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Technical Report 759

Spatial Cognition and Map Interpretation

Sharon Tkacz

Technologies for Skill Acquisition and Retention

Training Research Laboratory

U. S. Army

Research Institute for the Behavioral and Social Sciences

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The effectiveness of the Map Interpretation and Terrain Association Course (MITAC) developed by the Navy Personnel Research & Development Center was evaluated, in cooperation with the First Marine Division at Camp Pendleton, CA. MITAC instruction significantly improved subjects' ability to perform terrain association, a critical skill in position location.

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20. Abstract (Continued)

In addition, individual differences in spatial abilities were assessed to identify cognitive components underlying map interpretation. Two components, orientation and visualization, were found to be equally important for predicting real-world position location. Additionally, comparison of experimental and control groups' spatial aptitude scores indicated that the success of MITAC in improving terrain association was not a result of increased spatial aptitude. Instead, the course was effective because it taught a procedural, orientation strategy that can be learned by those with low spatial ability.

Finally, field and classroom performance was compared to wayfinding in a simulated (videogame) environment in which position coordinates were available during play. Game performance was significantly related to both field and classroom performance, and to spatial aptitude. High-spatial-aptitude individuals travelled farther between requests for position information, suggesting that they have larger spatial memory spans.

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Education and Training

FOREWORD

The Airland Battle doctrine calls for synchronization of battlefield operations in order to mass forces and firepower quickly. The high mobility required demands that troops navigate independently more frequently over long distances. Improved training in land navigation will be critical for soldiers operating in small elements dispersed throughout a battlefield without stable lines or areas of control. Units will need to operate independently, placing more emphasis on individual navigational skills. Failure to orient effectively in continuous operations will adversely affect mission accomplishments.

There are many skills required for proficiency in land navigation. Among these, position fixing, the ability to accurately determine location by means of map interpretation, is foremost.

The following report describes an evaluation of the Map Interpretation and Terrain Association Course developed by the Navy Personnel Research & Development Center (NPRDC). In addition, individual differences in spatial skills were assessed in order to understand the cognitive components underlying map interpretation. This work constitutes part of the personnel exchange program between NPRDC and the Army Research Institute, and was carried out in coordination with the First Marine Division, Camp Pendleton, CA.

Edgar M Johnson
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The author is grateful for the opportunity to work with Daira Paulson, Jill Hirsch, and Margie Morris, the geographers responsible for the development of the Map Interpretation and Terrain Association Course at NPRDC. The success of MITAC is due to their curriculum, which identifies critical map interpretation skills and systematically describes them, thus forming an orderly set of easily understood and remembered procedures. She also wishes to thank the First Marine Division, Camp Pendleton, CA, and NPRDC for their technical and logistic support; Dexter Fletcher, Dick Kern, and Rick Yekovich for their review of the manuscript; and ARI staff members, including George Dalton, Doug Duncan, Jerry Williams, Joe Duval, Cassi Fields, Patti Watson, and Zita Simutis, for their programming, statistical, and emotional support.

The views expressed in this paper are solely those of the author and not necessarily those of any of the aforementioned individuals, the U.S. Army Research Institute, or the Department of Defense. Portions of this research were presented at the Annual Meetings of the Eastern Psychological Association (Tkacz, Paulson, Hirsch, & Morris, 1986; Tkacz & Fields, 1987).

SPATIAL COGNITION AND MAP INTERPRETATION

EXECUTIVE SUMMARY

Requirement:

The purpose of this research was to determine the effectiveness of the Map Interpretation and Terrain Association Course (MITAC) developed by the Navy Personnel Research & Development Center. In addition, individual differences in spatial skills were assessed in order to understand the cognitive components underlying effective map interpretation.

Procedure:

Marines at Camp Pendleton, CA, comprised the experimental group (who received MITAC instruction) and three control groups (who received no instruction). They were compared on their ability to fix position in the field and in a simulated (videogame) environment.

Findings:

MITAC instruction significantly improved the experimental group's ability to perform terrain association, which has been found to be a critical skill in position location. Orientation ability was found to be the most important underlying cognitive component of terrain association. Rather than improving an individual's aptitude in spatial orientation, however, the course seemed to be effective in teaching an orientation strategy.

Utilization of Findings:

Results show that a cognitive strategy for orienting oneself is a critical factor in map interpretation, and that it is trainable. Previous research has also suggested that visualization is important, although it has been found that most soldiers do not possess this skill to a high degree. This research effort has identified a training strategy that is effective for individuals with average or low spatial aptitude. Future land navigation training should include instruction to improve soldiers' orientation strategies. Revised MITAC curricula have been implemented at Fort Benning in both OSUT (at a basic level) and PLDC (at an intermediate level).

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SPATIAL COGNITION and MAP INTERPRETATION

Cognitive psychologists focus on features of human memory and information processing systems, and study comprehension of spatial relations. In contrast, geographers focus on terrain features, and study spatial relations on the earth's surface. In the present study, psychologists and geographers combined their expertise to evaluate the effectiveness of the Map Interpretation and Terrain Association Course (MITAC). (Specific MITAC curriculum skills are described below.) In addition, this study assessed cognitive components assumed to underly map interpretation were assessed to determine the influence of individual differences on course success and on real world position location. Finally, this study tried to relate position location ability to videogame performance, comparing orientation in the real world to surrogate wayfinding in a simulated environment. High spatial subjects were expected to be better able to interpret topographic maps, to locate real world position, and to escape from a maze in a videogame environment. It was further hypothesized that characteristics of superior performance would be similar in each of these areas.

Psychologists studying spatial cognition have traditionally examined the kind of spatial representations that are formed (Sholl & Egeth, 1980), the way that spatial information is manipulated, how spatial knowledge is retrieved (McNamara, Ratcliff, & McKoon, 1984), or what kind of information is included on maps of familiar environments (Hintzman, O'Dell, & Arndt, 1981; Presson & Hazelrigg, 1984). This research seldom has real world applications, particularly for situations in which a map must be used in a novel environment. Soldiers are rarely called upon to reproduce a map from memory. Instead, they use maps as tools, and the problem becomes one of spatial reasoning, complex decision making, and symbol interpretation, rather than memory.

Results from individual differences research suggest that several factors directly influence the level of spatial performance on map interpretation tasks. Good cognitive "mappers" can be characterized by superior aptitudes such as visual memory, visualization, and spatial orientation ability (Thorndyke & Goldin, 1983). These individuals excel at manipulating spatial information in memory, and at learning an environment from either navigation or a map.

Previous research also has demonstrated individual differences in metacognitive strategies used in spatial problem solving. Thorndyke & Stasz (1979) showed that good learners spontaneously used superior strategies for encoding spatial information, evaluating their progress, and focusing attention on unlearned information. They concluded that the influence of appropriate strategies for processing information that is presented simultaneously, as maps are, outweighs the potential effects of previous experience with maps, since the rate and content of information availability depends entirely on the learner.

While these individual differences in strategy identification have implications for spatial training, it is important to remember that processing strategies are to some extent dependent on basic abilities. Tkacz & Drum (1985) showed gender differences in strategies subjects employed while playing a videogame called MAZE. Those results indicated that mental rotation and orientation skills were used primarily by males, while reasoning and verbal skills were used by females. Tkacz, Paulson, Hirsch, & Morris (1986) found that mental rotation and orientation also predict real world position location.

Cross, Rugge, & Thorndyke (1982) compared acknowledged expert to non-expert Marines on a contour-interpretation task. They identified strategies employed by expert subjects, and concluded that strategy training would yield substantial increases in position-fixing skills of military map users. One of the best expert strategies first involved large landforms (macrorelief) to reduce the area-of-uncertainty. Within a more restricted space, smaller landforms (microrelief) were then used to pinpoint their exact location. In contrast, non-experts performed poorly, and focused only on microrelief. Additionally, they found that neither experts nor non-experts were able to visualize the contour-portrayal of visible terrain, or the real world appearance of landforms portrayed with contour lines, and suggested that visualization training would be beneficial.

This suggestion, however, begs the question of whether visualization is necessary for contour interpretation. Simutis and Barsom (1984) used computer-based graphics in active and passive modes in an attempt to teach terrain visualization. High ability soldiers showed substantial improvement in the active mode, but soldiers of low and medium spatial ability showed no improvement, demonstrating again the importance of matching the basic abilities of the trainee to the training.

Another characteristic that influences individual differences in spatial cognition is working memory capacity. Working memory, in terms of processing or storage functions, has been implicated in individual differences in reading capacity (Daneman & Carpenter, 1980) and verbal ability (Hunt, Lunneborg, & Lewis, 1975). Quantitative measures of short-term memory, however, usually emphasize recall of verbal information. Liben (1981) described an analogous capacity for spatial problem solving, distinguishing between spatial storage and spatial thought (e. g., manipulation of tacit knowledge). Others (Foley & Cohen, 1984a, b) suggest that the working representation, or cognitive map, generated from long-term store, depends on the nature of the spatial task.

Milner (1971) used a clinical neuropsychological measure of spatial span called Corsi's Block Tapping Test. The test consists of nine fixed cubes, tapped in a given sequence at the rate of one per second. The spatial memory span is the longest sequence correctly reproduced by the examinee. This measure has been used to assess impairment after right temporal lobectomy (Milner, 1971) and to investigate cultural and gender differences in children (Orsini, Schiappa, & Grossi, 1981) and in adolescents (Smirni, Villardita, & Zappala, 1983). While the Block Tapping Test is spatially cued, it also relies on visual memory, since all the items are present simultaneously, and available in a single glance.

The current paper proposes an alternative, non-verbal capacity measure of "spatial span". It was hypothesized that high spatial subjects would be more likely to take better advantage of the position information provided by the videogame as a function of greater "spatial memory span". Four operational definitions of spatial memory span (discussed below) were evaluated. One in particular was successful in predicting both orientation ability and game performance. Before describing the experiment, a brief overview of the MITAC curriculum is given in the next section.

Curriculum. MITAC was developed to increase position location accuracy of enlisted Marines by improving map interpretation skills. More specifically, the objective was to teach students how to match their position in the real world with the map. This skill is called terrain association (TA). Several aspects of map interpretation, presented in Figure 1, were emphasized.

First, a landform assessment procedure was developed to teach recognition of both real world and mapped landforms in terms of their Shape, Orientation, Size, Elevation, and Slope (SOSES). The interpretation of contour-line portrayal is a difficult and important aspect of map interpretation (Cross et al., 1982). Accordingly, more than half of the lessons dealt with the identification of hills, saddles, ridges, draws, and fingers in terms of the SOSES. Second, analytical procedures, based on map design guidelines and terrain association factors, were developed for interpretation of hydrography, vegetation, and cultural features. Finally, these procedures were integrated into a terrain association strategy to locate one's position on a map. A key concept in the TA strategy is viewpoint, emphasizing that one's relationship to terrain features is dependent on viewing position.

The course consisted of approximately fifteen hours of lessons developed using an instructional system design approach. The five modules (Introduction, Topography, Hydrography, Vegetation, & Cultural Features) were developed by cartographers at the Navy Personnel Research & Development Center to systematically teach recognition of various categories of real world features and their map counterparts. This was accomplished by side-by-side presentation of photographs of real world features and map portrayals of those features. Graphic overlays indicated specific features on both real world and map slides while cassette tapes described important aspects of the scene. This simultaneous presentation encouraged students in the classroom to compare the real world to the map as they would in the field. Practice exercises, feedback, and discussion followed each lesson.

Figure 2 indicates more specifically the kind of knowledge that must be incorporated in the TA strategy. This knowledge is a combination of rules that would be applied in different instances, and a database of cartographic symbols and their definitions. For example, intermittent streams, shown as dashed blue lines, will probably all be shown in an arid region, but not every one will be shown in a humid region.

The SOSES were used to describe landforms in photographs of the real world, and on the map portrayal of the same features. SOSES are mnemonic cues that would be useful for identifying a feature in

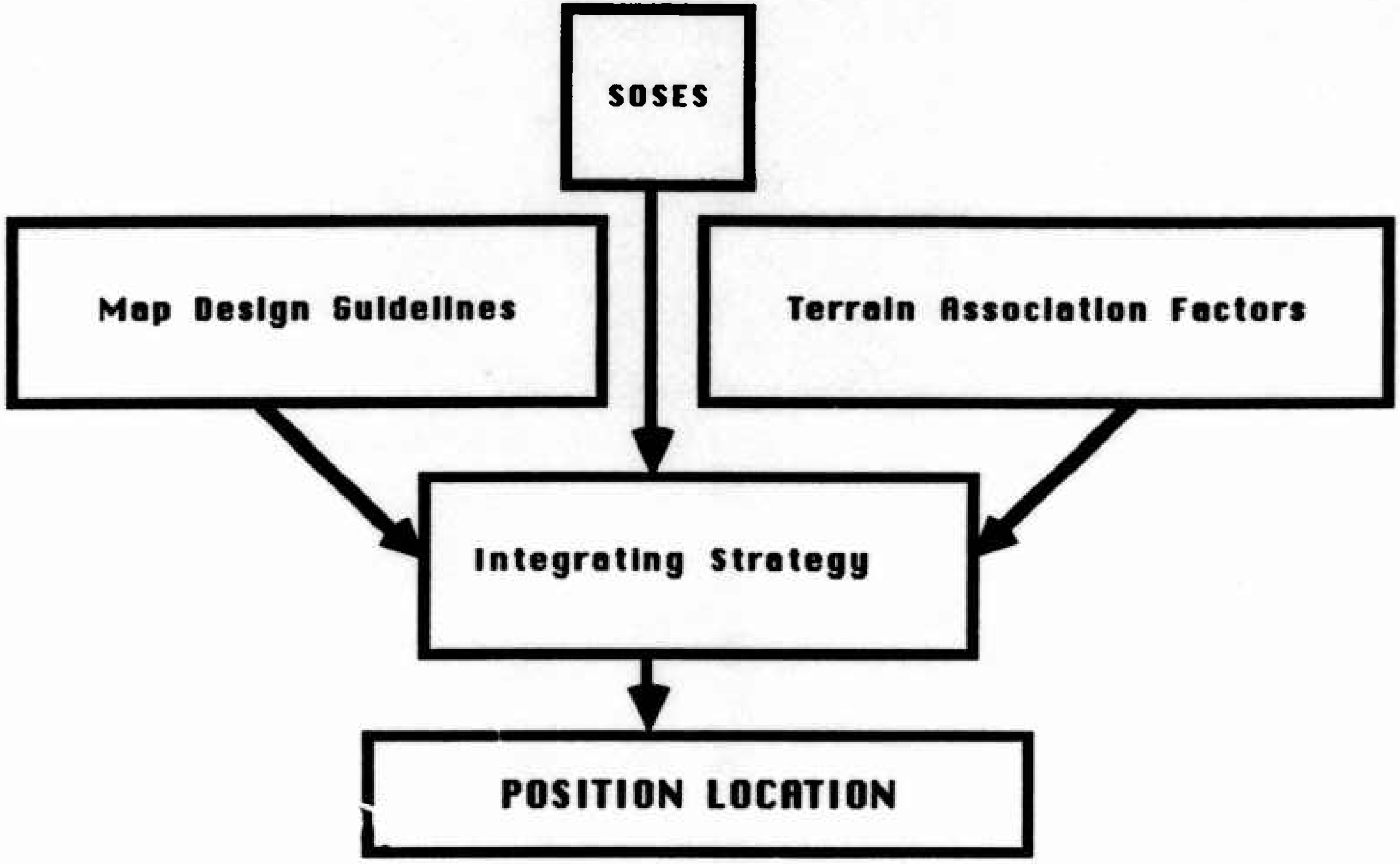

Figure 1. Map interpretation procedures

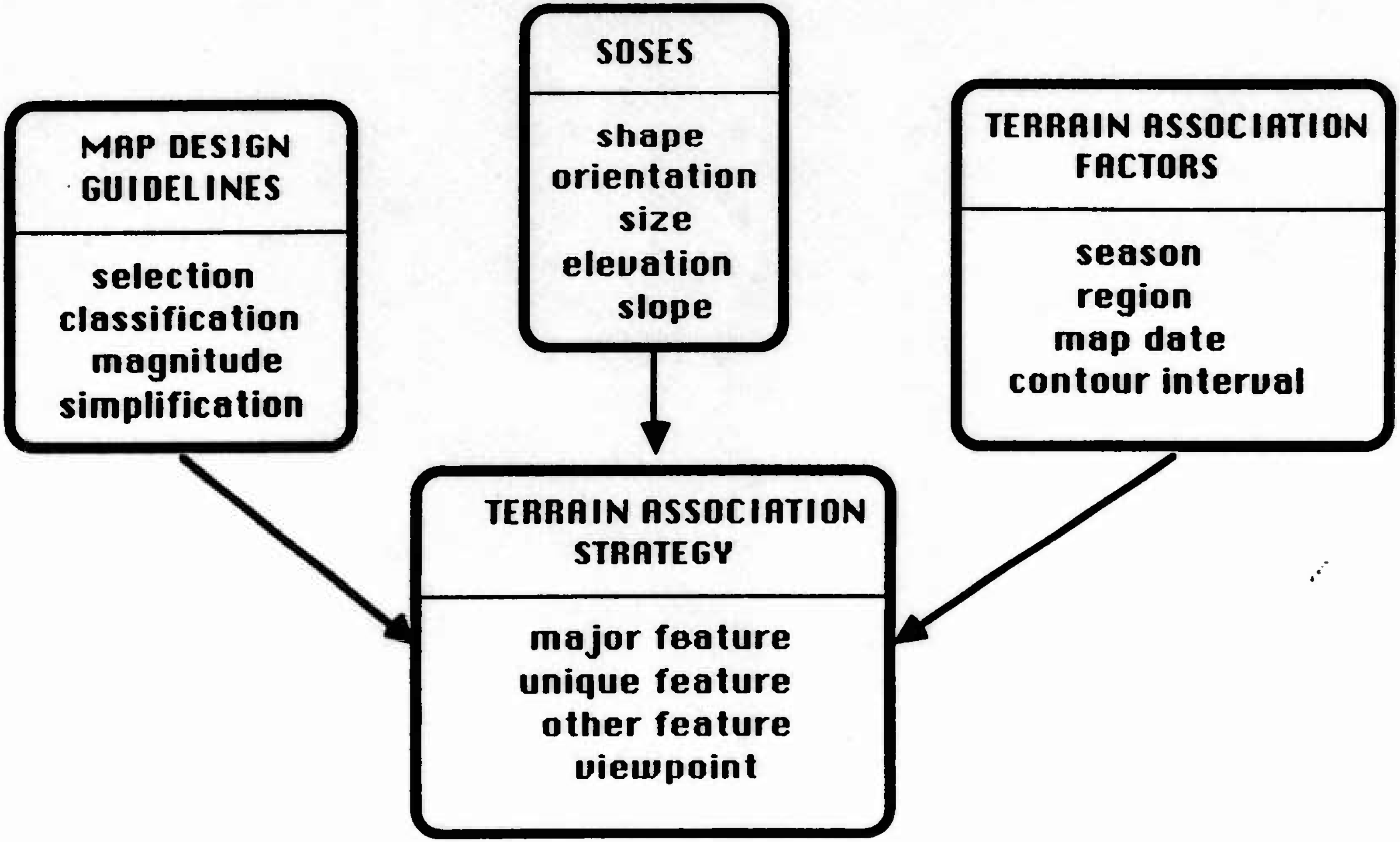

Figure 2. Knowledge incorporated into terrain association strategy.

the real world and finding a match on the map, but are not always useful for every feature. For example, hills are portrayed by round contours, so orientation cannot used to describe a hill. However, a ridge does have orientation, and this cue could be used to eliminate other ridges portrayed on the map that are similar in size or elevation but have a different orientation than the one being observed in the real world. Similarly, elevation is not a cue that describes a draw, but can be useful for identifying the highest hill visible in the real world, and then finding its map portrayal.

Map design guidelines explain which terrain features are portrayed, when they will be shown, and how they are symbolized. The selection guideline emphasizes that maps are selected samples of real world features, and should not be expected to be virtual representations. For example, a stand of trees will not be shown on a map unless it covers an area fifty meters by fifty meters. Similarly, the magnitude guideline emphasizes that related features (e. g., roads) vary in boldness (i. e., width of black line) to show relative size or use. Finally, symbols and associated colors were explained for hydrography (e.g., blue line representing a stream), cultural (e.g., dashed black line representing a secondary road), and vegetation (e.g., open green circles arranged in even rows and columns representing orchards) features.

T.A factors must also be considered when interpreting a map. Variables such as season and region are not explicitly presented on the map, but will affect the amount of water and vegetation present. For example, during the spring, annual vegetation, not shown on the map, may be present. In contrast, cultural features (such as a building) shown on the map may not be present. By looking at the map date, the observer can determine that a discrepancy like this is not critical if the map is very old.

Finally, all of the knowledge acquired in the individual lessons is combined into the TA strategy in order to match a combination of features in the real world with the map. The first step is to match a major feature (any feature that is large, obvious, or prominent), in the real world with its map portrayal. Next, another, unique feature (one that has an unusual characteristic) is located on the map. (Although identification of only two features may allow position to be fixed, students were encouraged to match other visible features with the map.)

After a combination of real-world features were matched to the map, "viewpoint" was determined. Figure 3 is a sample of a TA practice exercise that shows how viewpoint was presented in the classroom. The task was to choose the topographic feature (I or J) that matches the real world photograph if "viewed" from one of the triangles. By matching the center of one's viewpoint in the real world (top of Figure 3) with the imagined viewpoint from each of the triangles on the map (bottom of Figure 3), position on the map can be determined.

This emphasis on viewpoint teaches that one's position absolutely determines relationships amoung features and relationships between the observer and the terrain. The TA strategy is a generalization of this viewpoint technique, establishing position by iteratively determining location from several viewpoints until the observer reaches a criterion of confidence.

Method

Subjects

One hundred five Marines were assigned to participate. Only the experimental group (E), consisting of 31 noncommissioned officer (NCO) students, participated in training. Three groups, including 19 staff instructors (C1), 20 platoon sergeants (C2), and 35 NCO students (C3), served as control groups. The control groups were selected because they were readily available and because they represented a wide range of previous navigation training and military experience. All subject groups were either assigned to the First Marine Division at Camp Pendleton, California (C1) or were attending school to receive training in areas unrelated to land navigation (E, C2, C3). Their mean age was 23.6 years, with an average of 4.8 years of experience in the Marine Corps.

Measures

Several kinds of measures were collected that can be classified into four categories: Armed Services Vocational Aptitude Battery (ASVAB), SPATIAL, GEOGRAPHY, and PERFORMANCE. Each of these is described in detail below, and summarized in Figure 4. In contrast to the PERFORMANCE measures, the SPATIAL, GEOGRAPHY, and ASVAB categories consisted of paper-&-pencil tests.

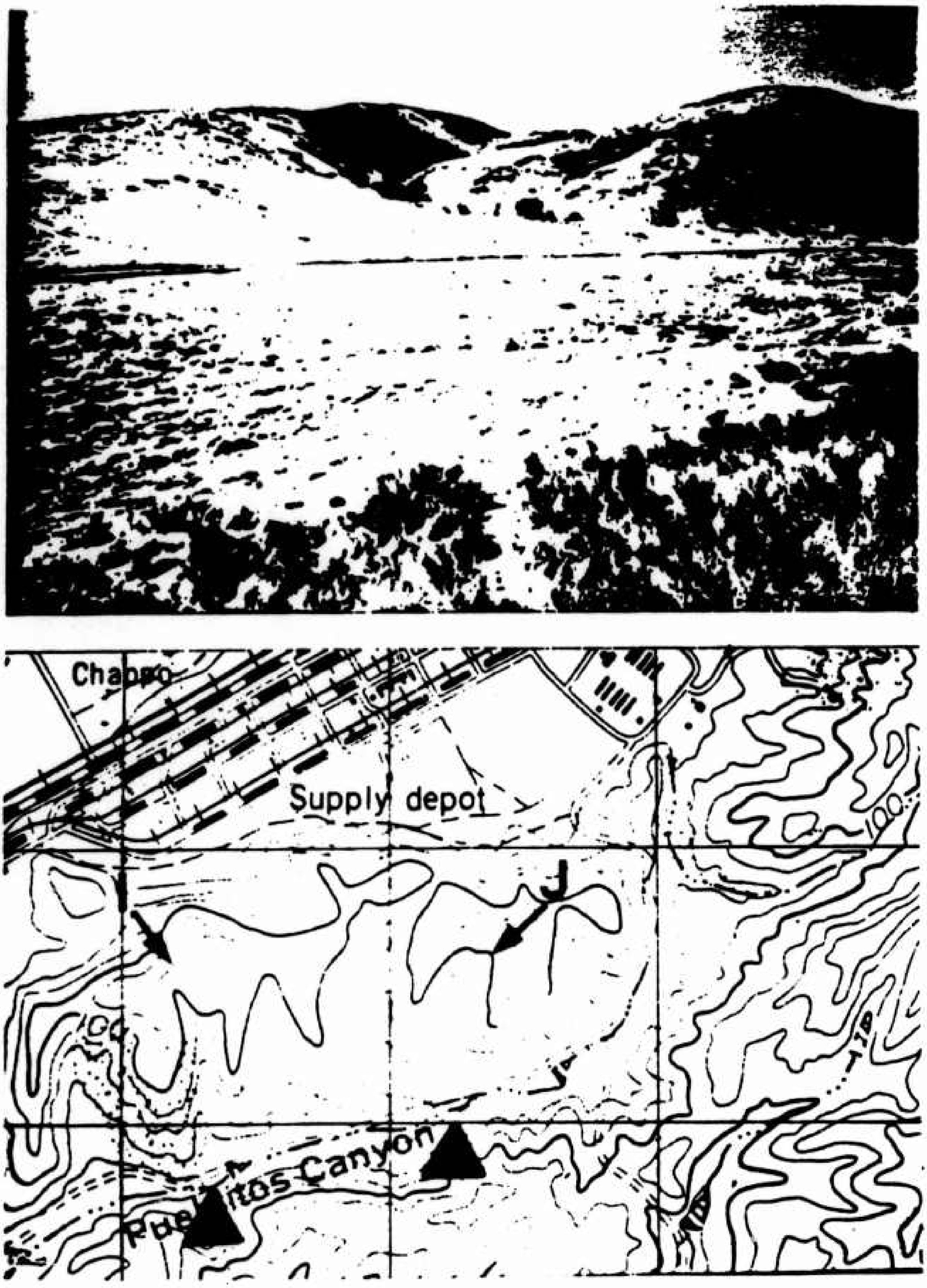

Figure 3. Sample item from the TA practice exercises indicating real world draw and two possible viewpoints.

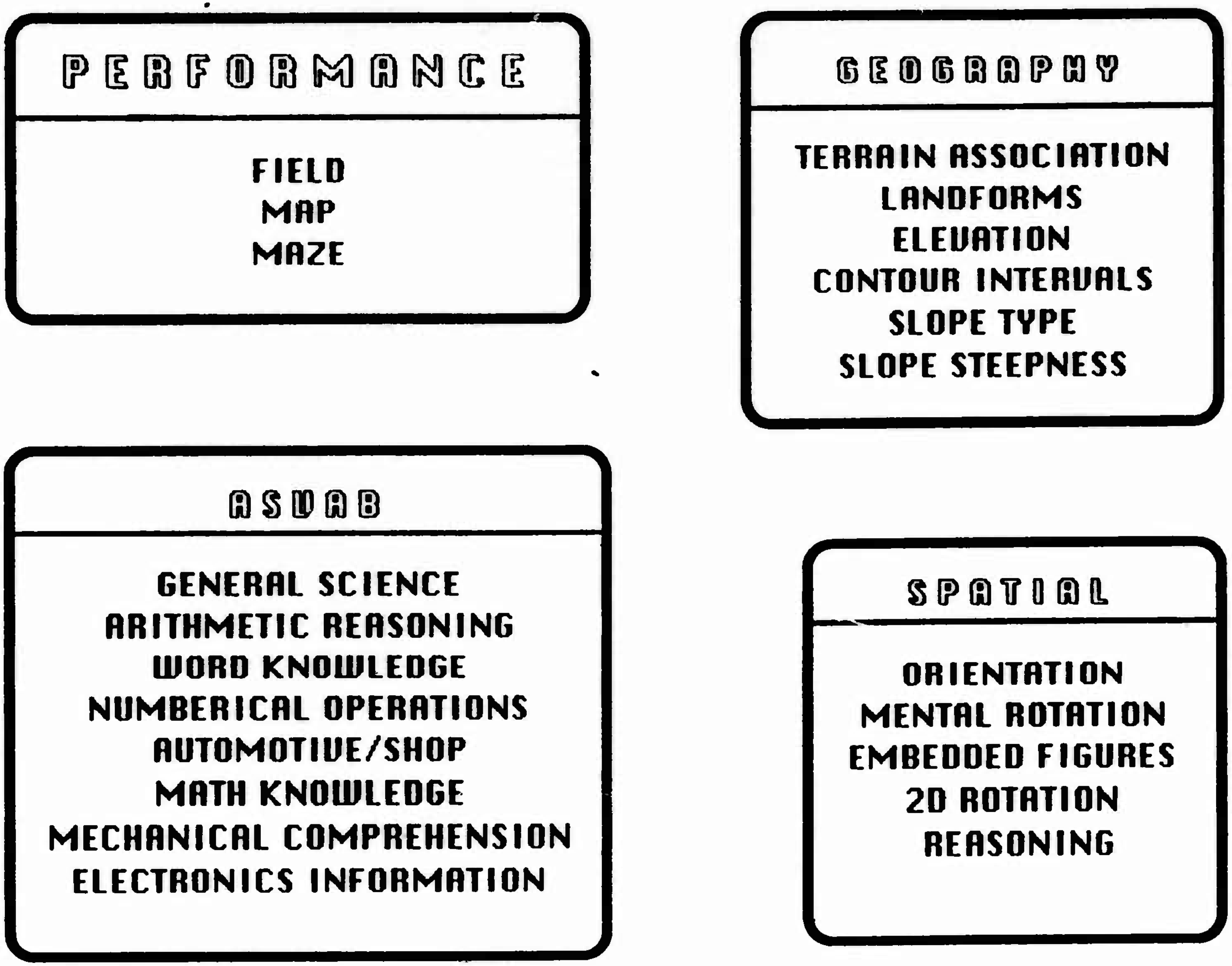

Figure 4. Four categories of variables

ASVAB. Because the ASVAB is administered to recruits at the time of their application to military service, different versions of previously collected subtest scores (ASVAB 5/6/7 or ASVAB 8/9/10) were available. Consequently, only standardized scores for subtests common to both versions of ASVAB were used in the analyses. These were general science (GS), arithmetic reasoning (AR), word knowledge (WK), numerical operations (NO), automotive/shop (AS), math knowledge (MK), mechanical comprehension (MC), and electronics information (EI).

SPATIAL. The spatial test battery assessed spatial cognitive skills not covered by the ASVAB. These tests were selected to cover a wide range of spatial aptitudes that might be involved in map interpretation. These were mental rotation (MR) in three dimensions (Shepard and Metzler, 1971), orientation (O), two-dimensional or flat rotation (2D), embedded figures (EF), and figural reasoning (R), (Wing, 1985). Appendix A provides sample items from each of these tests.

GEOGRAPHY. The geography measures were achievement tests designed in coordination with the curriculum to measure knowledge acquired during the course. The sum of all subtests is referred to as the MITAC score when an overall measure of course performance is compared to other variables. The MITAC test consisted of 46 items, comprising six sections: determining contour intervals (CI), calculating elevation (E), identifying slope type (ST), determining slope steepness (SS), landform recognition (L), and terrain association (TA). These measures were collected the same way that the instruction was presented. That is, slides of real world and mapped features were shown, and students recorded their responses on test sheets. For example, an Elevation item might present a location marked between two index contours on a map. The students' task would be to compute the contour interval and extrapolate in order to determine elevation. Other sections (such as Slope Type or Landforms) simply requested vocabularly (e.g., 'concave' or 'saddle', respectively). A sample item from the most important subtest, Terrain Association, has been presented in Figure 3.

PERFORMANCE. Performance measures consisted of real world position location (FIELD), a map reading "readiness" exercise (MAP), and simulated travel in a videogame environment (MAZE). FIELD was comprised of nine sites at Camp Pendleton where subjects were required to indicate their real world position on a topographic map. At each site, subjects were given one 8.5 x 11 inch section of a 1:50,000 scale map. The map was marked with four locations several hundred meters apart (see Appendix B). For each site, the subject had to select which of the four possible locations was their correct position. The total score consisted of the number of times a subject correctly chose their position for the nine sites.

MAP assessed basic map skills, assumed to be known by all Marines, such as reading grid coordinates or determining a contour interval on a map (see Appendix C). This test served as a pretest, similar to the Map Reading Diagnostic Pretest used in the Basic NCO Course at the Sergeant Major Academy, Ft. Bliss. This is a test of map reading, as opposed to map interpretation, because most of the information requested is available directly from the map.

MAZE was a microcomputer-based game that required subjects to escape from a 5 x 5 x 5 cubic maze by typing cardinal directions (e. g., "east") in order to move from one room to another (Tkacz & Drum, 1985). The object of MAZE was to move as quickly as possible through the 125 room structure to the goal room, and then find the door that led to the outside of the building. Subjects were asked to play a series of twenty games. Each game was played in a unique, randomly generated maze (with a unique exit door). For each maze, the probability that a wall would have an exit door was .8, resulting in a series of rooms and doorways relatively easy to negotiate. All subjects used the same mazes in the same order. However, initial position was randomly generated at the beginning of each game, so that subjects playing in exactly the same maze started in different rooms.

During the four practice games, both their current position and the goal room location were continuously displayed on the screen in terms of X, Y, Z coordinates, as were the cardinal direction they were facing (i.e., north) and the score (or elapsed time, in seconds). Figure 5 shows what the screen might look like during a typical practice game. During the next sixteen games, coordinate information was available to subjects only upon request, and every request for either their current position or goal location was recorded as they played.

These protocols of information requests were used to derive four spatial memory span measures, described in detail below. An individual protocol consisted of a linear record of key presses and

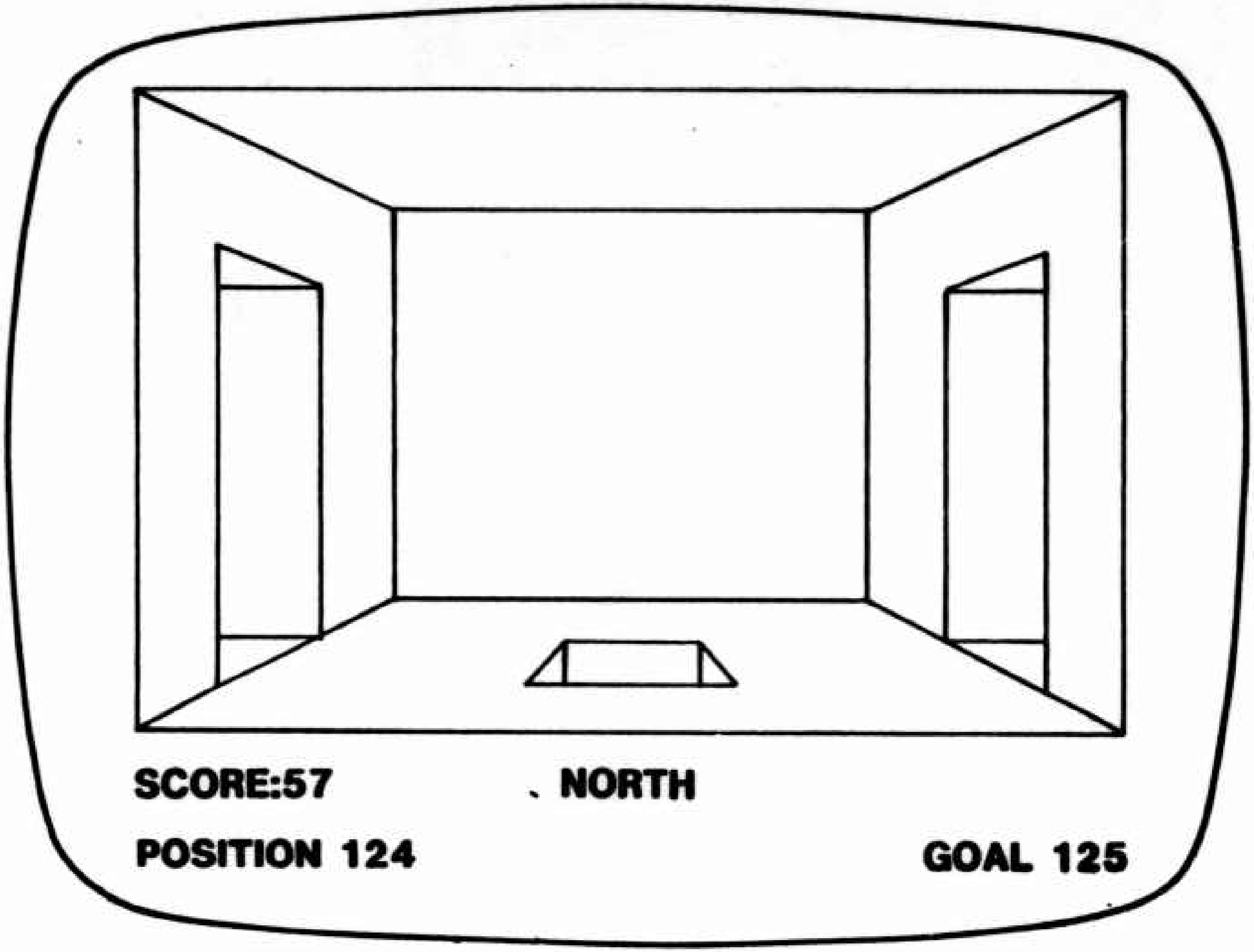

Figure 5. Sample screen during a MAZE practice game.

microcomputer clock times. Two measures were based on positionrequests (PR) and two on goal requests (GR). These measures were derived using an original PASCAL program developed at the Army Research Institute.

Subjects were given a handout to quickly acquaint them with information on how to play the game, and to reduce the memory requirement for that information. As shown in Figure 6, the handout presented the proper keys to request position (i. e., "?") or goal (i. e., "$") information, a perspective "map" of the building, and a diagram indicating the relationship of X, Y, Z coordinates to dimensions in the maze.

Difficulty level was increased by forcing the subject to change orientation every four games, first facing NORTH, then EAST, then WEST, and finally SOUTH. All games were played in one session, which lasted less than two hours for the average player.

Procedure

After the MAP exercise, approximately fifteen hours of MITAC instruction was administered to the E group over a two week period. The MITAC instruction was scheduled so as to interfere as little as possible with their Leadership School training. Upon completion of this instruction, GEOGRAPHY tests, designed to measure achievement in the course, and SPATIAL tests were administered. The three control groups took the SPATIAL tests, MAP exercise, and the GEOGRAPHY tests without receiving MITAC instruction. It was felt that comparison of the C groups' SPATIAL scores (i. e., "pre-test") and E group SPATIAL scores (i. e., "post-test") would reflect the effect of MITAC instruction on spatial skills.

Initially, only groups E, C1, and C2 were made available for participation in this study. Consequently, only these three groups played MAZE. Because of the limited number of microcomputers available, subjects were scheduled to play MAZE thoughout the data collection period.

The last measure to be collected for every group was the FIELD score. This data collection in the field involved logistic and administrative support from the First Marine Division, and was completed in two days.

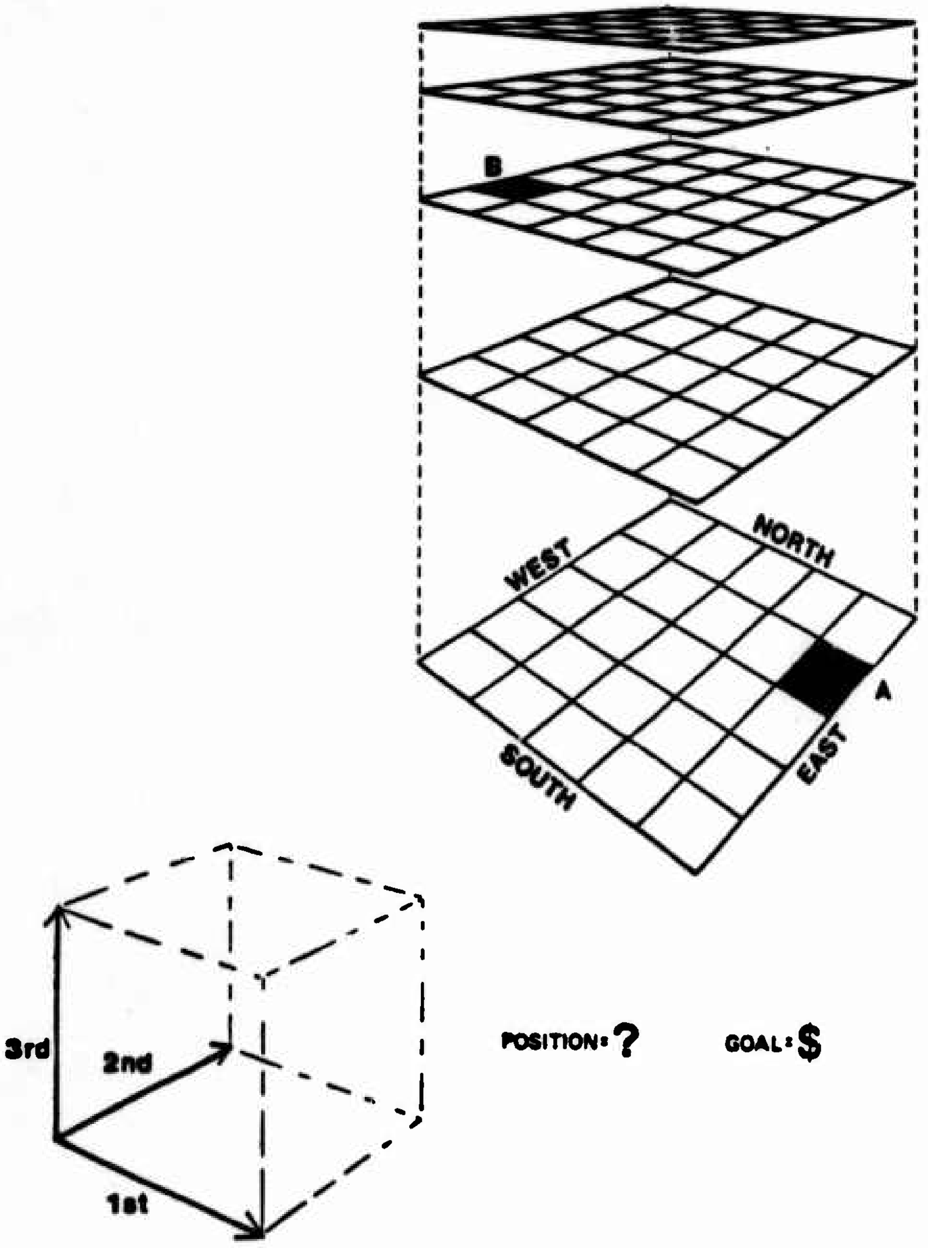

Figure 6. Videogame handout showing request keys, MAZE "map", and coordinates diagram.

Results & Discussion

Included below are several different types of data analyses. Each speaks to different, though related, questions concerning the nature of spatial cognition. First, multivariate analyses of variance examined means of E and C groups to describe the subject population in terms of the dependent variables (SPATIAL, GEOGRAPHY, and PERFORMANCE). The purpose of these analyses was to evaluate the effectiveness of MITAC in teaching terrain association skills to the E group. Next, multiple regression analyses are described that provide insight into individual differences in performance. These data are of greatest importance in identifying the cognitive components underlying performance in the field and in the classroom, and in understanding why MITAC is effective. Finally, a detailed analysis of videogame data attempted to relate the same cognitive components to spatial memory span.

Group Differences

A MANOVA comparing the four groups on eighteen variables indicated that there were overall group differences ($F_{(3,71)} = 4.66$, $p < .001$). The variables included were eight ASVAB subtests, five SPATIAL tests, one geography measure (MITAC score), two demographic measures (age, experience) and two PERFORMANCE measures (FIELD, MAP). Univariate tests showed that differences were obtained in age, experience, and MITAC score (see Appendix D for univariate statistics). (Recall that MITAC is a composite score of all GEOGRAPHY measures). The C2 group was older (26.6 years) than the other three groups (E, C1, C3: 23.1, 22.8, 22.1 years, respectively) and more experienced (7.8 years vs. 4.1, 3.8, 3.4 years). The C2 group consisted of platoon sergeant students who were in their second-tour. Consequently they were approximately three years older and had three years more experience in the Marines than the other groups. The E group, however, was superior (36.4) to all three other groups (C1, C2, C3: 30.8, 23.8, 18.0, respectively) on the overall MITAC score. In fact, post-hoc Newman-Keuls comparisons indicate that all groups differed significantly from each other ($p < .05$).

Because the groups differed significantly in age and experience, the possibility that these variables were mediating the MITAC effect was evaluated. Accordingly, the analysis was repeated with age and experience as covariates. The MANCOVA again yielded a significant overall effect (F = 4.45, p <.001), obtaining significant differences in MITAC score and two-dimensional rotation (see Appendix E for univariate statistics). Tables 1 and 2 show unadjusted mean scores (and standard deviations) for each group for SPATIAL tests, MAP pretest, and ASVAB measures, indicating that the groups were essentially equivalent in areas expected to be related to map interpretation. This equivalence of groups is critical because it demonstrates that the MITAC effect is not attributable to pre-existing individual differences in aptitudes.

Since the MITAC score is a composite of several subtests (described above under GEOGRAPHY), another MANCOVA was used to compare the four groups on each of these, with the same demographic measures as covariates. The multivariate F was highly significant (F = 15.9, p < .001), as were all univariate F-tests (see Appendix F). When compared to the most appropriate control group, the other NCO students (C3), the performance of the E group was superior on all six sections of the MITAC test, as shown in Table 3.

Although no group differences were found on the FIELD test, this performance measure was correlated with MITAC score (r = .275, p <.002). FIELD scores for all four groups show little variation (5.13, 5.37, 4.90, 4.89 for E, C1, C2, and C3 respectively). Unfortunately, FIELD consisted of only nine real world sites; this measure was not likely to be sensitive enough to demonstrate group differences in performance. However, taken together with the superiority of the E group on MITAC score, it seems reasonable to expect real differences in field performance with a more sensitive measure. Conversely, successful field performance depends on both task knowledge (i. e., MITAC score) and correct execution of procedures (i. e., FIELD). The lack of a FIELD effect may simply reflect previous results on performance measurement: "... for the most part different methods of measuring job performance yield quite different results" (Borman, White, Gast, and Pulakos, 1985).

Individual Differences

Correlations of dependent measures are provided in Table 4. MAZE is the mean score over sixteen games, indicating how fast, in seconds, the subject escaped from the maze. (Since it is a speed measure, lower scores indicate better performance, hence the negative correlations). Previous research (Tkacz and Drum, 1985) has shown that the MAZE measure involves both visualization (MR) and orientation (O), and that result is supported here. In

TABLE 1.
Unadjusted means (and standard deviations) for SPATIAL subtests.

SPATIAL SUBTEST	E	C1	C2	C3
ORIENTATION	10.1 (6.1)	10.1 (5.5)	10.9 (5.5)	9.6 (5.9)
MENTAL ROTATION	30.1 (8.3)	32.3 (6.2)	29.6 (6.7)	29.7 (8.0)
2D ROTATION	73.3 (18.4)	81.0 (7.2)	73.3 (10.9)	71.6 (16.8)
EMBEDDED FIGURES	28.5 (10.3)	30.1 (9.1)	27.3 (12.1)	29.8 (10.6)
REASONING	21.0 (5.9)	20.0 (4.7)	19.8 (6.8)	20.7 (4.9)
MAP PRETEST	10.6 (2.8)	12.0 (3.3)	10.0 (3.0)	9.3 (3.5)

TABLE 2.
Unadjusted means (and standard deviations) for ASVAB subtests.

ASVAB SUBTEST	E	C1	C2	C3
GENERAL SCIENCE	50.4 (10.4)	51.6 (5.3)	50.5 (8.5)	51.2 (8.9)
ARITHMETIC REASONING	52.9 (7.8)	52.9 (8.7)	49.0 (10.8)	53.3 (8.0)
WORD KNOWLEDGE	50.0 (7.8)	49.8 (6.7)	53.8 (8.4)	51.9 (6.4)
NUMERICAL OPERATIONS	51.9 (7.9)	51.9 (7.1)	49.5 (6.0)	53.4 (7.0)
AUTOMOTIVE/SHOP	50.4 (9.7)	53.3 (8.5)	51.9 (8.2)	50.7 (6.5)
MATH KNOWLEDGE	53.4 (7.5)	52.3 (7.8)	51.4 (9.2)	53.6 (9.2)
MECHANICAL COMPREHENSION	51.7 (10.1)	51.4 (9.2)	51.7 (7.4)	50.6 (6.6)
ELECTRONICS INFORMATION	49.9 (9.8)	49.7 (8.6)	47.6 (7.3)	49.4 (7.6)

TABLE 3.
Unadjusted means (and standard deviations)
for GEOGRAPHY subtests.

GEOGRAPHY SUBTEST	E	C1	C2	C3
TERRAIN ASSOCIATION	12.7 (2.8)	10.5 (3.3)	9.0 (3.0)	8.4 (2.8)
CONTOUR INTERVAL	2.5 (.8)	1.8 (1.1)	1.6 (1.1)	1.0 (1.2)
ELEVATION	5.1 (1.4)	4.4 (1.3)	3.2 (1.8)	2.8 (1.8)
LANDFORMS	4.8 (.6)	4.0 (1.1)	4.0 (1.0)	2.7 (1.7)
SLOPE TYPE	8.3 (1.9)	7.1 (2.2)	3.2 (4.0)	0.2 (.9)
SLOPE STEEPNESS	3.0 (0)	3.0 (.2)	2.7 (.6)	2.8 (.5)
MITAC (TOTAL)	36.4 (5.8)	30.8 (6.4)	23.8 (8.7)	18.0 (5.5)

Table 4.
Intercorrelations of MITAC, PERFORMANCE and SPATIAL measures.

	MR	O	EF	2D	MAP	MAZE#	MITAC	FIELD
R	.478	.559	.545	.454	.406	-.520	.332	.231*
MR		.505	.359	.511	.348	-.428	.310	.311
O			.490	.468	.541	-.445	.432	.309
EF				.349	.373	-.233**	.184**	
2D					.412	-.430	.292	.236*
MAP						-.363	.544	.294
MAZE#							-.323*	-.210**
MITAC								.275*

$p < .001$ for all values except those indicated
$p < .01$ for values indicated by *
$p < .05$ for values indicated by **

$n = 105$ for all correlations except those with MAZE
$n = 68$ for correlations with MAZE

addition, these data demonstrate that MAZE also taps skills involved in reading a topographic map (MAP), and in matching the map to the real world (MITAC score and FIELD). More detailed analyses of game data are described below.

The relationship among SPATIAL, GEOGRAPHY, and PERFORMANCE measures is more clearly described by the factor analysis illustrated in Table 5. All six GEOGRAPHY measures (i.e., MITAC subtests) load very heavily on the first factor, which accounts for 30.5% of variance. The second factor (13.0% variance) is a relatively pure 'method' factor of speeded SPATIAL tests. The last factor (8.3% variance) appears to be a 'performance' factor, with the heaviest loading by FIELD. This emergence of strong method factors is similar to results obtained by Hanser, Arabian, and Wise (1985). They demonstrated that different measurement methods capture slightly different aspects of performance. The current results indicate that each method measures different but related aspects of spatial performance. While the other PERFORMANCE measures (MAZE and MAP) load on Factor III, they also share considerable variance with Factors I and II, indicating that the relationship of MAZE and MAP to both SPATIAL and GEOGRAPHY factors are not the result of shared method variance. Instead, these PERFORMANCE measures incorporate complex spatial and geographic skills, suggesting that such performance measures may be required to capture complex skills such as position location.

To determine the importance of individual cognitive abilities on course success, several regression analyses were performed. When all thirteen SPATIAL and ASVAB tests were used to predict MITAC score, the multiple R was .549 (R^2 = .301). In order to estimate unique contributions of important predictors, these two sets of cognitive variables were also analyzed separately. A standard multiple regression of SPATIAL tests onto MITAC score yielded a multiple R = .464 (total R^2 = .215). Orientation, the best predictor, was then removed from the regression equation, and a new R^2 recalculated. The difference in variance accounted for (total R^2 - new R^2) is the usefulness index (UI), an estimate of the unique variance accounted for by the predictor that was removed (see Darlington, 1968). This procedure was used several times to obtain usefulness estimates for important SPATIAL predictors. Similarly, the regression of ASVAB subtests onto the MITAC score yielded a multiple R = .434 (R^2 = .188). Table 6 gives UIs, expressed as

Table 5.
Relationship among GEOGRAPHY, PERFORMANCE, and SPATIAL measures.

VARIABLES	FACTOR I	FACTOR II	FACTOR III
MENTAL ROTATION	.195	.735	.262
ORIENTATION	.371	.638	.299
REASONING	.325	.757	.022
EMBEDDED FIGURES	.109	.775	.123
2D ROTATION	.032	.709	.100
MAZE	.328	.437	.415
CONTOUR INTERVAL	.778	.276	.091
ELEVATION	.342	.218	.063
STEEPNESS	.469	.308	.558
SLOPE TYPE	.670	.298	.028
LANDFORMS	.731	.210	.287
TERRAIN ASSOCIATION	.779	.140	.187
MAP PRETEST	.484	.347	.393
FIELD	.187	.217	.648
% VARIANCE	30.5	13.0	8.3

Table 6.
Usefulness indices from regression analyses of MITAC performance in which SPATIAL and ASVAB variables were used separately as predictors.

Predictor(s)	UI	% of total systematic variance
(SPATIAL)		
Orientation	.064	.30
Reasoning	.009	.04
Mental Rotation	.004	.02
O & R	.092	.43
(ASVAB)		
Arithmetic Reasoning	.042	.22
Mechanical Comprehension	.027	.14
General Science	.002	.01
AR & MC	.085	.45

percent of total R^2, using both sets of cognitive variables separately as predictors. This procedure indicates that O is much more important than MR in predicting course success, and that the Arithmetic Reasoning subtest is the best predictor from the ASVAB. Further, since each predictor is not simply an additive subcomponent, significant composite predictors (e. g., O & R) are also provided.

Although MITAC score and FIELD scores were correlated, different UIs emerged when FIELD was used as the criterion in the regression analyses. When all three sets of variables were included in one regression, R was .695 (R^2 = .483). As before, separate analyses were performed to isolate variance for important predictors. The regression of SPATIAL tests onto FIELD yielded R = .375 (total R^2 = .141). Both orientation and mental rotation were important SPATIAL predictors. Table 7 presents UIs for individual predictors and for combinations of best predictors. Both ASVAB and GEOGRAPHY variables were also significantly related to FIELD. Regressing ASVAB scores onto FIELD resulted in R = .440 (R^2 = .194). The GEOGRAPHY subtests proved to be equally useful predictors, R = .437 (R^2 = .191).

Because the UIs reflect the unique contribution of different components, these analyses reveal important differences between of MITAC and FIELD performance. Both mental rotation and orientation ability were important in FIELD prediction, as indicated by essentially equivalent UIs for MR and O. This result suggests that either orientation or mental rotation ability (but not both) are necessary for position fixing in the real world. This is not true for MITAC performance, for which O accounts for much more variance. This finding indicates that the course is successful in teaching one of the components (i.e., orientation) of real world performance identified in the FIELD analysis as critical. Comparing the means of the four groups, however, indicates that the course did not actually improve orientation test scores. Table 1 shows that scores for the E group, obtained after MITAC instruction, are not higher than the other three C groups (who received no instruction). While this is not exactly a pre-post test comparison, the MANOVA performed on the data in Tables 1 and 2 suggests that no group differences exist apart from the demographic and MITAC score measures. Instead of changes in orientation aptitude, what appears to have been learned

Table 7.
Usefulness indices from regression analyses of FIELD performance in which SPATIAL and ASVAB variables were used separately as predictors.

Predictor(s)	UI	% of total systematic variance
(SPATIAL)		
Orientation	.026	.18
Mental Rotation	.023	.16
2D Rotation	.002	.01
O & MR	.063	.45
(ASVAB)		
Mechanical Comprehension	.091	.47
Auto/Shop	.073	.38
General Science	.014	.07
MC & AS	.110	.57
MC & GS	.134	.69
(GEOGRAPHY)		
Terrain Association	.069	.36
Landforms	.029	.15
Contour Interval	.011	.06
TA & L	.118	.62

is a higher-order orientation strategy.

The most important GEOGRAPHY subtest, in terms of predicting FIELD performance, was terrain association. Thirty-six per cent of total systematic variance is contributed by this subtest. Because it is a fundamental skill in position fixing (Dewey and O'Hanlan, 1986), this GEOGRAPHY subtest was examined more closely. It should be noted that MITAC, the sum total of the six GEOGRAPHY subtests, includes 46 items, 19 of which are TA questions (see Figure 3 for sample item). Orientation was reported above as the critical skill in MITAC test performance. In order to assess the underlying components involved in TA, the SPATIAL measures were used to predict the TA subtest score. Again, orientation was the best predictor, $R = .419$.

In sum, the E group demonstrated superior performance on the MITAC test, the primary cognitive component of which is orientation. In part, MITAC test performance is based on terrain association, for which orientation was again a primary component.

MAZE Performance

In addition to MAZE, the mean number of seconds to escape, videogame measures included four "spatial span" variables extracted from the sixteen games. Two of these described how long position information was remembered, by calculating either the time elapsed (in seconds) or the distance travelled (in rooms) between one request for position coordinates and the next. These are referred to as PR-time and PR-distance, respectively. The other two measures describe how long goal room location was remembered, and are referred to as GR-time, and GR-distance. Because the question of interest here is the general relationship of spatial span to previously identified cognitive processes, these analyses are collapsed over all three groups (E, C1, C2) for whom videogame data are available.

Overall game performance, indicated by MAZE (see Figure 7), significantly improves over sixteen games ($F = 95.47$, $p < .01$). It should be recalled that the facing direction changed every four games, accounting for the obvious non-linear trend. After the initial orientation change from NORTH to EAST, however, subjects seem to have little difficulty with subsequent changes. This interpretation is supported by a significant cubic trend, $F = 11.29$, $p < .01$.

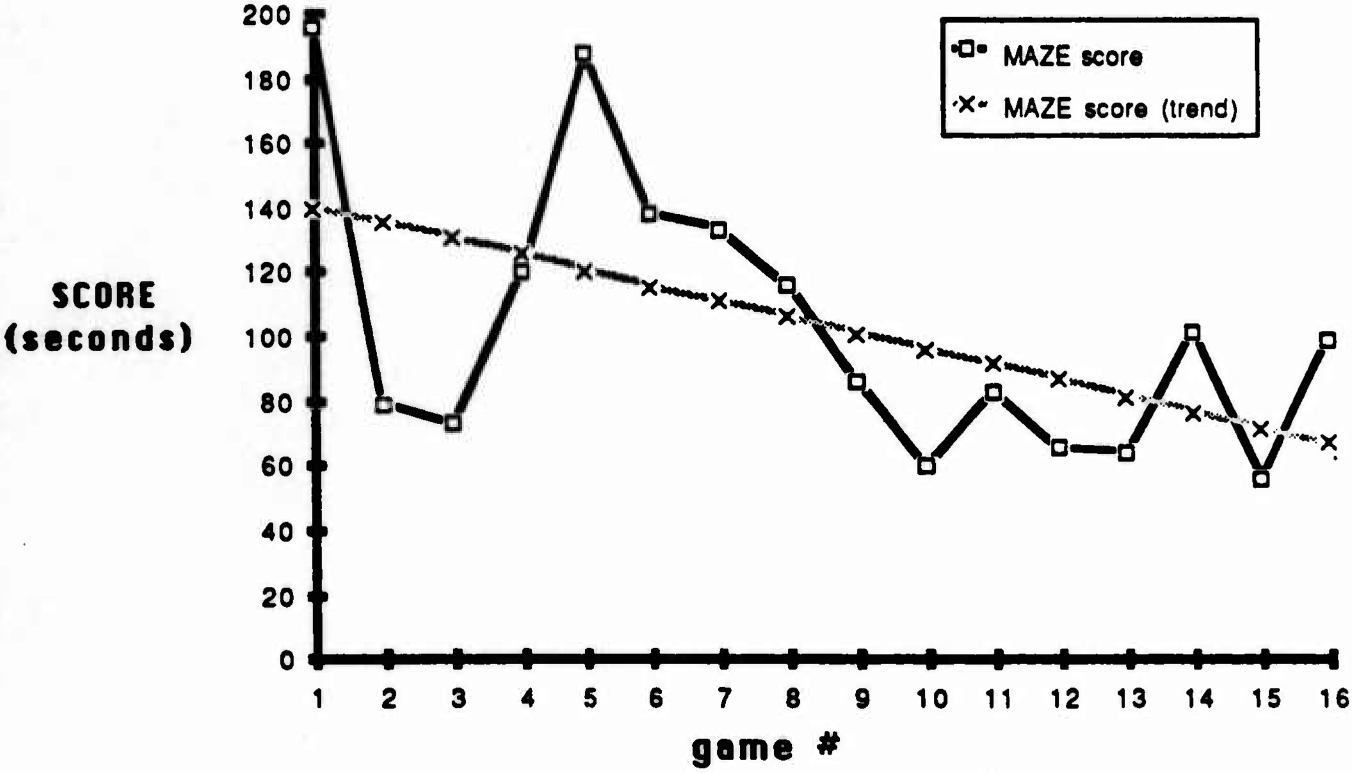

Figure 7. MAZE score as a function of practice.

TABLE 8.
Intercorrelations of spatial span variables with SPATIAL, PERFORMANCE, and MAZE measures.

VARIABLES	Position Requests		Goal Requests	
	time	distance	time	distance
(SPATIAL)				
R		.402	-.261+	
MR				
O		.415		
EF		.434		
2D		.294*		
(GEOGRAPHY)				
MITAC	.324*	.351		
(PERFORMANCE)				
FIELD				
MAP		.317*		
MAZE	.324*	-.201+	.468	

$p < .001$ for all values except those indicated
$p < .01$ for values indicated by *
$p < .05$ for values indicated by +

As seen in Table 4, all SPATIAL tests (except embedded figures) were significantly related to MAZE score. Table 8 shows all SPATIAL tests (except three-dimensional rotation) were highly correlated with one measure of spatial memory, PR-distance, supporting the hypothesis that high spatial individuals would have larger spatial spans. PR-distance was also related to other measures: MITAC score and map reading "readiness". Given the relationships with paper-and-pencil tests of spatial aptitude, and with hands-on measures involving spatial processing, this particular measure of spatial memory span derived from the videogame appears to be a valid construct, and was selected as the operational definition of spatial memory span as described below.

Figure 8a depicts the two spatial memory span measures defined in terms of distance travelled between two requests for information (of the same type). With practice, requests for both kinds of information occur over shorter distances. Figure 8b shows best-fit lines for these functions. Figure 9a depicts the two spatial memory span measures defined in terms of time elapsed between two requests for information (of the same type). Both of these also decrease with practice. Trends for these data are given in Figure 9b. All four functions obtain significant linear trends ($p < .01$).

The fact that all four span functions decrease with practice is curious. One counter-intuitive interpretation might be that playing MAZE reduces memory capacity. Another is that this is an indication of a strategy shift. Subjects may request information more frequently with practice in order to reduce working memory load as interference from previous games increases.

This change in spatial span with practice was examined more closely, using PR-distance as the operational definition of spatial memory span. The mean spatial span for all subjects was 1.4 rooms (standard deviation = .4). Subjects were divided into low span (< 1.2 rooms) or high span (> 1.6 rooms), and separate functions plotted for each. As seen in Figure 10, individuals with low spans show no change with practice, and request position information every time they enter a new room. The high span function does obtain a significant linear trend ($F = 6.55$, $p < .05$), suggesting a subtle strategy shift over games. A MANOVA performed over sixteen games, however, indicated that these lines are different ($F = 45.0$, $p < .001$). (See Appendix G for univariate statistics.) In contrast to low span individuals, those with high spans appear to maintain a

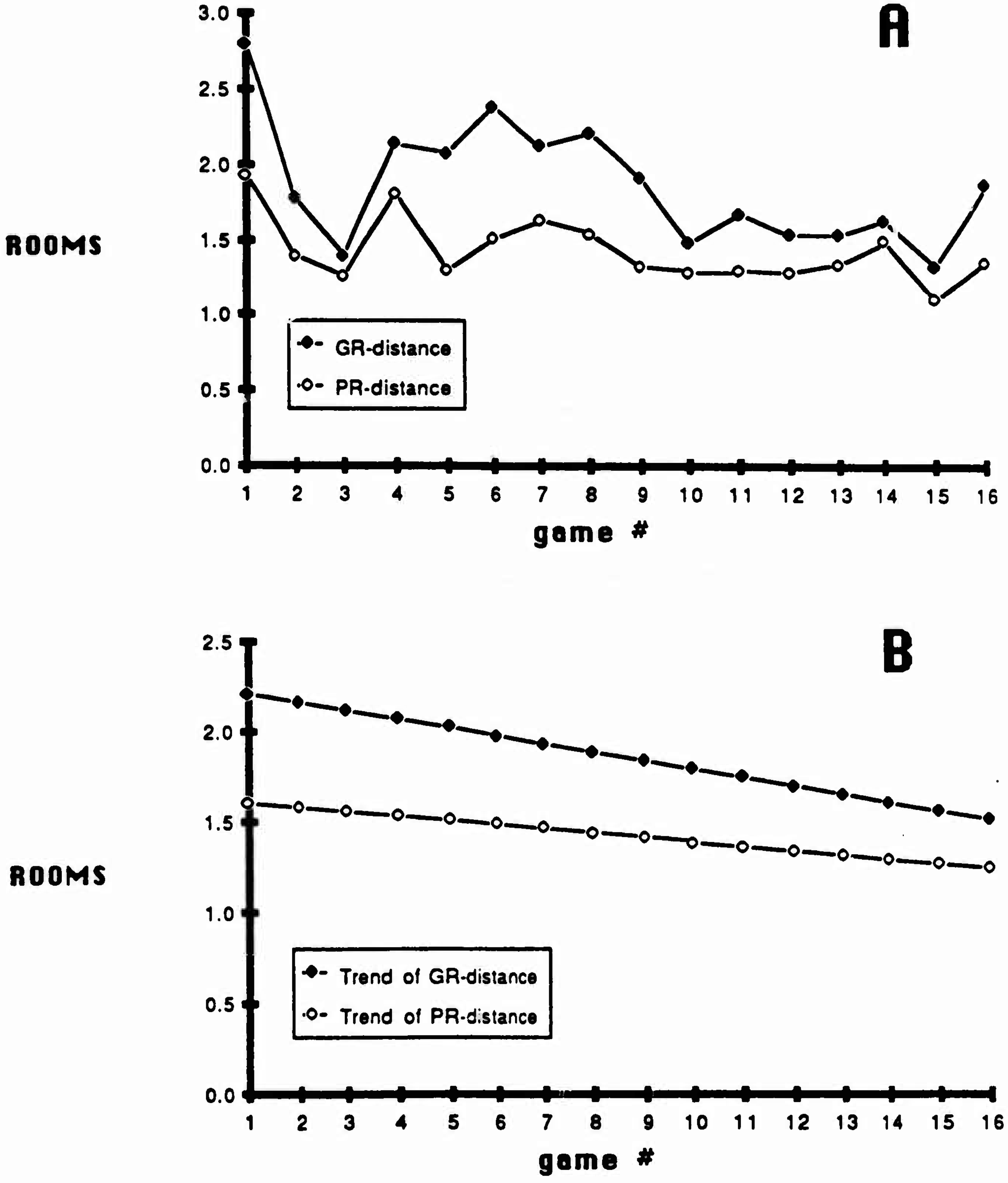

Figure 8. Spatial span (distance) as a function of practice.

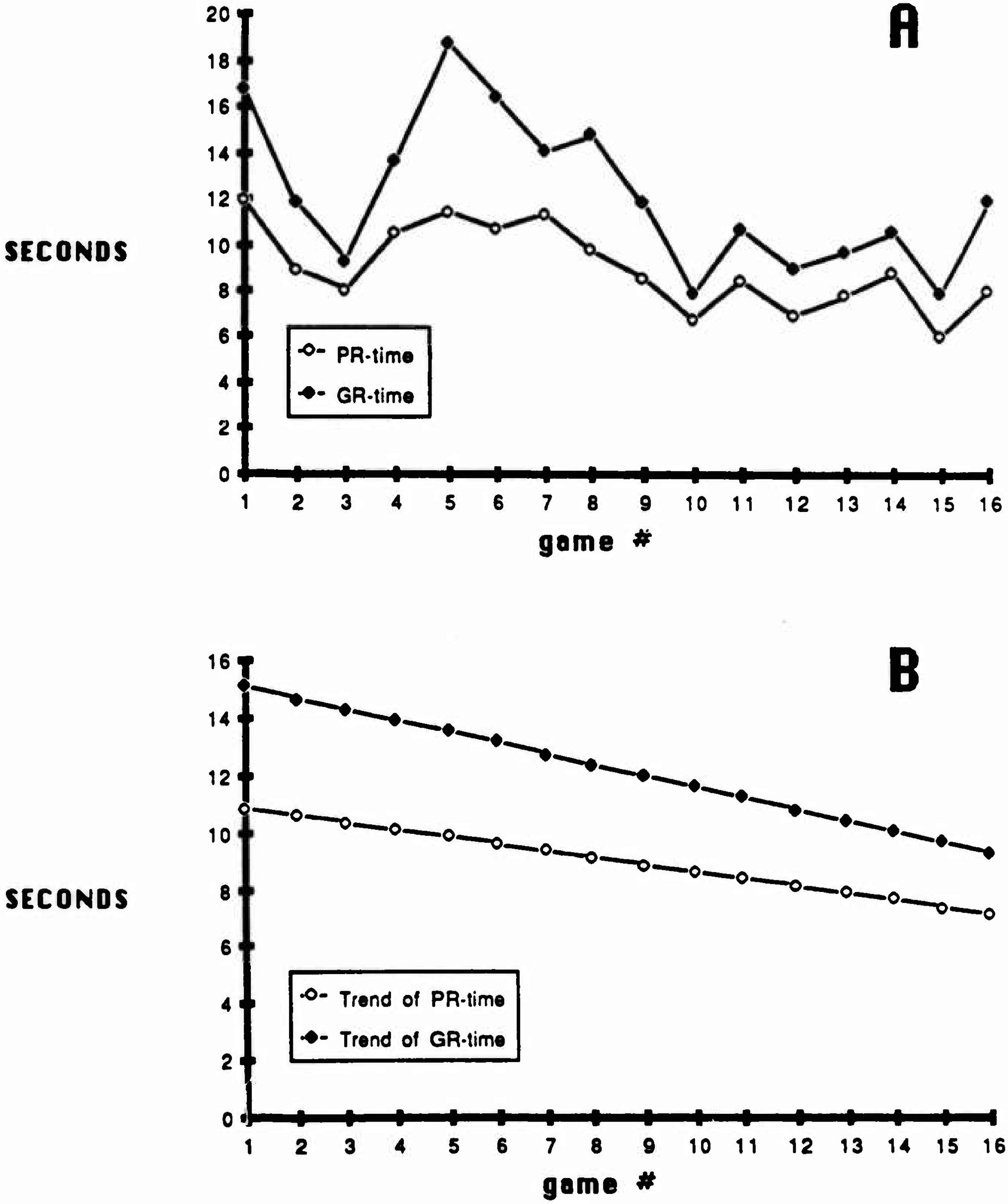

Figure 9. Spatial span (time) as a function of practice.

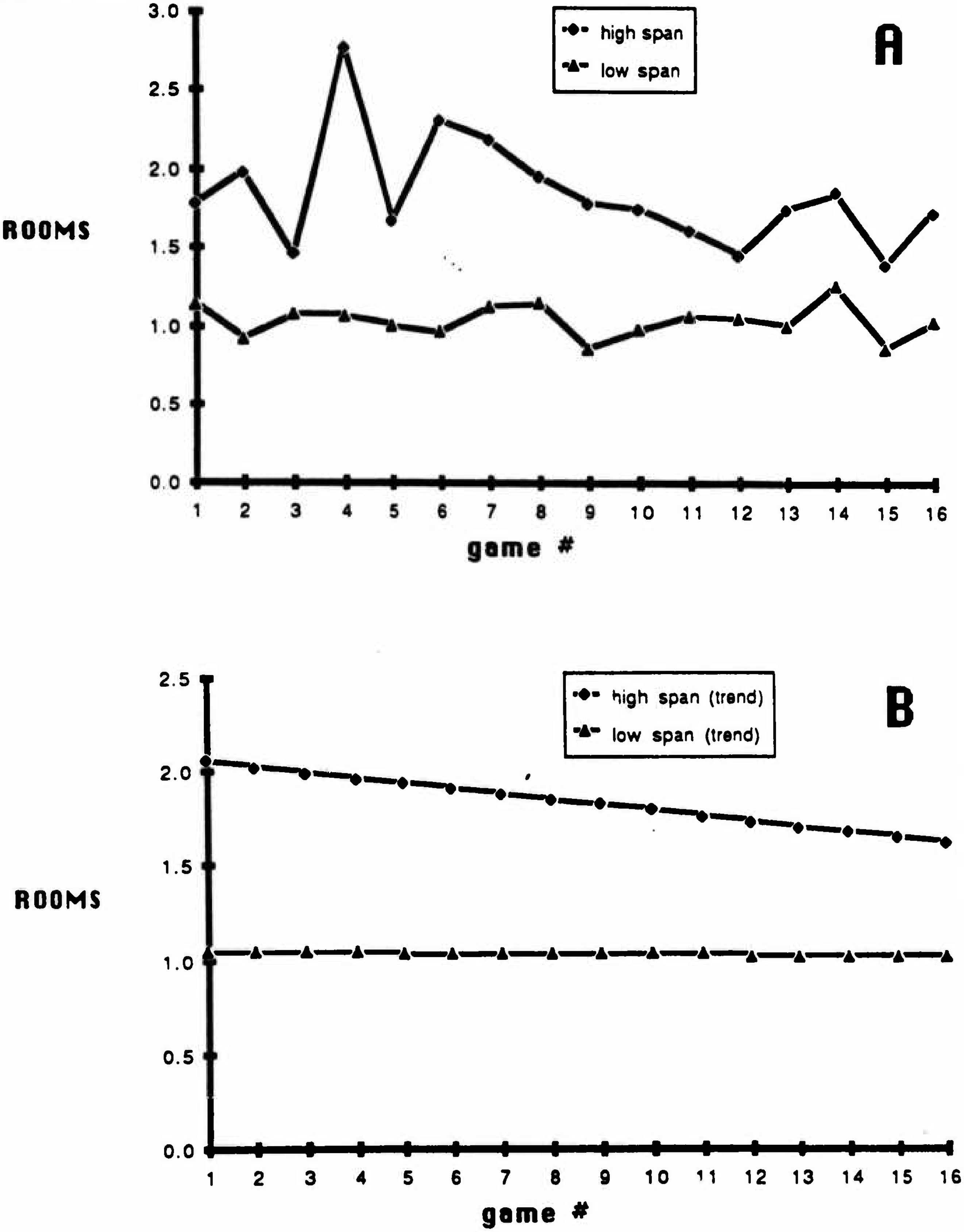

Figure 10. Spatial span functions as a function of practice and span size.

representation of their location twice as long. As with expert and novice chess players, however, memory capacity may not be the distinguishing feature (Kern, personal communication, 1987). Rather, high span individuals must be able to use or interpret both the stored position representation in conjunction with the current position information, updating their cognitive map as they move.

Conclusions

MITAC instruction significantly improved ability to perform terrain association and relate the real world scene to its topographic map representation. Individual differences analyses indicated that orientation is the most important cognitive component of terrain association. Since there were no group differences in orientation aptitude as measured by the paper-and-pencil tests, what appears to have been learned is an orientation strategy.

MITAC score was also related to MAP, the pretest of map reading "readiness". MAP assessed basic skills that are necessary for map interpretation, though not prerequisites for terrain association (e.x., reading grid coordinates). The relationship of MITAC to MAP may result from the common procedural nature of these two sets of skills. Those who are able to learn, remember, and execute a series of procedures correctly would tend to perform well on both the MITAC tests and MAP exercises.

Although some investigations have found three-dimensional rotation to be important in map learning (Stasz, 1980, Stasz and Thorndyke, 1980), it does not seem to be necessary for map interpretation. Sholl & Egeth (1980) suggested previously that map learning and map interpretation are two distinct skills, and that hypothesis is supported here. Other investigators (Cross et al., 1982) have suggested that map interpretation instruction include visualization training, even though experts were unable to visualize the contour-line portrayal of visible terrain, or visualize the real world feature of a contour-line portrayal. The present study has demonstrated that mental rotation, or visualization, is not a necessary condition, and that orientation ability is a sufficient condition for position location. The success of MITAC in teaching this equally successful skill is an important result. It is unquestionably easier for individuals who can perform complex spatial operations efficiently to demonstrate flexibility in choosing or developing an appropriate strategy. The challenge is to identify equally effective, non-spatial strategies for those without that facility.

Spatial aptitude was related to game performance in two ways. High spatial individuals escaped from the MAZE more quickly. They also had larger spatial spans as measured by PR-distance, indicating that they travelled farther than low spatial individuals between two position requests, remembering the position coordinates longer. Since their position was constantly changing, they held some representation or cognitve map of their previous location after they were no longer in that location, suggesting they were able to update the representation as they moved. Because this strategy characterizes high spatial individuals, we can speculate that the representation is spatial in form.

Finally, individual differences in MAZE performance suggest that this measure involves a combination of skills, including three-dimensional rotation, orientation, and those involved in map reading and map interpretation. Since movement is critical in learning about space and spatial relations, further research should determine whether these abilities can be improved by using a combination of computer graphics and simulated travel.

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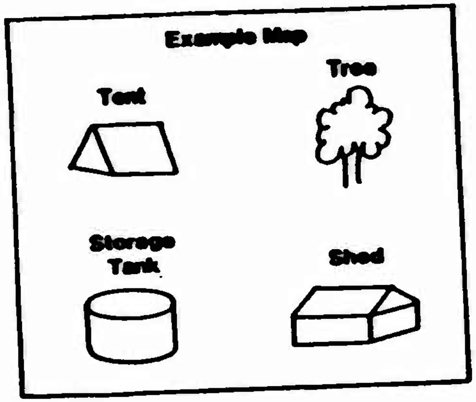
Appendix A

Sample items from SPATIAL subtests

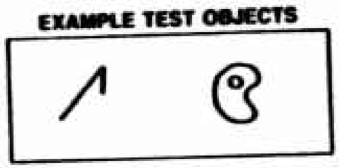
ORIENTATION

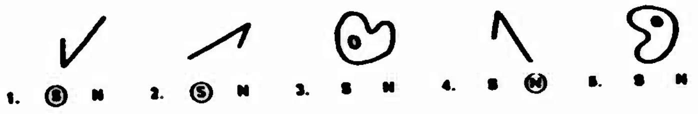


1. The shed is due north of the tree. You are at the storage tank. Which direction must you travel to reach the tent?

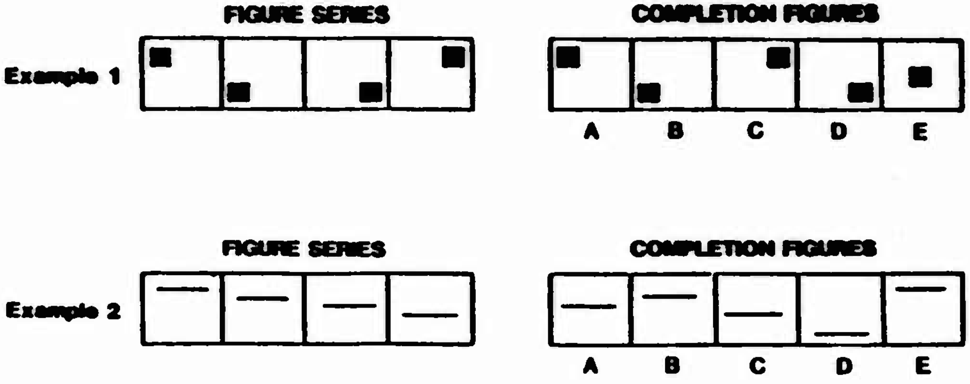
   1. N 2. NE 3. E 4. SE 5. S 6. SW 7. W 8. NW

TWO-DIMENSIONAL ROTATION TEST

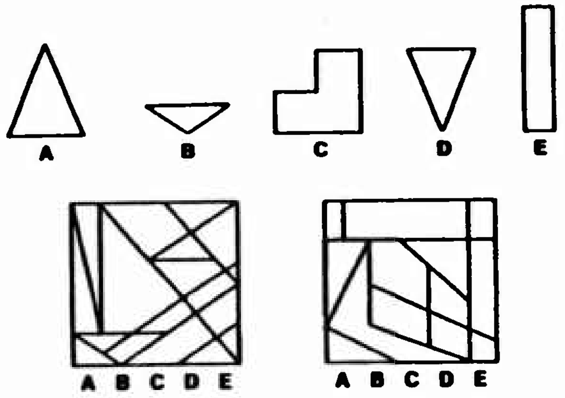




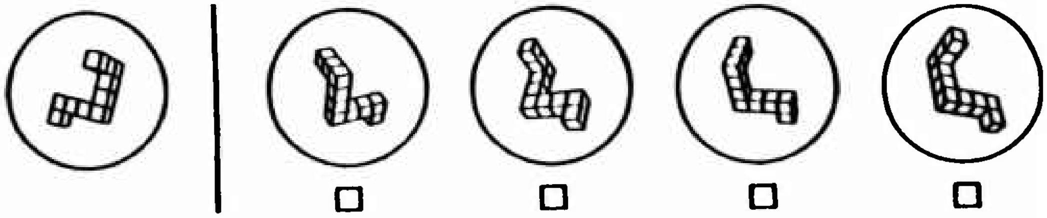
REASONING TEST



EMBEDDED FIGURES TEST

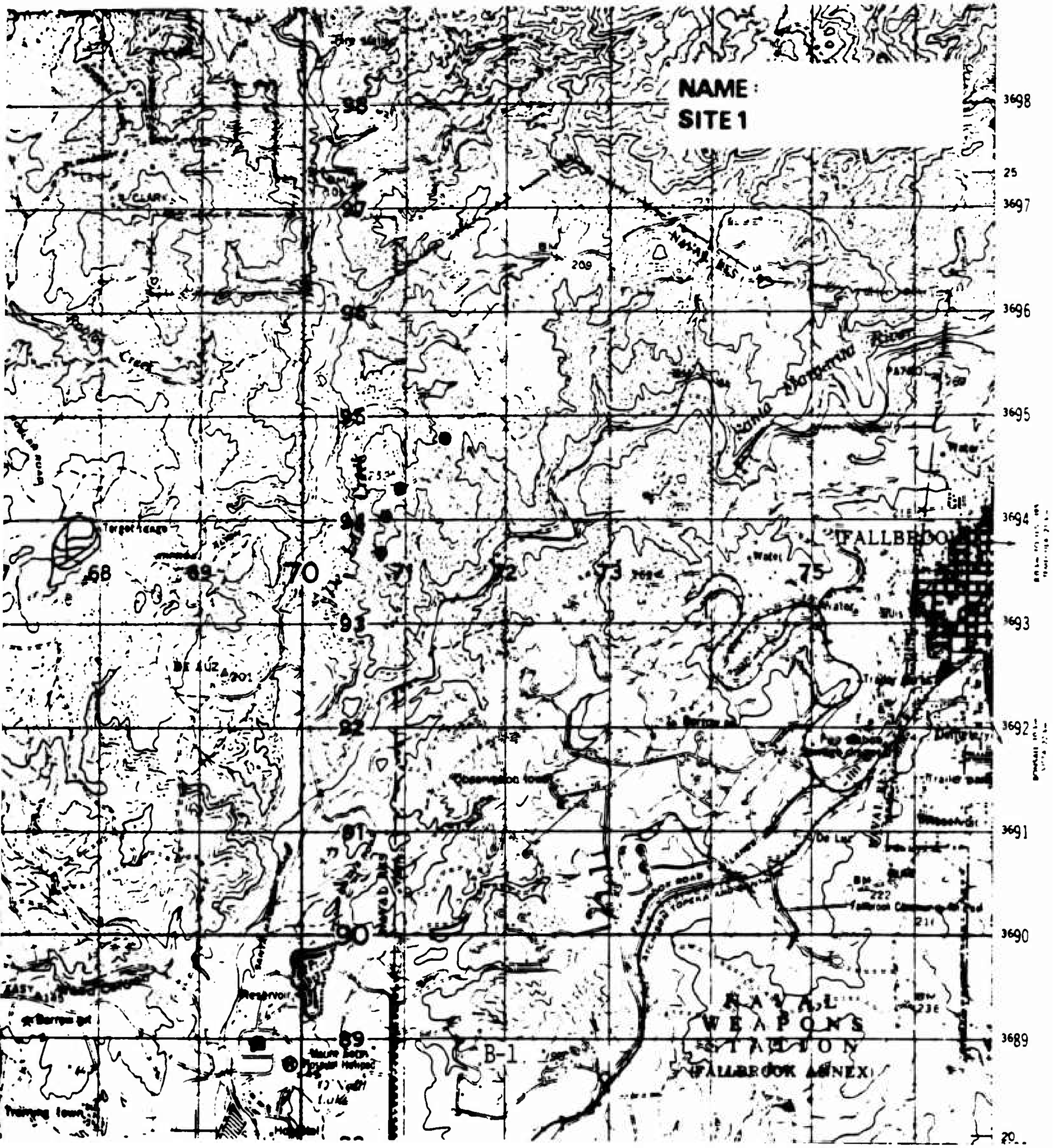


MENTAL ROTATIONS TEST



Appendix B

Sample FIELD test item showing multiple-choice options



Appendix C

Map reading pretest

#______________

MITAC Pretest

1. What is the sheet name?

2. What is the sheet number?

3. If you needed a map of the area north of this map, what is the adjoining sheet number you would ask for?

4. What is the scale of this map?

5. What is the contour interval?

6. How wide is one grid square (in meters)?

7. What letter of the alphabet is located at grid coordinates 630917?

8. What letter of the alphabet is located at grid coordinates 694040?

9. What are the 6-digit grid coordinates of the letter "O" in the word "OCEAN" (lower left corner)?

10. What are the 6-digit grid coordinates of the letter "M" in the word "MARINE" (middle)?

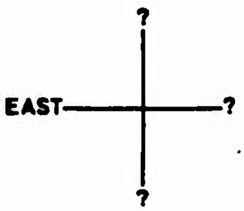
11. On the moveable brass rim of the compass, how many degrees equals one click?

12. It is dark, and you cannot see your compass. How many clicks do you put on your compass so that you can travel an azimuth of 35 degrees in the darkness?

13. For a magnetic azimuth of 80 degrees, what is the corresponding grid azimuth?

14. What is the distance (in meters) from the first letter in Pendleton to the last letter (center of map)?

15. Write the names of the compass direction indicated by the three question marks to the right:



Appendix D

UNIVARIATE F-TESTS FOR ALL MANOVA VARIABLES

VARIABLE	F	SIGNIFICANCE OF F
GENERAL SCIENCE	.077	.972
ARITHMETIC KNOWLEDGE	.854	.469
WORD KNOWLEDGE	1.056	.373
AUTOMOTIVE/SHOP	.454	.715
MATHEMATICS KNOWLEDGE	.297	.828
MECHANICAL COMPREHENSION	.437	.727
ELECTRONICS INFORMATION	.308	.819
NUMERICAL OPERATIONS	2.273	.087
REASONING	1.527	.215
2D ROTATION	1.556	.208
MENTAL ROTATION	.339	.797
EMBEDDED FIGURES	.795	.501
ORIENTATION	.277	.842
AGE	5.725	.001
EXPERIENCE	11.839	.001
MAP	2.172	.099
FIELD	.679	.568
MITAC	33.542	.001

Appendix E

UNIVARIATE F-TESTS FOR ALL MANOVA VARIABLES WITH AGE AND EXPERIENCE AS COVARIATES

VARIABLE	F	SIGNIFICANCE OF F
GENERAL SCIENCE	.232	.874
ARITHMETIC KNOWLEDGE	.089	.966
WORD KNOWLEDGE	.850	.471
AUTOMOTIVE/SHOP	.856	.468
MATHEMATICS KNOWLEDGE	.479	.698
MECHANICAL COMPREHENSION	.945	.424
ELECTRONICS INFORMATION	.108	.955
NUMERICAL OPERATIONS	1.107	.352
REASONING	1.534	.215
2D ROTATION	3.891	.013
MENTAL ROTATION	.177	.912
EMBEDDED FIGURES	.270	.847
ORIENTATION	1.146	.337
MAP	2.338	.081
FIELD	.885	.453
MITAC	38.471	.001

Appendix F

UNIVARIATE F-TESTS FOR THE GEOGRAPHY SUBTESTS, WITH AGE AND EXPERIENCE AS COVARIATES

VARIABLE	F	SIGNIFICANCE OF F
CONTOUR INTERVAL	11.419	.001
ELEVATION	14.563	.001
SLOPE STEEPNESS	4.452	.006
SLOPE TYPE	87.753	.001
LANDFORMS	17.959	.001
TERRAIN ASSOCIATION	13.026	.001

Appendix G

UNIVARIATE F-TESTS FOR SPATIAL SPAN ACROSS SIXTEEN GAMES

VARIABLE	F	SIGNIFICANCE OF F
SPAN (1)	9.7	.003
SPAN (2)	13.2	.001
SPAN (3)	6.3	.015
SPAN (4)	34.9	.001
SPAN (5)	31.0	.001
SPAN (6)	43.6	.001
SPAN (7)	13.3	.001
SPAN (8)	13.9	.001
SPAN (9)	16.3	.001
SPAN (10)	17.2	.001
SPAN (11)	11.0	.002
SPAN (12)	5.4	.023
SPAN (13)	16.7	.001
SPAN (14)	11.8	.001
SPAN (15)	14.5	.001
SPAN (16)	22.3	.001