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Working Paper
UCTC No. 214

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Survey Versus Route-Based Wayfinding in Unfamiliar Environments

by

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Abstract

An interesting controversy has recently arisen regarding the relative effectiveness of map based versus route based environmental learning. Although spatial theory suggests that map based (survey) knowledge should be more effective, recent research shows some contrary results. In this paper we describe an experiment in which subjects learn either from a map or a computer simulation (pseudo-virtual reality) of an environment. Tests of route reproduction, cue location, orientation and directional knowledge are undertaken. Results confirm the superiority of survey learning procedures, but interesting differences are found with respect to gender and geographic background of subjects.

Purpose

Cognitive scientists have argued that the acquisition of spatial knowledge is a "bottoms-up" process. Theories such as those put forward by Kuipers (1978) and Anderson (1982) have largely been developed from the point of view of how a robot would accumulate information about an unfamiliar environment. A bottoms-up search and learning hypothesis under these circumstances is understandable. Investigations of spatial knowledge acquisition from such a point of view have clarified our knowledge of exploratory behavior, and have produced a range of hypotheses as to how such knowledge might be stored, accessed, and used, particularly by a computer. While these hypotheses provide a reasonable base for speculating about the knowledge storage, and acquisition process, they appear to fall short of fully explaining how configurational or survey level knowledge, the highest and most articulate form of spatial understanding, is developed by humans. The purpose of this research is to articulate some important properties of configurational or survey level understanding and, via a series of experiments, to determine whether such properties can reasonably be produced in what Kuipers has called a "common sense" set of circumstances. This testing is to be achieved by comparing the performance of piecemeal learners (the "bottoms-up" procedure), with the performance of those exposed to a bird's eye (or top-down procedure). Learning about an environment by "walking" through a virtual building will simulate a piecemeal "bottoms-up" process. Learning from a map will simulate a top-down process. The aim of this testing is to determine the extent to which spatial properties such as distance, orientation, and angle comprehension that should appear in a configurational knowledge structure actually do appear after each type of learning.

While the "bottoms-up" spatial learning process has given us many insights into how a spatial knowledge structure might develop, it does not appear to satisfactorily account for our ability to integrate bits of knowledge so gained and infer from that base information about patterns, distributions, regions, hierarchies, or other components of configurational understanding. The question arises as to whether the integration of declarative or landmark type knowledge systems and procedural or rule based systems designed to allow wayfinding to take place, are sufficient to allow the integration and inferential processes that are a necessary part of configurational or survey level knowledge, to develop.

Background

The field of geography has as one of its continuing emphases, the discovery of spatial patterns of specific features, functions, and phenomena in different environments. These patterns often exist at scales well beyond the perceptual domain. They may consist of things such as the locational pattern of cities in a region, patterns of crop production at a regional or national level, or patterns of shopping centers or specific stores within a city. Since many individuals have no need to know about these spatial patterns, they may not develop an awareness of them. Once described or explained, the patterns often seem both understandable and common sensical. But few of these patterns can be abstracted from background environmental "noise" or readily recognized by most people (Golledge, 1992). Thus, one may postulate that the highest level of spatial knowledge may be an expert knowledge structure which requires training before it emerges in an individual. This does not mean that the individual lacks the capability for deducing the location of an unknown destination, finding a route to it, or integrating the unknown place into his/her existing knowledge structure. It may mean either that they have not been motivated to do so in any coherent way, or that they are unaware of their ability to complete such a task.

The process of spatial knowledge acquisition over time via the mechanism of repeated learning trials of selected routes within familiar and unfamiliar neighborhoods has been examined (Allen & Kirasic, 1985; Evans, et al., 1984; Lindberg & Gärling, 1981; Doherty & Pellegrino, 1986; Hirtle & Hudson, 1990; Doherty, et al., 1989; Gale, et al., 1990; MacEachren, 1992; Lloyd, 1989; O'Neill, 1992a, b; Golledge, et al., 1990). In addition to scene recognition and route learning experiments, a battery of tasks designed to test the ability of individuals to recognize and use components of their declarative and procedural knowledge base have been designed (Pellegrino & Golledge, 1987; Gibson & Schmuckler, 1989; Freundschuh, 1989; Maki, 1981). For example, actual navigation behavior over prescribed routes has been recorded as a descriptive measure of task-oriented environmental learning (Allen, 1981; Allen & Kirasic, 1985; Evans, et al., 1984; Gale, et al., 1990; Klatzky, et al., 1990; Hirtle & Hudson, 1990). Scene recognition tasks were created to evaluate sensitivity for different types of cues, scenes, views, and locations (Doherty & Pellegrino, 1986). Sketch maps have been used as a less structured means of testing a variety of knowledge components in post-trial debriefing sessions (Pellegrino & Doherty, 1985; Golledge, et al., 1991). Information on spatial layout (Gärling, et al., 1981; Gärling, et al., 1985), segmentation (Allen, 1981; Sadalla, et al., 1980), cue location and identity (Allen, et al., 1979; Anooshian, 1988; Erickson, 1975; Budd, et al., 1985; Pezdek & Evans, 1979; Sadalla, et al., 1980), and choice point definition (Golledge, et al., 1985; Lapin, 1992), have all been recorded. However, integrated information on hierarchical organization revealed in cue sequencing or distancing, effects of route segment and order on various on and off-route distance concepts, the impact of frame of reference on the ability to understand spatial patterns, the ability to determine direction and orientation from learned or experienced information, have received much less attention (but see Allen, et al., 1978; Baird, 1979; Beck & Wood, 1976; Byrne, 1979; Evans, et al., 1984; Herman, 1980; Stevens, 1976; Hirtle & Jonides, 1985; Hirtle & Mascolo, 1986; HIrtle & Hudson, 1990). It is hypothesized that these latter components are an essential part of the knowledge integration process and are key elements in what is generally known as *survey* or *configurational knowledge* (Hart & Moore, 1973; Siegel & White, 1975; Golledge, 1977). It is only by integrating specific landmark and route systems into a configurational whole, and referring that configuration to some bounding frame of reference, that survey level knowledge of spatial patterns and spatial relations among phenomena in a task environment can be developed.

This survey level knowledge is often described as the ability to discern elements of the environment "from a bird's eye view", a process sometimes called holistic imagery (Kosslyn, 1975, 1984). The process of observing and representing information is called cognitive mapping (Downs & Stea, 1973). Knowledge gained in this way is assumed to be the highest or most advanced level of spatial knowledge (Shemyakin, 1962; Hart & Moore, 1973; Siegel & White, 1975). In this paper the major question is whether the integration of landmark and route knowledge is sufficient to produce the survey level understanding of an environment obtained by learning routes (Freundschuh, 1989), and whether a single type of survey level understanding is achieved (Pellegrino, et al., 1990). This hypothesis has not, to my knowledge, been extensively tested in the research literature (but see Anderson, 1982; Siegel, 1982; Golledge, et al., 1991, 1992; Gibson & Schmuckler, 1989; Aitken, 1990 for partial treatments). Reiser, et al., 1980, Hollins & Kelley (1988) and Klatzky, et al. (1990) have conducted table top experiments to determine if knowledge acquired about individual locations at a microscale is sufficient to allow subjects to reproduce the pattern of those locations. Siegel (1982), Pellegrino, et al., (1990), and Golledge, et al. (1991, 1992) have examined whether subjects, having learned a set of locations, can use triangulation procedures embedded in pointing tasks to successfully locate other places whose locations in the same environment have been independently learned. Allen (1981), Sadalla & Staplin (1980a, b), Sadalla et al. (1979; 1980)and Montello (1990) have shown the importance of reference nodes or landmarks on interpoint distance estimation, stressing the essential asymmetry of cognitive distances. And a growing literature on the spatial abilities of the blind is examining whether configurational knowledge is dependent on visualization procedures (for overviews, see Cleaves & Royal, 1979; Easton & Bentzen, 1980; Klatzky, et al. 1990), and Loomis, et al. 1993).

From this work it may be inferred that a multi-level configurational (survey) knowledge structure may exist. Such an inference would help explain why many adults who, according to conventional theory, *should* have the ability to perform a wide array of spatial tasks, are unable to do so at a satisfactory level of competence. It may also help to explain what the fundamental components of survey level knowledge are and how they can be expressed, measured, or taught.

Concepts derived from the literature relating to the components of spatial knowledge include the idea of critical anchoring points in hierarchical knowledge structures (Golledge, 1978; Couclelis, et al., 1987; Hirtle & Jonides, 1985; McNamara, 1989; Hirtle & Mascolo, 1986; Stevens, 1976; Stevens & Coupe, 1978), along with general understanding of the notion of spatial distributions, spatial networks, and spatial patterns (Golledge, 1990; 1992). Other attempts to define properties related to survey knowledge include Allen, et al., 1978; Budd, et al., 1985; Curtis, et al., 1981; Gärling, et al., 1985, MacEachren, 1992; Lloyd, 1989; and Freundschuh, 1992.

Although some attention has been paid to the problem of defining what spatial relations should exist in survey level knowledge (Baird, 1979), it is hypothesized here that a configurational knowledge system should contain at least the following properties:

1. Sets of identifiable "occurrences" of different classes of spatial phenomena, (often referred to as "landmark" knowledge),

2. Knowledge of the spatial distributions to which occurrences belong,

3. Identifiable spatial processes that facilitate integration and understanding of phenomena (e.g. wayfinding, navigation, search and learning),

4. Spatial contiguity and spatial association,
5. Linkage and Connectivity (partly subsumed under the term "route knowledge"),
6. Geographic regions, and
7. Spatial hierarchies.

An overview of how these properties manifest themselves in spatial knowledge can be found in Golledge (1990). Past research has focused on the identification of spatial phenomena, such as landmarks, nodes, and choice points (Golledge, 1987; Anooshian, 1988; Evans, et al., 1984; Feinberg & Laylock, 1964) and this problem will not be further examined here. Knowledge of the spatial distributions to which phenomena belong has attracted the research attention of psychologists interested in visualization of patterns and shapes (Shepard, 1978, 1984; McGlone & Kertesz, 1973; Petersen, 1987; Stevenson, 1986; Tversky, 1981; Tversky & Hemmenway, 1984). While some attention will be paid to the ability of individuals to extract patterned information from a noisy visual background, only one task (sketch mapping) will be devoted to examining the spatial distribution problem.

Proposed Research Hypothesis and Tasks:

1. While subjects will be able to externally represent their declarative (landmark or place specific) knowledge gained through maps or route learning, they will remain unaware of many of the distributional and pattern properties of the knowledge they accumulate. This will be true for both active (route) and passive (map) learners.
2. As opposed to Anderson's hypothesis (1982) that a declarative knowledge base and a set of procedural rules alone will be adequate to understand configurational properties of environmental information, a hypothesis to be tested is that this

produces at best piecemeal knowledge (Carey & Diamond, 1977), and is insufficient to produce the knowledge integration required for configurational understanding.

3. Subjects who learn about an environment by accumulating information along and in the vicinity of specific routes, will be unable to integrate the information into an accurate representation of the study area, or to be able to comprehend the spatial relations among features in that area.

4. Map learners will be more likely to develop a configurational understanding of the study area than route learners.

5. Kuipers (1978) and MacEachren (1992) argue that survey level understanding is acquired by a "bottoms-up" process which is data driven; i.e. that configurational understanding is developed piecemeal as one experiences things in an environment. It is hypothesized here that this piecemeal production will not produce a satisfactory survey level understanding, but at most will produce a "common sense" environmental knowledge structure that exhibits few of the properties of configurational knowledge outlined earlier. Thus it is hypothesized that the most comprehensive survey level knowledge will be produced by those in the map reading situation and that the piecemeal accumulation of knowledge via route learning will result in less coherent and more distorted understandings of phenomena and spatial relations among them in the task environment.

6. There will be no significant gender differences in either map learning or route learning scenarios.

7. Subjects with substantial geographic training will be more likely to produce configurational understanding in both map and route conditions and from their

"expert" position should perform significantly better on distance and angle estimation and reproduction tasks than subjects with little geographic training.

8. Because each route consists of approximately the same structure (i.e., two short and two long segments), there will be no significant effect resulting from the order of presentation of the two routes.

Methods

Forty subjects, 20 females and 20 males, participated in the experiment. Subjects were paid for participating. Half of each gender group was formally trained in geography, having completed five or more courses in the discipline. All subjects were students or staff from the UC Santa Barbara campus.

Materials

The experimental environment and the routes through the environment were presented to subjects in one of two ways: (1) as two 8.5" x 11" paper maps of a building floor plan, each marked with a different route (*map condition*, Fig. 1), or (2) as two simulated walks through a building viewed on a computer monitor, each walk matching the routes presented in the maps (*simulated travel condition*)[1]. The routes were partially overlapping and were viewed independently of each other. The total length of each route was the same, each composed of four segments, two long and two short. Long segments were twice as long as short segments. The configuration of the routes differed in two substantive ways. Segments composing route A were short-long-short. Segments composing route B were long-short-short-long. Each route had three turns, all 90 degrees. The order of turns for route A was right-left-right; and for route B, left-right-

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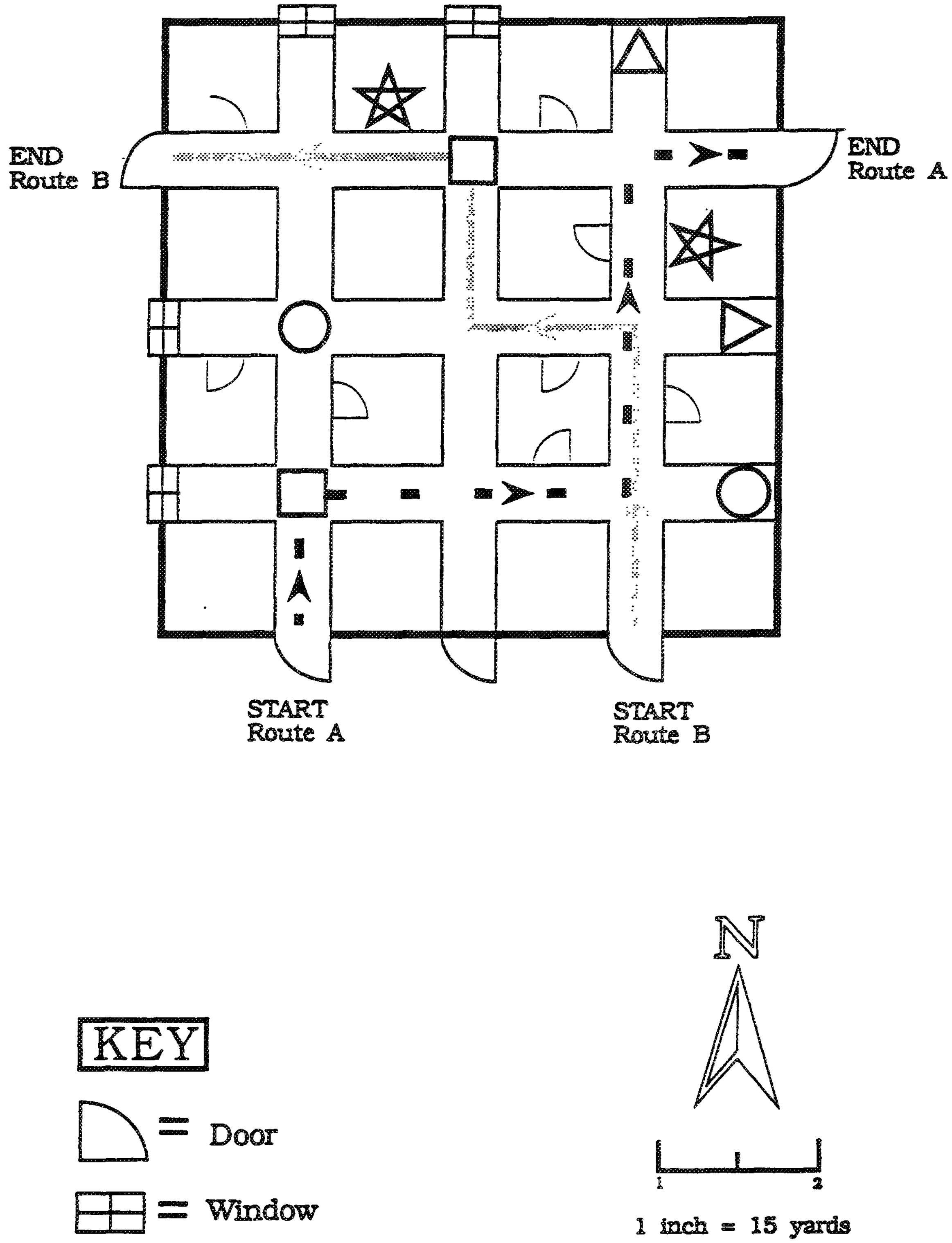
[1] We acknowledge the assistance of Jeff Boynton, who wrote the "Hallways" program used in our experiment.

Fig. 1


END
Route B
END
Route A
START
Route A
START
Route B
KEY
= Door
= Window
N
1
2
1 inch = 15 yards

left. The route on each map was labeled "START" and "END" and the direction of travel was indicated with arrows. A north arrow, scale, and key appeared on each map.

Beginning and end points for the simulated travel condition matched those on the maps. Subjects in the travel condition were instructed that their journey would begin in the north-facing direction for both routes. Eight simple geometric features (e.g., blue star, red square) were scattered throughout the environment, half on one of the two routes and half on neither route. All features were visible from both routes. Four colors and four shapes uniquely identified each of the eight features. Doors and windows were scattered throughout the environment as in a typical building. In the simulated travel condition, three features (red square, blue circle, yellow square) appeared on the floor, and the rest appeared on the wall. Position of geometric features, doors, and windows were the same for both conditions (Fig. 1).

Two sketch map tasks were undertaken. Subjects drew sketch maps of the environment and the features within it on 8.5" x 11" sheets of paper on which appeared a square, representing the outline of the building, a north arrow, and a scale. A second sketch map task, completed the experiment, and here the above process was repeated, but this time, a list of the features was given to each subject.

Subjects recorded judgments about locations of the geometric features in the environment using a CAD program (IBM CAD) adapted for this experiment.[2] Given one of the eight features, subjects estimated the distance and direction of all other features using the computer mouse to draw a line whose endpoints were defined by the center of an origin feature and the center of one of the seven target features. The origin feature appeared in the center of a drawing template on the computer monitor; shown also were a scale, a north arrow, and a circle representing the approximate size of the

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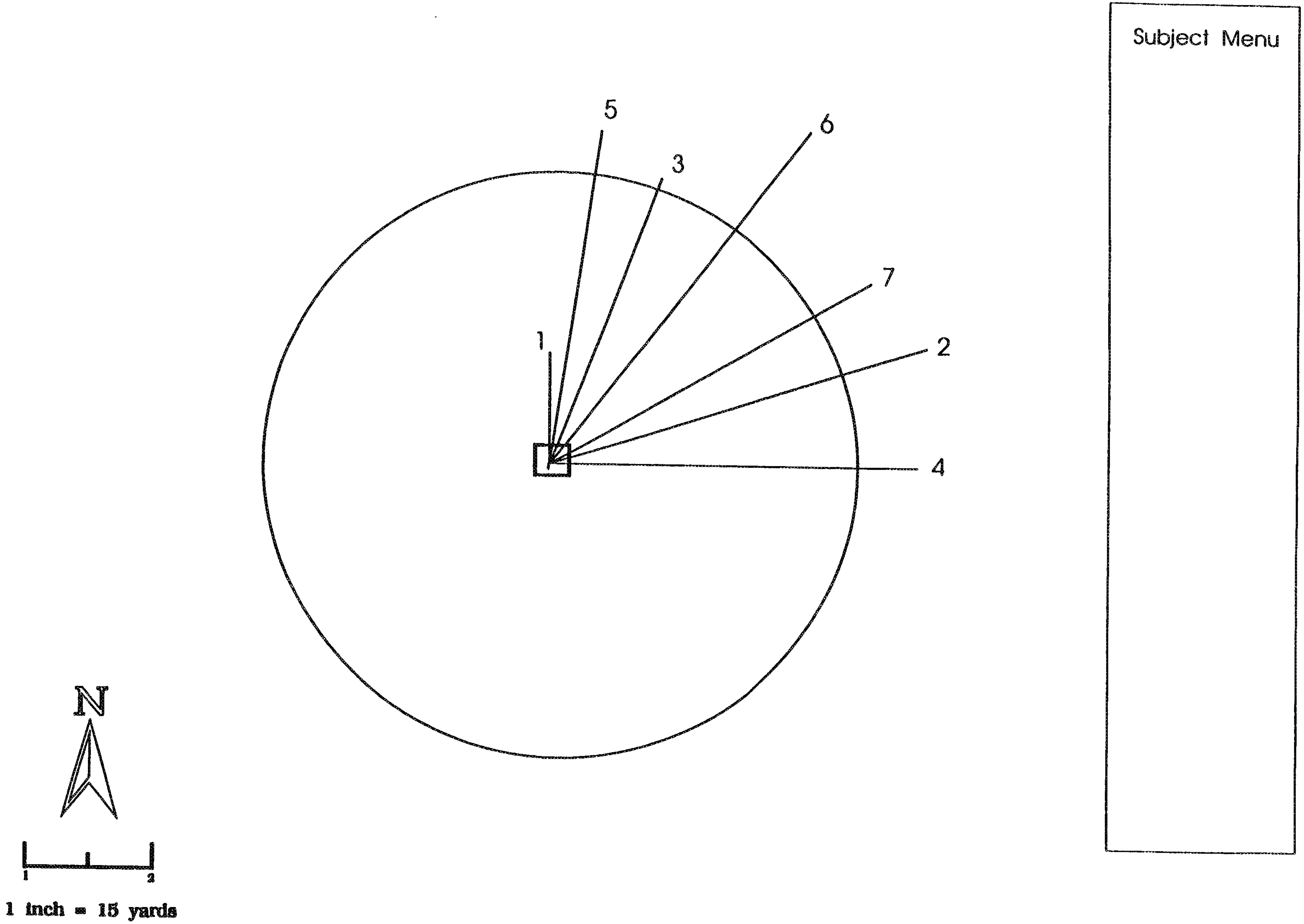
[2] We acknowledge the assistance of Jeff Hicke who developed special software to enable us to use the CAD in this way.

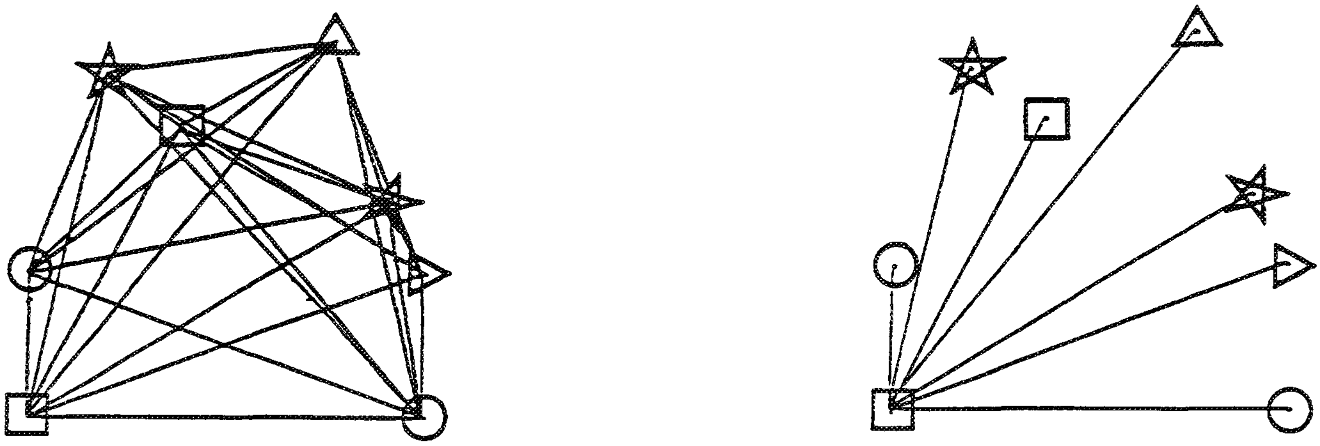
Fig 2



building outline (Fig. 2). The first endpoint of each line automatically snapped to the center of the origin feature. Subjects drew seven lines on each drawing template, one for each of the seven target features. Subjects could easily redraw lines as many times as they wished before advancing to the next drawing template with the next origin feature. Subjects were given a list for each drawing template, specifying the origin feature and the seven other target features. The task ended when all features had, in turn, served as the origin.

There are some interesting spatial patterns in the task configuration. First, the top of the environment has higher concentration of features, which are clustered more tightly than the features in the bottom half, which are dispersed. The result is increased overlapping of decision paths in the upper half of the environment (Fig. 3a). The four features that make up the lower half of the environment include the red square, blue circle, yellow circle, and green triangle; features in the upper half include the green star, yellow square, blue star and red triangle. If the environment is broken into 4 decision quadrants, each with a 90 degree range, we can more easily discuss the configurations of decisions for individual features. The first quadrant includes those decisions that fall between 0 and 90 degrees, 0 being due north or directly above the feature in question; the second quadrant includes 90 to 180 degrees; the third is from 180 to 270 degrees, and the fourth is from 270 to 360 degrees. Starting with the red square (Fig. 3b), the decision paths of the features are quite divergent ranging from all decision occurring in the same 90 degree quadrant, to decisions being spread throughout 360 degrees around a feature. All decisions from the red square are contained within the first quadrant (0 - 90 degrees); for the blue circle, decisions are within a 180 range in the first and second quadrants, for the green star, decisions are

Fig. 3

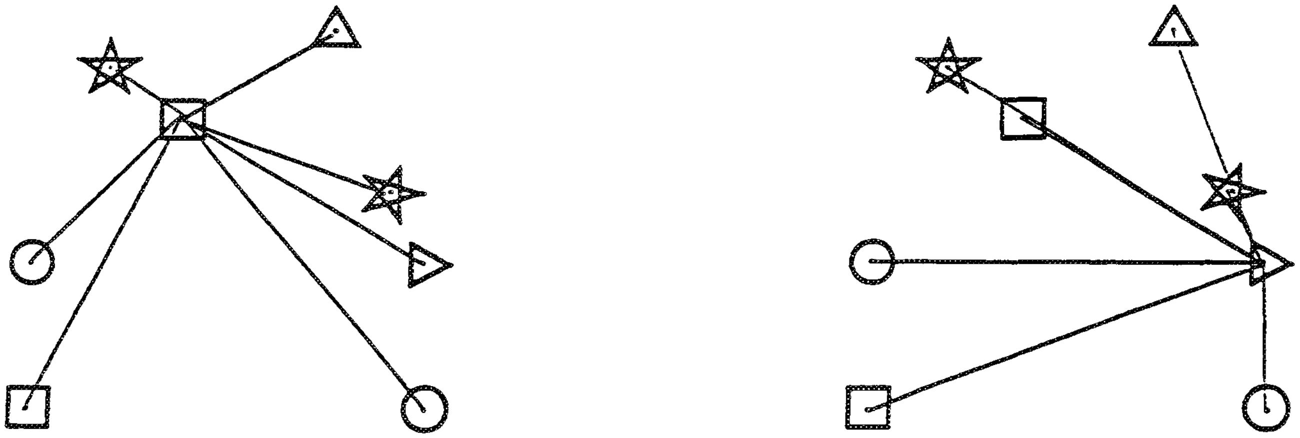


(a)

Physical Configuration of Distances & Directions

(b)

Sectoral Concentration: Decisions from the Red Squar



(c)

Uniform Spread: Decisions from the Yellow Square

(d)

Hemispheric Concentration: Decisions from the Green Triangl scattered in the first three quadrants: one in the first, four in the second and two in the third. For the yellow square (Fig. 3c), decisions are spread throughout all four quadrants, one each in the first and fourth quadrants, two in the third, and three in the second. For the red triangle, decisions are made in the second and third quadrants: three in the second and four in the third, but the range between them is only slightly greater than 90 degrees. For the blue star, decisions occur in the second, third and fourth quadrants with a range slightly greater than 180 degrees. The green triangle is situated just below the blue star and all of its decision paths are hemispheric within the third and fourth quadrant (Fig. 3d). The final feature is the yellow circle: its decisions all occur sectorially in the fourth quadrant and as a result the range of all decisions is 90 degrees.

Procedure

Subjects were tested in groups of four, all of whom experienced the map condition or the simulated travel condition. There were six phases to the procedure: (1) training for the CAD software, (2) exposure to the environment and the first route, (3) testing for the first route, (4) exposure to the environment and the second route, (5) testing for the second route, and (6) a final integration task. Twenty subjects participated in each condition (map vs. simulated travel) - five females and five males with geographic training, and five females and five males without geographic training. The order of route presentation was counterbalanced.

Subjects were seated individually at computers and were trained to use the CAD software by verbal instructions from the experimenter. Training was brief, lasting about ten minutes, but continued until subjects were comfortable with all procedures required for later testing.

Map condition: After the CAD training, subjects in the map condition were moved to a second location in the room where they were given a brief outline of the procedures to follow. They were told they would have the opportunity to learn about an environment by viewing two maps of a building, with a different route marked on each. After studying the first map for five minutes, subjects were seated near the computer where they were required to use the CAD program. Subjects were given a pencil and a sheet of paper with a building outline, north arrow, and scale, on which they were to sketch the environment they had examined, including the route and the features. Seven minutes were given to complete this task. Subjects were then seated at the computer and were given eight sheets of paper, each with one of the eight geometric features as targets. On the first sheet, the red square was the origin feature. On the computer monitor was a drawing template with the red square in the center, a north arrow, and a scale. Subjects were asked to imagine themselves at the origin feature facing north. From the origin feature, they were asked to draw a line representing the distance and direction from the origin feature to all other features in turn. Having drawn a line for each of the target features, subjects advanced the drawing template and turned to the next sheet, where a different feature would be considered as the origin feature. In turn, subjects were instructed to draw a line to all target features from all origin features, thus making a total of 56 (8 * 7) decisions. Subjects then studied the second map with the other route for five minutes, then completed the same sketch map task and distance/directional judgment tasks as before. For the final integration task, subjects were given a sheet of paper with the building outline, north arrow, and scale, and a separate list of the eight features. They were instructed to reproduce the environment, its features, and both routes. Seven minutes were given to complete this task (Figure 4)

Simulated travel condition: Procedures for the simulated travel condition followed the same general format as for the map condition with a few exceptions. Instead of viewing a map, subjects learned the experiment by following each simulated route four times, with testing following the fourth viewing. The sketch map reproduction task was the same. Before completing the distance/directional judgment tasks, subjects first completed an orientation task. Subjects were reminded that route travel began in the north-facing direction. Using the CAD software, they were asked to draw a line indicating the direction of the red square relative to the direction they were heading when they first started the route. The same distance/directional judgment tasks (using each feature in turn as an origin as described for the map condition) followed. Subjects then viewed a simulated walk along the second route four times, followed by the orientation task, then the distance/directional judgment tasks as before. The final integration task was the same as for the map condition. The critical variables to be explained consisted of distance and direction errors, and route or location reproduction errors in the sketch maps.

Results:

(1) Cross-tabulations. Cross-tabulation tables were computed for all variables against errors in both angle and distance measures. To get a general picture of how subjects estimated distances and angles the error data was classified into categories of error measures. For angle measures each category spanned 20 degrees of error (i.e., category 1 included all angle estimates that were within 20 degrees of the correct orientation, category 2 included all measures that were between 20 degrees and 40 degrees of the correct orientation, etc.). The range of angle errors was 0 - 179.988 in either direction thus producing 9 classes of errors. For distance measures two sets of categories were used, absolute distance error and actual distance error. The latter included both over and under estimation. Both used one inch for the category size. Distance errors ranged

from 2.64 inches of underestimation to 4.9 inches of over estimation, therefore the actual distance classifications had 8 categories while the absolute classifications had 5 categories. The actual estimation error were only used where there was an apparent over or under estimation difference between two sample groups, or conditions.
The first comparison examined was that between subjects who performed the map condition and those who performed the route condition (Hypothesis 4). Both angle and distance and angle error *increased* from the map to route condition. Distance measures for map subjects fell within one inch of the actual measurement 75.7% of the time for all estimates made, while estimates for route subjects were within one inch, only 70.5% of the time. For angle estimates, 64.1% of all map subject estimates were under 20 degrees of error, while route subjects were within the same limit only 56.7% of the time.

Under and over estimation proved to be a significant factor when considering male and female estimations of distance (Hypothesis 6). The cross tabulations show that males tended to over estimate more than they under estimated, while females showed little preference for either estimation error. Females underestimated within two inches of the correct location 49.1% of the time and overestimated within 2 inches 46.7% of the time. Male subjects, on the other hand, underestimated within two inches only 34.9% of the time, while they overestimated 59.6% of the time. Although both groups have similar results in absolute distance estimation, females were somewhat more accurate with 96.8% within two inches while males had 94.5% within two inches. Females and males both estimated angle with similar accuracy, 59.9% of female estimations were within 20 degrees of the actual location, while 60.8% of males were within the 20 degree threshold. When gender and background differences are taken into consideration, results show that female geographers were far more accurate in the angle estimation task for the map condition than were male geographers. Female geographers were within 20 degrees of the actual angle 76.3% of the time while male geographers were within the same threshold 55.9% for all angle estimates. Any other differences between gender and training were insignificant with most estimate differences below 5%.

Another interesting result of the cross tabulation was the differences resulting from the amount of training in geography (Hypothesis 7). Those trained in geography (5 course or more in geography) had better angle and distance estimation. Geographers' estimates of distance fell within 1 inch of the true distance 76.6% of the time while non geographers tallied 69.7% within the same range. Angle error cross-tabulations for the same subject groups showed 63.7% of geographers and 57.1% of non-geographers estimated within 20 degrees of the target features' correct angle. The difference represented by the amount of geography training received was amplified when results were broken down further into map or route condition for each sub-group. Geographers were even more accurate when they were performing the route condition than when performing the map condition. 74.7% of distance estimates for geographers performing the route condition were less than one inch from the target feature while non geographers had 66.3% of their estimates below one inch of error. The two groups were closer in the map condition, but they both improved dramatically in percentages. 78.3% of geographer distance estimates were within the one inch threshold, while 73.1% of non geographer estimates fell within the same limit. One interesting comparison is that geographers who performed the *route* condition were more accurate in their distance judgments than non geographers who performed the *map* condition; but for angle measures for the same comparison show that geographers were only 1% below the scores of non geographers for the percent of error within 20 degrees of the actual measure.

The order in which the routes were presented to subjects also proved to be a factor in subjects' ability to accurately identify correct distances apart of features, thus suggesting rejection of Hypothesis 8 (i.e., no difference).. For both route and map subjects accuracy was improved when route B was presented first. The bulk of this difference was taken up by map subjects, as route subjects only showed a slight increase in accuracy. Map subjects viewing route A first identified distance within one inch of the actual location 72.5% of the time while those viewing route B first were within one inch 78.9% of the time. For all subjects the difference in number of estimations within one inch went from 71.4% for those viewing route A first to 75% for those viewing route B first. Angle measures went from 57.7% of all subjects' estimates within 20 degrees of the true angle for route A first, to 63.3% for those viewing route B first. Map subjects went from 61.1% within 20 degrees to 67.1%, while route subjects went from 54.7% to 59.2%. An interesting result is that route subjects who did route B first identified only 2% fewer angle measures below 20 degrees than the map subjects who viewed route A first. One might assume the map condition would be much easier than route conditions, because the latter subjects could only see portions of the route at one time. But in some way the configuration of route B brought performances up almost to the map equivalent.

Regardless of which route was presented first, all subject groups showed improved ability to estimate distances and angles among features accurately when performing tasks associated with route B. For the distance task, judgments on route A had 63.3% of all estimates within the one inch threshold while route B judgments had 82.9% of all estimates within one inch. Going further, within the two inch limit, judgments of route A made up 92% of all estimates while route B judgments were within this same distance category 98.2% of the time. Angle judgments were even more disparate between those made for route A and those made for route B. Route A angle estimates

Table 1

Direction: Main Effects

Effect	F-Ratio	P
MAPRT	19.542	0.000
GENDER	8.998	0.003
TRAIN	49.639	0.000
ORDER	6.488	0.011

Table 2

Distance Error: Main Effects

Effect	F-Ratio	P
GENDER	16.412	0.000
TRAIN	43.569	0.000
ORDER	6.010	0.015

Table 3

GROUP MEAN SCORES (MAP/ROUTE * TRAINING * GENDER)

MAP/ROUTE	map	map	map	map	route	route	route	route
TRAINING	n-geog	n-geog	geog	geog	n-geog	n-geog	geog	geog
GENDER	female	male	female	male	female	male	female	male
Absolute Distance Error (inch)	.826	.614	.612	.645	.863	.825	.635	.711
Absolute Angle Error (degree)	32.617	29.742	15.773	36.537	42.752	34.571	32.834	31.422
N (decisions)	558	558	558	560	557	558	560	560
N' (subjects)	5	5	5	5	5	5	5	5

fell within 20 degrees of the correct angle 43.1% of the time, and within 40 degrees 59.4% of the time. 77.5% of all route B estimates were within 20 degrees of the correct angle and 88.5% were within 40 degrees. however, the cross-tabulation results highlighted a series of outcomes that suggest that further evaluation was needed. A second analytic phase was therefore undertaken using analysis of variance.

(ii) ANOVA

The following results are based on the analysis of estimate errors of two types: absolute distance errors (inch) and absolute angle errors (0-180 degrees).

ANOVA was performed using the two measures of error as dependent variables: absolute distance error and absolute angle error. Four main effects (map/route, gender, training, viewing order) and all possible interactions were considered for each ANOVA.

With regard to direction (angle error), all main effects were significant (Table 1).

Five of six 2-way interactions were significant, the only non-significant one was training and order. Two of four 3-way interactions were significant: (MAPRT/Gender/Training: F = 8.614, P = 0.003; Gender/Training/Order: F = 27.310, P = 0.000.) The 4-way interaction was also significant: (F = 12.102, P = 0.000).

With respect to distance errors, three of four main effects were significant: (Table 2).

Three of the six 2-way interactions were significant. Two of the four 3-way interactions were significant, but the 4-way interaction was not significant.

Interpreting these results provides the following conclusions (Table 3). First, the results for effect of gender considering training and condition showed that male non-geographers performed better on average than female non-geographers in both the map and the route conditions, estimating distance and angles more accurately in both cases.

Second, female geographers estimated distance and direction more accurately for the map condition than male geographers, but estimated only distance more accurately for the route condition than all other groups, including male geographers.Third, the effect of training considering gender and condition indicated that geographic training helped females for both the route and map conditions, but only helped males in the route condition. Distance and angle errors for female non-geographers were higher on average than for female geographers for both the map and the route conditions. Distance and angle estimates for male non-geographers were lower on average than for male geographers in the map condition, but were higher in the route condition.

Fourth, the effect of the condition Map/RT considering gender and training showed that female geographers, female non-geographers, and male non-geographers estimated both distance and angles more accurately on average in the map condition than in the route condition. Male geographers estimated distance more accurately in the map condition, but estimated angles more accurately in the route condition.

Fifth, for both distance and angle estimates, female geographers participating in the map condition performed the best and female non-geographers in the route condition performed the worst.

Sixth, the effects of viewing order on overall performance indicated that subjects who viewed route A first performed worse overall (on routes A and B combined) than subjects who viewed route B first, estimating both distance and angles less accurately. This was also true for each condition considered separately (Figs. 4a - 4b).

When comparing performance on route A vs. route B, it appeared that subjects consistently estimated distance and angles less accurately for route A than for route B. This was true for map and route condition subjects combined and for each condition considered separately, and for aggregated and disaggregated trials (Figs. 5a - 5b).

Some understanding of these results can be obtained by considering some spatial characteristics of the task environment. The actual range of distances between individual features shows that some of the judgments used may be explained by the distortion of actual distance from each point and to each point. For example, the range of mean distance errors for each feature (acting as a target) is from 1.75" for the yellow square to 2.63" for the red square. The actual difference between these two features becomes evident when one looks at their relative position in the environment (Fig. 1). The red square is in the bottom left corner, while the yellow square is in the middle of the upper half of the environment. Central features such as the yellow square, therefore, have a smaller range of distance to be estimated and as a result the task may be less difficult.

Features requiring large distance estimation include the red square, the yellow square, the yellow circle, the red triangle and the green star; features with smaller distance

Fig 4

Effect of Viewing Order Combined Performance on Routes A & B

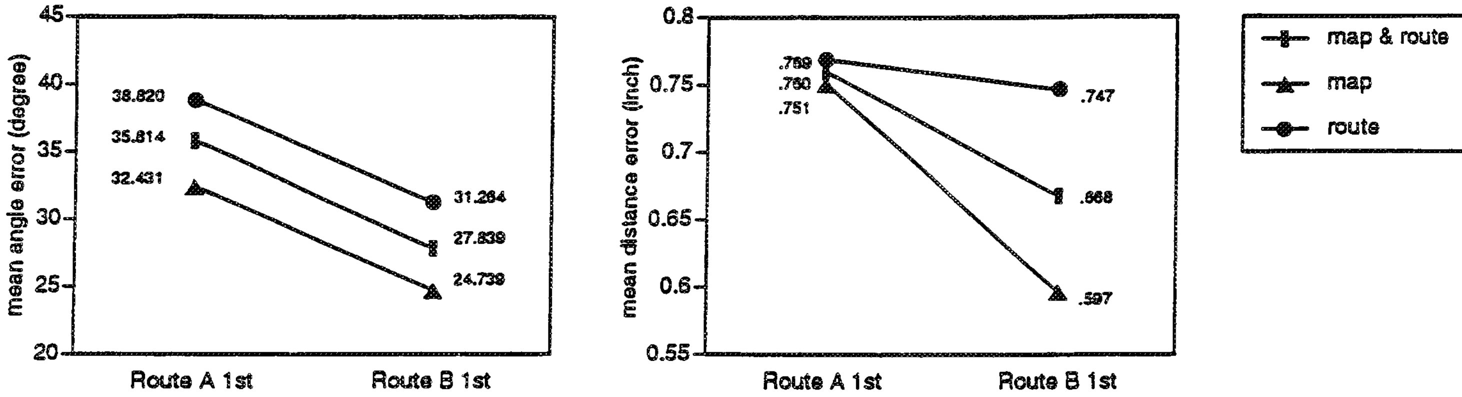
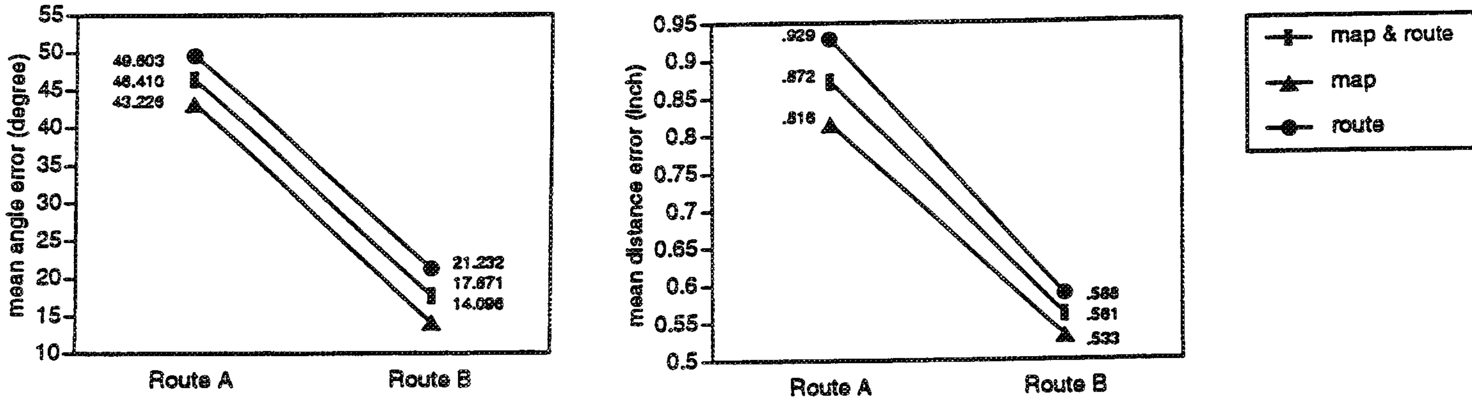

(a) (b)

Fig 5

Performance on Each Route Regardless of View Order


(a) (b)

estimation include the yellow square, the blue star, the green triangle and the blue star (Table 4).

A similar situation occurs with regard to the direction estimates; they may be less difficult for the peripheral features. Their position results in either a sectorial or hemispheric bias in estimation, which seemed condusive to more accuracy compared to estimates over multisectoral or global (360 degree) configurations.

Considering no other factors, subjects did only slightly better on average on the second trial than on the first trial. Considering map condition subjects alone, angle estimates were better for the second trial. For route subjects alone, both distance and angle estimates were better for the second trial, implying that learning over trials was a more important factor for route-based information than for map-based.

Subjects who viewed route B first performed *worse* in phase II than those who viewed route A first (Figs. 6a - 6e). Distance and angle errors were lower on the second trial for subjects who viewed route in the order A then route B. Distance and angle errors were higher on the second trial for those who viewed in the order route B then route A. This was true for map and route condition subjects combined and for each condition considered separately.

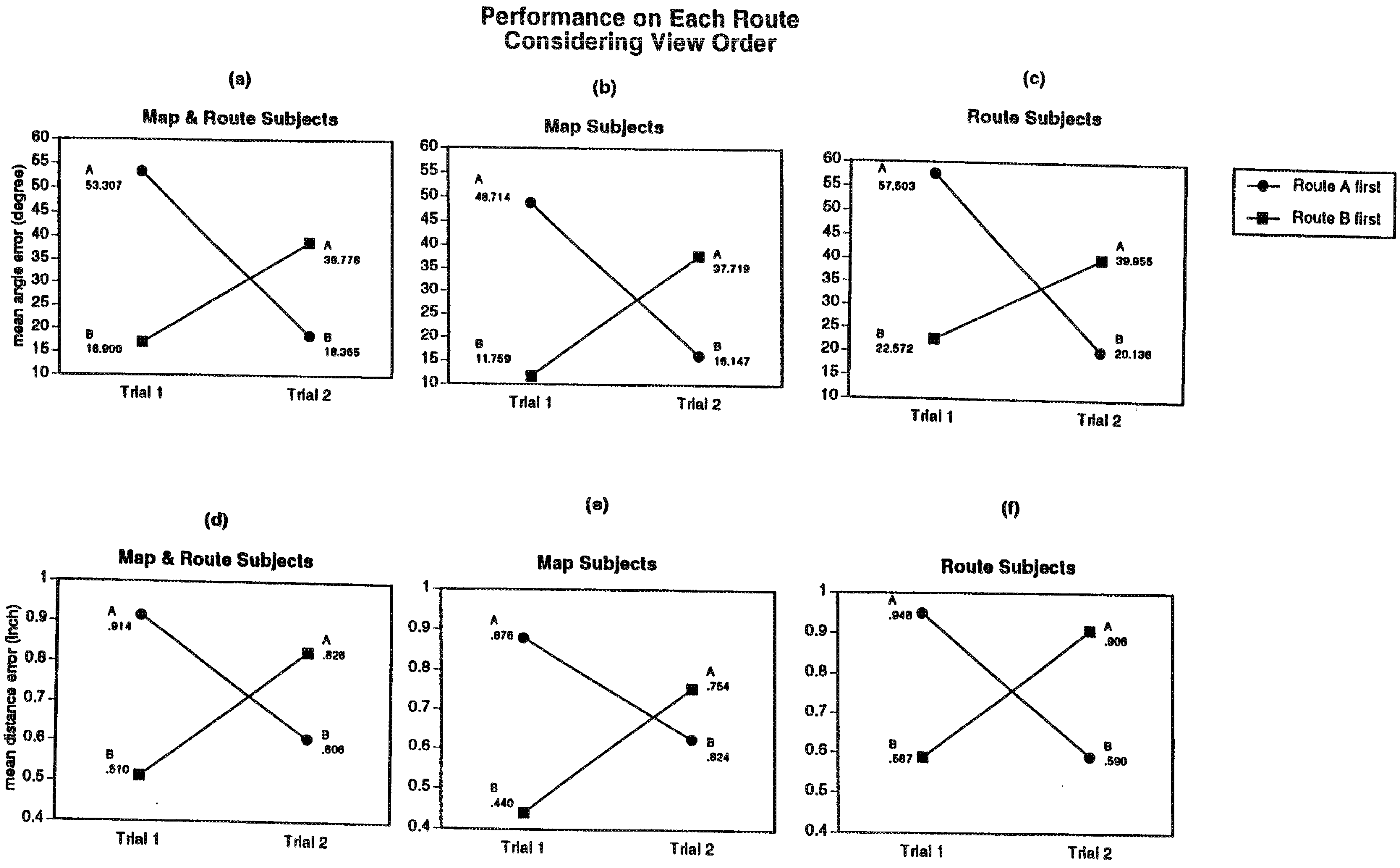
Overall, route A appears to be a substantially more difficult route. As one source of explanation for the apparent difference in difficulty, we next examined more closely the notion of mean errors associated with each feature in the task environment. To do this we separately considered each feature as target and as origin. Tables for map and route conditions combined and for each condition separately follow (Tables 5 - 8).

Table 4

Distance estimations by feature: largest to smallest means

Feature	Mean Error (Inches)
red square	2.63
yellow circle	2.52
red triangle	2.17
green star	2.11
blue circle	.2.03
green triangle	2.01
blue star	1.90
yellow square	1.75

Fig 6



Performance on Each Route Considering View Order

(a) Map & Route Subjects

(b) Map Subjects

(c) Route Subjects

(d) Map & Route Subjects

(e) Map Subjects

(f) Route Subjects

Table 5

MEAN ERRORS BY TARGET FEATURE FOR EACH ROUTE

MAP & ROUTE SUBJECTS COMBINED

absolute distance error (inch) and absolute angle error (degree)

		RED SQUARE	GREEN TRIANGLE	BLUE STAR	BLUE CIRCLE	YELLOW CIRCLE	GREEN STAR	RED TRIANGLE	YELLOW SQUARE
ROUTE A N = 40 SUBJECTS	distance error	.860	.936	.809	.883	.861	.846	.944	.840
	angle error	45.700	44.076	43.385	47.821	40.975	51.654	44.403	53.283
ROUTE B N = 40 SUBJECTS	distance error	.519	.595	.558	.523	.594	.541	.598	.555
	angle error	22.159	15.874	20.903	16.161	12.465	18.933	13.058	21.787

Table 6

MEAN ERRORS BY ORIGIN FEATURE FOR EACH ROUTE

MAP & ROUTE SUBJECTS COMBINED

absolute distance error (inch) and absolute angle error (degree)

		RED SQUARE	GREEN TRIANGLE	BLUE STAR	BLUE CIRCLE	YELLOW CIRCLE	GREEN STAR	RED TRIANGLE	YELLOW SQUARE
ROUTE A N = 40 SUBJECTS	distance error	.883	.935	.767	.881	.910	.895	.868	.841
	angle error	34.590	48.481	48.316	52.701	41.227	47.976	47.839	50.151
ROUTE B N = 40 SUBJECTS	distance error	.571	.581	.541	.598	.577	.586	.503	.529
	angle error	9.271	19.112	17.770	23.437	10.563	24.603	16.489	20.101

Table 7

MEAN ERRORS BY TARGET FEATURE FOR MAP/ROUTE * ROUTE

absolute distance error (inch) and absolute angle error (degree)

		RED SQUARE	GREEN TRIANGLE	BLUE STAR	BLUE CIRCLE	YELLOW CIRCLE	GREEN STAR	RED TRIANGLE	YELLOW SQUARE
MAP SUBJECTS ROUTE A	distance error	.760	.877	.774	.902	.727	.798	.860	.830
N = 20 SUBJECTS	angle error	35.324	42.883	41.558	48.180	44.895	43.797	40.561	48.592
MAP SUBJECTS ROUTE B	distance error	.449	.618	.509	.496	.561	.523	.582	.525
N = 20 SUBJECTS	angle error	9.205	14.049	16.682	14.747	13.808	13.407	11.267	19.581
ROUTE SUBJECTS ROUTE A	distance error	.959	.994	.846	.864	.996	.895	1.028	.850
N = 20 SUBJECTS	angle error	56.077	45.260	45.227	47.462	37.028	59.624	48.218	58.006
ROUTE SUBJECTS ROUTE B	distance error	.590	.572	.607	.550	.628	.559	.615	.586
N = 20 SUBJECTS	angle error	35.113	17.674	25.123	17.575	11.121	24.420	14.837	23.994

Table 8

MEAN ERRORS BY ORIGIN FEATURE
FOR MAP/ROUTE * ROUTE

absolute distance error (inch) and absolute angle error (degree)

		RED SQUARE	GREEN TRIANGLE	BLUE STAR	BLUE CIRCLE	YELLOW CIRCLE	GREEN STAR	RED TRIANGLE	YELLOW SQUARE
MAP SUBJECTS ROUTE A	distance error	.804	.820	.775	.861	.746	.857	.782	.882
N = 20 SUBJECTS	angle error	35.433	45.747	45.048	46.696	49.622	40.413	38.665	44.277
MAP SUBJECTS ROUTE B	distance error	.479	.509	.565	.564	.521	.579	.470	.574
N = 20 SUBJECTS	angle error	6.607	19.747	14.032	12.029	12.468	22.787	11.065	13.899
ROUTE SUBJECTS ROUTE A	distance error	.962	1.052	.760	.900	1.071	.934	.955	.800
N = 20 SUBJECTS	angle error	33.747	51.256	51.584	58.705	32.952	55.539	57.147	56.068
ROUTE SUBJECTS ROUTE B	distance error	.661	.652	.516	.632	.633	.593	.535	.484
N = 20 SUBJECTS	angle error	11.897	18.477	21.507	34.683	8.659	26.420	21.913	26.302

Discussion

The varied nature of our results leaves much to be considered. Our hypotheses concerning the better performance of map vs. route learners appear to be confirmed. We achieved somewhat surprising results when considering gender and training. In particular, gender and training appeared to interact, and although they had significant main effects alone, interpretation of the results showed that there was considerable interaction between the two with gender having perhaps a more significant effect when taking all tasks combined, and training having a more significant effect when looking at performance on maps vs. routes. What is clear is that no clear gender dominance emerged across all trials and all conditions. Although the combination *female/geographer* appeared to do very well on our tasks. The impact of geographic training appeared to be most dominant when considering performance on route-related tasks as opposed to performance on map-related tasks. This might suggest that map interpretation or acquisition of knowledge via survey procedures might be more "common sensical" and more widespread, while acquisition of spatial information from routes might be a more "expert" condition. Apparently, learning from routes appears to be helped by geographic training. Certainly repeated trials assisted overall performance most of all in the route condition.

Given that performance in the route learning task was generally worse than that of the map task, we looked more closely at the route condition. Initially we examined the degree to which task performance as measured by angle or distance error, might be related to feature viewing time (Table 9).

Table 9

Total viewing time vs. average angle error for routes A and B, features as targets	-.169
Total viewing time vs. average distance error for routes A and B, features as targets	.236
Total viewing time vs. average angle error for routes A and B, features as origins	.169
Total viewing time vs. average distance error for routes A and B, features as origins	-.438
Viewing time vs. angle error for routes A, features as origins	-.398
Viewing time vs. distance error for routes B, features as origins	-.806
Viewing time vs. distance error route condition, route A., features as origins	.159
Viewing time vs. angle error, route condition, route B, features as origins	.544
Viewing time vs. distance error, route condition, route A, features as targets	.442
Viewing time vs. distance error, route condition, route B, features as targets	.141
Viewing time vs. angle error, route condition, route A, features as targets	-.619
Viewing time vs. angle error, route condition, route B, features as targets	-.017

To this extent we calculated Pearsonian correlattions for total viewing time against angle and distance error for both routes combined, considering each feature as both an origin and as a target in turn, and repeated this exercise for each of the separate routes. The results revealed that when correlating total viewing time for both routes combined, the viewing time-angle error correlation was positive when features were considered as origins, and negative when features were considered as targets. The correlation between total viewing time-distance error for both routes combined showed the reverse of this - negative correlations when features were origins and positive correlations when features were targets.

Considering just route A and looking at correlations between *viewing time* and *angle error*, showed negative correlations regardless of whether features acted as origins *or* targets. For route A, when considering the correlation between *viewing time* and *distance error*, results were positive, whether features were used as origins or targets. The pattern changed, however, when considering route B. Here the correlation between *viewing time* and *angle error* was positive when features were viewed as origins, and negative when features were viewed as targets. Similarly, when correlating *viewing time* and *distance error*, negative results were obtained when features were origins and positive results were obtained when features were targets. These results tend to be somewhat confusing. A similar pattern of results were obtained for route B and the aggregate of both routes (i.e., positive relationships between viewing time and angle error when used as origins, negative relations between viewing time and angle error when features were used as targets, negative correlations between viewing time and distance error when features were used as origins, and positive correlations between viewing time and distance error when features were used as targets). But explaining why route A deviated from this is difficult. One explanation may lie in the physical nature of the configuration. Route A has short segments at the beginning and end, and longer segments in the middle; route B has the reverse structure. This in turn implies (a) that the two routes may require different types of cognitive processing, and/or (b) that the angle estimation and the distance estimation tasks use different cognitive processes. Apparently when one considers oneself at an origin and estimates distances to targets, the normal inverse square law for distance estimation and reproduction appears to hold. However, when considering features as targets and examining all the distance estimates made to a single target from all origins, there is a positive relation between viewing time and error, perhaps suggesting that snap judgments may be more precise than longer considered judgments. Apparently the reverse holds true when considering orientation and angle estimation. Here if one takes a single origin and looks at the distribution of angles to all targets, there is a tendency towards positive correlation between angle error and viewing time. When considering each place as a target and considering angle estimates to that target from all the origins, a negative relationship tends to dominate. It does appear, however, that focusing on the cognitive process involved alone will not provide a satisfactory answer, nor will focusing on the geography of the configuration alone. The fascinating question arises, then, as to how the mix of environment and cognition really works to produce the results we have obtained.

Conclusions

Overall, our hypotheses tended to be confirmed. As previously suggested in Thorndyke and Hayes-Roth (1979) and recently in Lloyd (1989) and O'Neill (1992a, b)ap learning produced lower distance and angle errors in estimation and reproduction than did route learning, even after an equivalent number of learning trials. No clear gender dominance existed. The results of the ANOVA showed females produced significantly lower angle errors than males, but males produced significantly lower distance errors than females. Overall, subjects with a geography background performed significanlty better than subjects without geographic training. And finally, there appeared to be some definite contribution to overall performance made by the spatial configuration of the two routes themselves. The routes had different arrangements of short and long segments, and the more difficult route had two right hand turns and one left hand turn, while the less difficult route had two left hand turns and one right hand turn. We are unable at this point to explain why these two slightly different configurations should produce such startlingly different angle and distance errors as a result of task completion. Obviously, both cognition and the environmental configuration contribute to comprehension, and the important question raised by Golledge (1988) and Wohlwill (1976) concerning exactly what contribution to spatial understanding is due to the configural structure of an environment still remains unclear.

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