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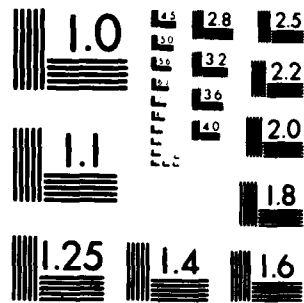
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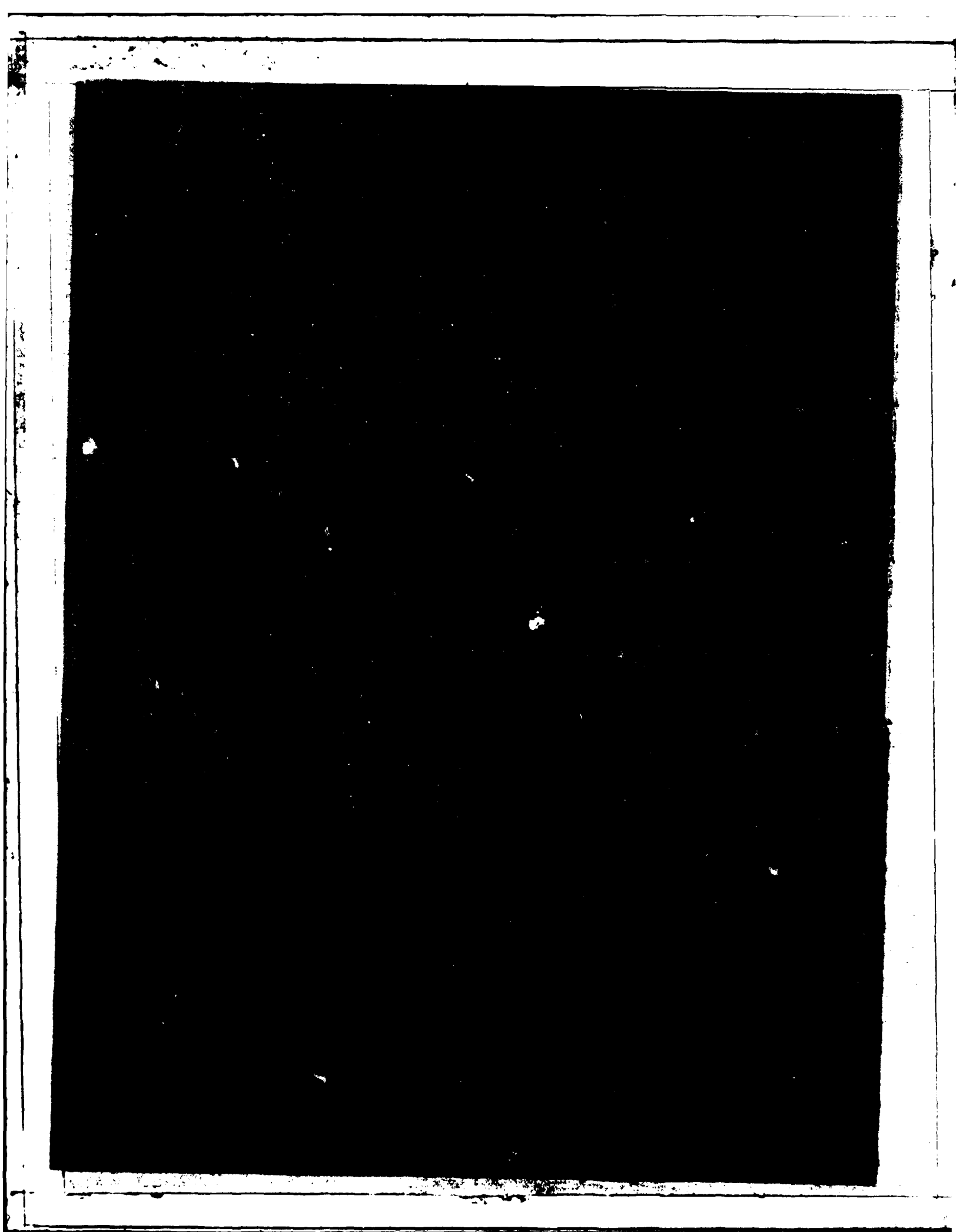
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THIS REPORT Compares actual and simulated navigation as alternative sources of environmental knowledge. Subjects experienced a 5.15-mile tour through an unfamiliar environment through either a bus ride or a film taken from an automobile driving along the route. In addition, subjects received either a map to be studied prior to navigation, a verbal narrative giving angle and distance information during navigation, or no supplementary information. Film (simulated navigation) groups performed as well as or better than tour groups on landmark and configural knowledge measures. They were inferior to tour groups in route sequence knowledge only on turning angles. Supplementary information affected only film groups. Narration tended to depress performance; map study enhanced configural knowledge but depressed route knowledge. The authors conclude that simulated navigation can substitute for actual navigation under some circumstances, and that map supplements can enhance abstraction of configural relations from simulated navigation.

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A RAND NOTE

SIMULATING NAVIGATION FOR SPATIAL KNOWLEDGE ACQUISITION

Sarah E. Goldin, Perry W. Thorndyke

May 1981

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Prepared For

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PREFACE

This Note describes completed research undertaken at The Rand Corporation for the Army Research Institute under Contract No. MDA903-79-C-0549, "Training Techniques for Terrain and Orientation Knowledge Induction." This work is a portion of a larger research effort investigating task requirements and human skills involved in spatial knowledge acquisition and spatial judgment. The study reported here compared actual and simulated travel as alternative sources of environmental knowledge. This research should interest researchers studying human spatial cognition as well as practitioners concerned with improving individual orientation and navigation skills.

SUMMARY

This Note compares actual and simulated navigation as alternative sources of environmental knowledge. Subjects experienced a 5.15-mile tour through an unfamiliar environment through one of two media: a live bus tour along the route, or a film taken from an automobile driving along the route. In addition to the primary navigation experience, subjects received one of three types of supplementary information: a map to be studied prior to navigation, a verbal narrative giving angle and distance information concurrent with navigation, or no supplement. All subjects completed tests of landmark knowledge and procedural (route sequence) and survey (config-ural relation) knowledge after exposure to the environment. Tests of spatial ability and imagery tendencies were also administered, to control for ability differences between groups. Results showed that film (simulated navigation) groups performed as well as or better than tour groups on measures of landmark and survey knowledge. On tests of procedural knowledge, film groups were inferior to tour groups only in their knowledge of relative landmark orientations. Supplementary information affected only the film groups: In general, narration tended to depress performance, while map study enhanced performance on survey knowledge tests but depressed performance on procedural knowledge tests. We conclude that simulated navigation can be used as a substitute for actual navigation under some circumstances, and that a map supplement can enhance the abstraction of survey knowledge from simulated navigation. Finally, we discuss the advantages and disadvantages of environmental simulation media other than film and make recommendations for further research.

ACKNOWLEDGMENTS

Several individuals contributed substantially to the preparation of this Note. Jackie Berman conducted the experimental sessions and analyzed the data. Kay McKenzie prepared the manuscript. Jim Beavers made the simulation film and slides. Kenneth Craik, Kristina Hooper, and Kenneth Zeidner provided consulting information on environmental simulation techniques. Finally, John Winkler provided useful comments on an earlier version of the manuscript.

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I. INTRODUCTION

People typically acquire their knowledge of a large-scale environment from many sources, including navigation experience, maps, pictures, verbal descriptions, and route specifications. Previous research on cognitive mapping has demonstrated that the source of spatial information can influence the content and accuracy of an environmental representation. For example, direct navigation experience results in relatively accurate estimates of orientation and route distances, while map study results in relatively accurate knowledge of the global configuration of landmarks and the straight-line distances between them (Thorndyke & Hayes-Roth, 1980). Driving through an environment leads to different patterns of distance estimation and place recognition than does walking (Carr & Schissler, 1969; Lynch, 1960).

This Note contrasts the spatial knowledge people acquire through two kinds of experience: direct navigation experience and simulated experience provided by a filmed trip through the environment. This comparison addresses both practical and theoretical issues. In the practical realm, situations arise in which individuals desire to familiarize themselves with the spatial layout of an environment before actually visiting it. Typically, people use maps for such familiarization. However, since navigation experience is a superior learning method for acquiring route and orientation knowledge (Thorndyke & Hayes-Roth, 1980), "navigational previews" may provide powerful learning experiences. If simulated navigation could produce learning comparable to that acquired by direct experience, such simulation could aid a trav-

eler planning a trip or a military commander training his forces on enemy terrain. On the theoretical side, a detailed comparison of the knowledge acquired from film with that acquired from direct experience could help establish the necessary conditions for navigational learning. Some environmental features available from direct experience are lost in simulated experience. Comparing the cues available in and the spatial knowledge resulting from the two types of experience may enable us to isolate the cues associated with specific types of knowledge.

SIMULATING ENVIRONMENTAL EXPERIENCE: PREVIOUS RESEARCH

McKechnie (1976) and Cohen (1980) have summarized prior studies of knowledge acquisition from simulated geographic experience. They conclude that the more similar the simulated experience to actual navigation, the more accurate and complete the resulting spatial representation. Isolated photographs of an environment fail to convey accurate knowledge of route sequences and spatial relations among landmarks (Hershberger, 1975; Winkel & Sasanoff, 1966). Sequences of photographs taken at frequent intervals along a route can convey sequential relations (Allen, Siegel, & Rosinski, 1978) and relations between distinctive regions in an environment (Allen, 1979; Allen, Kirasik, Siegel, & Herman, in press). However, they still fail to provide sufficient information to support the learning of relative positions of landmarks.

Some studies have experimented with film as a medium for simulating movement through an environment. Unfortunately, this work has left many questions unanswered. Craik (1977, 1978) and his colleagues exposed subjects to either a 9-mile automobile tour of a particular area in

northern California, a color film of the same tour, a color film shot in a scale model of the environment, or a black-and-white videotape made from the model-based film. They then administered a place recognition test using photographs and two questionnaires tapping knowledge of landmark contexts and locations. Performance in the auto tour condition exceeded performance in the model film and video conditions. However, the auto tour and color film tour conditions produced equivalent performance. These results are potentially confounded by effects of previous experience; some subjects were highly familiar with the tested environment, but Craik did not report the proportions of such subjects in each media group, nor did he separate experienced from naive subjects in this analysis. Ideally, an assessment of environmental simulation should control for prior experience.

The work of Ciccone, Landee, and Weltman (1978) illustrates a somewhat different approach to navigational simulation. These researchers created a computer-generated "movie map" of a fictitious Mideast town. The movie map depicted a tour through the town, showing buildings and streets from varying perspectives, including both street-level and aerial views. Descriptive narration and superimposed landmark labels supplemented the town scenes. Ciccone et al. found that subjects exposed to the movie map performed more accurately on tests of self-localization and spatial relations than subjects who studied a standard map. These results are not surprising, since the movie map included a great deal of information not available from the standard map (aerial views, panoramic views, labels, and narration). Thus, it is unclear to what extent the tour, independent of the supplementary information,

provided a more useful learning medium than the map. Nevertheless, this study demonstrates the practical utility of at least one simulation technique, albeit a complex and expensive one.

In a more straightforward and controlled comparison of environmental exposure media, Cohen (1980) provided subjects with a tour of the Philadelphia Art Museum in one of three conditions: a live tour, a "dynamic" film that simulated movement through the galleries along the same route as the live tour, and a "static" film that presented still shots of scenes and landmarks on the tour. Her measures of spatial knowledge included recall of the sequence of rooms on the sketch maps, recognition of scenes from the tour, and a cued recall ("association") task in which subjects listed whatever features they remembered in response to cue words (e.g., "Asian statue"). The method of environmental presentation influenced both the accuracy and the content of subjects' cognitive maps. The live-tour group performed more accurately on all four experimental tasks. The dynamic-film group performed significantly better than the static-film group on the recognition task but not on the map drawing or cued recall tasks. Following Lynch (1960), Cohen categorized the content of sketch maps and descriptions into four types of elements: landmarks, paths, nodes (path junctions or entry points), and districts (large areas). She found that the live-tour and dynamic-film groups produced similar patterns of element recall (paths > nodes > landmarks and districts), although the live-tour group recalled more elements in each category. The static-tour group produced a markedly different pattern of element usage (nodes > paths, landmarks, and districts).

Cohen concluded that "the information that individuals gain from traveling through an environment can be rudimentarily obtained through a dynamic simulation" (Cohen, 1980, p.111). The quantitative differences between the live-tour and dynamic-film groups suggest that some features of the dynamic simulation inhibit the development of rich environmental representations. Some possible features discussed by Cohen include lack of redundancy (the tour group could observe galleries from several vantage points and reinspect scenes within galleries), the imposition of a particular scanning strategy that may not have matched the individual's natural scanning strategies, and the distortion of distances due to the limited visual field in the film (Hagen, Jones, & Reed, 1978.)

Other differences in the treatment of the two groups, however, limit the conclusions that may be drawn from this study. The dynamic-film subjects received a restricted, controlled view. In each room, the camera panned counterclockwise along the wall, zooming to a close-up of each picture or group of pictures. In contrast, the tour subjects were restricted only in the sequence in which they visited the rooms and the time spent within each room. They could wander freely through each room, converse with one another, and look through doorways into adjoining rooms ahead of or behind them on the tour. This freedom provided learning opportunities not available to the dynamic-film group.

RATIONALE FOR PRESENT RESEARCH

In the present study, we attempted a more controlled and detailed comparison of learning from direct and simulated navigation. Subjects toured an unfamiliar area of Los Angeles either directly (in a bus

driven along a 5-mile circuit of the area) or by viewing a film taken from inside a car traveling along the same route. We then assessed subjects' acquisition of three types of knowledge about the environment: landmark knowledge, procedural knowledge, and survey knowledge (Bruner, 1964; Piaget & Inhelder, 1967; Siegel & White, 1975; Thorndyke, 1980).

Landmark knowledge refers to memory for salient perceptual features in the environment, such as an architecturally unique house or a building that dominates the skyline. We measured such knowledge, using a location recognition test, in which subjects identified slides of buildings and intersections seen during their tour. We expected that subjects viewing a filmed tour would acquire landmark knowledge as readily as those actually navigating in the environment.

Procedural knowledge refers to knowledge of specific routes navigated in the environment. We view such knowledge as a sequentially organized memory structure that can be retrieved and "replayed" to mentally simulate route traversal (Thorndyke & Hayes-Roth, 1980). Such knowledge comprises four important components: a sequence of actions performed at various locations that constitutes the route specifications; serial order of the perceptual features encountered along the route; distances between locations experienced as sensations of motion, speed, and time; and local angle information represented as bearing changes along the route. We expected that subjects receiving the filmed tour might display deficits in their procedural knowledge relative to actual tour subjects only in the fourth of these knowledge components. That is, the simulated-tour subjects would not have the benefit of

kinesthetic cues and a wide perceptual field to assist in their encoding of angle information.

We used three tests of procedural knowledge. A location sequencing task using slides of various locations along the tour assessed subjects' memory for the serial order of locations. We expected no group differences on this test. A test requiring estimates of route distances between landmarks assessed subjects' ability to mentally simulate their trip and quantify their perceptions of traversed distance. An orientation test required subjects to mentally assume a particular location and point in the direction of other locations. Both of the latter tests assessed subjects' ability to recall the sequence of turns on the route between the locations and estimate the distances along each leg (Thorndyke & Hayes-Roth, 1980). In addition, the orientation test required the subject to recall angle information associated with each turn. We expected that the degradation of the navigation experience provided by the film might adversely affect subjects' performance on the route distance and/or orientation estimation tasks.

The third type of spatial representation, survey knowledge, refers to knowledge of the two-dimensional configural relations among locations. Such knowledge is map-like in that the relationship between two locations may be apprehended without reference to any particular route between them. Individuals typically develop accurate survey knowledge slowly when they merely navigate in environment, but they develop it quickly when they study a map (Thorndyke & Hayes-Roth, 1980). We assessed survey knowledge on two tasks. A euclidean distance estimation task required subjects to estimate the straight-line distances between

pairs of locations. A landmark placement task required subjects to draw a map of the environment and place several landmarks in their correct relative locations. Since the tour provided only one exposure to the environment, we assume that subjects were unable to develop a survey representation of the environment to use on these tasks. We assume that they performed the required judgments for these tasks by using a set of informal mental computations based on their procedural knowledge (Thorndyke & Hayes-Roth, 1980). Thus, subjects who received the actual tour should perform at least as well as, and perhaps better than, the subjects who received the simulated tour.

In addition to contrasting these two learning media, we also assessed the influence of two types of supplementary information on subjects' derived knowledge. Some subjects in each tour condition heard a narration during their tour that indicated distances, directions, and names of particular streets traversed along the route. We expected that these subjects, to the extent that they encoded and used this supplemental information, would perform more accurately on the tests of procedural and survey knowledge than subjects receiving no supplement. Other subjects in each tour condition studied a map of the experimental route prior to their tours. We expected these subjects to demonstrate more accurate survey knowledge than other subjects. The Ciccone et al. study, cited above, demonstrated that a narrated movie plus a map was a particularly effective source of spatial information. In this study, we attempted to examine the influence of each type of supplement independently. We compared performance in both supplement conditions to control conditions in which subjects were exposed to the film or live tour

only. The issue of information supplements, however, was secondary to this research. Our primary interest was the overall effectiveness of the two simulation media.

II. METHOD

SUBJECTS

Ninety-four UCLA undergraduates (29 males and 65 females) participated in order to fulfill a course requirement. The majority of subjects (59 of 94) were 18 years of age (mean age across groups = 18.4). With the exception of one 45-year-old, all subjects were between 17 and 22 years of age. Means for the six experimental groups ranged from 18.8 to 17.8 (omitting the 45-year old). Subjects were assigned to one of six groups according to the day of the experimental session they chose, without prior knowledge of experimental conditions. All sessions were held in the early afternoon.[1]

DESIGN

A 2 (medium) by 3 (supplement) between-subject factorial design was used. The medium factor determined whether a subject was driven along the experimental route (tour groups) or saw the simulation film (film groups). The supplement factor determined the kind of supplementary information a subject received: concurrent verbal description (narrative groups), prior study of a map (map groups), or no supplement (control groups). Certain measures also provided within-subjects comparisons across item types. These are discussed in Section III.

[1] While our assignment procedures completely confound treatments with groups S, the overall homogeneity of our subject population suggests that artifacts due to preexisting group differences will be minimal. (See also the discussion of group ability scores on p. 17).

MATERIALS

Experimental Environment

We chose a 5.15-mile circuit in west Los Angeles as the experimental environment. Figure 1 displays a schematic map of this route. This area had several desirable characteristics: (1) it was unfamiliar to our subjects; (2) it included both residential and commercial areas (although the actual route traversed primarily residential sections); (3) it included both rectilinear and irregular street patterns; and (4) the streets were wide enough to accommodate the buses used for the actual tours.

Eight locations distributed at roughly even intervals along the route served as reference landmarks. The landmarks included a schoolyard, a church, and six distinctive dwellings. Each landmark was given a name that highlighted its more salient features (e.g., Spanish house, green gate house, Tudor house). Four of the landmarks were located in the irregular section of the route, which was traversed during the first half of the tour. The other four landmarks were located in the rectilinear section of the route.

Stimulus Film

A 24-minute, 16mm film was made of an auto tour along the route, using a hand-held camera positioned inside the car. The camera was a 16mm Eclair equipped with a 400-foot film magazine and a 17-64mm zoom lens. We used Kodak Ektachrome 7241[2] film, a fast film usually

[2] Kodak and Ektachrome are registered trademarks of the Eastman Kodak Company.

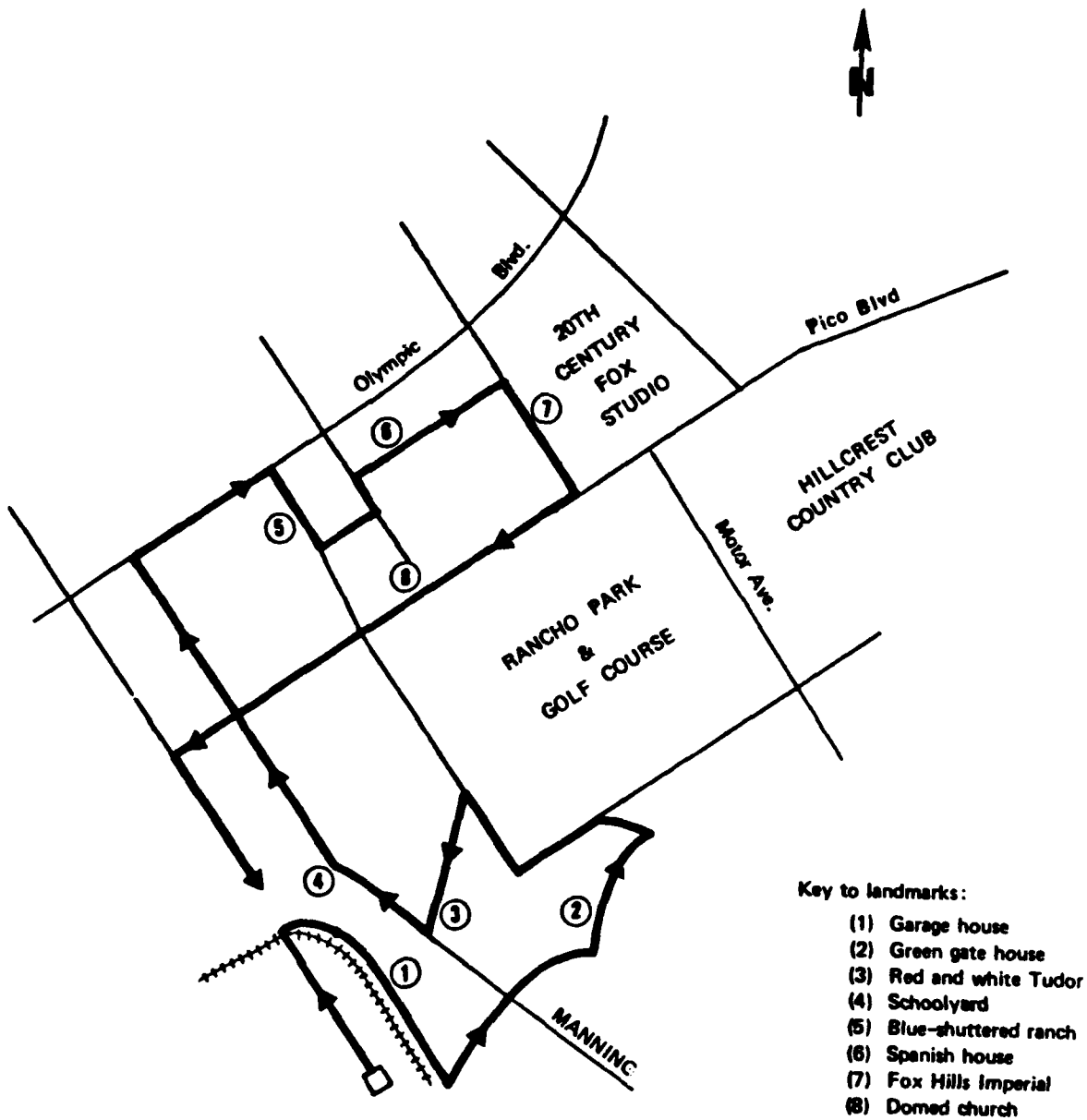


Fig. 1 — Schematic map of tour route

employed for indoor photography, because its fast speed (ASA 160) allowed us to use a small aperture (f22) and hence obtain maximum depth of field. The lens provided a focal length of 25 mm, and the focus was maintained at infinity, except when filming landmarks. The film was shot at 32 frames per second but was projected at 24 frames per second. This minimized the jerkiness in the film caused by uneven road surfaces.

During filming, the camera was pointed straight ahead through the front windshield except at turns in the route or at landmarks. Approximately 10 meters prior to a turn, the camera panned slowly in the direction of the turn and remained focused down the destination street during the actual turn. This procedure reduced the effective turning speed, provided a sense of continuity, and minimized disorientation. On the approach to each landmark, the camera panned slightly to focus on the landmark coming into view. The camera remained focused on the landmark while the car stopped opposite it. The camera then zoomed in on the landmark for approximately 10 seconds, focusing on the details, zoomed back out, and panned back to the street ahead as the car started.

Thus, the film contained no discontinuities except at points where the film roll was changed. These points were masked by dissolves.

PROCEDURES

General Procedures

Each experimental group was tested separately in a different session. Subjects reported to an assigned classroom at UCLA and were given preliminary instructions. They were told that they would tour or see a

film of a new environment and should learn as much as they could from that tour or film. Subjects in the map groups then studied a map of the environment with the route and landmarks clearly marked, for a period of 10 minutes.[3] Subjects in the narrative groups were informed that their tour would include a running commentary providing street names, directions, and distances. Subjects in the three tour conditions were driven in a large municipal bus to the experimental site. The bus traversed the route, requiring approximately 30 minutes to complete the circuit. The bus stopped briefly at each landmark, and the experimenter announced its name and location (in terms of street names). In the narrative condition, the experimenter also provided a standard description of the names of streets on the route from the previous landmark, the distance between intersections, and the current direction.

Subjects in the film groups saw the experimental film after receiving their instructions. Map condition subjects returned their maps before viewing the film. While they watched the film, narrative condition subjects listened to the same commentary received by the tour-narrative group.

After traveling the route, the tour subjects returned to the UCLA classroom for testing. Procedures after this point were essentially identical for all groups.[4] Subjects performed seven sets of tasks in

[3] Subjects in the tour-map group studied the map while traveling en route to the experimental environment. They returned their maps before traversing the experimental route.

[4] Film groups received their assessment tasks after a 5-minute break devoted to rewinding the film. For tour groups, the interval between exposure and test was slightly longer, due to travel time (approximately 10 minutes). Although the difference in retention interval is slight, the possibility remains that any superiority of the film group may be due to differential delay.

the following order: (1) location recognition; (2) location sequencing; (3) map drawing; (4) metric judgment tasks (orientation, route distance and euclidean distance estimates); (5) basic abilities tests (Building Memory, Form Board, Hidden Figures); (6) imagery tests; (7) spatial style and experience questionnaire. The various experimental tasks are described in detail below.

Experimental Tasks

Location Recognition. Subjects viewed 48 color slides in random sequence. Twenty-four of the slides represented scenes along the experimental route: 8 landmarks, 8 critical intersections (where the vehicle turned onto a new route), and 8 noncritical intersections (where the vehicle did not turn). The remaining 24 slides were distractor scenes taken mostly from streets in the neighborhood shown on the route. Each distractor was chosen to be highly similar to a particular scene from the tour. Each slide was presented for 10 seconds, during which time subjects recorded on an answer sheet whether or not the scene was on the tour. Subjects were not informed of the relative proportions of target and distractor scenes.

Location Sequencing. Subjects were shown 24 pairs of slides showing scenes from the route. For each pair, they judged which of the two scenes occurred first on the tour. Stimuli comprised the set of positive instances used on the Location Recognition Test. Landmarks were always paired with landmarks, critical intersections with critical intersections, and noncritical intersections with noncritical intersections. Each scene appeared in two pairs, one in which the two scenes

occurred in the same half of the route (near pairs), and one in which they occurred in different halves of the route (far pairs). Subjects were advised that each scene did appear on the tour and could occur more than once on the test.

Landmark Location Task. Subjects were given a sheet of paper containing two symbols labeled as the beginning point of the route and the first landmark. They were told to draw a map of the route and place the other seven landmarks, using the given information to establish the map scale and orientation. Subjects were given unlimited time for this task.

Orientation Estimates. Subjects were presented with pairs of landmarks from the experimental route. They were told to imagine standing at the first member of the pair, facing along the route, and then to estimate the direction of the second member of the pair from that location and orientation. They recorded their responses in degrees, using a large protractor marked in 10-degree intervals. Twenty-eight unique pairings of landmarks were presented. Each landmark served as the destination and the origin an equal number of times.

Euclidean Distance Estimates. Subjects were asked to estimate for the same 28 pairs of landmarks the straight-line distance, to the nearest quarter mile, between the members of each pair. A known distance along a straight street was provided for use as a standard.

Route Distance Estimates. For the same 28 pairs of landmarks, subjects were asked to estimate, to the nearest mile, the distance between the two landmarks along the experimental route. They were reminded that

route distances would always be at least as large as the corresponding euclidean distances.

Ability Tests. All subjects received three standardized ability tests drawn from the Kit of Factor-Referenced Cognitive Tests (French, Ekstrom, & Price, 1963). The Building Memory Test, a test of visual memory ability, required subjects to study a map-like display showing the location of a number of different buildings and then to recall later where each building had been located. The Form Board Test, a test of spatial visualization ability, required subjects to examine sets of geometric forms and to select the subset which could be rotated and combined to form a rectangle. The Hidden Figures Test, a test of "flexibility of closure" or perceptual independence, required subjects to decide which of a set of simple forms was embedded in a more complex form. All these tests were administered with the time limits specified in the directions.

Imagery Tests. Two tests of imagery ability, presented in the Appendix, were administered to all subjects. The Betts Test of Image Vividness asked subjects to imagine stimuli in different perceptual modalities and then to rate the vividness of each image on a 1 (most vivid) to 7 (least vivid) scale. The Gordon Test of Image Controllability asked subjects to imagine a series of successively more complicated transformations on a visual image. Subjects responded with a "Yes" to each transformation they could successfully perform on their image.

Questionnaire Measures. A two-page spatial style questionnaire administered at the end of the experimental session asked subjects to rate the truth of statements such as "I enjoy exploring new places," "I

have a good sense of direction," "I find maps hard to use," etc. It also included questions on the extent of subjects' geographic experience, familiarity with maps, and pre-experimental familiarity with the environment. A copy of this questionnaire is included in the Appendix.

III. RESULTS

ABILITY TESTS AND PRIOR EXPERIENCE

We included tests of visual memory, spatial visualization, flexibility of closure, and imagery ability in our experiment for two reasons. First, we wanted to compare the various experimental groups on abilities previously implicated in cognitive mapping skill (Thorndyke & Goldin, 1981; Thorndyke & Stasz, 1980). Substantial between-group differences in these abilities would suggest an artifactual interpretation for any observed differences between groups receiving different treatments. Second, we wanted to replicate with a larger sample our previous findings of within-subject dependencies between spatial abilities and mapping skill (Thorndyke & Goldin, 1981). Findings related to the latter objective are reported in the subsections that consider the different types of spatial knowledge. First, however, we consider possible ability differences among the experimental groups that might confound other results.

Scores on the three ability and two imagery tests were subjected to a 2 (medium) by 3 (supplement) analysis of variance. Table 1 presents the means for the six treatment groups on each of these tests. Only one significant effect emerged in the five analyses. On the Building Memory Test, the effect of supplement was reliable ($F(2,88) = 7.53, p < .001$). Specifically, the two control groups scored higher than the narrative groups (85 percent vs. 75 percent), which scored higher than the map groups (65 percent) (significant at $p < .01$ by Neuman-Keuls test).

Table 1
PERFORMANCE ON ABILITY AND IMAGERY TESTS

Test	Treatment Group						Mean
	Film			Tour			
	Control	Narration	Map	Control	Narration	Map	
^a Building Memory	81.6	73.3	70.9	87.5	77.9	59.2	74.9
^a Form Board	18.1	17.9	22.7	34.9	17.5	14.3	21.0
^a Hidden Figures	37.4	31.4	40.9	59.7	39.1	38.7	41.3
^b Betts Image Vividness	2.7	2.6	2.3	2.5	2.6	2.4	2.5
^b Gordon Image Controllability	9.1	9.2	9.5	9.3	9.3	9.1	9.3

^a
Percentage correct.

^b
Higher scores indicate more vivid or more controllable images.

Thus, we can conclude that, overall, our treatment groups were equated for spatial and imagery abilities. However, to control for possible differences due to visual memory, we introduced Building Memory scores as a covariate in any analysis that produced a significant effect of supplement with the same pattern as the ability scores.[1]

[1] In fact, none of our analyses produced a pattern like that of the Building Memory Test scores.

To rule out group differences in map-using experience and familiarity with the experimental environment, we performed analyses of variance on the qualitative ratings of map experience and environment (Rancho Park) experience that subjects provided in the questionnaire responses. Neither analysis yielded significant differences (largest $F(2,88) = 2.13$, $p = .125$). Thus, performance differences between groups cannot be attributed to differential prior experience with the experimental environment or with maps.

LANDMARK KNOWLEDGE

Proportions of correct recognitions and false alarms were scored separately for landmarks and critical and noncritical intersections. Discriminability (d') scores were computed from these values by looking up the Z scores corresponding to hit and false-alarm probabilities and taking their differences. These d' values were used in the subsequent analysis of performance.

Table 2 presents group means for the location recognition test. The results of this test show clear differences in the landmark knowledge subjects acquired. Subjects exposed to the film recognized tour locations more accurately than subjects who experienced the tour directly ($F(1,86) = 14.74$, $p < .001$). [2] The type of supplement subjects received also influenced their recognition accuracy ($F(2,86) = 4.20$, $p < .02$). Overall, control subjects performed better than narrative subjects but the map subjects did not differ significantly from

[2] Degrees of freedom are reduced in this analysis because two subjects, both from tour groups, did not return their slide recognition answer sheets.

Table 2
DISCRIMINABILITY ON LOCATION
RECOGNITION TEST

Medium	Supplement			Mean
	Control	Narration	Map	
Film	1.67 ^a	.68	1.22	1.17
Tour	.67	.71	.67	.68
Mean	1.14	.69	.96	

^a Larger d' values indicate better recognition performance.

either extreme group. A significant interaction between medium and supplement ($F(2,86) = 4.91, p < .01$) qualifies this result, however. As Table 2 shows, only subjects in the film groups differed, given different supplements.

The type of stimulus scene also influenced recognition performance, as shown in Table 3. A 2 (medium) by 3 (supplement) by 3 (stimulus type) analysis of variance indicated that subjects recognized landmarks more accurately than critical or noncritical intersections ($F(2,172) = 66.12, p < .0001$). We expected this result, since pauses in the tour and the experimenter's commentary focused subjects' attention on the landmarks. A reliable interaction between medium and location type ($F(2,172) = 3.95, p < .05$) does not compromise this conclusion. Tour subjects recognized critical intersections somewhat better than noncritical,

Table 3
DISCRIMINABILITY OF DIFFERENT
TYPES OF TOUR LOCATIONS

Location Type	Medium		
	Film	Tour	Mean
Landmarks	2.36 ^a	1.48	1.94
Critical intersections	.44	.36	.40
Noncritical intersections	.70	.20	.46

^a Larger d' values indicate better recognition performance.

while the reverse was true for film subjects. However, both groups recognized landmarks more accurately than other scenes.

One might expect that visual-spatial and/or imagery abilities might influence the encoding and retention of visual knowledge of locations. To test this hypothesis, we computed correlations between the ability test scores and the mean recognition d' over the three location types. Scores on the Form Board Test (a measure of spatial visualization ability) and the Building Memory Test (visual memory) were marginally correlated with slide recognition performance ($r = .18$ and $.17$, respectively, $p < .05$). Neither of the imagery tests correlated significantly with location recognition.

Thus, we conclude that either there is at best a weak relationship between ability and recognition performance or the treatment effects overwhelmed any effects due to ability.

PROCEDURAL KNOWLEDGE

Three tasks assessed different aspects of subjects' acquired procedural knowledge. The location sequencing task assessed subjects' memory for the order of locations encountered along the tour. The route distance estimation task assessed subjects' ability to recall and estimate the distances along the various legs of the routes between points. The orientation task assessed subjects' ability to recall the angles of turns along the route and combine this knowledge with route distance knowledge to produce relative bearing judgments.

The correct sequencing of slides of locations along the route presupposes correct identification of the locations those slides represent. Thus, we conditionalized the sequencing responses on the subjects' correct recognition of both locations in the previous location recognition task. We analyzed the percentage of correct sequencing responses, given prior recognition, in a 2 (medium) by 3 (supplement) analysis of variance. Treatment means for this analysis are presented in Table 4. Film groups performed significantly more accurately than tour groups (means of 27.5 percent and 22.8 percent, respectively, $F(1,86) = 5.11, p < .03$). Supplementary information also affected performance, with the narration groups performing significantly worse than the groups in the other two conditions ($F(2,86) = 3.58, p < .04$). Medium and supplement did not interact.

The location sequencing task included two types of trials: near trials, in which the two locations to be ordered were drawn from the same half of the route, and far trials, in which the locations were drawn from different route halves. We predicted that the far trials,

Table 4
PERCENTAGE OF CORRECT LOCATION SEQUENCING RESPONSES
CONDITIONALIZED ON LOCATION RECOGNITION

Medium	Supplement			Mean
	Control	Narration	Map	
Film	32.7 ^a (9.8)	20.8 (7.0)	29.4 (8.9)	27.5
Tour	23.2	21.4	23.6	22.8
Mean	(7.4) 27.6	(7.4) 21.1	(7.9) 26.7	

^a
Numbers in parentheses indicate mean number of trials where component slides were both correctly recognized.

which involved a less difficult order discrimination, would produce more accurate performance than the near trials. An analysis of variance performed on the unconditionalized proportions correct confirmed this hypothesis (means of .74 vs. .70, $F(1,88) = 6.04$, $p < .02$).[3]

Results of the route distance estimation test are displayed in Table 5. Neither medium nor supplement reliably affected accuracy on this task. The major cue for computing route distances is the travel time between landmarks. Since this information was readily available to all groups, their equivalent performance is not surprising.

[3] Unconditionalized scores were used in this analysis to insure that near and far conditions contributed equally to the data.

Table 5
CORRELATIONS BETWEEN TRUE AND ESTIMATED DISTANCES
IN THE ROUTE DISTANCE ESTIMATION TASK

Medium	Supplement			Mean
	Control	Narration	Map	
Film	.63	.68	.73	.68
Tour	.71	.71	.55	.66
Mean	.67	.70	.64	

On the other hand, the orientation task produced a highly significant effect of medium ($F(1,88) = 12.29, p < .001$). As Table 6 shows, tour subjects were approximately 10 degrees more accurate in their estimates than film subjects. However, all groups contained subjects with mean errors greater than 90 degrees. This means that a landmark due right of the current location would be judged to be straight ahead. We arbitrarily selected a criterion of 90 degrees error to define "complete disorientation" (Ciccone et al., 1978). Table 6 also indicates the percentage of subjects in each group who could be classified as disoriented according to this criterion. There were more disoriented subjects in the film groups than in the tour groups ($\chi^2 = 9.74, p < .01, df = 1$).

The analysis of judgment errors also yielded a significant effect of supplement ($F(2,88) = 8.92, p < .001$). Contrary to expectations, the supplementary information did not improve performance compared to that of control subjects. Error scores for these two condition were

Table 6
ANGULAR ERROR ON THE ORIENTATION TASK AND
PERCENTAGE OF COMPLETELY DISORIENTED SUBJECTS

Medium	Supplement			Mean
	Control	Narration	Map	
Film				
Angular error ^a	92.2	93.9	102.5	96.5
Percent disoriented ^b	64.3	68.8	82.4	72.4
Tour				
Angular error	81.9	81.6	96.4	86.7
Percent disoriented	31.2	26.7	62.5	40.4
Mean angular error	86.7	87.9	99.5	
Mean percent disoriented	46.6	48.4	72.8	

^a

Smaller scores indicate better performance.

^b

Disorientation is defined as a mean angular error greater than or equal to 90 degrees.

essentially equivalent (86.7 vs. 87.6 degrees for control and narrative conditions, respectively). Instead, groups provided with a map as a supplement performed significantly more poorly than other groups (mean error = 99.5, $p < .01$ by Neuman-Keuls test). Supplement and medium did not interact ($F(2,88) = .48$).

To determine the relationship between subjects' visual-spatial abilities and the accuracy of their acquired procedural knowledge, we correlated the ability measures with the location sequencing, route distance estimation, and orientation scores. On the orientation task, experimental treatments influenced judgment accuracy. None of the ability or imagery measures correlated significantly with orientation accuracy in the presence of these treatment effects. However, treatments had no effect on route distance estimates. On this task, judgment accuracy was significantly correlated with both Building Memory Test scores ($r = .23$, $p < .02$) and Form Board Test scores ($r = .21$, $p < .03$). Thus, on a task requiring the generation and manipulation of visual images, both visual memory and visualization ability predicted subjects' performance. For the location sequencing task, only the Form Board Test correlated significantly with conditionalized scores ($r = .19$, $p < .05$). The Form Board Test measures visualization ability, that is, the ability to perform accurate mental transformations on a spatial representation. Transformations of this type form the basis of mental simulation, which presumably is used to generate responses on the sequencing task.

SURVEY KNOWLEDGE

To evaluate subjects' acquisition of survey knowledge, we performed analyses of variance on (1) the accuracy of landmark placement on the map drawing task and (2) the correlations between true and estimated distances on the euclidean distance estimation task. On the landmark placement task, there was no effect of medium. Differences due to

supplement approached significance ($F(2,79) = 3.07, p = .052$), however, and the interaction was reliable ($F(2,79) = 5.11, p < .01$). [4] As Table 7 shows, film and tour groups performed equivalently, given no supplementary information. The interaction indicates that supplement affected the film groups but not the tour groups. The subjects who viewed the film and used a map performed significantly better than all other groups ($p < .05$ by a Neuman-Keuls test), while the tour subjects did not benefit from their access to the map prior to their tour. In addition, film subjects who received the narration supplement performed significantly more poorly than all other groups ($p < .05$ by Neuman-Keuls).

Table 7
MEAN ANGULAR ERROR IN LANDMARK PLACEMENT
ON MAP DRAWING TASK

Medium	Supplement			Mean
	Control	Narration	Map	
Film	28.9 ^a	36.9	19.5	27.8
Tour	27.4	26.8	29.0	27.7
Mean	28.2	32.0	23.6	

^a Smaller scores indicate better performance.

[4] Degrees of freedom for this analysis were reduced because nine subjects included less than half the landmarks on their map and so were excluded from the analysis.

The results from subjects' euclidean distance estimates, shown in Table 8, were consistent with the map drawing results. While the tour medium had no effect, supplementary information did influence distance estimates ($F(2,88) = 4.48, p < .02$). The significant interaction between supplement and medium ($F(2,88) = 6.54, p < .01$) indicates that once again, only the film groups were affected by supplement. The film group that received a map prior to film viewing performed more accurately than all other groups ($p < .05$). The film narrative group produced performance equivalent to that of the tour groups, while the film control group performed significantly less accurately.

Performance on the euclidean distance estimation test did not correlate significantly with any of the ability or imagery measures. The landmark placement task errors correlate significantly with Hidden

Table 8
CORRELATIONS BETWEEN TRUE AND ESTIMATED DISTANCES
ON EUCLIDEAN DISTANCE ESTIMATION TASK

Medium	Supplement			Mean
	Control	Narration	Map	
Film	.27 ^a	.38	.63	.44
Tour	.42	.46	.40	.41
Mean	.34	.42	.52	

^a Larger scores indicate better performance.

Figures Test scores ($r = -.20$, $p < .04$) and with Building Memory Test scores ($r = .21$, $p < .03$). The direction of the latter correlation is somewhat surprising, since it suggests that better visual memory is associated with larger location errors. It is possible that individuals with good visual memory focus more on learning perceptual details and less on abstracting survey knowledge. Previous research examining individuals' strategies for acquiring spatial knowledge from navigation does suggest that individuals who focus on perceptual information abstract survey knowledge more slowly than individuals who use symbolically oriented strategies (Thorndyke, 1980). Given the small magnitude of the correlation, however, these results should be viewed as tentative.

ENVIRONMENTAL COMPLEXITY AND SPATIAL KNOWLEDGE ACQUISITION

The experimental route in this study comprised two distinct sections. The half of the route south of Pico Boulevard contained winding streets that intersected in oblique angles (see Figure 1). The northern half of the route had a simpler, grid-like street pattern. Most streets in this section were perpendicular or parallel to each other. This design feature enabled us to compare the knowledge subjects acquired from the two halves of the route.

The results of previous research (Goldin & Thorndyke, 1981; Thorndyke & Hayes-Roth, 1980) suggest that subjects should acquire more accurate knowledge of the northern half of the route, since it should be easier to learn. Thus, distance and orientation estimates should be more accurate for landmark pairs located entirely in the northern half than for pairs in the southern half. Further, these accuracy differences

should be most pronounced for the map groups, who had the most information about the rectilinear street pattern in that half of the route. We tested these hypotheses by comparing the orientation, euclidean distance, and route distance estimates separately for the six landmark pairs located exclusively in either the northern or southern section.

The results of these analyses generally did not confirm our hypotheses. The analysis of the orientation error scores showed no effect of route half ($F(1,88) = .55$, ns). However, the interaction with medium by half did reach significance ($F(1,88) = 5.25$, $p < .03$). Route half had no effect on the orientation judgments of the film groups, but for the tour groups, the southern, more complex half of the route actually produced more accurate orientation performance than the northern, easy half. For route distance estimates, the analysis also showed no effect of route half ($F(1,88) = 1.67$, ns). Finally, euclidean distance estimates were unaffected by route half ($F(1,88) = .78$, ns).

Thus, there seems to be little evidence for an effect of environmental complexity on spatial knowledge acquisition. However, experimental groups who never saw a map of the environment may not have realized that the northern half formed a rectangular grid. Map groups should have been more aware of the simple structure of the northern half and hence should have been the groups most likely to show an effect of half. Table 9 presents the means for the northern and southern route halves in the film map and tour map groups. Although five out of six of these comparisons are in the predicted direction, planned contrasts indicated that only one of these differences is even marginally significant (easy

Table 9

PERFORMANCE ON ORIENTATION AND DISTANCE JUDGMENT TASKS FOR
EASY AND DIFFICULT HALVES OF ROUTE (MAP GROUPS ONLY)

	Easy Half	Difficult Half	Contrast <u>t</u> value
Orientation Task ^a			
(angular error)			
Film	107	120	-1.63
Tour	108	109	- .12
Route Distance Estimation (correlation)			
Film	.63	.58	.44
Tour	.46	.23	1.98 ^b
Euclidean Distance Estimation (correlation)			
Film	.38	.27	.86
Tour	-.09	-.02	- .53

^a
For this measure, smaller scores indicate better performance. For all others, the opposite is true.

^b
 $p < .05$.

vs. hard for route distance estimates in the tour map group). Hence, we conclude that environmental complexity did not strongly influence performance in this study.

IV. DISCUSSION

BASIC FINDINGS

Simulated vs. Actual Experience

These results indicate that simulated environmental experience can provide an adequate surrogate to actual navigation for the acquisition of some type of spatial knowledge. Table 10 summarizes the comparisons between the film and tour groups.

Table 10

SUMMARY OF COMPARISONS BETWEEN FILM AND TOUR GROUPS

Task Type	Result
<u>Landmark Knowledge</u>	
Location recognition	Film groups more accurate than tour groups
<u>Procedural Knowledge</u>	
Location sequencing	Film groups more accurate than tour groups
Route distance estimation	No difference between film and tour groups
Orientation judgment	Tour groups more accurate than film groups
<u>Survey Knowledge</u>	
Landmark placement	No difference between film and tour groups
Euclidean distance estimation	No difference between film and tour groups

Perceptual knowledge of locations in the environment can apparently be acquired at least as well from a film as from live navigation experience. On the location recognition task, subjects needed memory for visual details of the environment to discriminate scenes on the tour from novel scenes. Since both film and tour groups had roughly equivalent exposure to the visual aspects of the environment, we expected equivalent recognition performance. Two factors may have produced the unexpected superiority of the film groups. First, the film groups may have concentrated more on visual details than the tour groups because they did not have access to a wide field of view or as many depth, distance, and directional cues. In contrast, tour subjects may have allocated considerable attentional resources to learning distances and directions at the expense of visual detail. Second, film subjects may actually have had a better "view" of the environment. The tour subjects viewed the environment from inside a bus. While they had excellent visibility to the side, their front visibility may have been somewhat obscured. In any case, these results indicate that simulated navigation can support extensive learning of the perceptual information necessary for place recognition.

Live tour experience appears superior to simulated navigation for the acquisition of only one component of procedural knowledge: the angles of turns along the route. While we did not measure performance on angle estimation directly, we may infer these differences from subjects' route distance and orientation estimates. Film and tour subjects did not differ on the route estimation task, which required recall of the various legs along the route and judgments of their lengths.

Orientation estimates required this knowledge plus knowledge of the angles connecting those route legs. We found that tour subjects performed more accurately than film subjects in judging orientations.

However, neither group performed very accurately on the orientation task. At least a quarter of the subjects in every group were "disoriented" according to our criterion. This low level of performance probably resulted from three factors: the size and complexity of the environment, the limited exposure each subject had to the environment, and the passive nature of that experience. Our route was considerably longer and more circuitous than those used by Cohen (1980) or Ciccone et al. (1978) in their studies of navigational learning. Lynch (1960) and other environmental designers have noted that the "legibility" (i.e., distinctiveness, predictability) of an environment strongly affects the ease of learning and navigating within that environment. One trip through our environment probably provided insufficient information for subjects to develop a very accurate cognitive map. Furthermore, passive experience with an environment typically does not produce as accurate a representation as interactive experience involving information selection, decisionmaking, and problem-solving (e.g., Beck & Wood, 1976; Carr & Schissler, 1969). One reason for the large differences that Cohen (1980) found between live-tour and simulated-tour groups may be that her live-tour group interacted with the environment, choosing where to walk and where to look within each room, while her film groups did not have these opportunities for active exploration.

Finally, live and simulated environmental experience produced equivalent survey judgments, as indicated by performance on the location

and euclidean distance estimation tasks. In most environments, the abstraction of explicit survey knowledge from navigation requires repeated exposures to the environment over a considerable time period (Siegel & White, 1975; Thorndyke, 1980; Thorndyke & Hayes-Roth, 1980). Since our subjects had only one exposure to the environment, we presume they were unable to encode directly survey relations among locations. Rather, they computed their judgments of survey relations using their procedural knowledge. That the film and tour groups did not differ in their judgment accuracy again indicates that our simulation of navigation provided a reasonable source of procedural knowledge.

Supplementary Information

The influence of supplementary information on subjects' acquired knowledge was more complex than we expected. For one thing, only the film groups showed differential performance due to supplementary information. Furthermore, our two manipulations of supplementary information produced markedly different effects. Narrative supplements degraded performance when they affected it at all. Map supplements, on the other hand, sometimes enhanced performance and sometimes degraded it. Specifically, studying a map prior to exposure to the environment enhanced the performance of film subjects on tests of survey knowledge but degraded their performance on tests of procedural knowledge. Both narration and map supplements degraded performance on the test of landmark knowledge.

The inhibitory effects of supplementary information on the landmark knowledge tests probably reflect subjects' attentional limitations. Subjects viewing the film alone may have focused primarily on perceptual

features. Indeed, their recognition performance exceeds that of all other groups. The supplements may have directed attention toward non-perceptual aspects of the environment such as distances and angular relationships. Thus, this increased effort to acquire more abstract spatial knowledge may have come at the expense of learning visual details.

The inhibitory effects of a map on the orientation test (procedural knowledge) suggests that film subjects receiving a map may have judged orientations using the survey knowledge that they recalled from the map, rather than on the basis of their tour in the environment. Thorndyke and Hayes-Roth (1980) have demonstrated that orientation estimates derived from survey knowledge are less accurate than orientation estimates derived from procedural knowledge, because the former require a difficult perspective shift during the computation of a response. If the map groups did, in fact, generate their responses from a mental image of the map, their responses could well have been less accurate than those of the other groups.

The improved performance of film map subjects on the tasks that assessed survey knowledge suggests that in this case the map actually provided additional survey information. Prior map study improved both euclidean distance estimates and map drawing scores of the film subjects above the level of those of all live-tour groups.

The selective effect of supplementary information on the film groups may reflect subjects' strategies for acquiring information and using it to perform their judgments. Since the live tour provided a richer and more varied source of information than the film, tour

subjects may have devoted their attention to encoding knowledge from the route and may have more or less ignored the supplementary information. On the other hand, subjects who viewed the film may have felt that the film medium was impoverished in its portrayal of spatial information and hence may have deliberately attended more to the supplementary information. In the case of the narration, this would have meant encoding the verbal descriptions of location and distance along with the perceptual information they acquired. In the case of the pre-tour map supplement, film subjects may have worked harder to reconstruct the map relations for use in judging spatial relations than the live-tour subjects.

Individual Differences

Our previous research has demonstrated large individual differences in skill at acquiring spatial knowledge from maps and navigation (Goldin & Thorndyke, 1981; Thorndyke & Goldin, 1981). These individual differences have been linked to differences in spatial visualization, spatial orientation, and visual memory abilities. However, in this experiment we found visual-spatial abilities to be only weakly related to performance over a range of different tasks measuring spatial knowledge. Only 6 of 18 correlations between abilities and task performance reached significance, and none was larger than .30. Taken together, these results suggest that our experimental manipulations influenced learning to a greater extent than individual differences in abilities. Thus, performance/ability correlations were attenuated relative to our earlier work. A second possible reason for the small correlations may derive from differences between populations. Our previous work used middle-

aged subjects, largely housewives, recruited from the community. Furthermore, those subjects were selected to represent extremes in cognitive mapping skill. The current study used self-selected undergraduate psychology students, who probably represent a more homogeneous population of abilities. Therefore, we might well expect smaller performance/ability correlations in our present study.

PRACTICAL CONSIDERATIONS

Adequacy of Simulated Experience

This study demonstrates that under some conditions, environmental knowledge acquired through simulated navigation can equal knowledge acquired through live navigational experience in accuracy and completeness. In particular, when the goal is to convey either visual detail or configural relations, a film may provide at least as much information as a single live tour. Knowledge of routes, on the other hand, especially angular relations between route segments, may be better acquired through actual travel or other, more elaborate means of simulated travel.

These conclusions suggest cautious optimism concerning the use of simulated navigation as a substitute for actual navigation in military or civilian research contexts. At the same time, several limitations of our study constrain the generality of our results. First, we compared subjects after only one simulated or live navigational tour. Repeated exposures to the environment may produce larger performance differences between tour and film groups. Individuals receiving live tours might attend to different environmental cues on each trial, examine landmarks

from varying perspectives, and thus develop a richer and more varied environmental representation than film subjects. The range of cues that a film subject could sample on repeated trials is much more limited and does not change from trial to trial. Thus, film subjects might reach a lower asymptotic level of learning than live-tour subjects.

Second, both live-tour and film groups in this study received passive rather than active environmental experience. Tour subjects were driven around the route and did not make navigation decisions. Similarly, film subjects simply sat and watched a film in order to learn as much as possible about the environment. More active experience, such as requiring the subjects to drive the route themselves (see Goldin & Thorndyke, 1981), might well produce more rapid and accurate environmental learning. In this study, we chose passive travel experience to make the film and tour conditions as comparable as possible. However, as we discuss below, other simulation media can provide more interactive participation in the environmental tour.

Finally, we examined only one, fairly simple mode of environmental simulation: a continuous film, without cuts or pans, taken from a single point of view. We chose this mode because it was relatively quick, inexpensive, and similar to the view obtained by someone actually driving through the environment. Also, we wanted to avoid arbitrary decisions about appropriate content, viewing parameters, or filming conventions that would have been required by a more "sophisticated" medium. Clearly, another filmmaker might make very different decisions regarding the use of such parameters as camera angle, zooming, panning, continuity,

field of view, and editing. However, no standard conventions or empirical principles currently exist for producing environmental simulations.

Based on our results and observations in this study, however, we may propose a set of guidelines for the production of an ideal simulation medium:

1. It should accurately represent both perceptual details and local spatial relationships.
2. It should allow the viewer to interact with the environment, by selecting routes, perspectives, and rate of travel.
3. It should provide both ground-level and birds-eye views on the environment.
4. It should make a simulation of a particular environment relatively quick and inexpensive to produce.
5. It should support the simulation of either real or fictitious environments.

Existing techniques for environmental simulation satisfy some but not all of these criteria. In the following paragraphs, we discuss the currently available options for simulation, in terms of these criteria.

Film. Our use of film in this study did not exploit the full potential of that simulation medium. Creative filming and editing could produce a film that approximated normal viewing patterns and attentional shifts, thus providing a limited form of environmental interaction (see Cohen, 1980, for an example). Multiple cameras, projectors, and viewing screens (or 360-degree cameras and projection rooms) could allow the viewer to shift attention to various parts of the environment rather than forcing a particular perspective. This technique has been used in

automobile simulators.[1] Film has a number of advantages as a simulation medium: (1) new environments can be filmed relatively quickly and inexpensively; (2) film can portray both perceptual details and spatial relations; (3) film can potentially provide both aerial and ground-level views; (4) film provides at least a limited capacity for environmental interaction. Its disadvantages are (1) film does not support simulation of a fictitious environment; (2) the target environment must be available for filming (a potential problem for some military applications); (3) film provides limited flexibility for creating environmental interaction capabilities. Despite these disadvantages, film remains an attractive alternative for many applications because it does not demand sophisticated technology and it allows considerable flexibility in portraying the environment.

Model Filming. A film shot using scale models circumvents some of the disadvantages of filming a large-scale environment. This approach uses a miniature camera lens that can be moved through a scale model of an environment under micro computer control. For example, at the Berkeley Environmental Simulation Laboratory, this method is used to produce either films or videotapes that closely resemble an actual environmental tour (Craik, 1968, 1977). In contrast to film of actual environments, model filming allows simulation of fictitious or inaccessible environments. However, it also requires considerably larger expenditures of time, money, and effort to produce a detailed scale model and a controlled simulation.

[1] K. Zeidman, personal communication, 1979.

Slide Presentations. Some researchers have used color slides to simulate travel through an environment (Allen, 1979; Allen, Siegel, & Rosinski, 1978). Slides share both the advantages and the disadvantages of film. They are relatively inexpensive and simple to produce, but their use is restricted to real, accessible environments. More important, slides do not convey a sense of movement and hence may not convey distance and relational information as well as film does. Cohen (1980) found that a slide-like static presentation of successive still scenes along an experimental route resulted in less complete and accurate knowledge than a presentation of a film that incorporates movement. However, Allen et al. (1978) found that slides taken at fairly short intervals along a route could convey distance and ordering information. Unlike film, slides offer a fairly simple and inexpensive means of allowing the viewer to control movement through the environment. Using a random access slide projector, a slide indexing system, and a sufficiently large library of slides, one could construct an interactive environmental simulation system that allowed the user to select the locations, perspectives, and routes he or she wished to examine. This interactive system would approximate the behavior of a videodisc system, described below.

Videodisc. Videodisc technology provides a means for fast, flexible retrieval and display of visual scenes stored in a digitized data base. Negroponte and his colleagues at MIT have developed a videodisc system designed to help a naive user learn a new environment (Clay, 1978). The data base contains thousands of photographs of landmarks and views from various streets and perspectives in Aspen, Colorado. The

user, interacting with the system through a computer terminal and a light pen, chooses which paths to travel, where to turn, directions in which to "look," and so on. The videodisc system retrieves and displays the corresponding scenes in response to the user's commands. Thus, the videodisc system makes the entire environment available to the user, to be studied and explored at his or her own pace, using personally compatible strategies.

Videodisc is in many ways the ideal simulation medium. It portrays both visual details and spatial relations in a highly realistic manner. It permits significant interaction with the environment by allowing viewers to select their own routes and views. If the images are produced using a model or computer-generated graphics, a videodisc system can provide ground-level and aerial views and can simulate fictitious or remote environments. Its major drawback is the time, effort, technological, and financial resources required to simulate even a single environment. For example, photographing the Aspen environment and producing the Aspen videodisc system required more than three years.

Computer Graphics. Computer graphics systems offer another flexible, interactive environmental simulation medium. Current implementations vary in their detailed methods, but in general graphics systems utilize a data base of environmental features and routines for displaying, rotating, and manipulating those features on command. The film used by Ciccone et al. (1978) discussed in the Introduction was generated using computer graphics technology. Simutis and Barsam (1981) have used interactive and noninteractive graphics to teach terrain visualization from topographic relief maps. In addition, many flight simulators use

graphics displays of the terrain that vary according to the flight path flown by the pilot.

Computer graphics displays share many advantages with the video-disc. They can be highly interactive, can display the environment from a variety of perspectives, and can represent fictional or remote environments. Their main disadvantages, currently, are (1) lack of perceptual detail and (2) time and cost required to establish a new data base. However, both these problems should diminish with expected refinements to computer graphics technology.

Mixed Media. Probably the most effective way of simulating environmental experience would involve a combination of the above media with other forms of spatial information. The work reported here, for example, found that the effectiveness of the film was often enhanced by providing a map. Similarly, the film used by Ciccone et al., supplemented with descriptive narrative and labeling, proved to be a highly effective way of communicating spatial information. Combinations of the simpler media, such as slides or films, with supplementary information may produce simulation systems as powerful as the more technologically sophisticated graphics and videodisc media. Certainly, there is no lack of potential simulation media to be investigated.

V. CONCLUSIONS

Based on the results of this study, we may offer some tentative recommendations regarding the utility of film in simulating environmental experience. These recommendations are summarized below.

1. Consider using passive, film-based simulation as an alternative to live experience in situations where knowledge of perceptual details is important. If particular, distinguishing details are important, use zooming or other cinematographic devices to focus viewers' attention.

2. Consider using passive, film-based simulation supplemented by a terrain map when knowledge of global perceptual relations is important and viewers will later be expected to navigate in the environment. The film can provide an important aid for visualizing spatial relations depicted on the map from ground-level perspective and for recognizing critical landmarks that may facilitate navigation.

3. Consider using film-based simulation in situations where learning of sequences of locations along a route or distances between locations along a route is important; in situations where knowledge of angular relations between locations is important, consider using some experiential medium other than film. This recommendation is based on our findings that our film scenario produced sequencing and distance estimation performance equivalent to that produced by a live tour, but less accurate orientation performance. However, these conclusions are limited by our very simple film scenario. A more complex film that focused attention on angular changes at choice points along the route

and/or provided multiple views of an intersection from varying perspectives might produce orientation performance equivalent to that based on a live tour.

These are modest recommendations, but the results of a single study do not merit more extensive proposals. However, the results of this study do indicate that environmental simulation can be a promising alternative to live experience in some situations. Further research should be devoted to identifying these candidate situations and developing a more elaborate description of their characteristics. Research effort should also be devoted to exploring the generality of our results. In particular, further research should investigate the relative effectiveness of live versus simulated environmental experience over repeated exposures to the environment. This comparison will be particularly relevant to practical situations in which an individual must be intimately familiar with an environment before experiencing it directly, such as the planning of a commando raid. This comparison will also contribute to theoretical development. Previous research has shown that individuals gradually construct a survey representation of the environment over the course of extended experience. The mechanisms for this abstraction or construction process are not well understood; however, if a similar process occurs after extended experience with a filmed environmental simulation, this would considerably constrain possible mechanisms.

Future research should also investigate the relative effectiveness of live and simulated environmental experience when both media provide learners with equal opportunities to explore, select information, and

make decisions. Experiments that compare an interactive live experience with passive simulated experience (e.g., Cohen, 1980) are inherently biased in favor of live experience and may seriously underestimate the practical potential of environmental simulation.

Previous studies have indicated that extensive navigation experience produces a richer and more varied knowledge base than simply learning a map (Thorndyke & Hayes-Roth, 1980). The study reported here suggests that environmental simulation can provide extensive navigation experience under controlled conditions and can thus enhance performance on tasks that require accurate spatial knowledge.

Appendix A

SPATIAL COGNITION QUESTIONNAIRE

We would greatly appreciate your completing the following brief questionnaire to provide some background information on your experience, styles and preference in spatial tasks.

1. How true is each of the following statements about you? (circle one)

	Very true	Not at all true
I enjoy exploring new places.	1 --- 2 --- 3 --- 4 --- 5	
I tend to think visually, with lots of images.	1 --- 2 --- 3 --- 4 --- 5	
I always like to know where I am.	1 --- 2 --- 3 --- 4 --- 5	
I feel I have a "mental map" of places I know well.	1 --- 2 --- 3 --- 4 --- 5	
I find maps hard to use.	1 --- 2 --- 3 --- 4 --- 5	
I have a good sense of direction	1 --- 2 --- 3 --- 4 --- 5 .	
I enjoy looking at and studying maps.	1 --- 2 --- 3 --- 4 --- 5	
I can often find my way to a place without being able to give someone else directions.	1 --- 2 --- 3 --- 4 --- 5	
I tend to think of the environment in terms of compass directions.	1 --- 2 --- 3 --- 4 --- 5	
I can usually remember a new route after traveling it once.	1 --- 2 --- 3 --- 4 --- 5	
I hate being lost.	1 --- 2 --- 3 --- 4 --- 5	
I usually need a map to find my way around in a new area.	1 --- 2 --- 3 --- 4 --- 5	

2. Where do you live? _____
3. How long? _____ How long in greater Los Angeles? _____
4. In how many different cities or towns have you lived? _____
5. How many states have you visited (roughly)? _____
6. How many foreign countries have you visited? _____
7. How familiar are you with the Rancho Park area in which our experimental route was situated? (please check one)

☐ Totally unfamiliar before today; I had never seen the area before.
☐ Slightly familiar; I've been there once or twice.
☐ Moderately familiar; I've been there less than a dozen times.
☐ Quite familiar; I go there regularly.
☐ Very familiar; I live nearby or pass through the area almost every day.
8. How often do you perform each of the following activities?
Please answer by assigning each activity a number from 1 to 6, according to the following scale:

1 = seldom or never
2 = less than once a month
3 = several times a month
4 = roughly once a week
5 = several times a week
6 = almost every day

(Note that the more frequent the activity, the higher the numerical rating)

a) Use a map to find a route to someplace you want to go _____
b) Use a map to locate a place _____
c) Use a map to get some idea of the general relationships among several places _____
d) Use a map to determine how far away a place is or how long it will take to get there _____
e) Use a map to demonstrate to someone else the location of a place or the best route to get there _____

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f) Draw a map in order to give someone directions ____

Thank you for your cooperation.

Name _____ Age _____ Sex M F Date _____

Appendix B

THE GORDON TEST OF VISUAL IMAGERY CONTROL

The questions in this test are concerned with the ease with which you can control or manipulate visual images. For some people this task is relatively easy and for others relatively hard. One subject who could not manipulate his imagery easily gave this illustration. He visualized a table, one of whose legs suddenly began to collapse. He then tried to visualize another table with four solid legs, but found it impossible. The image of the first table with its collapsing leg persisted. Another subject reported that when he visualized a table the image was rather vague and dim. He could visualize it briefly but it was difficult to retain by any voluntary effort. In both these illustrations the subjects had difficulty in controlling or manipulating their visual imagery. It is perhaps important to emphasize that these experiences are in no way abnormal and are as often reported as the controllable type of image.

Read each question, then close your eyes while you try to visualize the scene described. Record your answer by underlining "Yes," "No," or "Unsure," whichever is the most appropriate. Remember that your accurate and honest answer to these questions is most important for the validity of this study. If you have any doubts at all regarding the answer to a question, underline "Unsure." Please be certain that you answer each of the twelve questions.

- | | | | |
|--|-----|----|--------|
| 1. Can you see a car standing in the road in front of a house? | Yes | No | Unsure |
| 2. Can you see it in color? | Yes | No | Unsure |
| 3. Can you now see it in a different color? | Yes | No | Unsure |
| 4. Can you now see the same car lying upside down? | Yes | No | Unsure |
| 5. Can you now see the same car back on its four wheels again? | Yes | No | Unsure |
| 6. Can you see the car running along the road? | Yes | No | Unsure |
| 7. Can you see it climb up a very steep hill? | Yes | No | Unsure |
| 8. Can you see it climb over the top? | Yes | No | Unsure |
| 9. Can you see it get out of control and crash through a house? | Yes | No | Unsure |
| 10. Can you now see the same car running alongside the road with a handsome couple inside? | Yes | No | Unsure |
| 11. Can you see the car cross a bridge and fall over the side into the stream below? | Yes | No | Unsure |
| 12. Can you see the car all old and dismantled in a car-cemetery? | Yes | No | Unsure |

Appendix C

THE BETTS VIVIDNESS OF IMAGERY SCALE

Instructions for doing test:

The aim of this test is to determine the vividness of your imagery. The items of the test will bring certain images to your mind. You are to rate the vividness of each image by reference to the accompanying rating scale, which is shown at the bottom of the page. Just write the appropriate number after each item. Before you turn to the items on the next page, familiarize yourself with the different categories on the rating scale. Throughout the test, refer to the rating scale when judging the vividness of each image. A copy of the rating scale will be printed on each page. Please do not turn to the next page until you have completed the items on the page you are doing, and do not turn back to check on other items you have done. Complete each page before moving on to the next page. Try to do each item separately independent of how you may have done other items.

The image aroused by an item of this test may be:

Perfectly clear and as vivid as the actual experience	Rating 1
Very clear and comparable in vividness to the actual experience	Rating 2
Moderately clear and vivid	Rating 3
Not clear or vivid, but recognizable	Rating 4
Vague and dim	Rating 5
So vague and dim as to be hardly discernible	Rating 6
No image present at all, you only 'know' that you are thinking of the object	Rating 7

An example of an item on the test would be one which asked you to consider an image which comes to your mind's eye of a red apple. If your visual image was moderately clear and vivid you would check the rating scale and mark '3' in the brackets as follows:

Item	Rating
5. A red apple	(3)

Now turn to the next page when you have understood these instructions and begin the test.

Think of some relative or friend whom you frequently see, considering carefully the picture that rises before your mind's eye. Classify the images suggested by each of the following questions as indicated by the degrees of clearness and vividness specified on the Rating Scale.

Item	rating
1. The exact contour of face, head, shoulders and body	()
2. Characteristic poses of head, attitudes of body, etc.	()
3. The precise carriage, length of step, etc. in walking	()
4. The different colors worn in some familiar costume	()

Think of seeing the following, considering carefully the picture which comes before your mind's eye; classify the image suggested by the following questions as indicated by the degree of clearness and vividness specified on the Rating Scale.

5. The sun as it is sinking below the horizon	()
---	-----

Rating Scale

Perfectly clear and as vivid as the actual experience	Rating 1
Very clear and comparable in vividness to the actual experience	Rating 2
Moderately clear and vivid	Rating 3
Not clear or vivid, but recognizable	Rating 4
Vague and dim	Rating 5
So vague and dim as to be hardly discernible	Rating 6
No image present at all, you only 'know' that you are thinking of the object	Rating 7

Think of each of the following sounds, considering carefully the image which comes to your mind's ear, and classify the images suggested by each of the following questions as indicated by the degrees of clearness and vividness specified on the Rating Scale.

Item	Rating
6. The whistle of a locomotive	()
7. The honk of an automobile	()
8. The mewling of a cat	()
9. The sound of escaping steam	()
10. The clapping of hands in applause	()

Rating Scale

The image aroused by an item of this test may be:

Perfectly clear and as vivid as the actual experience	Rating 1
Very clear and comparable in vividness to the actual experience	Rating 2
Moderately clear and vivid	Rating 3
Not clear or vivid, but recognizable	Rating 4
Vague and dim	Rating 5
So vague and dim as to be hardly discernible	Rating 6
No image present at all, you only 'know' that you are thinking of the object	Rating 7

Think of 'feeling' or touching each of the following, considering carefully the image which comes to your mind's touch, and classify the images suggested by each of the following questions as indicated by the degrees of clearness and vividness specified on the Rating Scale.

Item	Rating
11. Sand	()
12. Linen	()
13. Fur	()
14. The prick of a pin	()
15. The warmth of a tepid bath	()

Rating Scale

The image aroused by an item of this test may be:

Perfectly clear and as vivid as the actual experience	Rating 1
Very clear and comparable in vividness to the actual experience	Rating 2
Moderately clear and vivid	Rating 3
Not clear or vivid, but recognizable	Rating 4
Vague and dim	Rating 5
So vague and dim as to be hardly discernible	Rating 6
No image present at all, you only 'know' that you are thinking of the object	Rating 7

Think of performing each of the following acts, considering carefully the image which comes to your mind's arms, legs, lips, etc., and classify the images suggested as indicated by the degree of clearness and vividness specified on the Rating Scale.

Item	Rating
16. Running upstairs	()
17. Springing across a gutter	()
18. Drawing a circle on paper	()
19. Reaching up to a high shelf	()
20. Kicking something out of your way	()

Rating Scale

The image aroused by an item of this test may be:

Perfectly clear and as vivid as the actual experience	Rating 1
Very clear and comparable in vividness to the actual experience	Rating 2
Moderately clear and vivid	Rating 3
Not clear or vivid, but recognizable	Rating 4
Vague and dim	Rating 5
So vague and dim as to be hardly discernible	Rating 6
No image present at all, you only 'know' that you are thinking of the object	Rating 7

Think of tasting each of the following, considering carefully the image which comes to your mind's mouth, and classify the images suggested by each of the following questions as indicated by the degrees of clearness and vividness specified on the Rating Scale.

Item	Rating
21. Salt	()
22. Granulated (white) sugar	()
23. Oranges	()
24. Jelly	()
25. Your favorite soup	()

Rating Scale

The image aroused by an item of this test may be:

Perfectly clear and as vivid as the actual experience	Rating 1
Very clear and comparable in vividness to the actual experience	Rating 2
Moderately clear and vivid	Rating 3
Not clear or vivid, but recognizable	Rating 4
Vague and dim	Rating 5
So vague and dim as to be hardly discernible	Rating 6
No image present at all, you only 'know' that you are thinking of the object	Rating 7

Think of smelling each of the following, considering carefully the image which comes to your mind's nose and classify the images suggested by each of the following questions as indicated by the degrees of clearness and vividness specified on the Rating Scale.

Item	Rating
26. An ill-ventilated room	()
27. Cooking cabbage	()
28. Roast beef	()
29. Fresh paint	()
30. New leather	()

Rating Scale

The image aroused by an item of this test may be:

Perfectly clear and as vivid as the actual experience	Rating 1
Very clear and comparable in vividness to the actual experience	Rating 2
Moderately clear and vivid	Rating 3
Not clear or vivid, but recognizable	Rating 4
Vague and dim	Rating 5
So vague and dim as to be hardly discernible	Rating 6
No image present at all, you only 'know' that you are thinking of the object	Rating 7

Think of each of the following sensations, considering carefully the image which comes before your mind, and classify the images suggested as indicated by the degrees of clearness and vividness specified on the Rating Scale.

Item	Rating
31. Fatigue	()
32. Hunger	()
33. A sore throat	()
34. Drowsiness	()
35. Repletion as from a very full meal	()

Rating Scale

The image aroused by an item of this test may be:

Perfectly clear and as vivid as the actual experience	Rating 1
Very clear and comparable in vividness to the actual experience	Rating 2
Moderately clear and vivid	Rating 3
Not clear or vivid, but recognizable	Rating 4
Vague and dim	Rating 5
So vague and dim as to be hardly discernible	Rating 6
No image present at all, you only 'know' that you are thinking of the object	Rating 7

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