

## Asymmetrical Learning of Locations on Maps: Implicit Learning, Prior Knowledge and Sex Differences

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Women have been reported to have an advantage for the memory of unique objects in space while men have been reported to have an advantage on tests of knowledge of geographic information. The current research considers how prior knowledge and asymmetrical learning processes might be related to this apparent contradiction in the literature concerning spatial cognition. Asymmetrical brains allow us to encode map locations as both categorical and coordinate information. Categorical information is expressed verbally, for instance, "City A is located in the northwest quadrant of the map," and is easier to learn but not very precise. Coordinate information is more precise but takes longer to learn. Prior knowledge of locations may result in subjects relying more on coordinate information.

Human subject testing was used to examine differences in performance when women and men learned and recalled city locations on maps. Learning was achieved through the use of a repeated search task. Results indicated that subjects implicitly learned the locations of cities during the search task. The distribution of the cities on the maps and whether the cities were known or novel affected performance. The evidence supports the assertion that men may have a greater interest in geographic information, and the additional attention they devote to such information allows them to utilize prior knowledge and gives them an advantage when processing well-known places. The evidence also supports the assertion that women may generally have an advantage learning novel maps because they tend to encode more categorical information, and this information is useful for remembering general locations and can be learned faster.

**Key Words:** maps, prior knowledge, sex, gender, asymmetrical learning, categorical information, coordinate information.

The universe is asymmetric (Pasteur 1874, 76).

### INTRODUCTION

Consider how someone might encode the spatial locations of a set of cities on a cartographic map into memory. One strategy might be to encode a whole image of the map. Once acquired, this image could provide coordinate information. One could recall that image if information on the map, for instance, a location, distance, or direction, were needed for a subsequent task. A map reader could also use a verbal strategy to encode spatial information, such as, "City A is in the center of the map" or "City B is in the upper-right quadrant of the map." This information would also be useful for tasks that did not require precise information. The current

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research considers asymmetrical learning processes as an explanation for a puzzling inconsistency in the spatial cognition literature. Men have been reported to have an advantage on tests of knowledge of geographic information while women have been reported to have an advantage for the memory of unique objects in space. For an excellent and thorough review of the advantages and disadvantages of having an asymmetrical brain, see Vallortigara and Rogers (2005). For a discussion of brain lateralization related to spatial abilities, see Lloyd 2003. For examples of brain lateralization issues related to cartography, see Lloyd and Bunch (2005, 2008).

This research is based on three primary postulates. Postulate One: *Spatial information can be learned and stored in different ways* Asymmetrical brains are an advantage in spatial cognition in that they provide cognitive processing abilities that are adapted to a variety of situations that might require the learning and use of spatial knowledge. This asymmetry allows relationships among objects in space to be represented as both category information and coordinate information. The category information is abstract, verbal, and associated with the left hemisphere of the brain. The coordinate information is metric and associated with right hemisphere activity (Jager and Postma 2003). If coordinate information has been encoded, one can recall spatial knowledge that is more precise. In a very familiar environment, a person you might know there are fifty steps between the front door and the mailbox. Less precise spatial knowledge can be recalled if one has encoded categorical information. In a novel environment, people might know that they parked their cars on the top of a parking garage (Kemmerer 2006). In the context of acquiring a cognitive map by learning information directly from the environment, an individual might use alternate cognitive processes based on a need for a type of processing or a strategy for producing the best performance (Lawton and Kallai 2002; Choi et al. 2006). The selection of a given cognitive process might be made consciously or unconsciously. It is also possible that the use of learning styles might become habitual behaviors that are neither consciously preferred nor strategic (Danner, Aarts, and de Vries 2007). Nori and Giusberti (2006) suggested different cognitive styles were correlated with performance. Their results indicated relative success on nine different spatial tasks was related to three cognitive styles.

Postulate Two: *The most efficient learning strategy for individuals can change with experience.* Individuals who are very familiar with a map (or an environment) are more likely to have encoded prior knowledge that can provide flexible, top-down guidance to maximize the efficiency of visual processes such as searching for a particular place (Wolfe et al. 2004). The most efficient learning process for a novice, however, is not always the most efficient learning process for an expert (Kalyunga et al. 2003). The accuracy of one's cognitive map and the ability to use it efficiently (as in a visual search process) is dependent on both categorical and coordinate information (Huttenlocher, Hedges, and Duncan 1991). Categorical spatial information should be easier to encode than coordinate information and should be more useful for individuals who are less interested, less motivated, or have had less time to encode coordinate information into their cognitive maps. Although coordinate information takes longer and is more difficult to encode, it ultimately will produce the most accurate cognitive maps that can be used most efficiently.

Postulate 3: *Sex differences related to cognitive mapping are related to asymmetrical learning strategies.* It has been suggested that females and males may prefer different strategies for processing spatial information (Dabbs et al. 1998). When levels of experience are low, an individual relying more on categorical learning strategies should perform better than individuals rely-

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ing more on coordinate learning strategies. As the time and effort devoted to learning increases, the effect should reverse, with individuals relying more on coordinate strategies performing better than individuals relying more on categorical strategies.

## BACKGROUND LITERATURE

### Spatial Information: Categorical and Coordinate Strategies

Evidence that spatial locations are encoded as categorical and coordinate information by separate coding processes in the left and right hemispheres of the brain was first presented by Kosslyn (1987), followed by Kosslyn, Gitelman, and Alpert (1989)<sup>1</sup>. For a review of the topic, see Jager and Postma (2003) and Postma and Laeng (2006). Other researchers have recently supported this hypothesis with evidence from brain scanning studies (Slotnick and Moo 2006; Trojano et al. 2006; van der Lubbe et al. 2006). Research that has supported this notion has connected it to divergent strategies for processing spatial information that are thought to be preferred by females and males (Rybash and Hoyer 1992; Saucier et al. 2002; Coluccia, Iosue, and Brandimonte 2007). Categorical or verbal strategies, processed in the left hemisphere, are hypothesized as more preferred by females; and coordinate strategies, processed in the right hemisphere, are hypothesized as more preferred by males. Sex differences in cognitive processing have been connected to evolutionary theories of brain asymmetry that have genetic explanations (Casey 1996; Annett 2002; Lloyd 2003). Evidence for preferred strategies have been shown for mental rotation tasks (Butler et al. 2006; Hugdahl, Thomsen, and Erslund 2006), navigation (Choi et al. 2006; Barkley and Gabriel 2007), map drawing (Lee and Bednarz 2005; Coluccia, Iosue, and Brandimonte 2007), and spatial memory tasks (Frings et al. 2006; Voyer et al. 2007).

Geographers have considered how sex is related to a variety of basic spatial tasks (Montello et al. 1999). They reported that male subjects located world cities more accurately than females, and female subjects were superior on an object-location memory task. Performance differences between male and female subjects also have been reported for rotated and animated maps (Lloyd and Bunch 2005; Griffin et al. 2006). Lloyd and Bunch (2008) argued that gender could be a more informative explanatory variable than sex for explaining map-reading performance. Their results supported other studies suggesting non-linear relationships relating sex, brain lateralization, and accuracy.

An individual may not consciously decide to encode either categorical or coordinate information but could spontaneously encode both types. It has been argued that coarse-grained categorical and fine-grained coordinate information are both encoded in memory and combined to make estimations of learned spatial information. Huttenlocher, Hedges, and Duncan (1991) introduced the idea that some location errors are due to what they called *prototype effect* and suggested, "These processes introduce bias in reporting even when memory is unbiased, but nevertheless may improve overall accuracy (by decreasing the variability of reports)" (352). They reported on a simple experiment where subjects reported the location of a dot in a circle. If the circle were to become a more complex map outline and the dot were to represent a city, the basic idea could easily be transformed into a cognitive mapping investigation.

The Huttenlocher, Hedges, and Duncan (1991) study suggested that subjects apparently partitioned the circle into left-right and upper-lower regions, and dots were encoded as being in one of the four quadrants,

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for example, in the upper-right quadrant. The center of a quadrant represented the most probable coordinate location to estimate if only the dot's quadrant category were remembered. Someone who ignored categorical information and only encoded coordinate information might estimate locations with relatively lower accuracy because coordinate information is more difficult to encode. Someone who ignores coordinate information and encodes only categorical information could never be extremely accurate over a set of locations in an extended space because only coarse-grained prototype information could be used to make estimates. Since people are capable of encoding both categorical and coordinate information, how they combine the two information sources determines overall performance. This becomes even more complicated when multiple visual fields must be considered.

When a cartographic map is larger than a viewer's visual field, the viewer has to focus on part of the map and refocus attention to move the visual field. The sequence of such moves can potentially cause response times that are spatially biased. Performances on spatial tasks involving visual search and learning locations on maps should vary with the size of the map and the number of potential target locations. The size of the viewer's visual field relative to the size of the map being searched determines how frequently attention must be refocused to reposition the visual field. Eye-movement and experimental studies on optimal visual field size have indicated a window with a visual angle of approximately 9 degrees produced optimal performances (Enoch 1959; Wood 1993; Hodgson 1998; Lloyd, Hodgson, and Stokes 2002).

Theories of visual search are related to how attention is allocated during the search for a target (Proulx and Egeth 2008). Evidence from studies on how cartographic maps are searched suggests map readers may make categorical distinctions between central locations and locations near peripheral boundaries. Spatial search studies involving searching for color boundaries on choropleth maps have reported asymmetrical response times for targets in central versus peripheral locations (Brennan and Lloyd 1993; Bunch and Lloyd 2000). It has yet to be determined if asymmetrical performances should be expected with other map reading tasks and types of maps, or if the same asymmetries should be expected for the accuracy of recalled locations.

### **Prior Knowledge**

Early studies that used real-world maps have suggested that categorical information affected location accuracy. Stevens and Coupe (1978) first reported results that suggested a hierarchical organization in cognitive maps with super-ordinate categories, such as states, affecting the accuracy of subordinate locations, such as cities, in cognitive maps. Tversky (1981) first reported that people tend to align continents, and, therefore, inaccurately recall the locations of cities on the continents. More recently, experiments requiring subjects to recall the latitude and longitude of cities indicated cognitive mappers tended to group cities into categories, such as regions, and align the regions, thus affecting the accuracy of city locations (Friedman and Brown 2000a, 2000b).

A recent study considered if recalling location information from a newly learned hypothetical map was similar to recalling location information from a well-learned real-world map. The authors concluded, "Overall these experiments suggest that 'book learning' of geography is likely to be much more figurative and much less categorical than knowledge of real geography, which is gained partly from text read and thought about over

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many years, as well as from film, TV shows, conversations and actual travel” (Newcombe and Chiang 2007, 908). Although there are many potential sources for information that might provide spatial knowledge in a cognitive map, it is possible under controlled learning conditions to assume information about the spatial locations of cities is new and only learned from map-reading experiences.

The notion that reference points and linear or aerial features in the environment have an important influence on environmental learning is not a new idea. Examples related to urban environments are the anchor point theory (Couclelis et al. 1987) and the elements of the environment (paths, edges, districts, nodes, and landmarks) that provide the image of a city (Lynch 1960). More recently, a parallel map theory has been discussed in the literature (Jacobs 2003; Jacobs and Schenk 2003; Jacobs 2006). This theory argues the hippocampus encodes spaces with two mapping systems that can be integrated into cognitive maps. One system encodes frames of reference that can provide context and structure, and the other system encodes positional cues for landmarks. The theory argues the two spaces are integrated to provide a third space that is a usable cognitive map.

Adam, Hommel, and Umiltà (2003, 308) argue, “There is strong behavioral and neurophysiological evidence that the brain codes visual information in multiple frames of reference, with the frame of reference dominating performance being dependent on the task demands.” If this notion is generally true for encoding visual information, aggregate cognitive maps encoded from cartographic maps should be the product of individual encoding processes based on multiple frames of reference. The question then becomes, at any given time, what frames of reference dominate performance with the task demands associated with map learning?

Even if cognitive mappers are not using information that is extremely precise, they may still be able to encode useful spatial information. It is possible with precise information to encode either a polar or Euclidean coordinate for an object in space. A point as a reference object would allow the assessment of the proximity to other objects and their direction from the reference object. In the Figure 1a example, Cities 3 and 1 are east and west of the home reference city, and City 1 is twice as far from home than City 3. A line as a reference object would allow one to encode other objects’ locations on either side of the line and their proximity to the line. In the Figure 1b example, Cities 3 and 4 are each the same distance from the river on the river’s left and right banks as it flows toward the top of the figure. The boundary of an area could serve as a container. One could encode objects as being inside or outside the container and their proximity to the center or edge of the container. In the Figure 1c example, Cities 1 and 4 are inside and Cities 2 and 3 are outside the bounded region. City 4 is closer to the center of the region, and City 1 is closer to the boundary.

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### Sex Differences and Cognitive Maps

Although the evidence is not completely consistent, the general notion that females will perform better than males on many tasks that require the processing of verbal information appears to be accepted (Maccoby and Jacklin 1974; Voyer, Voyer, and Bryden 1995; Halpern 2000; Kimura 2000). Males appear to have a similar advantage on many tasks that require the processing of spatial information. An exception to any general spatial advantage for males is a consistent female advantage for object location memory (Voyer et al. 2007). Silverman and Eals (1992) proposed the hunter-gatherer theory to explain the sex differences in spatial abilities.

The evolutionary argument for a male advantage is that pre-agricultural males had a greater home range than females, resulting in experiences with larger geographic environments (Jones, Braithwaite, and Healy 2003; Ecuyer-Dab and Robert 2004a). Successful hunters were frequently in unfamiliar environments where they needed to navigate, track game, and throw objects at prey (Watson and Kimura 1991; Silverman and Eals 1992; Silverman et al. 2000). Natural selection allowed successful hunters to survive and pass on their traits (Choi and Silverman 2003). Sexual selection of these traits also provided an evolutionary advantage for good hunters (Hawkes 1991; Miller 2001; Ecuyer-Dab and Robert 2004b).

Pre-agricultural females evolved an advantage in memory for object locations (Eals and Silverman 1994; Tottenham et al. 2003; Neave et al. 2005). Women had child-care responsibilities and a more limited spatial range (McBurney et al. 1997). They increased their chance of survival if incidental learning allowed them to recall food sources in relatively small and familiar local environments (McGivern et al., 1997; 1998).

It is not clear what one should expect about the relative success of males and females on spatial tasks that required learning and recalling information on maps. The hunter-gatherer theory predicts advantages for males and females that were evolved through environmental experiences that may or may not translate into map-reading abilities.

Considerable evidence suggests that men tend to do better on general tests of geographic knowledge (Cross 1987; Bein 1990; Eve, Price, and Counts 1994; Henrie et al. 1997; Dabbs et al. 1998; Nelson, Aron, and Poole 1999). Zinser, Palmer, and Miller (2004) had subjects match city names with map locations using cartographic maps to support the task. No significant sex difference was found when females and males matched names with campus buildings or blank U.S. states. In other experiments, they allowed cities to vary in distance by using sets of local (within 100 miles), national, and international cities. Their results indicated a significant advantage for men at all three scales. They concluded that this advantage was "a joint product of nature and nurture" (Zinser, Palmer, and Miller 2004, 661). The authors used a preparedness theory to come to this conclusion (Seligman 1970). It was suggested that "Women and men have an opportunity to overcome any lack of preparedness (unpreparedness) with additional effort" (Zinser, Palmer, and Miller 2004, 681). They argued men had enough experience with the campus buildings to overcome a natural verbal advantage of women in this local environment, and women had enough educational experience with U.S. state maps to overcome a natural advantage men have with this larger environment. It was argued, "that men displayed

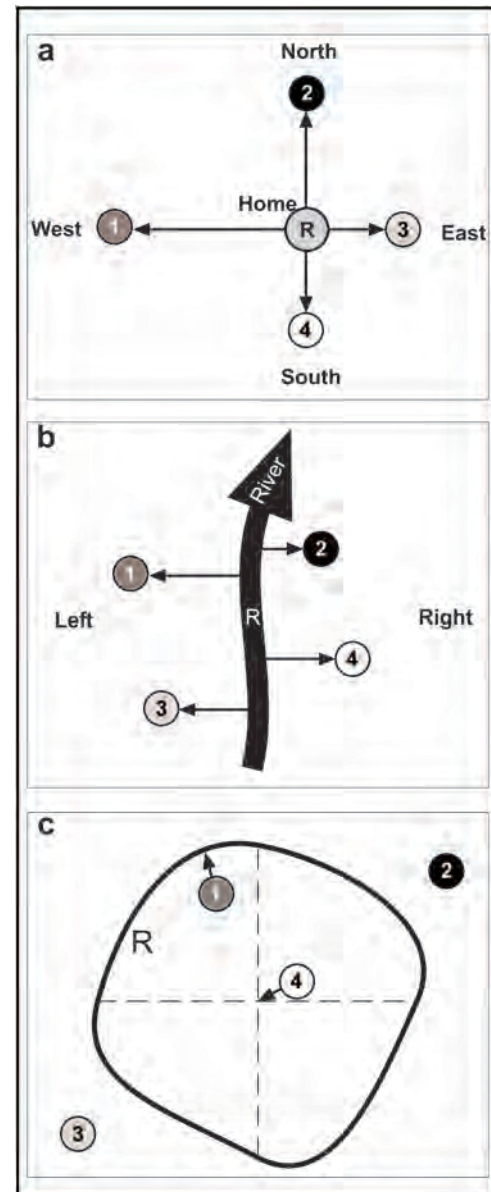


Figure 1. A point, line (b), or area (c) could be used as a reference frame.

Cities could be remembered by coding their relative location to a home city (a), their relative location with respect to a river (b), and relative location inside or outside a region or near a central or boundary location (c).

greater knowledge of cities and international sites suggests that they have a greater interest in geography than do women" (Zinser, Palmer, and Miller 2004, 661). This notion is supported by other studies that compared geographic knowledge for females and males (Beatty and Bruellman 1987; Beatty and Tröster 1987; Liben 1995).

## RESEARCH DESIGN

There were two main tasks for this experiment, a learning task and a recall task. All subjects were presented with an outline map with thirty cities labeled as point features on a color computer monitor. Using the computer mouse to interact with the map, subjects searched for and located each of the thirty cities as quickly and accurately as possible. Cities' names were presented to the subjects randomly one at a time on the screen above the map. This task was repeated seven times to ensure that the subjects had an opportunity to learn the locations of the cities on the map. For the final task of the experiment, subjects were presented the same outline map with no cities. City names, with points, were then presented to the subjects randomly, one at a time, and their task was to drag the city to its correct position on the map. Three different outlines and city combinations were used in the experiment. Details of each map condition are described below.

### Subjects

Ninety subjects, enlisted from undergraduate students enrolled in geography courses at Central Michigan University, participated in the experiment. Thirty subjects, balanced for sex, viewed each of the three test maps described below. A brief statement was read to the student describing the nature of the experiment. The potential subjects were told that the experiment would involve working with a map presented on a computer monitor to find a series of cities on the map. They were also informed that the experiment would take approximately twenty minutes to complete, that there would be no compensation for participation, and that they could quit at any time. While all of the subjects came from introductory geographic information science (GISci) courses, most were not GISci majors. It was assumed the subjects represented a population of young adults that had more than a typical interest in maps and geographic information since they selected a geography course as part of their curriculum. Most of the subjects were from Michigan, and all currently reside in Michigan. Other than a general knowledge of cities in the United States that could be expected from someone living in Michigan and some interest in geography, no specific expertise or skills were required for this experiment.

### Experimental Maps

Three maps were presented to subjects in this experiment (Figure 2). Each map consisted of a background base map showing land area with a coastline and a set of thirty labeled points. No additional reference features, such as state or provincial boundaries, roads, rivers, or inland lakes, were provided, and no graticule was presented with the map.

For Map 1 the base map was a simplified version of the eastern two-thirds of North America centered within the view window approximately on Indianapolis, Indiana. The points labeled for Map 1 were thirty well-known cities in the U.S. and Canada. The only city that might not be considered "well known" was Sault St. Marie, Michigan. All of the subjects for

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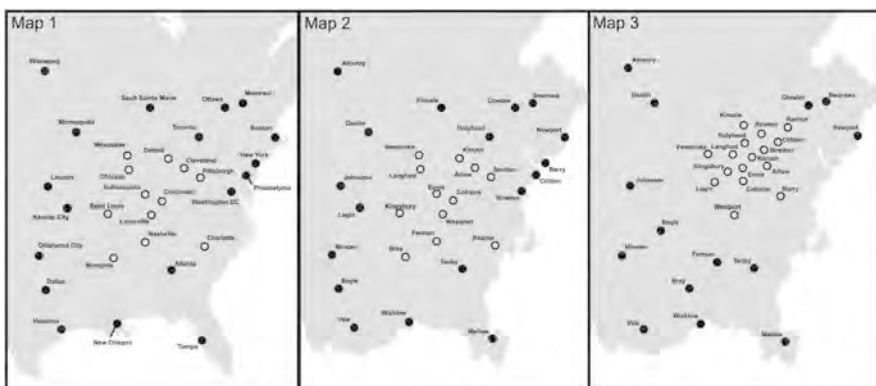


Figure 2. Map 1 represented a true background and true city locations and names. Map 2 represented a false background with true city locations and false names. Map 3 represented a false background with clustered city locations and false names. (see page 89 for color version)

this experiment, however, were currently living in the State of Michigan, and Sault St. Marie is well known to Michigan residents.

Map 2 was presented with a fictional base map that covered approximately the same area of the view window as Map 1 but would not be recognizable to the subjects as a known place. While the map was not recognizable as a real place, it shared many of the general characteristics of the North American map, such as an eastern coastline, bays, and peninsulas. The labeled points for Map 2 were located in exactly the same position as the thirty cities from Map 1, but the names were all changed. The names selected for Map 2 were all Anglo-Saxon in origin, but were not well-known U.S. city names. The subjects who viewed Map 2 viewed cities with the same spatial pattern as the subjects who viewed Map 1, but the Map 2 subjects had no prior knowledge of the places they were viewing.

Map 3 was presented with the same base map and the same city names as Map 2. For Map 3, however, the location pattern for the cities was altered to create an obvious central cluster.

### Visual Fields on the Map

City locations were represented on the maps as small black dots and labeled with only their appropriate names (Figure 2). Although not represented on the map viewed by the subjects, each city was assigned for the purpose of analysis as an inner focus city or an outer focus city (the inner focus cities are grey on the maps shown in Figure 2). This was done to represent in a binary way where one would have to focus attention to find that city. Following Wood (1993), the inner focus region was defined as a square area centered on the center of the map and defined by a 9-degree visual angle. An outer focus city was defined as any city nearer the boundary of the map that was outside the central region. The inner focus region represented a single central visual field, while the outer focus regions represented multiple visual fields around the outer edge of the maps. All cities in the cluster of cities on Map 3 were inside the central visual field.

### Experimental Procedures

There were four parts to the experiment, which all subjects completed. During part one, subjects were shown one of the maps discussed above. They were told to study the names and locations of the cities on the map

*“The inner focus region represented a single central visual field, while the other focus regions represented multiple visual fields around the outer edge of the maps.”*

*“Each subject determined independently how the explicit learning could be achieved.”*



*“The goals for the third stage were to ensure that learning was actually occurring while the subjects searched the cities on the experimental map and to determine if there were any significant patterns to their learning.”*

and that, later, they would be asked to locate the cities from memory. All test groups were given two minutes to study the map to obtain a general knowledge of the map that they would be learning. For this explicit learning stage, subjects were not instructed on how they were to encode the city locations into memory. Each subject determined independently how the explicit learning could be achieved.

After viewing the map for two minutes, the subjects were prompted to click a “next” button and move on to part two. For part two, the subjects practiced a search task to become familiar with the experimental search task. The base map was presented with a set of five cities that were not on the experimental map. (Names used during this phase were “alpha,” “beta,” “delta,” etc.) They were told that once they clicked the “next city” button, the name of one of the cities would appear at the top of the display and their task was to search the map for that city and identify it by using the computer mouse and clicking on the city’s point. A millisecond clock was started when the “next button” was clicked and stopped when the selected city name was clicked. *Reaction time* was defined as the number of milliseconds that elapsed between the first and second mouse click. Subjects were informed that the goal was to find each city as quickly and accurately as possible. After locating the five practice cities, the average time needed to locate the cities and overall accuracy were presented in a window to the right of the map. It was expected that accuracy would be close to 100 percent for the practice search task and the experimental search task. This was found to be true.

The subjects were told that they would complete the same task for part three but would be searching for the thirty cities they had studied in part one. They were then given the opportunity to either repeat the practice search task or to continue on to do the experimental search task with the thirty cities. They were also told at this time that they would repeat the search task for all thirty cities seven times and their goal was to be as fast and accurate as possible for each round.

The goals for the third stage were to ensure that learning was actually occurring while the subjects searched the cities on the experimental map and to determine if there were any significant patterns to their learning. A pilot study had established that times might be expected to decrease significantly for approximately seven rounds of learning and then remain at a threshold level. To eliminate any order bias, the cities were presented to the subjects in random order for each round. Subjects were able to dictate the pace of the experiment by their selection of the “next city” button. A new city name would not appear at the top of the screen and the clock would not start measuring reaction time until the subjects clicked the “next city” button.

For the fourth part of the experiment, subjects completed a memory task. After completing the experimental task (part three), the complete map appeared on the screen, and subjects were given a second opportunity to study the complete map. It was explained that, when they were ready, they would be shown a blank map (with no cities), and that a point with a city name would appear on the right side of the display. Their task was to grab the city using the mouse and drag it to the position on the map where they recalled that city’s dot being located. They continued this for all thirty cities. Once a city was added to the map, it remained. Subjects were able to make adjustments to locations as they went along. Once they had placed the final city and then clicked for a new city, the program controlling the experiment wrote the final coordinates to a file. Reaction time was not recorded for the memory task.

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## Variables and Hypotheses

For the learning stage of the experiment, the dependent variable was always reaction time measured in milliseconds for the following Repeated Measure Analyses of Variance. Reaction time was measured for the trials of the search task for seven separate repeated learning epochs. An epoch was the repeated measure in the analyses. The tested null hypothesis related to epoch was that mean reaction times would be constant over the epochs. Implicit learning would be confirmed if the null hypothesis for epoch was rejected.

One main effect in the models was the map viewed by the subjects. The map main effect represented a difference in prior knowledge when comparing the performance of Map 1 and Map 2 subjects. It represented a difference in the spatial distribution of the cities when comparing the performance of Map 2 and Map 3 subjects. The tested null hypothesis related to map was that mean reaction times would be equal for the maps being compared. Rejecting the null hypothesis for map would indicate a significant processing time advantage for the subjects using one of the maps.

Another main effect in the models was sex. The tested null hypothesis related to sex was that the mean performance of female and male subjects would be equal. Rejecting the null hypothesis would indicate either female or male subjects had a significant performance advantage on the experimental task.

The final main effect in the models was focus. The tested null hypothesis related to focus was that subjects performed the experimental task equally well when searching for central and peripheral city locations. Rejecting the null hypothesis would indicate the regional location of cities significantly influenced task performance and could add support for the prototype effects posited by Huttenlocher, Hedges, and Duncan. (1991). This is based on the notion that subjects would code prototype locations for multiple visual fields.

For the recall portion of the experiment, the dependent variable was the cognitive, or recalled, locations from the subjects. The recalled locations were compared to the actual locations. Several types of positional errors were possible; therefore, indices were calculated to establish if differences in the cognitive and actual locations were related to horizontal or vertical shifts, rotations, or scale changes. The ideal expectation was that subject's recall of the city locations would match the actual locations of the cities based on the maps they studied.

### Results: Map 1 versus Map 2

The primary reason subjects were required to do seven replications of the search task was to provide them a controlled structure that allowed them to easily learn the city locations. Subjects searching Map 1 were expected to have a faster and relatively flat learning curve because of the advantages provided by prior knowledge of the city names and locations. Subjects searching Map 2 were expected to have a slower and relatively steep learning curve because they started the first search with relatively little prior knowledge but could acquire useful information during each epoch that could be used in later epochs.

Male subject were expected to have more prior knowledge related to known cities and, therefore, were expected to have faster mean reaction times for Map 1. Female subjects were expected to learn the locations of novel cities more easily and, therefore, were expected to have faster mean reaction times for Map 2.

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*“Female subjects were expected to learn the locations of novel cities more easily and, therefore, were expected to have faster mean reaction times for Map 2.”*

Following the claim of Huttenlocher, Hedges, and Duncan (1991) that viewers encode both categorical and coordinate spatial information, the focus main effect also was expected to be significant with peripheral cities having a mean reaction time advantage, particularly when learning novel city locations.

#### *Repeated Measure Analysis*

The reaction times for the seven search tasks performed by each subject were aggregated over the subjects and used as the dependent variables in a repeated measure analysis of variance (Table 1). In this model, learning epoch (Epoch 1 through Epoch 7) was the repeated measure. Within-subject effects considered the significance of the repeated measure epoch and epoch's interaction with experimental map (Map 1 or Map 2), sex (female or male), and focus (inner or outer). The repeated measure epoch was found to be significant as was interaction effect epoch X map and epoch X focus. The interaction of epoch X sex was only marginally significant, but the three-way interaction effect epoch X map X sex was significant. The significant change of mean reaction time over the seven epochs indicated a general downward trend of times. Faster reaction times were associated with more successful search processing and indicated successful learning was generally taking place for subjects during this stage in the experiment. Plots for the learning curves illustrate this point (Figures 3a and 3b).

As expected, the reaction time means for subjects who viewed Map 1 were relatively fast and defined relatively flat learning curves (Figure 3a). There was, however, a decrease in mean reaction time from the first to the last epoch for both female inner focus (2023 ms to 1565 ms) and outer focus (1778 ms to 1548 ms) cities and male inner focus (1713 ms to 1365 ms) and outer focus (1582 ms to 1323 ms) cities. Note that the reaction time means for male subjects viewing Map 1 were faster than those of female subjects over the seven search tasks' epochs and that times for outer focus cities were faster than inner focus cities for both sexes.

As expected, the reaction time means for subjects who viewed Map 2 were relatively slow and defined relatively steep learning curves (Figure 3b). There was a relatively large decrease in mean reaction time from the first to the last epoch for both female inner focus (3359 ms to 2204 ms) and outer focus (2836 ms to 1766 ms) cities and male inner focus (4099 ms to 2427 ms) and outer focus (3050 ms to 2284 ms) cities. Note that the reaction time means for female subjects viewing Map 2 were much faster than those for male subjects over the seven search task epochs and that times for outer focus cities were faster than inner focus cities for both sexes. Note also that the means for the seventh Map 2 epochs were still slower than the first Map 1 epochs for all but the female outer focus category.

Between-subjects effects were computed to complement the repeated measure analysis by averaging reaction times over the seven epochs and using this average as the dependent variable (Table 1). The between-subject effects indicated the main effect map was significant, as was the main effect focus, but the main effect sex was only marginally significant. The interaction effect map X sex was also significant. The category means for these effects illustrate the differences (Figure 4). As expected, Map 1 subjects had the faster mean reaction time (Figure 4a). Reaction times for outer focus cities were also found faster than inner focus cities (Figure 4b). A more complex pattern related to sex that parallels the learning curves shown in Figure 3 was revealed by the significant interaction effect map X sex (Figure 4c). Male subjects were faster for the Map 1 category, and female subjects were faster for the map 2 category.

*“Faster reaction times were associated with more successful search processing and indicated successful learning was generally taking place for subjects during this stage in the experiment.”*

*“Male subjects were faster for the Map 1 category, and female subjects were faster for the Map 2 category.”*

Within Subject Effects		
Repeated or Interaction Effect	F-Value	Probability of > F
Epoch	51.2	0.000
Epoch X Map	24.4	0.000
Epoch X Sex	1.9	0.079
Epoch X Focus	3.4	0.004
Epoch X Map X Sex	2.5	0.027
Epoch X Map X Focus	1.8	0.106
Epoch X Sex X Focus	0.7	0.610
Between Subject Effects		
Main or Interaction Effect	F-Value	Probability of > F
Map	144.5	0.000
Sex	3.2	0.078
Focus	5.2	0.024
Map X Sex	16.4	0.000
Map X Focus	2.1	0.154
Sex X Focus	0.0	0.959

Table 1. Within and between subject effects comparing Map 1 and Map 2 search times.

### Discussion

It is not possible to know the exact learning processes being used by subjects by considering the reaction time patterns provided by the learning curves. Differences in the mean reaction times can, however, reveal difference patterns among the epoch categories and between map, sex, and focus categories.

A comparison of the performances of Map 1 and Map 2 subjects verified performance differences related to processing familiar versus unfamiliar named cities. The much lower mean reaction time values for subjects processing Map 1 indicated they already had some advantage when they started the experiment. This is reflected by the average Epoch 1 reaction time for Map 1 (1774 ms) versus Map 2 (3336 ms). As expected, prior knowledge of the names and locations of the cities appeared to significantly aid the Map 1 searches. The Epoch 7 mean reaction time was still considerably lower for Map 1 subjects (1453 ms) versus Map 2 subjects (2170 ms). The relatively flat slopes of the learning curves for Map 1 subjects also supported the expected effect of prior knowledge (Figure 3a). The relatively small improvement in mean reaction time for Map 1 subjects over the seven epochs suggested they did not learn much new information during the experiment.

Males showed a time advantage performing the search task with Map 1. This agrees with the notion that males may have more geographic knowledge related to U.S. city locations stored in their memories (Zinser, Palmer, and Miller 2004). Females, however, showed a larger time advantage performing the search task with Map 2. This agrees with the argu-

*“This agrees with the argument from the hunter-gatherer theory that females are naturally better at learning and recalling the locations of objects . . .”*

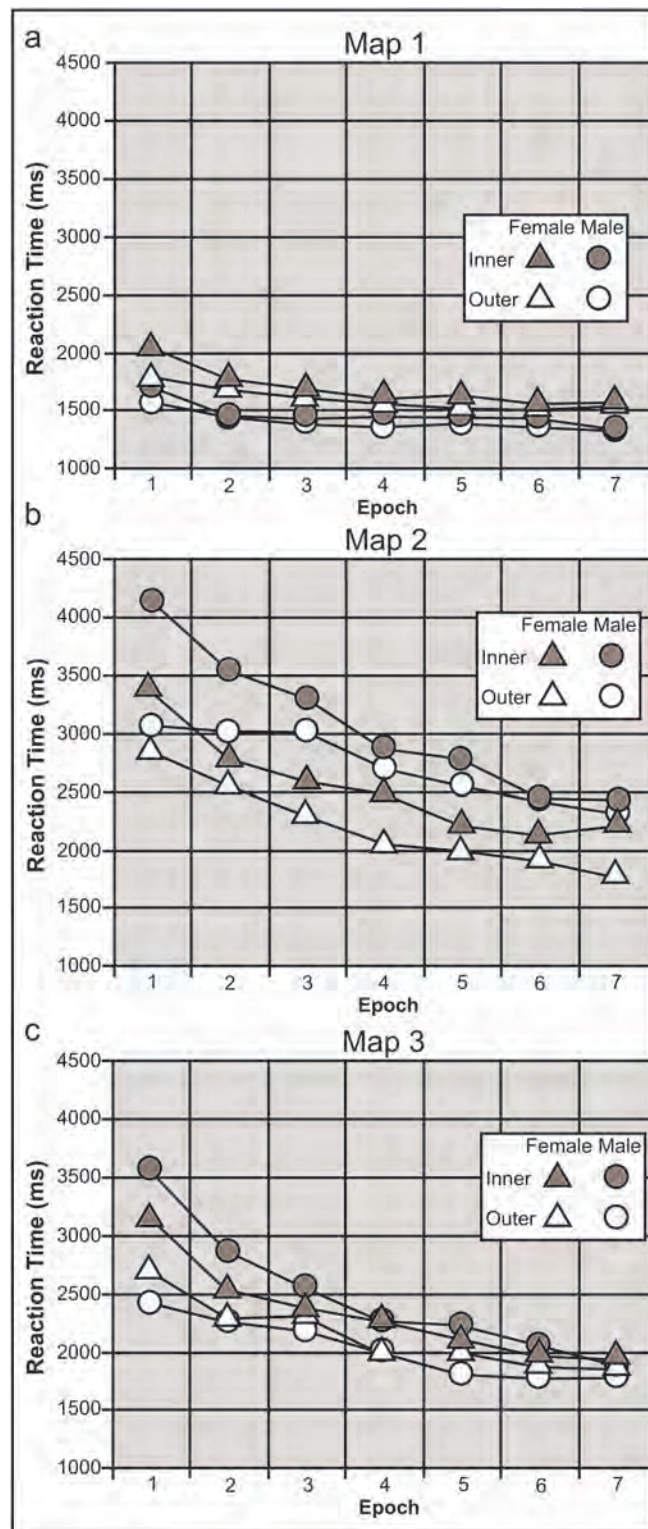


Figure 3. Inner and outer learning curves for female and male subjects for the experimental conditions using Map 1 (a), Map 2 (b), and Map 3 (c). Reaction time indicates the relative difficulty of the search and a decrease of reaction times over the epochs indicates learning.

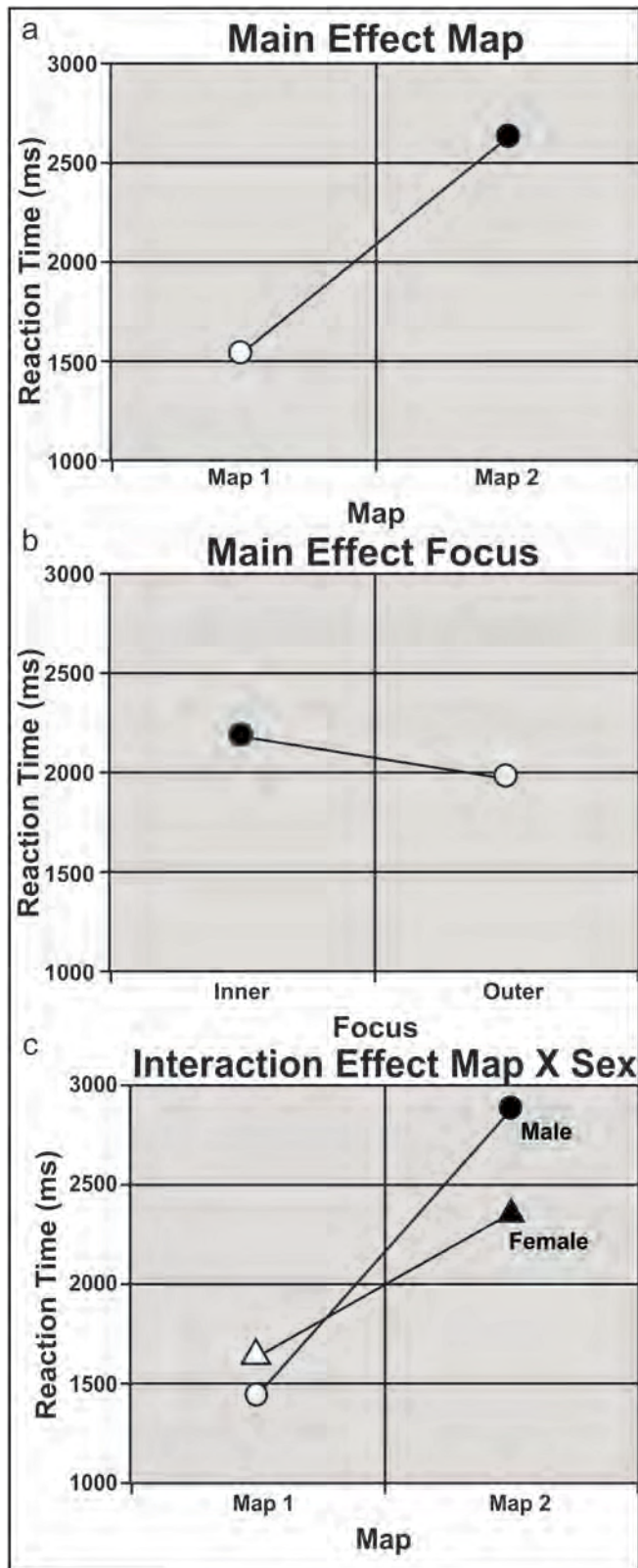


Figure 4. Category means for significant between-subject main and interaction effects for the repeated measure analysis of reaction times for Map 1 and Map 2 subjects.

*“Subjects also tended to perform the search task significantly faster when the target city was in a peripheral region.”*

ment from the hunter-gatherer theory that females are naturally better at learning and recalling the locations of objects (Silverman, Choi, and Peters 2007). Zinser, Palmer, and Miller (2004) would argue that the differences in the sexes would disappear if both exerted more effort to be prepared. Females would need to be more interested in the geographic information associated with the real cities to inspire additional learning that could aid their searches for those real cities on Map 1. Since males have no prior knowledge of the hypothetical cities on Map 2, they need to spend more time than females studying Map 2 so they can overcome the natural advantage females have learning the locations of objects in space.

Subjects also tended to perform the search task significantly faster when the target city was in a peripheral region. This supports the arguments made by Huttenlocher, Hedges, and Duncan (1991) that categorical spatial information can have a significant influence on performance.

Some of the improvement for all subjects could be related to factors unrelated to knowledge of city names and locations. As the number of trials increased, more successful strategies for searching the map could be developed and subjects could improve physical skills related to moving, aiming, and clicking the mouse.

### Results: Map 2 versus Map 3

Map 2 and Map 3 subjects viewed the same novel city names on their maps that should not be connected to any useful prior knowledge. The two maps, however, presented the cities with different spatial distributions. If a clustered distribution is harder or easier to learn for either sex, the differences should be reflected in the learning curves for the maps.

#### *Repeated Measure Analysis*

Another repeated measure analysis was performed, comparing the Map 2 and Map 3 data (Table 2). The repeated measure epoch was found to be significant as was the interaction effect epoch X focus. The interaction effect epoch X map was not significant and interaction effect epoch X sex was marginally significant. One three-way interaction effect, epoch X sex X focus, was also interestingly significant. The significant change of mean reaction time over the seven epochs indicated a general downward trend of times. Plots for the learning curves illustrate this point (Figure 3b and 3c).

The reaction time means for Map 3 subjects indicated a relatively large decrease in mean reaction time from the first to the last epoch for both female inner focus (3136 ms to 1935 ms) and outer focus (2687 ms to 1823 ms) cities and male inner focus (3566 ms to 1881 ms) and outer focus (2418 ms to 1784 ms) cities. Note that the average Map 3 subjects (2952 ms to 1856 ms) were performing faster searches than the average Map 2 subjects (3336 ms to 2170 ms).

The most distinctive pattern for the learning curve means for Map 2 was that female subjects were generally faster than male subjects (Figure 3b). The most distinctive pattern for the learning curve means for Map 3 was that outer focus cities were generally found faster than inner focus cities (Figure 3c). The learning curve patterns for female subjects were very similar for Map 2 and Map 3 searches. This suggests female subjects may have used a similar search strategy with both maps. In both cases, outer focus cities were generally found faster than inner focus cities. The learning curves for male subjects revealed a different pattern. Males showed the worst performance searching for inner focus cities on both maps, but showed a marked improvement searching for outer focus cities on Map 3

*“Males showed the worst performance searching for inner focus cities on both maps, but showed a marked improvement searching for outer focus cities on Map 3 compared to Map 2.”*

Within Subject Effects		
Repeated or Interaction Effect	F-Value	Probability of > F
Epoch	80.6	0.000
Epoch X Map	1.2	0.336
Epoch X Sex	2.0	0.077
Epoch X Focus	4.9	0.000
Epoch X Map X Sex	1.1	0.367
Epoch X Map X Focus	1.0	0.447
Epoch X Sex X Focus	3.0	0.009
Between Subject Effects		
Main or Interaction Effect	F-Value	Probability of > F
Map	13.3	0.000
Sex	6.9	0.010
Focus	10.0	0.002
Map X Sex	5.7	0.019
Map X Focus	0.0	0.958
Sex X Focus	0.4	0.531

Table 2. Within and between subject effects comparing Map 2 and Map 3 search times.

compared to Map 2. For Map 3, the male mean outer focus reaction times were equal to or faster than comparable female means (Figure 3c).

The between-subjects analysis indicated the main effects map, sex, and focus were all significant as was the interaction effect map X sex (Table 2). The means for these effects illustrate the categorical differences (Figure 5). The reaction time mean for Map 3 indicated these subjects had a significant advantage over Map 2 subjects (Figure 5a). Female subjects also responded significantly faster than male subjects (Figure 5b), and the outer focus cities were responded to faster than inner focus cities (Figure 5c). The significant interaction effect map X sex indicated females and males responded differently to the two maps. Female subjects responded consistently to the two maps. Male subjects were relatively slow when responding to Map 2 and much faster and approximately equal to female subjects when responding to Map 3 (Figure 5d).

#### Discussion

It is clear that subjects generally searched Map 3 more efficiently than Map 2 (Figure 5a). The only difference in the two maps was the spatial distribution of the cities. This had to play a key role in explaining the performance difference. The patterns of the learning curves do not allow one to determine the exact processes subjects used to search the maps and implicitly learn the locations of the cities, but one can easily see the significant decrease of mean reaction time over the epochs and the categorical differences in the reaction time patterns for the main effects (Figure 3). Female subjects generally had consistent reaction time patterns for the

*“This suggests female subjects were using a more effective encoding process than males and used it more successfully with both maps . . .”*



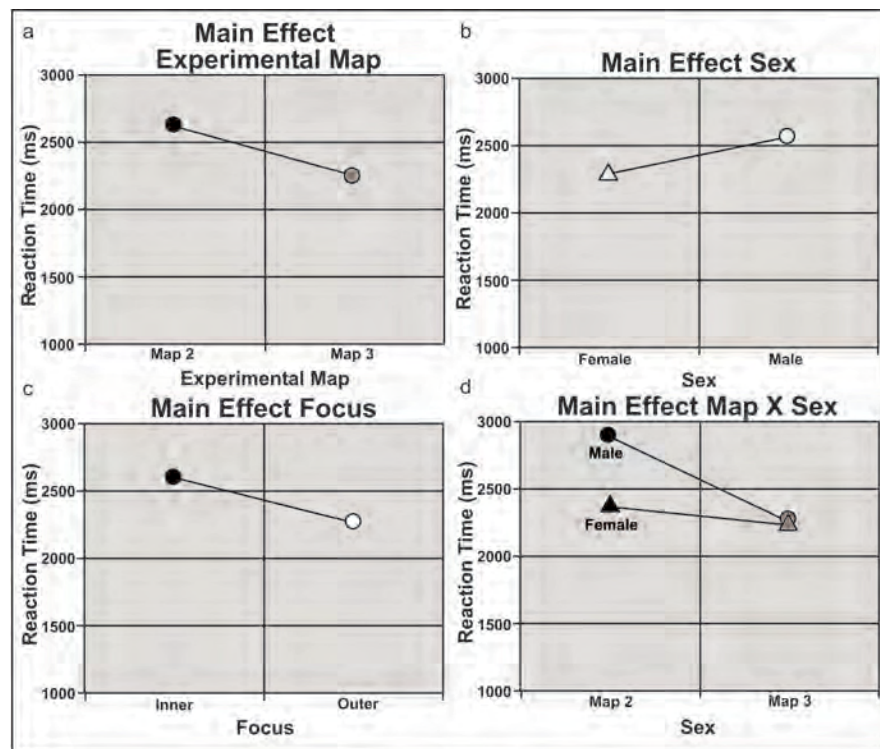


Figure 5. Category means for significant between-subject main and interaction effects for the repeated measure analysis of reaction times for Map 2 and Map 3 subjects.

two maps and significantly outperformed male subjects (Figure 5b). This suggests female subjects were using a more effective encoding process than males and used it successfully with both maps (Figure 5d). Based on the literature, one possible explanation is that they were using a process that encoded categorical information (Frings et al. 2006). Male subjects were consistently slower than female subjects searching Map 2, but male subjects performed better with Map 3, particularly with outer focus cities (Figure 5d). Subjects were generally able to find outer focus cities faster than inner focus cities (Figure 5c).

Given Huttenlocher, Hedges, and Duncan's (1991) contention that people can learn both categorical and coordinate spatial information and combine the two types to estimate a location, why might there be a difference in female and male reaction time learning curves? If female subjects tended to encode categorical information and male subjects tended to encode coordinate information, this could explain some sex differences. For example, female subjects performed the search task with Map 2 significantly faster than male subjects over the seven epochs (Figure 3b). This could simply be because categorical information is easier to retain in memory than coordinate information (van der Ham et al. 2007). Because male subjects are learning coordinate information, they will need more time to retain enough of this type of information to equal the performance of female subjects with categorical information. This assumes that having both types of spatial information, once encoded, will aid subsequent search tasks. Evidence from Map 1 would seem to support this assumption (Figure 3a). It also seems reasonable to assume categorical spatial knowledge would be sufficient for doing the search task. One does not have to recall precisely where a city is, but just have enough spatial knowledge to guide attention to a place on the map with enough precision to be able to verify

*"One does not have to recall precisely where a city is, but just have enough spatial knowledge to guide attention to a place on the map with enough precision to be able to verify the name labeling the city."*

the name labeling the city. Knowing that the city is in the southwest corner of the map may be all one needs to quickly find a city.

The relative clustering of cities on Map 2 and Map 3 (Figures 2b and 2c) impacted male performance but did not seem to affect female performance (Figures 3b and 3c). Females were apparently using the same process with both maps. If the hunter-gatherer theory is correct, most female subjects will encode categorical information, for instance, verbal descriptions of city locations (Silverman, Choi, and Peters 2007). Since categorical codes are by nature not providing precise information, the relative clustering of the cities on the two maps may not have a great impact on this type of processing.

The results for Map 2 and Map 3 suggested Male subjects did not have consistent learning curves and performed the search task better with Map 3 (Figures 3b and 3c). Why did the clustering of cities on Map 3 improve Male performance? It could be that the obvious cluster of cities in the center of the map focused attention there enough to inspire Male subjects to encode and use more information that is categorical. The Male subjects were able to make a quick distinction between cities in the cluster (Inner Focus) and cities on the periphery (Outer Focus). Once that initial categorization was made, the Males learned the Outer Focus cities more efficiently than the Inner Focus cities. This might be due to the larger number of Inner Focus cities in the central cluster compared to the smaller number of Outer Focus cities. The general trend showing that Males learned the Map 3 cities less efficiently than Females could be explained by Males' lack of preparedness using categorical codes to encode location (Zinser et al. 2004). By the seventh Epoch, however, the Males were able to adapt to the new strategy and came close to reaching parity with Females (Figure 3c).

*“Why did the clustering of cities on Map 3 improve Male performance?”*

### **Results: Spatial Location Error**

The final stages in the experiments, following the learning stages, involved the subjects reconstructing the distribution of cities on the maps they had viewed. The coordinate data were averaged over the subjects and the mean cognitive city locations were represented for all map categories, along with the actual city locations for both sex categories (Figures 6, 7, and 8). The lines connecting the cognitive and physical locations represent mean location errors. The differences between physical and mean cognitive locations are relatively small for Map 1 subjects and not oriented in a consistent pattern. Mean errors appear to be particularly low for cities located along the coastline for female subjects and otherwise small and evenly distributed (Figure 6a). Male subjects appear to generally have lower mean errors for peripheral locations and higher, but still small, mean errors for cities that are centrally located (Figure 6b).

A different pattern is evident for Map 2 subjects (Figure 7). Mean location errors were relatively large throughout the maps and generally were oriented in consistent patterns. Cognitive locations tended to be more centrally located relative to their physical counterparts. Mean location errors generally appeared to be smaller for Map 2 female subjects (Figure 7a) compared with Map 2 male subjects (Figure 7b).

Map 3 subjects did visual searches with a map that had a definite cluster of cities. Location errors for cities outside the cluster were oriented toward the cluster with cognitive locations being closer to the cluster than their physical counterparts. The cluster of cities, as represented by cognitive locations, appeared to have been shifted northwest for both female (Figure 8a) and male (Figure 8b) subjects.

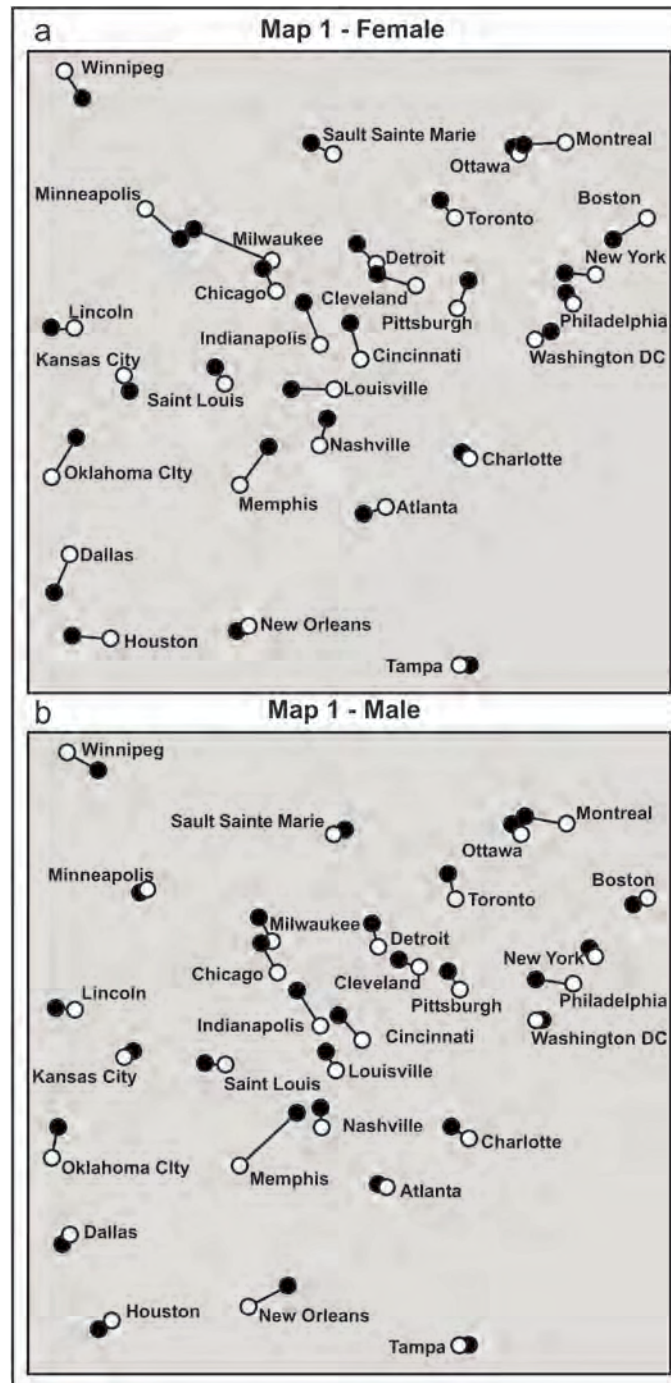


Figure 6. Physical (white) and cognitive (black) locations for the Map 1 cities for female (a) and male (b) subjects.

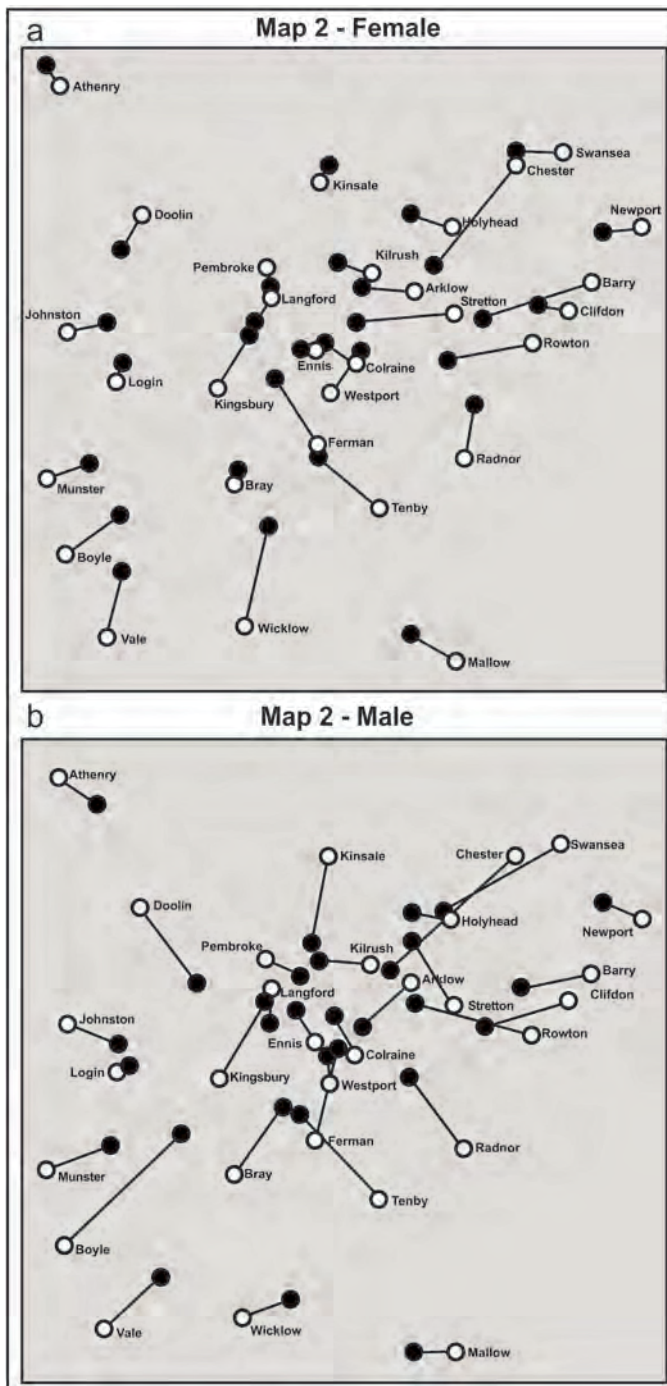


Figure 7. Physical (white) and cognitive (black) locations for the Map 2 cities for female (a) and male (b) subjects.

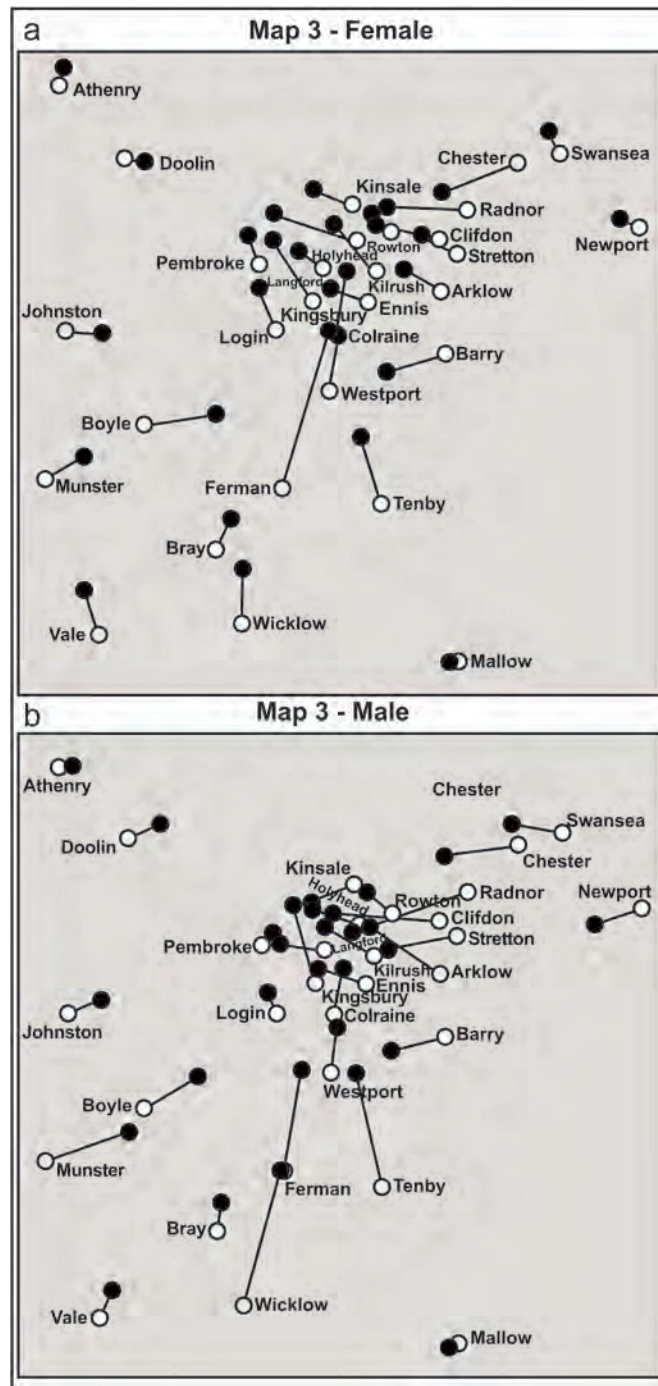


Figure 8. Physical (white) and cognitive (black) locations for the Map 3 cities for female (a) and male (b) subjects.



### Euclidean Regressions

Separate Euclidean regressions were performed for the female and male mean city location data related to Map 1, Map 2, and Map 3 subjects (Figures 6, 7, and 8). For all regressions, the dependent space was represented by the cognitive locations for cities, and the independent space was represented by the physical locations for cities (Friedman and Kohler 2003). The horizontal shift, vertical shift, scale change, and rotation needed to achieve a best fit between the dependent and independent spaces are reported in Table 3.

The horizontal shift and vertical shift parameters indicate the translation needed to shift the physical locations of cities to best align them with the mean cognitive locations. A value of 0.0 would indicate no shift change was required for the horizontal or vertical axis. These parameters support the visual impression provided by Figures 6, 7, and 8 with data for Map 1 requiring the least adjustment and the data for Map 2 requiring the most adjustment (Table 3). Males had a small advantage for Map 1 and females had a larger advantage on Map 2 and Map 3.

The scale parameters indicate the scale change needed to expand or contract the physical space to best align it with the cognitive space. A parameter equal to 1.0 would indicate no change. These parameters show the same pattern with values for Map 1 indicating small contractions and values for Map 2 indicating the most required contraction. The required scale change was the same for female and male Map 1 subjects while female subjects had the advantage for Map 2 and Map 3 (Table 3).

The rotation parameters indicate the number of degrees the physical spaces must be rotated to align them with the cognitive spaces. These values were small ( $< 3^\circ$ ) for all map and sex combinations (Table 3). The  $r^2$  values for the Euclidean regressions were relatively high for all the analyses. The best fit was for Map 1 male subjects ( $r^2=0.99$ ) and the lowest fit was for Map 2 male subjects ( $r^2=0.91$ ) (Table 3).

*“This result supports other studies that have argued that prior knowledge enhances the performance of spatial tasks and learning processes . . .”*

### Discussion

It should not be surprising to find that Map 1 subjects recalled city locations more accurately than Map 2 or Map 3 subjects. This result supports other studies that have argued that prior knowledge enhances the performance of spatial tasks and learning processes (Lloyd 1988; Kulhavy et al. 1993; Schwartz et al. 1998). The sex differences apparent in the aggregated cognitive maps also support results previously reported in the literature.

Parameters	Map 1		Map 2		Map 3	
	Female	Male	Female	Male	Female	Male
Horizontal Shift	-4.76	<u>0.46</u>	<u>75.09</u>	120.87	<u>34.29</u>	55.54
Vertical Shift	8.24	<u>3.37</u>	<u>55.53</u>	106.76	<u>29.35</u>	51.55
Scale	0.98	0.98	0.81	0.75	0.88	0.83
Rotation	0.94	0.68	0.21	2.43	2.06	2.50
$r^2$	0.98	<u>0.99</u>	<u>0.96</u>	0.91	<u>0.95</u>	0.94

\*Underlined table values indicate a female or male advantage on that parameter. Ideal values for horizontal shift, vertical shift, and rotation are 0.0. Ideal values for scale and  $r^2$  are 1.0.

Table 3. Summary of Euclidean regression results for map and sex combinations using average cognitive map city locations. The dependent space was always the cognitive locations of the cities and the independent space of their physical locations.\*

*“This would indicate male subjects had learned to do the search task as fast as the female subjects but lagged behind in having an equally accurate cognitive map encoded through implicit learning.”*

Male subjects having a small advantage processing Map 1 supports the notion that males generally have more interest in geographic information, and this extra attention provides useful prior knowledge when searching for well-known cities (Zinser, Palmer, and Miller 2004). Female subjects having a larger advantage processing Map 2 supports the frequent finding that females perform significantly better than males on location memory tasks (Silverman and Eals 1992; Neave et al. 2005). Perhaps the most interesting reaction time comparison for female and male subjects was found for the Map 3 searches. The overall mean reaction time was similar for female (2229 ms) and male (2256 ms) subjects (Figure 5d), but the learning curve patterns were not the same for inner and outer focus cities (Figure 3c). Male subjects (3566 and 2418 ms) had a greater difference in mean reaction time than female subjects (3136 and 2687 ms) for Epoch 1, but differences for both male (1880 and 1784 ms) and female (1935 and 1823 ms) subjects had nearly vanished by Epoch 7, with males having a slight advantage. Since female subjects outperformed male subjects doing searches of Map 2 and the same false names were used on both maps, the clustering of cities must have inspired the male subjects' improving reaction time performance.

Although male subjects had achieved reaction time parity with female subjects by Epoch 7, the accuracy maps (Figure 8) and Euclidean regressions for Map 3 indicated a female superiority. This would indicate male subjects had learned to do the search task as fast as the female subjects but lagged behind in having an equally accurate cognitive map encoded through implicit learning. Although male subjects appeared to be using a different process for doing the search task with Map 2 and Map 3, it is also possible male subjects may have used the same strategy processing Map 2 and Map 3, and the clustering of cities on Map 3 allowed them to process the information faster. In any event, the accuracy advantage for Female Map 2 and Map 3 subjects offers support for the superior location memory hypothesis for females (Silverman, Choi, and Peters 2007).

## CONCLUSIONS

*“This research also tested the hypotheses that performance would be influenced by whether or not the map features were familiar (prior knowledge, where map features were located in the visual field (center versus periphery), and how map features were distributed (dispersed or clustered).”*

The literature indicates that asymmetrical brains should be an advantage in spatial cognition because they provide cognitive processing abilities that can be adapted to a variety of situations when learning spatial knowledge (Huttenlocher, Hedges, and Duncan 1991). Specifically, asymmetrical brains allow relationships among objects in space to be represented as both category information and coordinate information. The degree to which someone uses these alternate methods to acquire information could affect the nature of his/her cognitive map[s]. Cartographers might be interested in who uses these learning strategies and when they use them as they consider constructing a map that will be used to enhance learning.

An individual may not consciously decide to encode either categorical or coordinate information, but could spontaneously encode both types. Based on the literature, one possible explanation for the results is that people may have conscious or unconscious preferences toward a given encoding process that could affect their processing of spatial information (Choi et al. 2006). Based on research in cognition and evolutionary biology, the current research tested the hypothesis that males and females would tend to utilize different cognitive processes when learning spatial information from maps, and those differences would affect map-reading performances (Zinser, Palmer, and Miller 2004; Silverman and Eals 1992). Anyone who teaches with maps, uses maps to communicate ideas to groups of experts or novices, or designs Web pages that include maps might find this notion interesting. Anyone concerned with the degree of participation of seventh and eighth grade females and males in the National Geographic's

Geography Bee might be interested in studies that address the causes of individual differences (Hardwick et al. 2000). This research also tested the hypotheses that performance would be influenced by whether or not the map features were familiar (prior knowledge), where map features were located in the visual field (center versus periphery), and how map features were distributed (dispersed or clustered).

Three general conclusions can be made from the analyses of performance. First, it is clear from the results of the search portion of the experiment that learning did occur through the visual search task. All subject groups for all map conditions significantly improved their times from Epoch 1 to Epoch 7 without a decline in accuracy. It was expected that there would be greater improvement for the Map 2 and Map 3 conditions because those subjects started with little prior knowledge. (They were given two minutes to examine the map before the search task began.) It was, likewise, expected that the subjects who viewed Map 1 would demonstrate less improvement over the seven epochs because they started with substantial prior knowledge. (They viewed a map of a portion of North America with well-known cities.) The results supported both of these expectations.

The cognitive mapping results also showed that learning occurred. As expected, the positional error associated with the recall of Map 2 and Map 3 locations was greater than that of Map 1 (Figures 6, 7, and 8). The errors for Map 2 and Map 3, however, were clearly not the result of "guessing." The general patterns of the cognitive maps were correct; for example, peripheral cities were located on the periphery, central cities were located in the center, eastern cities were located in the east, northern cities were located in the north, etc. Prior knowledge provided the Map 1 subjects with a significant advantage, but considerable locational knowledge was obtained by the Map 2 and Map 3 subjects through learning.

Second, it is clear from the reaction time and location accuracy results that the average male and female experimental subjects performed differently. Cartographers should be interested in the nature of this difference as they design their maps for specific audiences. The apparent contradiction in the literature that suggests males perform better on tests of specific geographic knowledge (Dabbs et al. 1998; Nelson, Aron, and Poole 1999), and females have a better memory for the locations of objects in space (Silverman, Choi, and Peters. 2007; Voyer et al. 2007) is illustrated in the experimental data (Figures 4 and 5). There may be no contradiction if one considers the timing of the learning. The typical male is thought to perform better encoding coordinate information, and this process is more difficult to use effectively (Van der Ham et al. 2007). If males are forced to use a categorical style of coding or they do not have sufficient time to learn the coordinate information, they will be disadvantaged. Fitting this expectation, males performed the search task better when they had prior knowledge for well-known cities. The typical female is thought to learn spatial information by encoding categorical information, and this is less difficult to encode and use effectively. If females are forced to compete with a coordinate style over a long period of time, they should be disadvantaged. Fitting this expectation, females performed the search task much better than males under conditions of little prior knowledge and a novel map. Differences between the sexes follow this pattern for both the reaction time data (Figures 4 and 5) and for the comparisons of recalled maps (Table 3).

Third, the nature of the learned map significantly affected the learning performance of the subjects. Although reaction times significantly decreased over the seven learning epochs for all maps, the learning curves were flatter for Map 1 subjects and steeper for Map 2 and Map 3 subjects

*"If males are forced to use a categorical style of coding or they do not have sufficient time to learn the coordinate information, they will be disadvantaged."*

*"If females are forced to compete with a coordinate style over a long period of time, they should be disadvantaged."*



*“One could also have one group of subjects learn the cities explicitly and another set of subjects learn the cities implicitly and compare their relative success.”*

(Figure 3). This is a strong indication that the search tasks were relatively easy with a familiar map and relatively difficult with a novel map. Subjects also recalled city locations more accurately for Map 1 than for Map 2 or Map 3 (Table 3). Significant differences for reaction time and location accuracy comparing Map 2 and Map 3 also indicated the distribution of cities on the maps affected subjects' performances (Figure 4 and Table 3).

The current study used subjects that had enrolled in geography classes to acquire both female and male subjects that had expressed an interest in geography. This increased the likelihood that the subjects would have prior knowledge for U.S. cities. This could also mean the subjects also had better spatial abilities than average males and females (Casey 1996; Lloyd and Bunch 2005). Future studies might compare performance for a sample of geographers and non-geographers to explicitly test for the effect of prior knowledge.

Future studies could also focus on explicit learning processes and directly compare female and male cognitive maps for subjects who were given instructions to use categorical or coordinate encoding strategies. This would provide comparisons of performances for females and males who were consciously trying to use a common learning strategy. One could also have one group of subjects learn the cities explicitly and another set of subjects learn the cities implicitly and compare their relative success.

#### NOTES

<sup>1</sup>The terms categorical and coordinate information are used here to conform to the terms used by Kosslyn (1987) as he related learning to encoding spatial information into memory. Researchers have also made similar binary distinctions using terms such as verbal versus visual information, propositions versus imagery, or route versus survey perspectives (Kosslyn and Pomerantz 1977; Bunch and Lloyd 2006; Péruch et al. 2006).

<sup>2</sup>These three examples were selected because they generally should be found on reference maps commonly available for public use and because some were selected for use in the current study. They are not the only potentially important reference frames. Important cities that are not home locations, rivers, and physiographic regions are other examples of point, line, and area reference frames. Also important on some maps are graticules that can be used to define locations with some degree of precision.

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