WORKING MENTAL REPRESENTATIONS OF THE ENVIRONMENT

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ABSTRACT: Performance on a direct distance estimation task in a large, complex environment was studied as a function of variation in some members of the set of test locations. Features of the multidimensional scaling solutions—along with effects on the imagery that subjects reported experiencing while engaged in the spatial task—support the notion that a working representation is constructed for the solution of a spatial problem. It is hypothesized that this construction draws selectively upon various mental representations of the environment available in long-term store, depending on the way the task is structured. Subjects who were highly familiar with the environment reported more abstract and less scenographic imagery than less-experienced subjects and were superior in their sensitivity to distance variation.

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The solution of real-world spatial problems requires some mental representation of the environment, frequently referred to as a *cognitive map.* Very often the implicit focus of interest in discussions of cognitive mapping is the information represented in the long-term memory store. However, Liben (1981) has stressed a distinction between spatial storage—which is tacit knowledge—and spatial thought—which is knowledge that individuals have access to, can reflect upon, or can manipulate (as in spatial problem solving or spatial imagery). Downs (1981) suggests that people have available a range of mapping functions that can convert tacit knowledge of the environment into explicit knowledge.

Along the same lines, Foley and Cohen (1984) have argued that the information used during performance of a spatial task by no means includes all that is known by the subject about the environment. They suggest that an active or working representation may be constructed for the purposes of the task at hand. Many locations known to the subject but not cited by the experimenter, for example, are unlikely to be included in the working representation generated to address an experimental task. As well, various different kinds of information may be generated in the working representation. In some cases, perceptual and/or motor representations of places or routes may be involved; in others, more abstract maplike representations may be consulted. This view acknowledges the idea expressed by many investigators that environmental spatial cognition entails qualitatively different encodings or representations (e.g., Chase and Chi, 1981; Hardwick et al., 1976; Kaplan, 1976; Kuipers, 1982; Liben, 1981; Lindberg and Garling, 1982; Siegel and White, 1975; Thorndyke and Goldin, 1983).

We believe that the report of mental imagery experienced while performing particular spatial tasks can inform us about the type of representation (spatial thought) used in the solution of the task. In particular, variables such as the degree of experience in the environment and selection of the set of locations to be considered in the task may influence the kinds of imagery generated. If, for example, the subject had encountered the environment infrequently, he or she might be less likely to form a maplike representation and might be more likely to report images of scenes. If the locations selected in the task were all in the same horizontal plane, the subject might be encouraged to construct a maplike representation; but if the locations were separated vertically, he or she might be encouraged to think in terms of a three-dimensional model.

The success of the subject in performing the spatial task also yields information about the working representation, such as how well the essential spatial information is represented. However, most enlightening will be evidence of a relation between imagery report and performance. For example, if imagery report of one type is always associated with good performance-and occurs only under particular conditions—then we can see what influences the type of information selected for the working representation and how effective a data base it is.

We therefore maintain that the identification of variables that affect the performance of subjects in environmental spatial tasks—along with their reported imaginal activities while addressing those tasks—can shed light on the perceptual-cognitive skills underlying the manifestation of spatial knowledge. Our conviction owes much to the discussion by Kolers and Smythe (1979) of imagery as a mental sketchpad, and to their exhortation to investigate its use in the performance of cognitive skills. Our focus is not on the image per se, or on its ontological status, but rather on variables that affect the kind of imagery reported along with measures of spatial performance.

The study reported here examined performance on a spatial task, with reference to a large, complex environment as a function of variation in only some members of the set of test locations. Unidimensional and multidimensional scaling techniques were applied to direct distance estimations by subjects. To aid in their interpretation, imagery reports were obtained from subjects after completion of the distance estimation task.

METHOD

THE ENVIRONMENT AND THE TEST LOCATIONS

Scarborough College is a large, complex, multifunctional university building, constituting a self-contained arts and science campus that serves approximately 4000 users. The multilevel building comprises three irregular wings, connected at the level of the main pedestrian concourse by a large, vaulted square "meeting place" (see Figure 1, encircled). The floor of the meeting place is at Level 2. It is surrounded by a balcony on Level 3 onto which various offices and facilities open. A large, open staircase (B) connects these two levels. The whole area can be seen from smaller balconies on Levels 4 and 5 as well.

The distribution of campus functions through the building ensures that students have exposure throughout.

Thirteen locations visited frequently by students were selected for use in the study (see Figure 1). Four locations were on levels 2 and 3 in the immediate vicinity of the meeting place (A, B, C, and D). These four were included in each of three sets of seven locations. The other three locations in each set were unique to the set, although each included a large lecture theater and two other well-frequented locations. In Set I, these locations ($E_I F_I$, and G_I) were centrally located on Levels 1, 4, and 5, respectively. In Set II, E_{II}, F_{II}, and G_{II} were along the three wings of the building on the main pedestrian level; the first two were on Level 2 and the last on Level 3. In Set III, E_{III}, F_{III}, and G_{III} were at the ends of the three wings on the same levels as E_{II}, F_{II}, and G_{II} (see Figure 1). The three unique members of the sets were chosen to vary the relative salience of the vertical and horizontal dimensions; that of the vertical was highest

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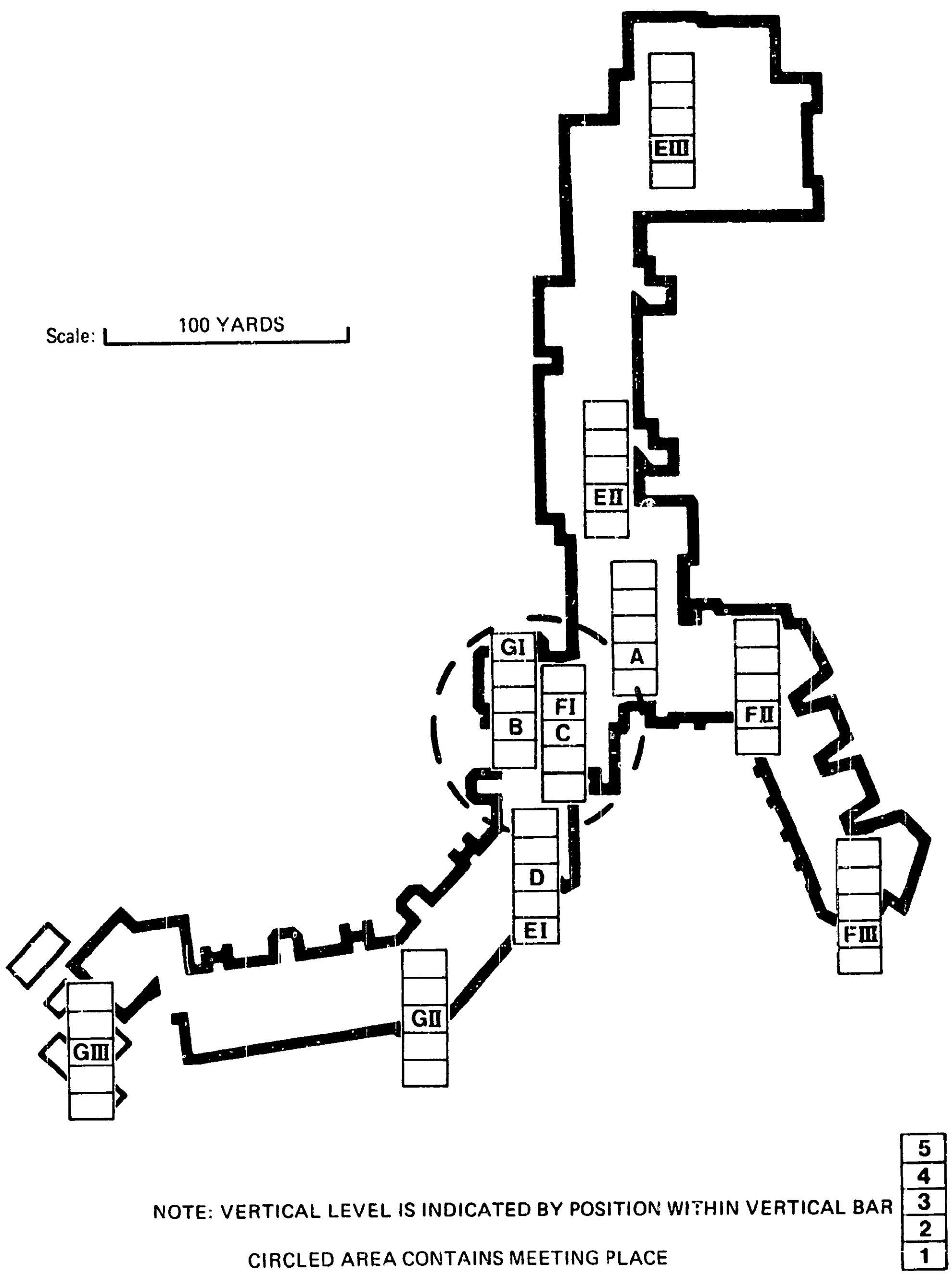

COMMON	SET I	SET II	SET III
A. Radio Station	EI Lecture Theatre	EII Information Desk	EIII Gymnasium
B. Stairway	FI Fees Office	FII Cafeteria	FIII Lecture Theatre
C. Health Service	GI Library	GII Lecture Theatre	GIII Bookstore
D. Lecture Theatre			

Figure 1: Plan of the Environment Showing the Test Locations

in Set I and that of the horizontal was greatest in Set III. Although it cannot be guaranteed that the locations in the different sets were equally familiar, all were invariably recognized by subjects when slides were shown; there were no known strong biases in the selection.

SUBJECTS AND PROCEDURES

The subjects were 36 first-year and 36 fourth-year undergraduates who were regular users of the building. The first-year subjects were drawn unsystematically from the introductory psychology subject pool and contacted by telephone. The fourth-year subjects all had taken introductory psychology and responded to an appeal for volunteers at the end of a class. All were unpaid. Subjects were randomly assigned to be tested on one of three sets of locations, with the restriction that six males and six females from each experience level were tested on each of the three sets.

Subjects were given a listing of the seven locations in the set assigned and shown slides to ensure that there was no confusion about the locations intended. Next instructions were given for magnitude estimation of distance. The distance between B (on Level 3) and D (on Level 2) was chosen as the modulus, and subjects were told to assign the value of 100 to it. Straight-through or direct distances ("as the crow flies") were to be judged in all cases. The distances between all possible pairs of the seven locations (excluding the modulus B-D) were judged, each pair being presented in every order for a total of 40 trials. A different random order of trials was generated for each subject.

After completion of all distance judgments, subjects reported on their strategy for doing the distance estimation task. The specific instruction was as follows:

> Please answer the following questions regarding your strategy for doing the previous task. Circle 1 if the statement below never

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applied, 2 if it hardly ever applied, 3 if it sometime applied, 4 if it usually applied, and 5 if it always applied.

In estimating distance did you think of

(a) the exterior appearance of the building
1 2 3 4 5

(b) walking through the building
1 2 3 4 5

(c) a maplike image of the building
1 2 3 4 5

(d) a three-dimensional model of the building
1 2 3 4 5

(e) other than the above, please explain.

Finally, subjects rated—on a 5-point scale—how demanding the distance estimation task was in the use of imagery and in the use of logic.

RESULTS

MAGNITUDE ESTIMATION FUNCTIONS

Magnitude estimation functions were computed for individual subjects using a method of iteratively weighted least squares (Mosteller and Tukey, 1977). The slope n of the log-log function is indicative of the subject's sensitivity to variation in distance. A linear system has a slope of 1.00. The general height of the function, or scaling factor, is often expressed by the y-intercept (k). However, unless the modulus is very small in relation to other stimuli, this parameter is not independent of n. The relationship for the ideal subject is $k = 2 - 2n$. An ideal subject who knows nothing about the environment and is guessing will produce $n = 0$ and $k = 2$ (log 100, the value assigned to the modulus); an ideal knowledgeable subject with $n = 1$ will

TABLE 1
Contexts Ordered for Decreasing Vertical Salience

SUBJECT	POPULATION	SET I DIMENSIONS 1	2	3	SET II DIMENSIONS 1	2	3	SET III DIMENSIONS 1	2	3
Female	Freshmen	0	0	1	0	1	0	0	1	0
Male	Freshmen	0	1	0	0	1	0	0	1	0
Female	Seniors	0	1	0	0	1	0	0	1	0
Male	Seniors	0	0	1	0	1	0	0	1	0
Total		0	2	2	0	4	0	0	4	0

produce k = 0. In order to assess scale variations that are independent for n we derive i = k – (2 – 2n). It is equivalent to the departure of the magnitude estimation function from the value y = 2.00 at x = 2.00—that is, the extent to which distances physically equal to the modulus would be over-estimated or underestimated.

The n values for individual subjects were subjected to analysis of variance with the between-subject variables of condition (Sets I, II or III), sex (male or female) and experience (first or fourth year). Only the main effect of experience was significant, with n increasing from .83 for first year to .93 for fourth year ($F(1,60) = 3.86$; $p < .05$).

The i values were subjected to the same analysis. Only the main effect of condition was significant ($F(2,60) = 3.84$; $p < .03$); the index of scale being significantly larger for Set I (.09) than for Set II (– .02), which does not differ significantly from zero, with Set III (.06) between.

MULTIDIMENSIONAL SCALING

Two- and three-dimensional metric scaling solutions (Ramsay, 1977) were obtained for each group of six subjects of the same sex and level of experience. Table 1 indicates that for two of the four groups tested on Set I, a three-dimensional solution provided a significantly better fit than a two-dimensional solution by the chi-square test of dimensionality (Ramsay, 1977). For all four groups in the Set I condition, the vertical dimension was obviously the most salient in the solution, as determined by visual inspection of the resulting maps. In no case was a three-dimensional solution superior to two for subjects tested in Sets II or III. For all groups in the Set III condition, the two dimensions emerging in the solutions were horizontal. The data for Set II were also consistent with this identification of the dimensions.

IMAGERY REPORTS

Individual ratings of the four specified types of imagery were subjected to analysis of variance with the between-subject variables of condition, sex, and experience, and the within-subject variable of image type. The mean rating of exterior imagery (1.6) was lower than of walking imagery (3.0), maplike imagery (2.9), and three-dimensional representations (3.4). Of greater interest than the main effect of image type was the interaction of this variable with each of the variables of experience and condition. Both of these interactions were significant.

The interaction of image type and experience ($F(3,180) = 3.04$; $p < .03$) is shown in Figure 2. Walking imagery had the highest report for first-year students and decreased with experience, whereas reports of the more abstract maplike and three-dimensional representations increased with experience.

The interaction of image type and condition ($F(6,180) = 5.3$; $p < .0001$) is shown in Figure 3. For Set I, three-dimensional ratings were high and maplike imagery low, relative to Sets II and III. Only Set III produced substantial reports of images of the external appearance of the building.

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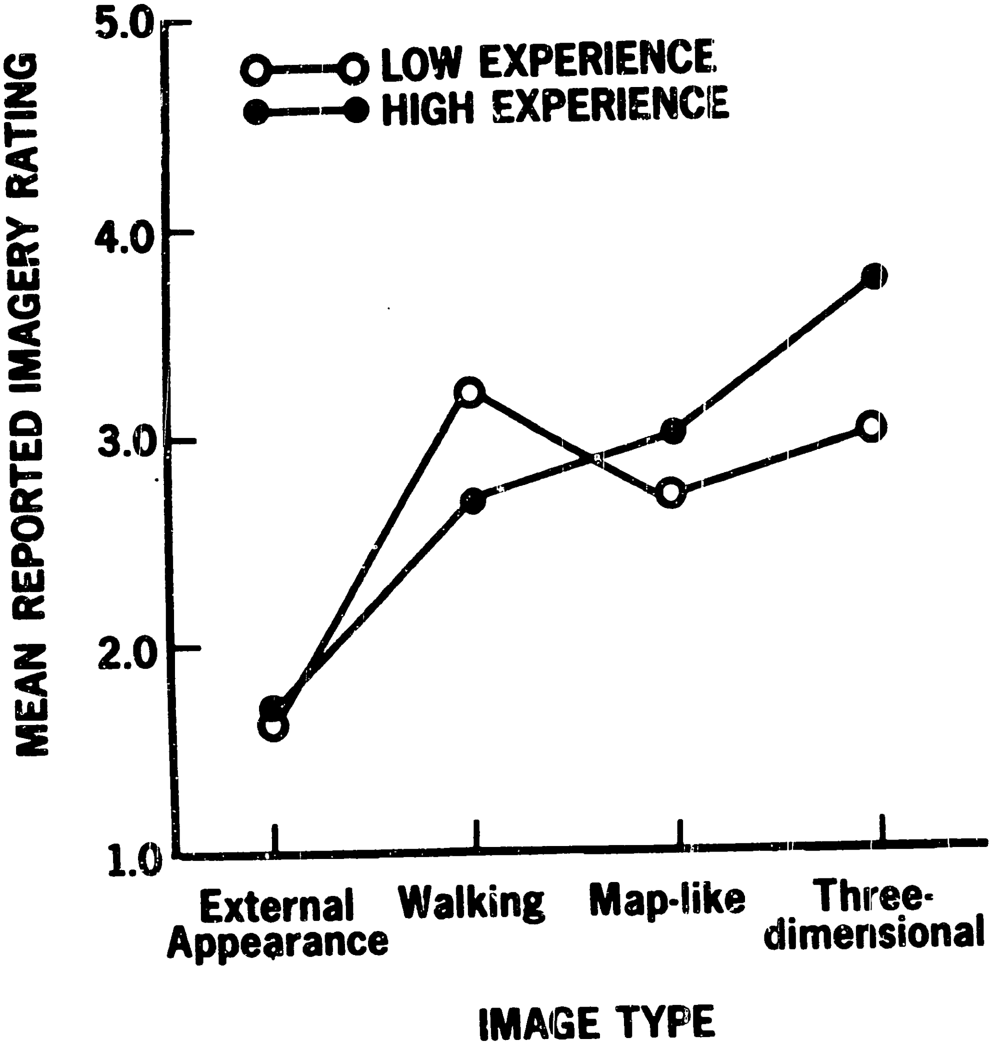
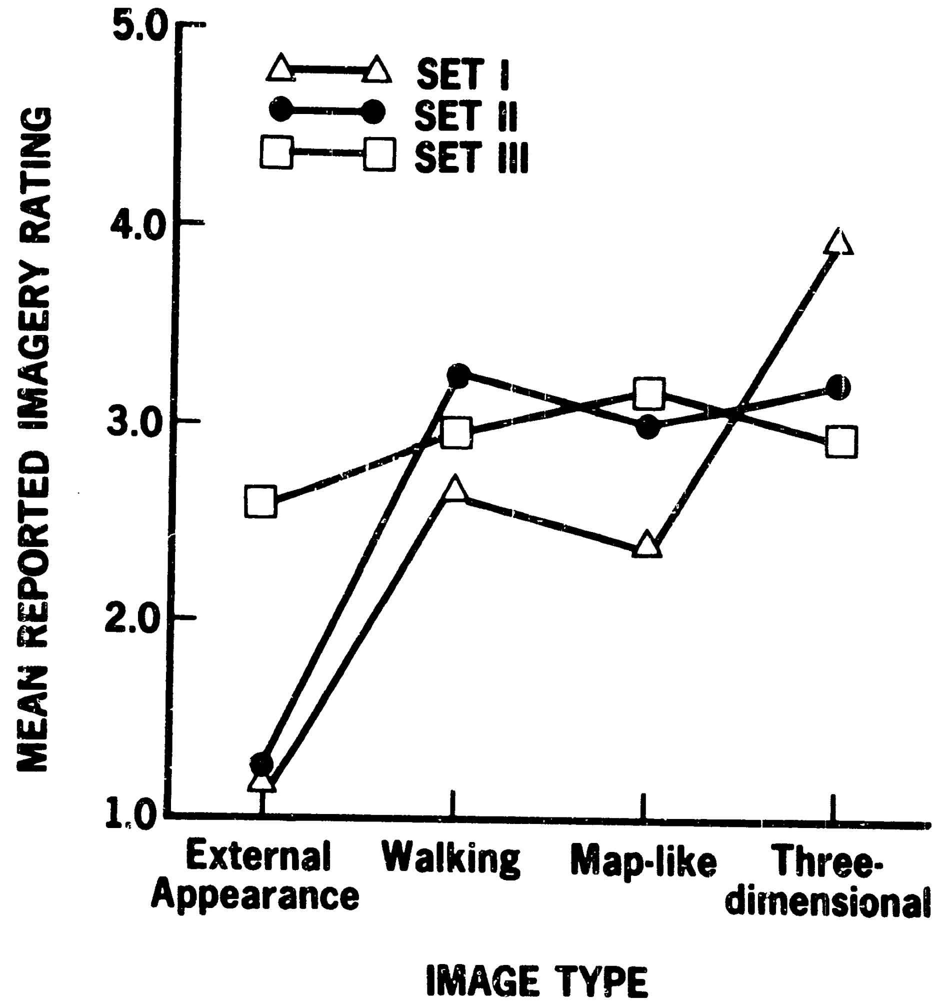


Figure 2: Mean Reported Imagery Rating for Freshmen (low experience) and Senior (high experience) Subjects

The "other" category (e) produced only a few idiosyncratic reports (e.g., time, a stretched string) that were not apparently related to the independent variables.

TASK DEMANDS

The three conditions were judged equally demanding with respect to imaginal activity (Set I, 4.5; Set 2, 4.3; and Set 3, 4.6). However, Set I (4.0) was said to demand



NOTE: Relative salience of the vertical decreases from SET I to SET III.

Figure 3: Mean Reported Imagery Rating as a Function of Condition

significantly more use of logic than Sets II (3.6) or III (3.4) ($F(2,60) = 3.1$; $p < .05$).

DISCUSSION

Subjects in all conditions and at both levels of experience tend to report that a multiplicity of images was experienced when performing the distance estimation task. According

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to these reports, some types of imagery are more likely to be primed than others by particular selections of test locations. This suggests that the representation generated for the solution of a spatial problem (i.e., spatial thought) depends on the nature of the problem. Because the environment is no longer present, it may be concluded reasonably that either a number of representations are encoded into long-term memory by the user or the long-term encoding is susceptible to a variety of translations. The nature of the spatial problem influences the selection of representations or, alternatively, of translations.

Set I, in which the vertical dimension was emphasized, elicited the highest report of three-dimensional representations and the lowest of maplike imagery. The introspective report of subjects is consistent with the statistical significance of a three-dimensional (over a two-dimensional) solution of distance estimations for some groups, and with the salience of the vertical in the solutions for all groups in this condition. Set I also had a high mean scale value (see Pick and Lockman, 1981). This does not necessarily imply overall disproportional representation of the vertical dimension as such in the cognitive map. Exaggeration has been said to arise from intruding memory of bends and turns in routes (see Briggs, 1976; Lowrey, 1973; Sadalla and Staplin, 1980), but if this were responsible for the overestimation observed in Set I, we might expect it to be accompanied by high reports of walking imagery. This is not found. If anything, this condition yields a somewhat lower report of walking than others. Reports of external imagery are also low. More likely, overestimation arises from poor integration of the horizontal coordinates of vertically separated locations, other than those in the common set on Levels 2 and 3 close to the open meeting place. This interpretation is supported by the report of subjects that Set I is unusually demanding in the use of logical operations.

Subjects tested on Sets II or III report walking, maplike and three-dimensional imagery with about equal fre-

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quency, but only in Set III is imagery of the exterior of the building also a factor. External imagery is almost never reported in Sets I or II. Apparently, only locations at the ends of the wings effectively prompt external scenographic imagery. Somewhat exaggerated estimates were characteristic of Set III, perhaps related to the use of external imagery. Alternatively, as this set includes the longest distances of all three conditions, by contrast, the modulus may seem small.

Reports of walking imagery decrease with experience whereas reports of the more abstract maplike and three-dimensional representations increase with experience. The shift is accompanied by improvement in sensitivity to variation in distance between locations (slope parameter of magnitude estimation functions), in accordance with other evidence that scenographic/route representations provide a relatively poor basis for direct distance judgments (Cohen and Foley, 1983; Foley and Cohen, 1984; Lindberg and Gärling, 1982; Thorndyke and Goldin, 1983). The direction of the effect of experience on imagery reports is consistent with the frequent contention that sequential, route encoding of a new environment precedes simultaneous "survey" mapping. Nevertheless, abstract representations are reported frequently by our less-experienced subjects, and we have presented evidence elsewhere (Cohen and Foley, 1983; Foley and Cohen, 1984) that they are available to adult subjects from their first encounter with a new environment. If, as Lindberg and Gärling (1982) suggest, the function of the different systems of representation is to provide "back-up", a degree of independence would be expected; the different representations would be developed concurrently but not necessarily at the same rate. In this view, survey knowledge acquired by an adult through navigation of an environment would not be built on route knowledge, as is frequently suggested (e.g., Siegel and White, 1975; Thorndyke and Goldin, 1983), nor would the systems necessarily be hierarchically linked (e.g., Hardwick et al., 1976; Kaplan, 1976).

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The spatial thinking of subjects who are highly familiar with an environment might well differ from those who are less experienced, not only in the availability and quality of abstract representations but also in the skilled interactive use of abstract and scenographic representations (see Chase and Chi, 1981; Kuipers, 1982; Thorndyke and Hayes-Roth, 1980). This skill deserves empirical investigation. The methodology of the present experiment does not permit examination of the imagery present on particular trials. There is an indication, however, that subjects may experience more than one type of image in generating at least some individual distance judgments, in that the total mean report of all kinds of imagery is 11.0, considerably greater than the theoretical maximum of 8.0 (= 5 + 1 + 1 + 1) if any type were present exclusively on each trial. However, because this departure could arise for other reasons—such as nonlinearity in subjects' use of the imagery rating scale—a more refined technique for imagery report is required (see Lohman and Kylonen, 1983) to investigate this aspect of spatial thought.

APPENDIX A
Analysis of Variance Table for Report of Image Type as a Function of Sex, Set and Experience

Factor	Degrees of Freedom	Sum of Squares	F-Ratio
Image Type	3,180	119.20 294.21	24.31**
Sex	1,60	0.28 114.96	0.15
Set	2,60	6.86 114.96	1.79
Experience	1,60	1.53 114.96	.78
Image Type x Sex	3,180	8.23 294.21	1.68
Image Type x Set	6,180	52.0 294.21	5.30**
Image Type x Experience	3,180	14.93 294.21	3.04*
Sex x Set	2,60	0.25 114.96	0.65
Sex x Experience	1,60	0.59 114.96	.31
Set x Experience	2,60	4.33 114.96	1.13
Image Type x Sex x Set	6,180	7.03 294.21	.72
Image Type x Sex x Experience	3,180	1.87 294.21	.38
Image Type x Set x Experience	3,180	9.33 294.21	.95
Sex x Set x Experience	6,180	4.86 114.96	1.27
Image Type x Sex x Set x Experience	2,60	7.47 294.21	.76

APPENDIX B

Analyses of Variance Slope, Intercept, Task Demands re Imagery and Logic as a Function of Sex, Set, and Experience

Sum of Squares and F-Ratios

Factor	Degrees of Freedom	Slope		Intercept		Task Demand-Imagery		Task Demand-Logic	
		ss	f	ss	f	ss	f	ss	f
Sex	1	.008	.16	.05	2.58	3.13	5.14*	1.68	1.88
	60	2.772		1.27		36.50		53.50	
Set	2	.166	1.80	.16	3.84*	1.08	.89	5.44	3.05*
	60	2.772		1.27		36.50		53.50	
Experience	1	.178	3.86*	.02	.90	1.68	2.76	0.35	.39
	60	2.772		1.27		36.50		53.50	
Sex x Set	2	.104	1.13	.03	.61	0.75	.62	.11	.06
	60	2.772		1.27		36.50		53.50	
Sex x Experience	1	.030	.65	.07	3.27	.01	.02	.35	.39
	60	2.772		1.27		36.50		53.50	
Set x Experience	2	.230	2.49	.06	1.50	.69	.57	1.78	1.00
	60	2.772		1.27		36.50		53.50	
Sex x Set x Experience	2	.011	.12	.12	2.74	.03	.02	.44	.25
	60	2.772		1.27		36.50		53.50	

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