the route walked as part of the Campus Route Learning task. Several variables were obtained from this task (Table 6): the total number of words used; the total amount of filler, including repeated words, pauses, and irrelevant asides; total number of turns mentioned; total number of mentioned turns that were correct; total number of landmarks mentioned (almost all of which were correct); total number of maintenance statements (such as "keep going"); total number of nonmetric-distance terms (such as "next" or "beyond"); total number of fuzzy and precise metric-distance terms (such as "quite a ways" or "about 50 feet"); and the number of terms referring to cardinal directions. Of these, females referred to cardinal directions less frequently than males, t(77) = –4.04. Females also used marginally more nonmetric-distance terms, t(77) = 1.82, p = .07, and marginally fewer metric-distance terms, t(77) = –1.75, p = .08. None of the other measures approached statistical significance.

Table 5. Mean Performance by Males and Females on the Extant Geographic Knowledge Tasks[a]

	Male	Female
Santa Barbara Distances (units)	135.0 (108.9)	129.8 (62.2)
City Cardinal Locations[b]	74 (23)	67 (18)
City/State Ordinal Distances[b]	66 (9)	64 (10)
City Placements* (mi)	941.2 (600.0)	1273.1 (716.1)

[a] Mean raw scores (standard deviations).
* $p < .05$
[b] percentage correct.

Table 6. Mean Performance[a] by Males and Females on the Verbal Description of the Campus Route

Description	Male	Female
Total words	263.2 (115.3)	260.7 (122.5)
Filler expressions	58.6 (38.6)	49.3 (35.2)
Turns mentioned	7.3 (2.5)	7.1 (2.5)
Turns correct	6.2 (2.5)	5.8 (2.0)
Landmarks mentioned	17.2 (8.2)	18.4 (5.9)
Maintenance statements	6.8 (2.8)	7.9 (3.2)
Nonmetric-distance terms	1.4 (2.0)	2.5 (3.2)
Metric-distance terms	3.1 (3.1)	1.9 (3.3)
Cardinal-direction terms	2.4 (2.7)	0.6 (1.1)****

[a] Mean raw scores (standard deviations).
**** $p < .0001$

Self-Report Measures. Finally, self-report variables were compared for males and females. "Environmental spatial style" consisted of the answers to 10 self-report items dealing with abilities and preferences. Calculated as a simple mean of the 10 items, males did not rate themselves very differently than did females on environmental spatial style, and the difference did not reach significance (Table 7). Furthermore, self-reports of spatial style did not differ much as a function of order; both overall and within each sex, they were similar whether provided before or after the other tasks performed that session (including the campus-route task). Analyzed individually, males rated themselves significantly higher on item 3 (Table 1), about judging distances, and item 5, on thinking in terms of cardinal directions. The sexes did not significantly differ on any other item.

Self-report measures also included the demographic variables of age, income, and education, and several geographic familiarity variables, including years living in Santa Barbara, mean contact with Santa Barbara landmarks, familiarity with the university campus, and familiarity with the U.S. and world cities whose location was tested for in the geographic-knowledge tasks. On none of these variables did males and females differ much (Table 7), and none of the differences approached statistical significance.

Multivariate Results

Conducting separate univariate analyses has some real limitations as an approach to understanding these data. The primary reason is that interrelationships between measures are ignored by the univariate approach; it is definitely not the case that each variable in the dataset represents an independent assessment of some aspect of spatial ability. Furthermore, alpha inflation is a real danger with multiple univariate statistical tests. A laundry list of univariate results does not provide us with the clearest answer possible to the question of whether males and females differ in some aspects of spatial ability. Because of these limitations, we use the approach of multivariate discriminant analysis to gain further perspectives on the data.

The first question addressed by the discriminant analyses is whether some linear combination or composite of measures can reliably distinguish males from females, and how strongly does it do so. The answer is clearly yes, as an optimally

Table 7. Mean Values for Self-Report Variables for Males and Females[a]

	Male	Female
Environmental spatial style[b]	5.1 (.8)	4.8 (.9)
Age	48.0 (12.6)	46.9 (13.5)
Income	3.3 (1.3)	3.2 (1.4)
Education	4.9 (1.1)	4.6 (.9)
Years in Santa Barbara	25.0 (14.4)	22.1 (12.2)
Contact with SB landmarks	3.2 (.5)	3.2 (.5)
Campus familiarity	4.9 (1.7)	5.0 (1.7)
U.S. city familiarity	3.3 (1.1)	3.2 (1.0)
World city familiarity	2.8 (1.2)	2.5 (1.1)

[a] Mean raw scores (standard deviations).
[b] Items were reverse-scored as appropriate.

weighted composite of all of the measures analyzed above quite reliably distinguishes the 40 females from the 36 males, $F(33, 42) = 2.70$, $p < .001$ (three females were excluded from the analyses because of missing data). The squared canonical correlation indicates that the shared variance between sex and the linear composite of spatial measures is 67.9 percent. Another informative way to consider how well scores on the linear composite are discriminated by sex is to have the function predict the sex of a given person from his or her pattern of performance on the spatial measures. In this way, the composite categorizes 37 of the 40 females as female, and 33 of the 36 males as male. In other words, given an individual's performance on this set of spatial tasks, you could use the discriminant function to predict his or her sex with only about 8 percent probability of being wrong. That is much better than a simple guess, where you would be wrong approximately 50 percent of the time (knowledge of the unequal numbers of males and females allows a little better than 50 percent).

After establishing the reliable existence and predictive strength of a linear composite, we next attempted to characterize the pattern of the composite that maximally discriminates males and females based on their spatial task performance. A stepwise discriminant analysis is an informative way to do this. This analysis constructs an efficient linear composite using only the subset of the spatial task variables that most strongly discriminates between the two sexes. We first used a forward selection approach that selectively includes variables with the largest R^2 as long as there is at least one that is predicted better than some threshold. Using an entrance criterion at the .15 probability level or better results in the model reported in Table 8. Out of 33 variables available, a set of 10 discriminated males and females strongly enough to be included in the model. Participant sex accounts for some 61 percent of the variance in these 10 variables (this is smaller than the sum of the partial contributions of each variable selected because of overlap between them). Males used more cardinal-direction terms in their verbal description of the campus-route, estimated campus-route distances with less error, had higher scores on the Card Rotation Test, estimated the direction from the end to the start of the campus route with less error, reported higher spatial ability, and used more metric spatial terms in their verbal description of the campus route. Females made fewer topological errors in the object-location memory task, estimated distances from the Grand Forks map with less error, used more maintenance terms in their verbal description of the campus route, and made fewer mistakes recalling landmarks from the campus route.

Selection procedures like these can be misleading insofar as the variable chosen at each step depends on what is already in the model at that point (variable overlap). We therefore performed another stepwise discriminant analysis, using a backward selection approach. This starts with a model that includes all of the variables, selectively removing them as long as there is at least one that discriminates worse than some threshold. Again using a removal criterion that only variables that discriminate participant sex at the .15 probability level or worse are removed, Table 9 presents the final set of variables in the discriminant function. This is very similar to the set arrived at with forward selection. Out of 33 variables available to the model, a set of 10 again

Table 8. Results of Stepwise Discriminant Analysis, Forward Selection

Variable Entered	Step Entered	Partial[a]				
		R^2	F	p-level	Better	More
Cardinal direction references	1	.17	15.46	.0002		M
Campus route-distance error	2	.13	10.68	.0017	M	
Object memory: Topological errors	3	.12	10.04	.0022	F	
Card rotation score	4	.13	10.53	.0018	M	
Campus survey-direction error	5	.07	4.92	.0299	M	
Self-report spatial ability	6	.06	4.21	.0439	M	
Grand Forks distance error	7	.08	5.68	.0199	F	
Maintenance terms	8	.05	3.22	.0771		F
Metric terms	9	.05	3.82	.0550		M
Campus route-landmark errors	10	.04	2.36	.1289	F	

[a] Need not be in strictly descending order, because only variables entered at an earlier step are partialed. Partialing an additional variable can strengthen the relationship of sex with the variable being entered because of suppression.

Table 9. Results of Stepwise Discriminant Analysis, Backward Selection

Variable Remaining	Rank	Partial R^2	F	p-level	Better	More
Cardinal direction references	1	.26	23.10	.0001		M
Campus route-distance error	2	.22	18.24	.0001	M	
Card rotation score	3	.17	13.32	.0005	M	
Object memory: Metric errors (all objects)	4	.14	10.39	.0020	F	
Grand Forks distance error	5	.10	7.57	.0077	F	
Object memory: Metric errors (topo correct only)	6	.10	7.14	.0095	F	
Self-report spatial ability	7	.08	5.37	.0237	M	
Campus survey-direction error	8	.07	5.07	.0277	M	
Campus route-landmark errors	9	.05	3.62	.0616	F	
Maintenance terms	10	.05	3.41	.0695		F

discriminated males and females strongly enough to be kept in the model. Participant sex accounts for 60 percent of the variance in these 10 variables. As with the forward approach, males used more cardinal-direction terms in their verbal description of the campus route, estimated campus-route distances with less error, had higher scores on the Card Rotation Test, estimated the direction from the end to the start of the campus route with less error, and reported higher spatial ability. Unlike the forward model, the use of metric spatial terms in the verbal description of the campus route did not end up in the final model. Like the forward model, females estimated distances from the Grand Forks map with less error, used more maintenance terms in their verbal description of the campus route, and made fewer mistakes recalling landmarks from the campus route. Topological errors from the object-location memory task did not end up in the model, but the smaller metric errors by females did, whether based on all of the objects or just those recalled topologically correctly.

Discussion

There are both theoretical and practical reasons why it is important to explain sex-related differences in the performance of various tasks. Understanding such differences should have implications for educational, scientific, and societal strategies for ameliorating occupational inequities in fields that frequently involve spatial abilities. In this respect, it is important to recognize that even genetically determined differences can possibly be attenuated by interventions such as training programs. For example, body size clearly has a strong genetic component but may be modified by diet, exercise, steroids, and so on.

The results of this study largely confirm what is suggested by much of the research literature, though we expand the relevance of what are mostly laboratory studies with microscale materials to larger-scale and more complex settings that are more geographically relevant. Our results clearly show that males and females differ on average in their spatial abilities and styles on particular tasks, and not only on abstract and artificial spatial tasks that may have little relevance to spatial performance in realistic, ecologically valid settings. Our study contributes significantly to the literature insofar as it assesses a single sample of community residents, spanning the adult age range on a large and comprehensive set of measures of environmental and geographic spatial knowledge. Analyzed univariately, several variables reliably differ between males and females. The multivariate discriminant analysis we conducted perhaps demonstrates the existence of reliable differences most clearly. An optimally weighted composite of all task variables in the study accounts for more than 60 percent of the variance in assigning participants to their sex, strong enough to correctly categorize the great majority of participants as females or males from their spatial task performance only. The utility of sex as a variable in predicting some aspects of spatial behaviors in geographic and real-world environments is clearly evinced. Statements such as that by Evans (1980:276), concluding that "the preponderance of evidence from real-scale spatial tasks indicates few sex differences in environmental cognition," are no longer tenable.

It is also quite wrong, however, to say that males in general have better spatial ability than females. There are many "spatial tasks" on which the two sexes do not differ, or at least differ to such a small degree that research with reasonable power does not detect the difference. Even on most of the tasks for which the sexes can be shown to reliably differ, the distributions of each sex's performance largely overlap. Thus, knowledge of the reliable differences would not help one predict the relative performance of two individuals very much, though it may have large, important implications for the representation of the two sexes at the tails of the distributions. Finally, in at least one spatial task that has been identified, females outperform males on average.

Replicating a firmly established finding, we report that males outscore females on the paper-and-pencil Mental Rotations Test. On our test of newly acquired knowledge of the campus from direct experience, males estimate distances along the route more accurately and estimate the straight-line direction from the end to the start more accurately. Females do make marginally fewer errors in recalling landmarks along the campus route. And as suggested by results in the literature, males and females differ little on their extant knowledge of geography brought into the study, including knowledge of distances within the local community, and the relative directions and distances of world cities. We do find that males place world cities on a map more accurately than do females.

Finding sex-related differences more clearly with newly acquired knowledge of a local environment, but not with extant knowledge, is important. One likely explanation is that maps normally play an important role in the acquisition of spatial knowledge of places as large as a campus or town. As is often reported in the literature, we find almost no reliable differences on our tasks involving knowledge acquired only from maps (the World City Placements task was the sole exception). One of our tasks involves learning a route from a map of a fictitious amusement park. Even though the geometry of this route is identical to that of the campus route acquired directly during the study, and on which the sexes differ, males and females perform very similarly on this map task. On a second task involving a fictitious map of Grand Forks, males and females estimate distances between landmarks equally accurately.

Although its characterization needs to be made more precise, our results do support the existence of a stylistic difference between the sexes in their environmental knowledge along the lines of a "route-survey" distinction. The results of our tests of directly acquired knowledge discussed above are consistent with this, insofar as males are significantly more accurate at estimating metric distances and straight-line directions, and females marginally more accurate at recalling landmarks. Verbal descriptions of the route are also largely consistent with a route-survey distinction. Female descriptions contain a marginally greater number of nonmetric-distance terms and marginally fewer metric-distance terms; males use significantly more cardinal-direction terms. The sexes differ little, however, in their use of verbal terms referring to turns, to landmarks, and to travel maintenance, all of which females might be expected to use more if they, in fact, have greater preference or skill for a "route" style of navigation and spatial learning. Future research should continue to compare patterns of spatial style as evidenced from verbal descriptions to that derived from nonverbal knowledge tests, and to consider further whether the route-survey distinction is actually a more one-sided preference for the survey style by males.

We do replicate a female superiority on the object-location memory task, as first reported by Silverman and Eals (1992). Our replication involves recall of the locations of objects in a blocked-off corner of a large room. Because participants are given a list of object names during the recall phase, rather than being asked to recall object identities, our test is a purer evaluation of location memory alone. We also make the potentially important distinction between topological and metric errors. The former occur when objects are located on the wrong surface, such as an object on the wall being placed on the table. The latter refers to errors in location measured in metric units such as centimeters. This distinction is a recognition that the two types of error are qualitatively different; we believe it is important for fully characterizing patterns of error from the task. Topological errors alone may be insufficiently sensitive to detect a sex-related difference, but failure to consider topological correctness may result in inflated and misleading estimates of metric error. In our study, in fact, females make significantly fewer topological errors, about half as many as males. They also make significantly smaller metric errors, about 5 cm less, when the topological placement of objects is ignored. When metric errors are aggregated only for objects located topologically correctly, females still make smaller errors, about 3 cm less, though this does not quite reach significance at the .05 level.

The pattern of results from the multivariate discriminant analyses largely echoes the univariate findings. This is important because it provides a clearer answer to the question of whether males and females differ overall, and it allows the detection of independent contributions to variance between the performance of the sexes. Whether based on forward or backward selection, the discriminant analyses agree with the univariate analyses in finding that males use more cardinal-direction terms in their verbal descriptions of the campus route, estimate metric distances along the route with less error, and estimate the direction from the end to the start of the route with less error. Females again make fewer mistakes recalling landmarks from the campus route. Only the forward selection finds, as do the univariate comparisons, that males use more metric spatial terms in their verbal description of the campus route, and that females make fewer topological errors on the object-location task. Backward selection agrees with the univariate analyses, however, in finding that females make smaller metric errors on this task, whether topological errors are removed or not.

Both selection procedures differ from the univariate analyses in finding that females estimate distances from the Grand Forks map with less error and use more maintenance terms in their verbal description of the campus route. Only two findings from the discriminant analyses differ from the univariate results, both of which are consistent with expectations from the literature. Whichever selection direction is used, males have higher scores on the Card Rotation Test, but not on the Mental Rotation Test, and self-report a different spatial style. This suggests that variance in the MRT is captured by other variables that do make it into the final discriminant models, but that self-report spatial style contributes unique variance to discriminating the sexes.

Self-report spatial style in fact includes ability questions, preference questions, and emotional response questions. One apparent disagreement of our results with those reported in the literature is with respect to some of these measures of spatial style. We do find that males report a greater ability to judge distances and more use of cardinal directions in their thinking about the environment. Although females have frequently been found to report a poorer sense of direction and higher spatial anxiety, we find very little difference between the sexes on these items. When all 10 items are combined to produce one spatial style measure, the sexes do not differ when analyzed univariately. It is possible that self-report spatial style would be more differentiated in a younger sample or one lower in socioeconomic status. Our spatial style measure does, however, help discriminate the sexes in the discriminant analyses.

Conclusions

Our results have implications for geographic research, educational practice, societal understanding, and science and technology. For years, human geographers have included a "sex" variable in their studies of human activities, interactions, and relationships, without fully understanding why it might be important. Because sex is confounded with so many other attributes and variables, its importance was often hidden. Until the emergence of a feminist research tradition in geography and elsewhere, it was rare to see a study that used only females as participants, or to find a study in which gender relations, and not just "sex," was a major explanatory variable. The usual assumption in analytic studies has been that males and females do not differ significantly in their geographic activities, and that any differences that exist can be detected by incorporating a binary variable into the model (1 = females; 0 = males). Our research goes beyond these traditional limitations by seeking to explore the nature of spatial abilities, using a geographic context for our tasks, and consequently obtaining insights into why differences in performance should or should not be expected when analyzing certain everyday geographic activities. Our work also supports the claim of much recent feminist research in geography that, to paraphrase Massey, "sex matters." But we have also shown in this paper that we need to understand the contexts in which sex matters—there are specific geographic activities in which sex matters because of the abilities needed to undertake them, and there are others in which it appears not to matter as much (i.e., females and males might be expected to be very similar in their performance or activities). It is obvious that the discipline needs much more work in this area to refine current knowledge and to produce understanding of which geographic activities are performed from a sex-biased perspective, and which are not.

An obvious spin-off from this broad finding is in the area of geographic education. Self and Golledge (1994) suggested that every geography educator should be aware that males and females may differ in their abilities to interpret or use spatial or geographic information presented in different ways. The finding that males favor survey-type knowledge acquisition with embedded metric relations, while females favor route-type knowledge acquisition emphasizing nonmetric relations, implies that educators should use a mixed-mode teaching strategy in the classroom. The results of the object-location memory task suggest that females may obtain more geographic knowledge from some types of environmental models than do males. The implication here is that presentation and representation of geographic information for educational purposes need to be carefully considered in light of different modes that might favor one sex or the other, if equity in geographic learning among males and females is to be the goal. As we move to a future where computer displays will replace table-top models or cartographic maps, new challenges are presented to us in our attempts to ensure that our teaching environments are equitable.

Practically speaking, there has been a long if sometimes implicit tradition of assuming that male spatial abilities are superior to those of females, and consequently that certain job classifications and tasks (e.g., engineering, physical science, and occupations involving navigation skills, such as pilots or delivery services) are "male territory." Women are now breaking down these gendered occupational barriers by demonstrating that the abilities and knowledges needed to complete spatial tasks in real-world environments may not be as sex-specific as previously thought. But there is a continued residue of stereotype in this regard. Such a stereotype is probably one factor that accounts for disparities in the numbers of males and females in academic geography, where male Ph.Ds outnumber females by 4 to 1. This extreme disparity certainly cannot be explained solely by reference to differences in spatial style and abilities, as these differences are not comprehensive across different tasks and traits, and the magnitudes of average differences that do exist, while statistically reliable, are of small or modest size.

Clarification of the nature and magnitude of differences in abilities where they exist, and identification of areas where they do not exist, are important areas for continuing research. As this kind of clarification has increased, science itself has begun changing, particularly, in the recognition that many abilities needed for scientific investigation are not peculiar to males. And as we discover more about the influence of genetics, hormones, learning, and stereotyping, implications for geographic research and the accumulation of geographic knowledge become clearer. The training and education of both sexes to enhance their abilities and compensate for their different modes of acquiring and employing spatial information become possible. As with other areas of human science, geography needs to participate in this search for the clarification of people's abilities, and more studies such as those reported in this paper are called for.

Acknowledgments

We thank Belinda Campos, Alma Campos, and Diane Guttierrez for assistance with data collection and processing, and Ann Richiazzi for preparing our graphics for publication. Support for this work was provided by NSF grant SBR-9318643. Barbara Tversky made valuable comments on an earlier draft of this manuscript. We also gratefully acknowledge the assistance of the participants in this research; without such assistance, theoretical speculation would go unchecked.

References

Allen, G.L.; Kirasic, K.C.; Dobson, S.H.; Long, R.G.; and Beck, S. 1996. Predicting Environmental Learning from Spatial Abilities: An Indirect Route. *Intelligence* 22:327–55.

Beatty, W.W., and Tröster, A.I. 1987. Gender Differences in Geographical Knowledge. *Sex Roles* 16:565–90.

Bowers, C., and LaBarba, R. 1988. Sex Differences in the Lateralization of Spatial Abilities: A Spatial Component Analysis of Extreme Group Scores. *Brain and Cognition* 8:165–77.

Bryant, K.J. 1982. Personality Correlates of Sense of Direction and Geographical Orientation. *Journal of Personality and Social Psychology* 43:1318–24.

———. 1991. Geographical/Spatial Orientation Ability Within Real-World and Simulated Large-Scale Environments. *Multivariate Behavioral Research* 26:109–36.

Caplan, P.J.; MacPherson, G.M.; and Tobin, P. 1985. Do Sex-Related Differences in Spatial Abilities Exist? A Multilevel Critique with New Data. *American Psychologist* 40:786–99.

Cooper, L.A., and Mumaw, R.J. 1985. Spatial Aptitude. In *Individual Differences in Cognition*, ed. R.F. Dillon, pp. 67–94. Orlando, FL: Academic Press.

Deaux, K. 1993. Commentary: Sorry, Wrong Number—A Reply to Gentile's Call. *Psychological Science* 4:125–26.

Devlin, A.S., and Bernstein, J. 1995. Interactive Wayfindng: Use of Cues by Men and Women. *Journal of Environmental Psychology* 15:23–38.

Eals, M., and Silverman, I. 1994. The Hunter-Gatherer Theory of Spatial Sex Differences: Proximate Factors Mediating the Female Advantage in Recall of Object Arrays. *Ethology and Sociobiology* 15:95–105.

Eliot, J. 1996. Personal communication, March 26.

———, and Smith, I.M. 1983. *An International Directory of Spatial Tests*. Windsor, Berks, U.K.: NFER-NELSON Publishing.

Evans, G.W. 1980. Environmental Cognition. *Psychological Bulletin* 88:259–87.

Foley, J.E., and Cohen, A.J. 1984. Mental Mapping of a Megastructure. *Canadian Journal of Psychology* 38:440–53.

French, J.W.; Ekstrom, R.B.; and Price, L.A. 1963. *Kit of Reference Tests for Cognitive Factors*. Princeton, NJ: Educational Testing Services.

Galea, L.A.M., and Kimura, D. 1993. Sex Differences in Route-Learning. *Personality and Individual Differences* 14:53–65.

Gärling, T.; Böök, A.; and Ergezen, N. 1982. Memory for the Spatial Layout of the Everyday Physical Environment: Differential Rates of Acquisition of Different Types of Information. *Scandinavian Journal of Psychology* 23:23–35.

Gilmartin, P.P., and Patton, J.C. 1984. Comparing the Sexes on Spatial Abilities: Map-Use Skills. *Annals of the Association of American Geographers* 74:605–19.

Goldstein, D.; Haldane, D.; and Mitchell, C. 1990. Sex Differences in Visual-Spatial Ability: The Role of Performance Factors. *Memory and Cognition* 18:546–50.

Golledge, R.G.; Dougherty, V.; and Bell, S. 1995. Acquiring Spatial Knowledge: Survey versus Route-Based Knowledge in Unfamiliar Environments. *Annals of the Association of American Geographers* 85:134–58.

Guilford, J.P. 1967. *Nature of Human Intelligence*. New York: McGraw Hill.

Harris, L.J. 1981. Sex Variations in Spatial Skill. In *Spatial Representation and Behavior Across the Lifespan*, ed. L.S. Liben, A.H. Patterson, and N. Newcombe, pp. 31–54. New York: Academic Press.

Henrie, R.L.; Aron, R.H.; Nelson, B.D.; and Poole, D.A. 1997. Gender-Related Knowledge Variations within Geography. *Sex Roles* 36:605–23.

Holding, C.S. 1992. Clusters and Reference Points in Cognitive Representations of the Environment. *Journal of Environmental Psychology* 12:45–55.

——— and Holding, D.H. 1989. Acquisition of Route Network Knowledge by Males and Females. *The Journal of General Psychology* 116:29–41.

Kail, R.; Carter, P.; and Pellegrino, J.W. 1979. The Locus of Sex Differences in Spatial Ability. *Perception and Psychophysics* 26:182–86.

Kimura, D. 1992. Sex Differences in the Brain. *Scientific American* September:119–25.

Kirasic, K.C.; Allen, G.L.; and Siegel, A.W. 1984. Expression of Configurational Knowledge of Large-Scale Environments: Students' Performance of Cognitive Tasks. *Environment and Behavior* 16:687–712.

Kitchin, R.M. 1996. Are There Sex Differences in Geographic Knowledge and Understanding? *The Geographical Journal* 162:273–86.

Kozlowski, L.T., and Bryant, K.J. 1977. Sense of Direction, Spatial Orientation, and Cognitive Maps. *Journal of Experimental Psychology: Human Perception and Performance* 3:590–98.

Law, D.J.; Pellegrino, J.W.; and Hunt, E.B. 1993. Comparing the Tortoise and the Hare: Gender Differences and Experience in Dynamic Spatial Reasoning Tasks. *Psychological Science* 4:35–40.

Lawton, C.A. 1994. Gender Differences in Wayfinding Strategies: Relationship to Spatial Ability and Spatial Anxiety. *Sex Roles* 30:765–79.

———. 1996. Strategies for Indoor Wayfinding: the Role of Orientation. *Journal of Environmental Psychology* 16:137–45.

Lawton, C.A.; Charleston, S.I.; and Zieles, A.S. 1996. Individual- and Gender-Related Differences in Indoor Wayfinding. *Environment and Behavior* 28:204–19.

Linn, M.C., and Petersen, A.C. 1985. Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-analysis. *Child Development* 56:1479–98.

Lloyd, R. 1989. Cognitive Maps: Encoding and Decoding Information. *Annals of the Association of American Geographers* 79:101–24.

Lunneborg, P.W. 1984. Sex-Differences in Self-Assessed, Everyday Spatial Abilities: Differential Practice or Self-Esteem? *Perceptual and Motor Skills* 58:213–14.

Maccoby, E.E., and Jacklin, C.N. 1974. *The Psychology of Sex Differences*. Stanford, CA: Stanford University Press.

Masters, M.S., and Sanders, B. 1993. Is the Gender Difference in Mental Rotation Disappearing? *Behavior Genetics* 23:337–41.

McGee, M. 1979. Human Spatial Abilities: Psychometric Studies and Environmental, Genetic, Hormonal, and Neurological Influences. *Psychological Bulletin* 86:889–918.

McGlone, J. 1980. Sex Differences in Human Brain Asymmetry: a Critical Survey. *The Behavioral and Brain Sciences* 3:215–63.

McGuinness, D., and Sparks, J. 1983. Cognitive Style and Cognitive Maps: Sex Differences in Representations of a Familiar Terrain. *Journal of Mental Imagery* 7:91–100.

Miller, L.K., and Santoni, V. 1986. Sex-Differences in Spatial Abilities: Strategic and Experiential Correlates. *Acta Psychologica* 62:225–35.

Newcombe, N., and Dubas, J.S. 1992. A Longitudinal Study of Predictors of Spatial Ability in Adolescent Females. *Child Development* 63:37–46.

Pearson, J.L., and Ferguson, L.R. 1989. Gender Differences in Patterns of Spatial Ability, Environmental Cognition, and Math and English Achievement in Late Adolescence. *Adolescence* 24:421–31.

——— and Ialongo, N. S. 1986. The Relationship Between Spatial Ability and Environmental Knowledge. *Journal of Environmental Psychology* 6:299–304.

Presson, C.C.; DeLange, N.; and Hazelrigg, M. D. 1989. Orientation Specificity in Spatial Memory: What Makes a Path Different from a Map of the Path? *Journal of Experimental Psychology: Learning, Memory, and Cognition* 15:887–97.

Self, C.M., and Golledge, R.G. 1994. Sex-Related Differences in Spatial Ability: What Every Geography Educator Should Know. *Journal of Geography* 93:234–43.

Self, C.M.; Gopal, S.; Golledge, R.G.; and Fenstermaker, S. 1992. Gender-Related Differences in Spatial Abilities. *Progress in Human Geography* 16:315–42.

Serbin, L., and Connor, J. 1979. Sex Typing of Children's Play Preferences and Patterns of Cognitive Performance. *Journal of Genetic Psychology* 134:315–16.

Sharps, M.J.; Price, J.L.; and Williams, J.K. 1994. Spatial Cognition and Gender: Instructional and Stimulus Influences on Mental Image Rotation Performance. *Psychology of Women Quarterly* 18:413–25.

Shute, V.J.; Pellegrino, J.W.; Hubert, L.; and Reynolds, R.W. 1983. The Relationship Between Androgen Levels and Human Spatial Abilities. *Bulletin of the Psychonomic Society* 21:465–68.

Signorella, M.L., and Jamison, W. 1986. Masculinity, Femininity, Androgyny, and Cognitive Performance: A Meta-analysis. *Psychological Bulletin* 100:207–28.

Silverman, I., and Eals, M. 1992. Sex Differences in Spatial Ability: Evolutionary Theory and Data. In *The Adapted Mind: Evolutionary Psychology and the Generation of Culture*, ed. J.H. Barkow, L. Cosmides, and J. Tooby, pp. 533–49. New York: Oxford University Press.

Spencer, C., and Weetman, M. 1981. The Microgenesis of Cognitive Maps: A Longitudinal Study of New Residents of an Urban Area. *Transactions of the Institute of British Geographers* 6:375–84.

Vandenberg, S.G., and Kuse, A.R. 1978. Mental Rotations: Group Test of Three-Dimensional Spatial Visualization. *Perceptual and Motor Skills* 47:599–604.

Voyer, D.; Voyer, S.; and Bryden, M.P. 1995. Magnitude of Sex Differences in Spatial Abilities: A Meta-analysis and Consideration of Critical Variables. *Psychological Bulletin* 117:250–70.

Ward, S.L.; Newcombe, N.; and Overton, W.F. 1986. Turn Left at the Church, or Three Miles North: A Study of Direction Giving and Sex Differences. *Environment and Behavior* 18:192–213.

Correspondence: Department of Geography, University of California, Santa Barbara, CA 93106 (Montello, Golledge); Department of Psychology, UC, Santa Barbara (Lovelace); Department of Anthropology, UC, Santa Barbara (Self); email montello@geog.ucsb.edu.