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ABSTRACT

This report describes the third study in a program of research dealing with the relationships between the characteristics of human tasks and the abilities required for task performance. The goal of the program is to generate principles which can be used to identify ability requirements from knowledge of the characteristics of a task and of variations in the conditions of task performance. The study investigated the relationship between variations in a prototypic problem-solving task, concept identification, and consequent changes in the abilities related to problem-solving performance. Characteristics of the problem-solving task were manipulated by varying the formal difficulty and perceptual complexity of the problems. Subjects performed the criterion task under the different experimental conditions, and then received a battery of reference tests designed to measure abilities which were hypothesized to relate to problem-solving performance. The test battery was factor analyzed to identify a reference ability structure. The loadings of the various criterion task conditions on that structure were then estimated. Results suggested that certain task variations change the nature of the task in such a way that subjects change their approach or strategy for dealing with the task. Such changes may require different ability profiles; thus they may account for changes in abilities related to performance as a function of changes in task characteristics. Further analysis is planned to examine the interactions of task variation, subject strategies, and ability profiles. (Author/BJG)

Methods for Predicting Job-Ability Requirements:

III. Ability Requirements as a Function of Changes in the Characteristics of a Concept Identification Task

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Technical Report

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This report describes the third study in a program of research dealing with the relationships between the characteristics of human tasks and the abilities required for task performance. The goal of the program is to generate principles which can be used to identify ability requirements from knowledge of the characteristics of a task and of variations in the conditions of task performance. Such knowledge has important implications for both selection and training of personnel.

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Block 20. ABSTRACT (Continued)

The present study investigated the relationship between variations in a prototypic problem-solving task, concept identification, and consequent changes in the abilities related to problem-solving performance. Characteristics of the problem-solving task were manipulated by varying the formal difficulty and perceptual complexity of the problems. Subjects performed the criterion task under the different experimental conditions, and then received a battery of reference tests designed to measure abilities which were hypothesized to relate to problem-solving performance. To determine the relationship between task characteristics and ability requirements, the test battery was factor analyzed to identify a reference ability structure. The loadings of the various criterion task conditions on that structure were then estimated.

Six separate ability factors were identified; four were found to be related to criterion task performance. The ability relationships seemed not only to reflect task variations, but also to depend on the various dependent variables. These dependent variables were hypothesized to relate to different aspects of performance.

The results of the study suggested that certain task variations change the nature of the task in such a way that subjects change their approach or strategy for dealing with the task. Such changes in approach may require different ability profiles; thus they may account for changes in abilities related to performance as a function of changes in task characteristics. Further analysis is planned to examine the interactions of task variation, subject strategies, and ability profiles.

AIR-31300-4/75-TR

METHODS FOR PREDICTING JOB-ABILITY REQUIREMENTS:

III. Ability Requirements as a Function of Changes in the Characteristics of a Concept Identification Task

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INTRODUCTION

The ability to make accurate personnel decisions has become increasingly important in the modern Navy. The imposition of severe budget constraints, the creation of a volunteer service, and the introduction of new systems, jobs, and tasks have all contributed to the need to maximize the efficient utilization of manpower. For the past several years the American Institutes for Research has been involved in studying an important aspect of this problem: the development of systems for the description and classification of tasks which would permit more effective selection, placement, and training of personnel. Support for this work has come from many sources, including ARPA, NTEC, and, currently, ONR.

Research by Fleishman and his associates focused on the development of several systems or taxonomies for the description and classification of tasks (e.g., Fleishman, Kinkade, & Chambers, 1968; Fleishman & Stevenson, 1970; Fleishman, Teichner & Stephenson, 1970; Theologus, Romashko, & Fleishman, 1970; Wheaton, Mirabella, & Farina, 1971; Levine, Romashko, & Fleishman, 1971; Farina & Wheaton, 1971; Wheaton & Mirabella, 1972). The fundamental hypothesis underlying this research was that tasks might usefully be described not only in terms of more physically descriptive task taxonomies focusing on display, control, and procedural dimensions, but also in terms of the abilities necessary to perform them. Given such an abilities description of a task, the personnel decision maker would be capable of selecting, placing, or determining appropriate training for any individual by comparing that individual's abilities with those required by any job in question.

A second and related hypothesis which has emerged from this work is that there may exist a set of principles which could be used to relate the objective, physical characteristics of a task to task demands or the abilities required by the task. For example, Fleishman (1957) demonstrated that in a choice reaction time task where stimulus and response locations were intially in a simple spatial correspondence, individual differences were accounted for primarily as a function of the factor-analytically defined Perceptual Speed ability. However, as spatial correspondence of the stimuli and response decreased (the display surface was rotated relative to the response surface), two other factors became important--Spatial Orientation and Response Orientation. This finding suggested the possibility of translating between the two kinds of task descriptive languages: that which is based on ability requirements, and that which describes tasks in terms of their physical characteristics.

By demonstrating that as a physical task characteristic was manipulated, abilities could play a changing role in performance, the study suggested the need for further research on how tasks, having scalable physical differences, might be described in terms of task demands or ability requirements. Based on such research, physical changes which occur as a task characteristic is varied would be translated into new ability requirements appropriate to the new version of the task.

A system for translation of physical task dimension changes into ability requirement changes must be capable of dealing with the many kinds of relationships which are possible, since each pattern may have different personnel implications. For example, the correlation between a given ability and performance may remain constant as the task characteristic in question is varied. This would suggest that no change would be necessary in selection instruments or training programs for a newly developed system which includes changes along this particular characteristic, for this given ability.

A second possible pattern could occur if an ability-performance correlation increased as a task characteristic was systematically changed. For example, in the 1957 Fleishman study cited above, the correlation between Spatial Orientation and task performance increased as display rotation increased, while the correlation between Perceptual Speed and criterion task performance decreased. In this case one might want either to screen candidates more stringently for their abilities in Spatial Orientation or provide special training for responding to display rotations. Other possible task dimension-ability patterns include decreasing correlations, and non-monotonic trends, each with its own personnel processing implications. The full (and often complicated) picture emerges when all of the required abilities are considered simultaneously, and multiple task characteristics are varied.

The study by Fleishman (1957) and another by Zimmerman (1954), using the experimental-correlational method, each varied a single task characteristic. Wheaton, Shaffer (Eisner), Mirabella, & Fleishman (1973) used the same method to examine task demands in an auditory signal identification task. Unlike the earlier studies, however, two task characteristics (signal duration and signal-to-noise ratio) were experimentally m [illegible] using a factorial design. In line with the overall goal of fi [illegible] task characteristics which related reliably to task demands or abilities, it was hoped in this study that each task characteristic would generate its own set of task demand patterns. Instead, the findings indicated that changes in either characteristic produced similar changes in task demands. Correlations of the Auditory Perception factor with performance increased as either (or both) task characteristic made the task more difficult, while four other ability factor-performance correlations were small and remained constant as the task characteristics were changed.

Rose, Fingerman, Wheaton, Eisner, & Kramer (1974) extended the use of the experimental-correlational method to the cognitive area, using electronic fault-finding as the criterion task. The characteristic "formal difficulty" was manipulated by varying the number of possible faults; "perceptual complexity" was manipulated by varying the layout of components in the circuit, while the circuits themselves remained functionally isomorphic. A reference battery of 21 tests was assembled to collect data on five cognitive ability factors which were hypothesized to relate to performance on the fault-finding task. Four of these factors were correlated with performance on the criterion task. One of these (Syllogistic Reasoning) had a fairly constant relationship to criterion performance across the task manipulations, while another (Flexibility of Closure/Spatial Scanning) increased in importance as both formal difficulty and perceptual complexity increased. The remaining two factors (Induction and Associative Memory) decreased in importance as perceptual complexity increased, but remained constant across all levels of formal difficulty.

Thus, in this study, three different patterns of task demand-task characteristic patterns were observed: one factor had a constant correlation with performance, unaffected by the task characteristics manipulated; a second had increasing loadings as both characteristics were varied; two other ecreasing loadings as one characteristic changed, while their loa were unaffected by changes in the second characteristic. Finally, one additional and important result was obtained: the task characteristic-ability relationship interacted with the dependent measure examined. Five such measures were used and a three-way interaction among ability factors, task characteristics, and measure of performance was uncovered. This interaction was interpreted in terms of a strategy model of performance. The authors suggested several strategies which, if adopted by subjects of varying ability levels, could produce the findings they obtained.

Because of the provocative outcomes in the previous study, investigation of another cognitive task was undertaken. Concept identification was selected because it is a prototypic problem-solving task, which has been extensively investigated in the experimental laboratory (e.g., Bourne, 1966; Bourne, Ekstrand, & Dominowski, 1971). In concept identification tasks, subjects must determine the basis for classification of a series of stimuli. Thus it corresponds to such Navy tasks as aircraft or ship identification, where a large number of targets must be classified based on attributes such as track on a radar display, visual silhouette, or sound. In the present study, two classes of visual stimuli were used, and the classification was based on a single attribute. Two task characteristics, formal difficulty and perceptual complexity, were varied to provide a correspondence between this study and the fault-finding experiment described above. A modified version of the cognitive reference battery developed in the previous study was used to obtain data on seven ability factors hypothesized to relate to performance in the concept identification task.

METHOD

Approach

The general approach was similar to that used in the previous studies in this series (Wheaton, et al., 1973; Rose, et al., 1974). The study was conducted using an experimental-correlational method, in which a chosen criterion task was experimentally manipulated along selected physical dimensions in a within-subjects design. Each subject performed under all versions of the task. In addition, all subjects were administered a reference battery designed to provide (through factor analysis) a description of their abilities. Subjects' ability scores were then correlated with performance on each version of the criterion task. The result was a table of correlations between abilities and performance at each level of any specified task dimension.

Subjects

The subjects employed in this study were 128 college students (59 males and 69 females) recruited from the American University via an advertisement in the university newspaper. They were paid $20.00 for their participation upon completion of a single day (approximately 6.5 hours) of testing.

Experimental Criterion Task

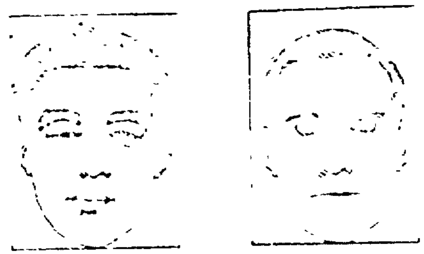
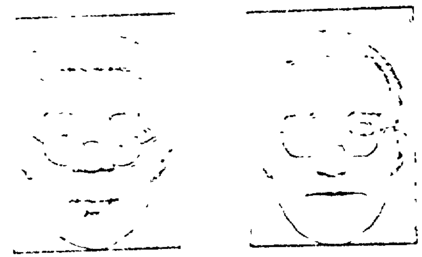
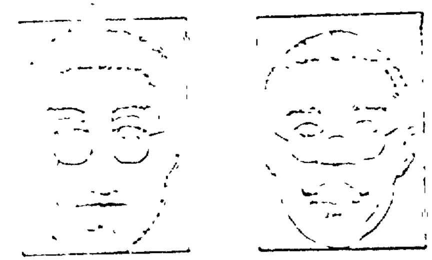
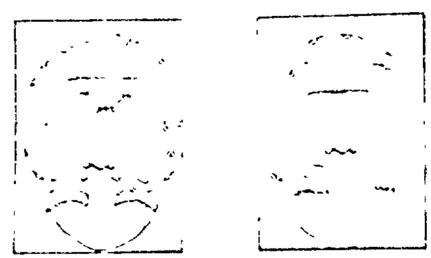
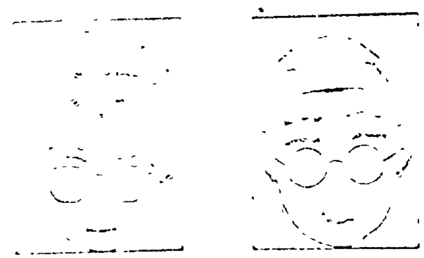
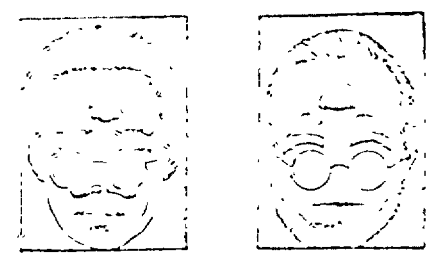
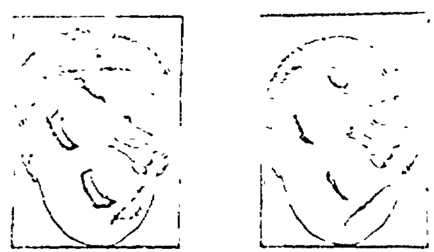
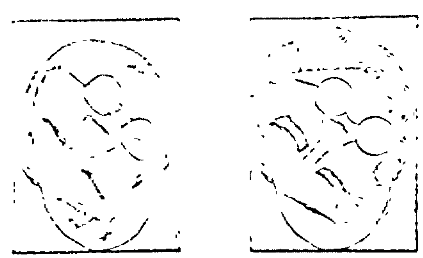
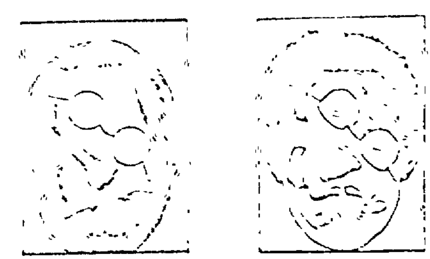
In the current research effort, a concept-identification task was employed as the criterion task. Concept identification can be defined broadly as the ability to discern "regularity in real or imagined events or objects" and to employ instances of this regularity in a manner appropriate to the circumstances (Bourne, et al., 1971). In laboratory research studies it frequently involves the formation and testing of hypotheses in a problem-solving situation in order to identify correctly a classification rule or principle. In the current study subjects were presented with a sequence of five pairs of faces in which one facial feature had been designated as the solution to the problem. For each pair, subjects were to guess which face had the correct feature. After responding they were told which face contained the relevant feature, and were then presented with the next stimulus pair. Their task was to infer which feature was common to all the "correct" faces and was, therefore, the solution to the problem.

Stimuli. The stimuli were facial composites constructed from a police identification kit manufactured by the IdentiKit Company (1960, Bangor Punta Operations, Inc.). The kit contained a variety of individual facial characteristics, including such specific features as eyes, eyebrows, noses, chins, ears, lips, and hair, which could serve as stimulus dimensions. The kit also offered many potential values (or attributes) for each dimension (e.g., eyes might be "wide" or "squinty"). These features were drawn individually on clear plastic sheets so that by overlaying various sheets, a composite face could be constructed. Stimuli were projected on a screen in front of the subjects using an overhead projector.

Two task characteristics or stimulus dimensions were chosen for manipulations: 1) the number of stimulus dimensions which varied (formal difficulty); and 2) the extent to which location of features varied from normal appearance (perceptual complexity). Three levels of formal difficulty were used: faces contained either four, six, or eight facial features which varied from trial to trial. There were two possible values for each feature (e.g., hair could be either "curly" or "straight"). Three levels of perceptual complexity were utilized. At the first and simplest level, the facial features appeared in their normal positions. At the second level the facial features were rearranged vertically (e.g., the mouth and eyes were switched), but the facial features remained in their normal horizontal orientation. At the third and most complex level, the features were moved both horizontally and vertically. Examples of each resulting stimulus are presented in Table 1.

For each problem, a set of five slides was constructed, each consisting of two complete faces placed side by side. Each pair of faces was constructed so that both values of each dimension appeared on each slide; if the eyes were "wide" on the right face, they were "squinty" on the left face. The particular association of values on each face varied from slide to slide. One facial characteristic or dimension (e.g., eyes) and one value of that dimension (e.g., "squinty") were preselected by the experimenters as the solution to each problem. The subject's task was to determine the solution

TABLE 1. PROTOTYPIC STIMULI

Levels of Perceptual Complexity: Manipulations	Dimensions: Four	Dimensions: Six	Dimensions: Eight
1			
2*			
3*			

* Precise arrangement of features varies from problem to problem.

by guessing which of the pair of faces was correct (e.g., contained the preselected characteristic). After each of the subject's responses, he was told which face was correct. Thus, over the course of several trials he could find the solution by a process of elimination.* Each problem consisted of five trials (i.e., five pairs of faces) with feedback following each trial.

Ten problems each of four, six, and eight dimensions were presented, with the first problem in each group always being a sample problem. Of the remaining nine problems at each difficulty level, there were three problems at each perceptual-complexity level. The order of these problems was randomized, with the constraint that no more than two consecutive problems were from the same level of perceptual complexity. Subjects were presented first with the complete set of ten four-dimension problems, then all of the six-dimension problems, and finally the eight-dimension problems. Problems were presented in this fixed manner in order to avoid the confusion which pilot testing indicated would result from the addition and deletion of various features from problem to problem. Each subject thus completed thirty experimental problems; the first, eleventh, and twenty-first were sample problems to introduce the new dimensions.

Procedure. The experiment was conducted using groups of three to eight subjects each day. Subjects first solved a set of four preliminary three-dimension problems. While viewing the first pair of faces, subjects were told that faces could vary across a number of dimensions, such as the texture of the hair (curly or straight), size of the lips (full or thin), or denseness of the eyebrows (bushy or sparse). They were told that the "correct" faces all had one specific facial characteristic in common, and their task was to discover that characteristic. Five trials of the facial pairs were

*The arrangement of stimuli in each problem was orthogonal and counterbalanced (Levine, 1966). This arrangement provides maximum information to subjects on each trial, by switching exactly half the attribute values from one trial to the next. An optimal problem solver had enough information after exactly three trials to solve all four-dimension problems. Four trials were the minimum necessary to solve the eight-dimension problems; six-dimension problems required either three or four trials.

then presented. Subjects were told to mark the corresponding left or right circle in their answer booklet depending upon which face they believed had the correct feature. After all subjects had responded for a given trial, feedback was given (e.g., "the left side was correct"). After feedback was given for trial 5, subjects were told to write down the one single characteristic they thought was the solution to the problem. After each problem was completed, the experimenter gave the correct solution.

On the third preliminary problem, the probe technique was introduced. After subjects marked their choice of left-hand or right-hand face and were given feedback, they were told to turn to a probe page listing all possible solutions to the problem and to check all of those facial characteristics that they still thought could be the solution to the problem. On the probe page for the three-dimension sample problem, the six possible solutions were listed in alphabetical order: bushy eyebrows, curly hair, full lips, sparse eyebrows, straight hair, and thin lips. A poster listing the possible solutions was placed in a location where all subjects could see it, and subjects were urged to refer to it as often as necessary in order to become accustomed to the descriptive lables used. Every remaining problem contained five probes, one after each feedback. Two additional preliminary problems implementing the probe technique were run, with the entire preliminary stage of the experiment lasting about 30 minutes.

Immediately following the preliminary problems, the set of four-dimension problems was presented. After a first four-dimension sample problem, subjects were shown two slides with features rearranged (one at the second level of perceptual complexity and one at the third level), reminding them that the features could appear at various levels of disorganization. They then proceeded through the remainder of the four-dimension problems and were given a ten-minute break. The six-dimension problems were next, and once again subjects were shown an initial sample problem, followed by two slides with features rearranged. Another short break followed, and then the eight-dimension problems were presented, using the same procedure.

The solutions to each of the thirty experimental problems were selected randomly, with the following restrictions: all dimensions were used for solution at least once within a given set of 10 problems, no two problems in either the six- or eight-dimension set had the same solution, and no dimension was used for solution more than three times in the four-dimension problems, nor more than twice in the six- or eight-dimension problems. The actual order of problems and solutions, as well as the complete instructions used and a sample answer booklet, are presented in the appendix. After the eight-dimension problems, subjects were given a break for lunch.

Reference Test Battery

Project staff reviewed definitions of many empirically determined abilities, and selected sets of abilities judged as relevant to the criterion task. Tests defining the selected abilities were then combined to form a reference battery of 21 tests which was administered to all subjects in the afternoon following their participation in the concept-identification task. The tests represented seven well-established factors in the cognitive, perceptual, and memorial domains of performance. To insure adequate factor definition, each of the factors was represented by three tests.

In assembling the battery, considerable use was made of the Kit of Reference Tests for Cognitive Factors prepared by French, Ekstrom, and Price (1963). While each test taken from the kit had two equivalent forms, only one form of each test was administred due to time limitations. Three other tests from a set of tests developed by Rose (1974) were also included in the battery. Factor loadings of these tests from the previous phase of the project dealing with performance on an electronic fault-finding task (Wheaton, et al., 1974) were of sufficient magnitude to use them as marker tests in the current effort. The entire test battery was composed of group tests of the paper-and-pencil variety.

Brief descriptions of the reference tests are given below with references to further sources of information. The reliability reported for each test is shown in Table 2. In cases where this information was unavailable, reference was made either to the original test from which the present version came or to a similar test. The order in which the tests were administered is shown in the second column.

TABLE 2

RELIABILITIES OF REFERENCE TESTS[1]

Induction Factor	Order	r	Source
Letter Sets Test	8	.64	Lemke, et al. (1967)
Locations Test	6	.82	Lemke, et al. (1967)
Permutations Task	10	.83[4]	Rose (1974)
Associative Memory Factor			
Picture-Number Test	3	.76	Duncanson (1966)
Object-Number Test	21	.79	Duncanson (1966)
First and Last Names Test	7	.81	Duncanson (1966)
Flexibility of Closure Factor			
Copying Test	15	.88[2]	Thurstone (1938)
Closure Flexibility (Concealed Figures)	20	.78	Buros (1965)
Designs Test	14	.94	Pemberton (1952)
Perceptual Speed Factor			
Neisser Search Task	2	.80[4]	Rose (1974)
Number Comparison Test	19	.79	Duncanson (1966)
Identical Pictures Test	16	.88	Duncanson (1966)
Syllogistic Reasoning Factor			
Nonsense Syllogisms Test	18	.88[3]	Lemke, et al. (1967)
Inference Test	5	.53	Guilford, et al. (1952)
Grammatical Reasoning (A-B) Task	1	.80[4]	Baddeley (1968)
Spatial Scanning Factor			
Maze Tracing Speed Test	4	.94	Frederiksen (1965)
Choosing a Path Test	17	.77	Frederiksen (1965)
Map Planning Test	13	.79	Frederiksen (1965)
Speed of Closure Factor			
Gestalt Completion Test	11	.62	Guilford, et al. (1952)
Concealed Words Test	9	.80	Guilford, et al. (1952)
Four Letter Words Test	12	.92	Pemberton (1952)

[1]All reliabilities, unless otherwise indicated, are split-half reliability coefficients corrected for full length with the Spearman-Brown formula.
[2]Reliability estimated by the tetrachoric correlation of odd and even items.
[3]Kuder-Richardson 20 estimate.
[4]Pearson product moment test-retest reliability.

Reference Tests and Ability Factors. The Induction factor has been defined as the ability to find general concepts that will fit sets of data. It involves the formulation and testing out of hypotheses. The following three tests are marker tests for this factor:

Letter Sets Test--Five sets of four letters each are presented. The task is to find the rule which relates four of the sets to each other and to mark the one set which does not fit the rule. There are 15 items (7 mins.). Score is the number correct minus a fraction of the number incorrect (French, et al., 1963).

Locations Test--Each problem consists of five rows of small dashes separated into groups of dashes by blank spaces. In each of the first four rows, one place in each row is marked according to a rule. The task is to discover the rule and to mark one of five numbered places in the fifth row accordingly. There are 14 problems in all (6 mins.). Score is the number correct minus a fraction of the number incorrect (French, et al., 1963).

Permutations Task--In this task, developed by Leskow and Smock (1970) and adapted by Rose (1974), the subject is asked to write down on separate slips of paper (which he then turns face down) as many different license plate numbers containing only the digits 1, 2, 3, and 4 as he can think of (3 mins.). Scores are: 1) the total number of correct new permutations, and 2) a frequency count of numbers held constant from one trial to the next in the first position, and a similar count for the second position, given the first was held constant.*

Associative Memory has been defined as the ability to remember bits of unrelated material. The marker tests are:

Picture-Number Test--The subject studies pictures of common objects, each paired with a two-digit number. Later, when the pictures are presented to him in a different order, he is required to write in the number associated with them. There are 21 items in all (4 mins. for memorizing, 3 mins. for testing). Score is the number correct (French, et al., 1963).

Object-Number Test--The subject studies 20 word-number pairs and must recall the appropriate number when the words are presented to him in a different order. There are 15 items (3 mins. for memorizing, 2 mins. for testing). Score is the number correct (French, et al., 1963).

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*The frequency count data, although computed, are not reported in the present study.

First and Last Names Test--The subject studies 20 full names, including first and last, and is required to write in the appropriate first name when the last names are presented in a different order. There is a total of 15 items (3 mins. for memorizing, 2 mins. for testing). Score is the number correct (French, et al., 1963).

The Closure Flexibility factor has been defined as the ability to retain a complex idea in spite of distraction. The marker tests are:

Copying Test--Each item consists of a geometrical figure composed of four connecting line segments. The task is to copy the figure onto a square matrix of dots. There are 32 figures (3 mins.). Score is the number correct (French, et al., 1963).

Closure Flexibility Test (Concealed Figures-Form A)--Each item consists of a figure on the left followed by a row of more complex drawings, some of which contain the original figure. The subject marks those drawings which contain the figure. Test developed by Thelma G. Thurstone and T. E. Jeffrey. There are 40 problems (10 mins.). Score is the number correct minus the number incorrect.

Designs Test--In this test of L. L. Thurstone's (1938), 300 designs are presented, in 40 of which the Greek capital letter "sigma" is embedded. The task is to mark as many as possible of the figures containing the "sigma" in a two-minute period. Score is the number correct.

The Perceptual Speed factor has been described as the ability to compare visual configurations and identify two figures as similar or identical. The marker tests selected are:

Neisser Search Task--In this task, developed by Neisser (1967) and adapted by Rose (1974), the subject is given a page containing columns of groups of five letters and is asked to search for a particular letter or letters, placing a check next to each item (i.e., group) he finds with one of the targeted letter(s). There are six trials: in the first two trials the subject is given one letter to search for (20 secs.); in the next two he searches simultaneously for two letters (30 secs.); and in the last two, he searches simultaneously for four letters (30 secs.). The second trial of each pair uses a different target (s), but the masking letters remain the same. The entire procedure is repeated, using the same target(s) but different masking letters. Scores are: 1) the average time per correct item (in secs.) over all conditions, and 2) the slope of the best fitting regression line of the time per item (in secs.) by target set size function (Rose, 1974).*

Number Comparison Test--The subject examines pairs of multi-digit numbers and indicates whether the two numbers in each pair are the same or different. There are 48 pairs of items (1 1/2 mins.). Score is the number correct minus the number incorrect (French, et al., 1963).

Identical Pictures Test--For each item the subject is to check which of five numbered geometrical figures or pictures in a row is identical to the reference figure at the left end of the row. There are 48 rows or items (1 1/2 mins.). Score is the number correct minus a fraction of the number incorrect (French, et al., 1963).

The Syllogistic Reasoning factor has been described as the ability to reason from stated premises to their necessary conclusions. The three marker tests selected for this factor are:

Nonsense Syllogisms Test--In this test, suggested by Thurstone's False Premises, the subject is presented with formal syllogisms made up of nonsense words so that they cannot be solved by reference to past learning. The task is to indicate which of the stated conclusions follow logically from the premises and which do not. There are 15 items (4 mins.). The score is the number correct minus the number incorrect (French, et al., 1963). A constant of 10 was later added to each subject's score to eliminate any negative numbers.

Inference Test--In this test adapted from Guilford, the subject's task is to select the one of five conclusions that can be drawn from each given statement. There are 10 items (6 mins.). Score is the number correct minus a fraction of the number incorrect (French, et al., 1963).

Grammatical Reasoning (A-B) Task--Each item in this task, developed by Baddeley (1968) and adapted by Rose (1974), consists of a statement followed by a pair of letters (either AB or BA). The statements claim to describe the order of the two letters (i.e., to say which precedes or follows the other). The subject's task is to determine whether each statement is a true or false description of the letter pair which follows it. The test is made up of two parts, each containing 32 items (1 min./part). Score for each part is the number correct (Rose, 1974).

*The slope data, although computed, are not reported in the present study.

The Spatial Scanning factor has been defined as the ability to visually explore a wide or complicated spatial field. A planning ability may also be involved. The marker tests for this factor are:

> Maze Tracing Speed Test--The task is to find and mark an open path through a moderately complex series of paper mazes. There are 24 interconnecting mazes (3 mins.). Score is the number of mazes through which a line has been correctly drawn (French, et al., 1963).

> Choosing a Path Test--Each item of this test, adapted from AAF Printed Classification Tests (Guilford, et al., Eds., 1947), consists of a network of lines (as in an electrical-circuit diagram) having many intersecting and intermeshed wires with several sets of terminals. The task is to trace the lines and to determine for which pair of terminals, marked S (start) and F (finish), there is a complete circuit through a circle at the top. There are 16 items (7 mins.). Score is the number of problems marked correct minus a fraction of the number incorrect (French, et al., 1963).

> Map Planning Test--In this test, adapted from AAF Printed Classification Tests (Guilford, et al., Eds., 1947), the subject sees diagrammatic sections representing city maps. The streets are blocked at various points by barriers represented by circles. The task is to find the shortest route between two given points without crossing any roadblocks. There are two maps with ten routes per map (3 mins.). Score is the number correct (French, et al., 1963).

The Speed of Closure factor has been described as the ability to unify a complex perceptual field of apparently disparate elements. The marker tests are:

> Gestalt Completion Test--The subject is required to identify and label a number of incomplete pictures under speeded conditions. There are 10 items in all (3 mins.). Score is the number correct (French, et al., 1963).

> Concealed Words Test--Words composed of partially obliterated letters are presented. The subject is required to write out the full word in an adjacent space. There are 25 words (3 mins.). Score is the number correct (French, et al., 1963).

> Four Letter Words Test--Twenty-two 46-letter lines of capital letters are presented. The task is to circle all the 4-letter words contained in this array. Score is the number of words correctly circled in 2 1/2 minutes (French, 1954).

RESULTS

The results of three sets of analyses are presented below. The first set deals with the factor structure of the reference battery. The second set is concerned with the impact of experimental manipulations of the criterion task on several measures of performance. The third set describes the relationships between ability factors and criterion task performance.

Reference Battery

The intercorrelations among reference tests are presented in Table 3. Six major factors were extracted from this matrix using a principal components solution. Orthogonal rotation of the factors was performed using a varimax criterion. Table 4 presents the rotated factor loadings; the algebraic signs for Factor IV have been reflected for convenience. Factors were interpreted for psychological meaningfulness from the projections of the reference tests on the rotated axes.

Factor I is defined primarily in terms of the high loadings exhibited by seven of the reference tests. Three of the tests--Copying, Designs, and Closure Flexibility--have previously been used as marker tests for a Flexibility of Closure factor (see Table 2 above and French, et al., 1963). The substantial loadings of Maze Tracing, Map Planning, and Choosing a Path (included in the battery as marker tests for a Spatial Scanning factor) suggest not only that a broader interpretation of the obtained factor may be necessary, but also lend further evidence to Royce's (1973) argument that the Flexibility of Closure and Spatial Scanning factors may be components of a second-order Visualization factor. It is interesting to note that in the previous study (Rose, et al., 1974), using a somewhat different reference battery, the hypothesized Flexibility of Closure and Spatial Scanning factors also collapsed into one factor. The high loading of the Identical Pictures test on this factor may be due to the rapid scanning of stimuli and low-level processing of the stimuli demanded by the task. Factor I will again be tentatively interpreted as a combined Flexibility of Closure/Spatial Scanning factor.

TABLE 3

MATRIX OF INTERCORRELATIONS* AMONG REFERENCES TESTS

	Reference Tests																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Grammatical Reasoning	-																				
2. Neisser Search	-16	-																			
3. Picture-Number	24	-19	-																		
4. Maze Tracing Speed	32	-25	10	-																	
5. Inference	47	10	17	13	-																
6. Locations	27	-04	09	31	20	-															
7. First and Last Names	19	-07	48	03	12	06	-														
8. Letter Sets	36	-19	23	27	29	42	20	-													
9. Concealed Words	20	-18	09	24	02	14	15	15	-												
10. Permutations	29	-19	28	15	17	16	14	30	04	-											
11. Gestalt Completion	23	-00	06	37	13	30	02	14	47	08	-										
12. Four Letter Words	15	-30	11	27	-08	05	19	19	26	12	08	-									
13. Map Planning	44	-19	22	47	34	44	12	45	15	20	32	04	-								
14. Signs	35	-25	22	47	29	25	11	35	27	21	29	15	46	-							
15. Copying	31	-18	20	57	16	42	15	36	29	21	32	30	51	60	-						
16. Identical Pictures	12	-37	09	52	08	22	-05	17	27	06	19	31	34	40	58	-					
17. Choosing a Path	35	00	04	43	27	43	05	34	17	20	36	05	46	38	39	24	-				
18. Nonsense Syllogisms	41	-01	06	16	29	26	-10	17	08	13	22	-00	26	21	23	10	24	-			
19. Number Comparison	13	-39	24	29	-05	07	13	29	21	08	03	30	22	31	38	32	01	06	-		
20. Closure Flexibility	45	-15	20	54	33	45	13	46	32	33	48	19	54	71	73	43	59	28	22	-	
21. Object-Number	23	-08	57	14	09	20	50	15	12	23	10	06	10	28	26	17	14	-05	17	27	-

$r > .228$, $p < .01$

* Rounded to two places, decimals omitted

TABLE 4

FACTOR LOADINGS* IN ROTATED FACTOR MATRIX

	Reference Tests	Factors I	II	III	IV	V	VI	h^2
1.	Grammatical Reasoning	16	20	15	72	17	24	69
2.	Neisser Search	22	05	74	03	-03	01	59
3.	Picture Number	09	79	16	20	-04	02	69
4.	Maze Tracing Speed	71	-03	17	07	19	18	60
5.	Inference	15	14	-21	72	-06	12	62
6.	Locations	34	02	-14	06	14	66	59
7.	First and Last Names	-08	79	07	-01	14	14	67
8.	Letter Sets	20	14	26	23	-02	68	64
9.	Concealed Words	16	10	22	05	82	-02	75
10.	Permutations	-01	26	23	24	-07	50	43
11.	Gestalt Completion	30	-00	-18	14	74	14	71
12.	Four-Letter Words	08	06	64	-13	32	17	58
13.	Map Planning	55	06	02	35	01	39	58
14.	Designs	71	20	09	28	09	05	65
15.	Copying	78	15	15	08	16	22	73
16.	Identical Pictures	75	-03	31	-07	09	-06	67
17.	Choosing a Path	46	-01	-24	17	20	53	62
18.	Nonsense Syllogisms	12	-19	02	72	15	06	59
19.	Number Comparison	35	17	63	05	-02	-06	56
20.	Closure Flexibility	69	15	-02	27	26	37	78
21.	Object Number	24	83	-06	-04	03	03	75

*Factor loadings reflected and rounded to two places; decimals omitted.

Factors are tentatively defined as:

I - Flexibility of Closure/Spatial Scanning
II - Associative Memory
III - Perceptual Speed
IV - Syllogistic Reasoning
V - Speed of Closure
VI - Induction

Factor II is readily defined from the high loadings on the Object-Number, Picture-Number, and First and Last Names tests as the Associative Memory factor. This same factor is defined by French, et al., using the same three marker tests, as the ability to remember unrelated bits of information.

Factor III is defined primarily from high loadings of the Neisser Search and Number Comparison tests as the Perceptual Speed factor. The third marker test hypothesized to load on this factor--Identical Pictures--loaded only marginally (.31), suggesting that the test (with its very high loading on Factor I) may be less factorially pure than hitherto thought. The Identical Pictures Task also differs from the other tests loading on the Perceptual Speed factor in that it involves pictures as stimuli, rather than symbols (i.e., numerals or letters). The presence of the Four Letter Word test on the obtained factor may be due largely to its speed component. The test also broadly resembles those tests loading on the Perceptual Speed factor in that it requires the ability to look at a visual configuration (i.e., row of letters) and to identify a common four-letter pattern. In this sense it is most similar to the Neisser Search task, with the primary difference being that in the latter the subject searches only for a given letter(s) while in the Four Letter Word Test he searches for four letters which form a recognizable word.

Factor IV is readily defined by the high loadings of the Grammatical Reasoning, Inference, and Nonsense Syllogisms tests as the Syllogistic Reasoning factor. This factor is defined by French, et al., as the ability to reason from stated premises to their necessary conclusions.

Factor V is defined primarily by the high loadings of the Concealed Words and Gestalt Completion tests as the Speed of Closure factor. Although the loading of the Four Letter Words test, also expected to load on this factor, was marginal (.32), this appears to be the same Speed of Closure factor defined by French, et al. It represents the ability to unify a complex perceptual field.

Factor VI is defined primarily in terms of the high loadings exhibited by the Letter Sets, Locations, and Permutations tests as the Induction factor. French, et al., used the first two of these measures as markers of an Induction factor and defined it as the ability to find and test out hypotheses which will explain sets of data. The relatively high loadings of the Choosing a Path and Map Planning tests, which also loaded on the Flexibility of Closure/Spatial Scanning factor, suggest that neither of the tests is a pure measure of a factor and probably involves a complex array of abilities in its performance.

Criterion Task

Nine raw and derived measures of performance on the concept identification task were available. The first was the proportion of problems solved; the other eight were based on the probe data available for every trial of every problem. On each probe page of his answer booklet, the checkmarks made by a subject were assumed to indicate the hypotheses he held at that point about the solution to the problem (Bruner, Goodnow, & Austin, 1956; Kornreich, 1968; Wandersman & Wandersman, 1973). Measures based on this data reflect additional information about how subjects solved the problems under various task conditions.

All nine of these measures were subjected to analyses of variance; all showed a substantial impact of dimensions and perceptual complexity on performance. Three dependent measures were selected as being representative of the others, and were used for all subsequent analyses:

1. Proportion of problems solved under each task condition.
2. A/B--This measure reflected the degree to which subjects tested an optimal number of hypotheses on each trial. Since the stimuli were constructed to be orthogonal (Levine, 1966), an unambiguously optimal strategy could be defined for each problem, and an optimal or ideal number of hypotheses on each trial (B) could be derived. The number of hypotheses checked on a particular trial (A) was divided by B to provide the score for that trial. Thus a subject who checked three hypotheses on a trial where four were optimal received a score of 3/4 = .75 on that trial. Since showing too many hypotheses was not optimal, those few cases in which A

exceeded B were corrected by using the following formula: $\frac{2B-A}{B}$. Thus, a subject who showed one too many hypotheses received the same score as a subject who showed one too few. This index ranges from zero to one, and was available for every trial of every problem, as a measure of how optimal the number of hypotheses tested by each subject was.

3. C^2/AB--This measure yielded a general index of efficiency, available at each trial of every problem. The term C was the number of hypotheses in a subject's set (A) that were also in the set of optimal hypotheses (B). Thus, if a subject checked mustache squinty, square, and long (A), and if the optimal set consisted of mustache and squinty (B), C for that subject would be two. Note then that C/A was the proportion of hypotheses that a subject checked that were valid for, or consistent with, an optimal strategy. C/B was the proportion of valid or consistent hypotheses that a subject checked. C^2/AB, the product of these two proportions, could assume a value between zero and one, and was a measure of the strategic efficiency of the actual hypotheses that subjects tested on each trial.

The impact of formal difficulty (number of dimensions) and perceptual complexity on criterion task performance was examined in a series of analyses of variance on these three dependent variables. In the first such analysis, a five-factor analysis of variance was performed using the proportion of problems solved as the dependent variable. The five factors were sex (X), subjects (S), dimensions (D), perceptual complexity (P), and replications (R)*.

*Three factors included in the analyses described in this section (sex, replication, and trials) served as control variables to increase the power of the analyses of variance. The primary goal of the analyses was to determine whether number of dimensions and levels of perceptual complexity impacted upon group performance, thus indicating the creation of "new" tasks. If "new" tasks were created, the experiment would be a reasonable analogue to the Navy situation where a new task would require reevaluation of personnel procedures. Systematic study of all of the possible effects emerging from these analyses lies beyond the scope of this report; therefore, all but an abbreviated discussion of the effects of the main variables of interest, as well as the control variables, will be deferred to a later report in this series.

The results of this analysis are presented in Table 5. The dimensions effect (D) was highly significant, and two linear contrasts were tested to determine the nature of the effect. A Scheffe test revealed that the four-dimension problems (mean proportion solved equaled .864) were solved significantly more often than the (pooled) six- and eight-dimension problems (means of .685 and .700, respectively, $F(1,252)=35.52$, $p<.001$), while there was no significant difference between six- and eight-dimension problems. Although main effect of perceptual complexity (P) was not significant, the R x P and D x P x R terms were significant. This suggested that perceptual complexity did impact on performance as measured by proportion of problems solved, albeit in a complicated manner, since its influence was modulated by level of problem difficulty and replication.

The results of a six-factor analysis of variance performed on the A/B measure are presented in Table 6. Once again the dimensions effect was significant. Two linear contrasts were examined to clarify this effect. The mean for the four-dimension problems (.856) was significantly different from the pooled means (both .800) of the six- and eight-dimension problems (Scheffe, $F(1,252)=14.92$, $p<.001$). No significant difference was found between the six- and eight-dimension problems. Thus, subjects showed a more nearly ideal number of hypotheses when solving four-dimension problems than when solving six- or eight-dimension problems.

No significant main effect was found for perceptual complexity using the A/B dependent variable, but a significant D x P interaction was obtained. This interaction is depicted in Figure 1. A set of simple main effects tests (Kirk, 1968) was performed on the interaction to examine the effect of each independent variable at every level of the other independent variable. The effect of dimensions was found to be significant at every level of perceptual complexity [$F(2,381)=3.292$, $p<.05$; $F(2,381)=16.867$, $p<.001$; $F(2,381)=28.207$, $p<.001$, for levels one, two, and three of perceptual complexity respectively]. The effect of perceptual complexity was found to be significant only for four- and eight-dimension problems ($F(2,381)=10.458$, $p<.001$ and $F(2,381)=3.972$, $p<.025$, respectively). Tukey's HSD statistic (Kirk, 1968) was used to test pairwise within each of the significant

TABLE 5

ANALYSIS OF VARIANCE OF CRITERION DATA
(Proportion Solved)

Source	df	MS	F
Between Subjects:			
X (Sex)	1	.000	.000
S/X	126	1.008	
Within Subjects:			
D (Dimensions)	2	11.444	53.909***
DX	2	.125	.588
DS/X	252	.212	
P (Perceptual Complexity)	2	.217	1.435
PX	2	.049	.323
PS/X	252	.151	
DP	4	.231	1.810
DPX	4	.214	1.674
DPS/X	504	.128	
R (Replications)	2	.964	6.956***
RX	2	.580	4.187*
RS/X	252	.139	
DR	4	.211	1.380
DRX	4	.374	2.447*
DRS/X	504	.153	
PR	4	1.056	6.845***
PRX	4	.121	.781
PRS/X	504	.154	
DPR	8	.545	4.056***
DPRX	8	.073	.545
DPRS/X	1008	.134	

* $p < .05$
** $p < .01$
*** $p < .001$

TABLE 6

ANALYSIS OF VARIANCE OF CRITERION DATA
(A/B)

Source	df	MS	F
Between Subjects:			
X (Sex)	1	1.032	.316
S/X	126	3.270	
Within Subjects:			
D (Dimensions)	2	6.475	24.107***
DX	2	1.792	6.672**
DS/X	252	.269	
P (Perceptual Complexity)	2	.095	1.030
PX	2	.011	.121
PS/X	252	.092	
DP	4	.662	7.087***
DPX	4	.265	2.833*
DPS/X	504	.093	
R (Replications)	2	.328	2.775
RX	2	.074	.629
RS/X	252	.118	
DR	4	.486	4.810***
DRX	4	.196	1.944
DRS/X	504	.101	
PR	4	1.916	19.005***
PRX	4	.117	1.164
PRS/X	504	.101	
DPR	8	.738	7.802***
DPRX	8	.100	1.053
DPRS/X	1008	.095	
T (Trials)	4	14.093	26.689***
TX	4	3.443	6.520***
TS/X	504	.528	
DT	8	.781	7.889***
DTX	8	.205	2.070*
DTS/X	1008	.099	

* $p < .05$
** $p < .01$
*** $p < .001$

TABLE 6 (Cont.)

ANALYSIS OF VARIANCE OF CRITERION DATA
(A/B)

Source	df	MS	F
PT	8	.118	2.205*
PTX	8	.042	.788
PTS/X	1008	.053	
DPT	16	.156	2.852***
DPTX	16	.027	.499
DPTS/X	2016	.055	
RT	8	.224	4.063***
RTX	8	.105	1.911
RTS/X	1008	.055	
DRT	16	.104	1.795*
DRTX	16	.030	.508
DRTS/X	2016	.058	
PRT	16	.252	4.724***
PRTX	16	.048	.906
PRTS/X	2016	.053	
DPRT	32	.180	3.283***
DPRTX	32	.043	.775
DPRTS/X	4032	.055	

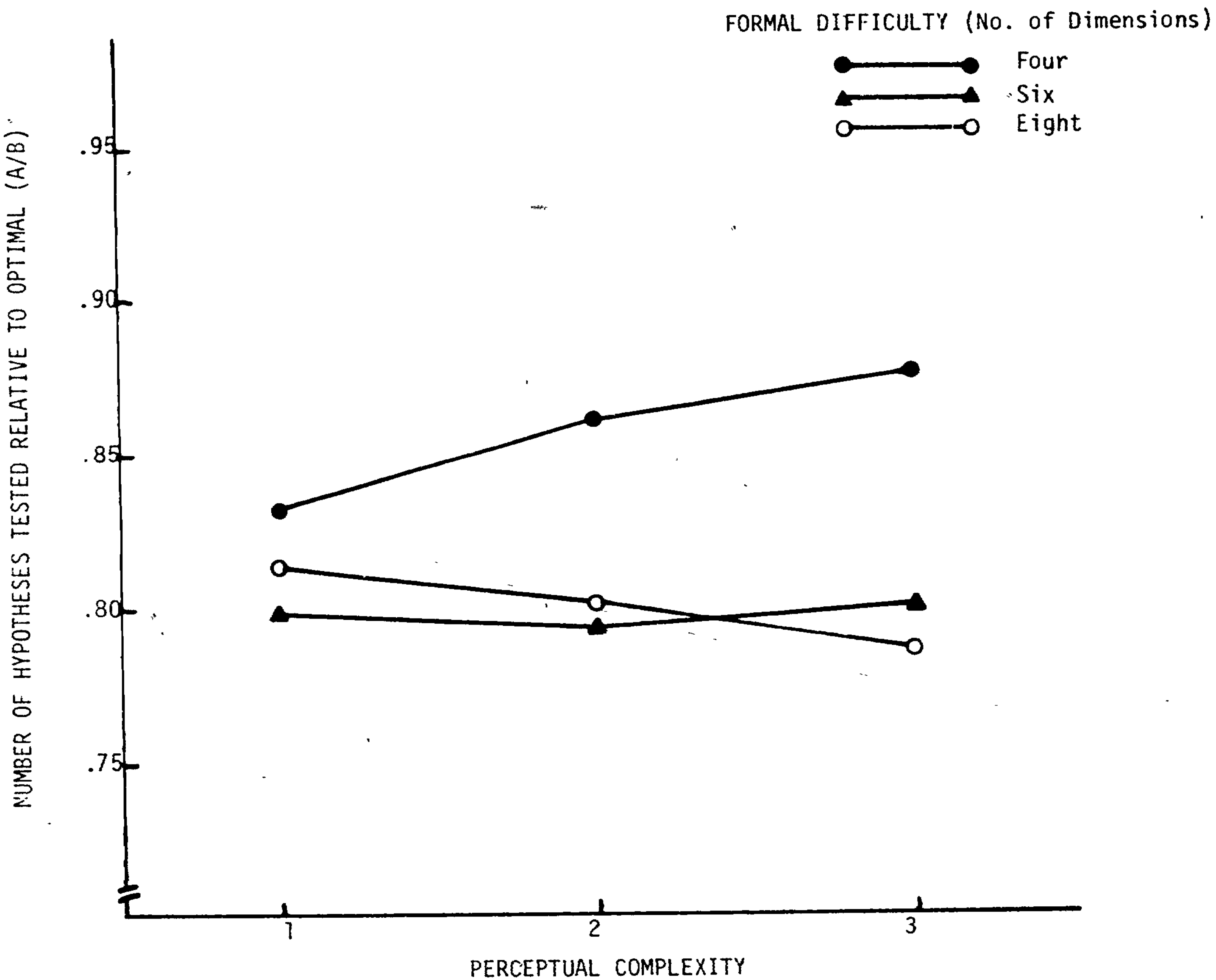

Figure 1. Testing an optimal number of hypotheses (A/B) as a function of formal difficulty and perceptual complexity.

simple main effects. At all levels of perceptual complexity, four- and six-dimension problems were significantly different (q (381) = 3.62, $p < .05$; q (381) = 7.47, $p < .01$; q (381) = 7.80, $p < .01$, respectively), while six- and eight-dimension differences were never significant. Four-dimension problems were significantly different from eight-dimension problems only at the second and third levels of perceptual complexity (q (381) = 6.70, $p < .01$; q (381) = 10.17, $p < .01$). Within the four-dimension problems, level one complexity was significantly different from level two (q (381) = 4.18, $p < .01$), but levels two and three were not different; at six dimensions none of the levels of perceptual complexity was significantly different; at eight dimensions, the only significant difference was between levels one and three (q (381) = 4.06, $p < .05$). In summary, a more optimal number of hypotheses was shown in four-dimension problems than in six or eight, and, while subjects approached the ideal number of hypotheses as perceptual complexity increased on four-dimension problems, they behaved less optimally as complexity increased on the eight-dimension problems. As dimensions (difficulty) increased, optimal performance changed from an increasing to a decreasing function of perceptual complexity.

A six-factor analysis of variance was also performed on the C^2/AB dependent variable, and the results are presented in Table 7. On this measure, the main effects of both dimensions and perceptual complexity were significant. Scheffe tests of linear contrasts showed that subjects were more efficient (F (1,252) = 42.58, $p < .001$) on four-dimension problems (mean of .773) than on six- or eight-dimension problems (means of .643 and .630, respectively), but that there was no significant difference in performance on the six- and eight-dimension problems. Additional Scheffe comparisons on the perceptual-complexity effect revealed that level one (mean of .659) differed significantly (F (1,252) = 5.17, $p < .025$) from levels two and three (means of .699 and .687, respectively), while there was no significant difference between levels two and three. Thus, it seems that while efficiency decreases as the number of dimensions (difficulty) increases, efficiency increases as perceptual complexity increases.

These relationships are further clarified in Figure 2, which shows the significant interaction of perceptual complexity with replications. If the

TABLE 7

ANALYSIS OF VARIANCE OF CRITERION DATA
(C^2/AB)

Source	df	MS	F
Between Subjects:			
X (Sex)	1	3.632	.621
S/X	126	5.845	
Within Subjects:			
D (Dimensions)	2	36.764	65.625***
DX	2	1.409	2.515
DS/X	252	.560	
P (Perceptual Complexity)	2	2.407	8.416***
PX	2	.031	.108
PS/X	252	.286	
DP	4	.175	.688
DPX	4	.583	2.292
DPS/X	504	.254	
R (Replications)	2	1.375	4.626*
RX	2	.623	2.094
RS/X	252	.297	
DR	4	1.221	3.948**
DRX	4	1.007	3.257*
DRS/X	504	.309	
PR	4	5.147	19.778***
PRX	4	.286	1.099
PRS/X	504	.260	
DPR	8	3.086	11.433***
DPRX	8	.127	.470
DPRS/X	1008	.270	
T (Trials)	4	16.442	68.829***
TX	4	1.926	8.061***
TS/X	504	.239	
DT	8	1.054	13.684***
DTX	8	.077	1.003
DTS/X	1008	.077	

* $p < .05$
** $p < .01$
*** $p < .001$

TABLE 7 (Cont.)

ANALYSIS OF VARIANCE OF CRITERION DATA
(C^2/AB)

Source	df	MS	F
PT	8	.207	3.827***
PTX	8	.049	.907
PTS/X	1008	.054	
DPT	16	.222	4.110***
DPTX	16	.088	1.622
DPTS/X	2016	.054	
RT	8	.244	3.900***
RTX	8	.106	1.693
RTS/X	1008	.063	
DRT	16	.373	6.357***
DRTX	16	.113	1.925*
DRTS/X	2016	.059	
PRT	16	.324	5.893***
PRTX	16	.044	.795
PRTS/X	2016	.055	
DPRT	32	.306	5.430***
DPRTX	32	.035	.625
DPRTS/X	4032	.056	

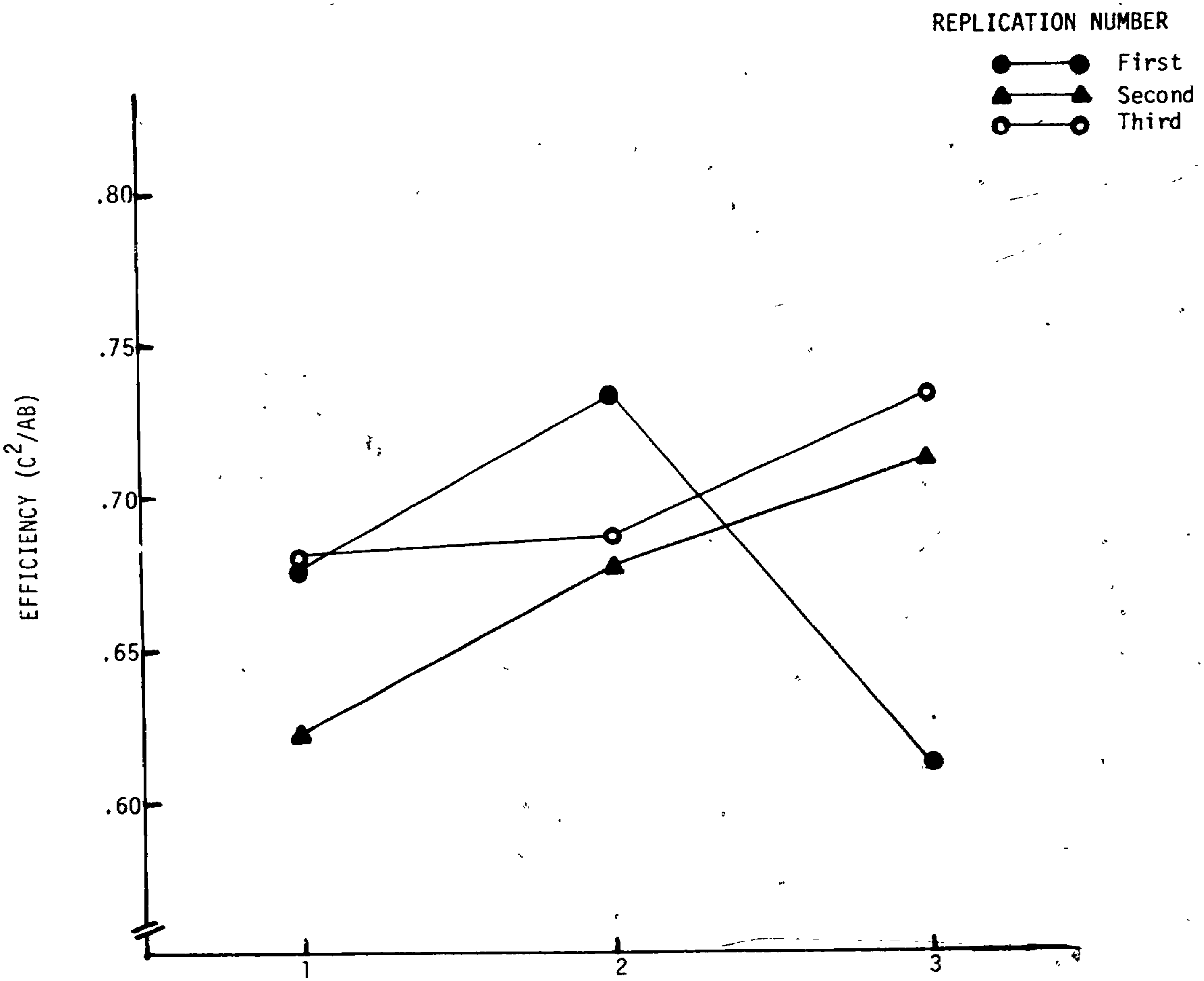

Figure 2. Efficiency (C^2/AB) as a function of number of replications and perceptual complexity.

first replication of the third level of perceptual complexity is ignored, efficiency clearly increases as a function of perceptual complexity. This is borne out by several post-hoc tests performed on the interaction. For example, when level-one perceptual complexity is collapsed across the second and third replications, and compared with level three similarly collapsed, the level-one problems are solved significantly less efficiently (Scheffe, $\underline{F}$ (1,504) = 9.63, $\underline{p} < .005$). When levels two and three are compared, collapsed similarly across the second and third replications, the difference approaches significance (Scheffe, $\underline{F}$ (1,504) = 3.26, $\underline{p} < .10$).

The analyses performed on the three selected dependent variables, proportion of problems solved, number of hypotheses (A/B), and efficiency of selected hypotheses (C^2/AB), reveal many strong effects on performance due to the two task variables. In general, increasing the number of dimensions from four to six or eight impairs performance across all three measures. Increasing the perceptual complexity results in different effects for the two probe measures: added complexity results in an increase in processing efficiency, while the effect on numbers of hypotheses varies as a function of problem difficulty. Finally, while many first- and higher-order interactions of replications with these task variables were significant, suggesting a more complicated picture, these effects were not of immediate concern in the present study.

Projection of Criterion Data on Reference Factors

The purpose in conducting this final set of analyses was to relate variation in the two criterion task characteristics to the pattern(s) of abilities contributing to performance. While an analysis of the relationship between abilities and performance in each cell of the design was possible, only the relationships of abilities to changes in the dimension and perceptual-complexity variables were explored by examining the main effects and their interaction.

A Stoloff regression procedure (Stoloff, 1973) was performed to obtain the estimated loadings of the difficulty and perceptual-complexity effects as well as the D x P interaction on the factor structure underlying the reference battery. The coefficients estimated by the Stoloff procedure for the main effects on each of the three dependent variables are presented in Table 8. The communalities (h^2) are generally high, and indicate that from 24% to 45% of the variance in criterion task performance can be accounted for by individual differences on the six, factor-defined abilities. Since coefficients for Factors III and V (Perceptual Speed and Speed of Closure) are uniformly low, most of the variance in performance is accounted for by the Flexibility of Closure/Spatial Scanning (I), Associative Memory (II), Syllogistic Reasoning (IV), and Induction (VI) factors.

To assist in determining the patterns of these loadings, they are plotted in Figures 3, 4, and 5, for proportion solved, A/B, and C^2/AB, respectively (loadings on Factors III and V are omitted). From these figures several conclusions may be drawn. The loadings on Factor I (Flexibility of Closure/Spatial Scanning) are at best moderate for all levels of formal difficulty, increasing from four- to six-dimension problems and decreasing from six- to eight-dimension problems. Although still modest in size, the loadings on Factor I increase across levels of perceptual complexity for proportion solved, as well as for the measure of efficiency in task performance (C^2/AB). Loadings for the A/B measure across perceptual complexity on this factor are moderate and remain relatively constant.

The loadings for Factor II (Associative Memory) are fairly high for all three dependent measures, generally increasing as difficulty increases (especially for A/B), while remaining quite constant over levels of perceptual complexity. The loadings on Factor IV (Syllogistic Reasoning) are reasonably high for the two dependent variables based on the probe data (A/B and C^2/AB), and modest for proportion solved. The loadings on this factor decrease from level one to level two of perceptual complexity, and increase from level two to level three. The opposite pattern is found (an increase and then a decrease) as formal difficulty increases. Finally, loadings on Factor VI (Induction) are low and remain fairly constant as perceptual complexity increases; Factor VI loadings tend to remain fairly constant for the two probe data measures as formal difficulty increases, while increasing for the proportion-solved measure.

TABLE 8

ESTIMATED LOADINGS* OF CRITERION VARIABLE MARGINALS
ON REFERENCE FACTOR STRUCTURE

Criterion Variables		Factors** I	II	III	IV	V	VI	h^2
Proportion Solved:								
Perceptual Complexity	1	.14	.33	.15	.29	.11	.17	.27
	2	.27	.34	.00	.20	.12	.25	.30
	3	.30	.33	-.01	.31	.06	.20	.33
Dimensions	4D	.23	.27	.13	.21	.17	.16	.24
	6D	.32	.37	.00	.27	.01	.16	.34
	8D	.15	.32	.02	.27	.11	.26	.28
A/B :								
Perceptual Complexity	1	.25	.28	.15	.36	.10	.25	.37
	2	.31	.26	.14	.35	.08	.28	.39
	3	.26	.28	.15	.36	.09	.27	.38
Dimensions	4D	.24	.15	.23	.36	.02	.28	.34
	6D	.29	.27	.09	.38	.10	.25	.38
	8D	.26	.34	.11	.28	.13	.24	.35
C^2/AB :								
Perceptual Complexity	1	.17	.37	.15	.38	.14	.24	.41
	2	.27	.39	.07	.32	.09	.30	.43
	3	.28	.35	.04	.35	.10	.26	.40
Dimensions	4D	.22	.29	.15	.35	.09	.27	.36
	6D	.30	.40	.04	.35	.10	.24	.45
	8D	.18	.36	.07	.31	.12	.26	.35

* Signs have been reflected to relate superior performance to superior ability.

** Factors are identified as: I - Flexibility of Closure/Spatial Scanning; II - Associative Memory; III - Perceptual Speed; IV - Syllogistic Reasoning; V - Speed of Closure; VI - Induction.

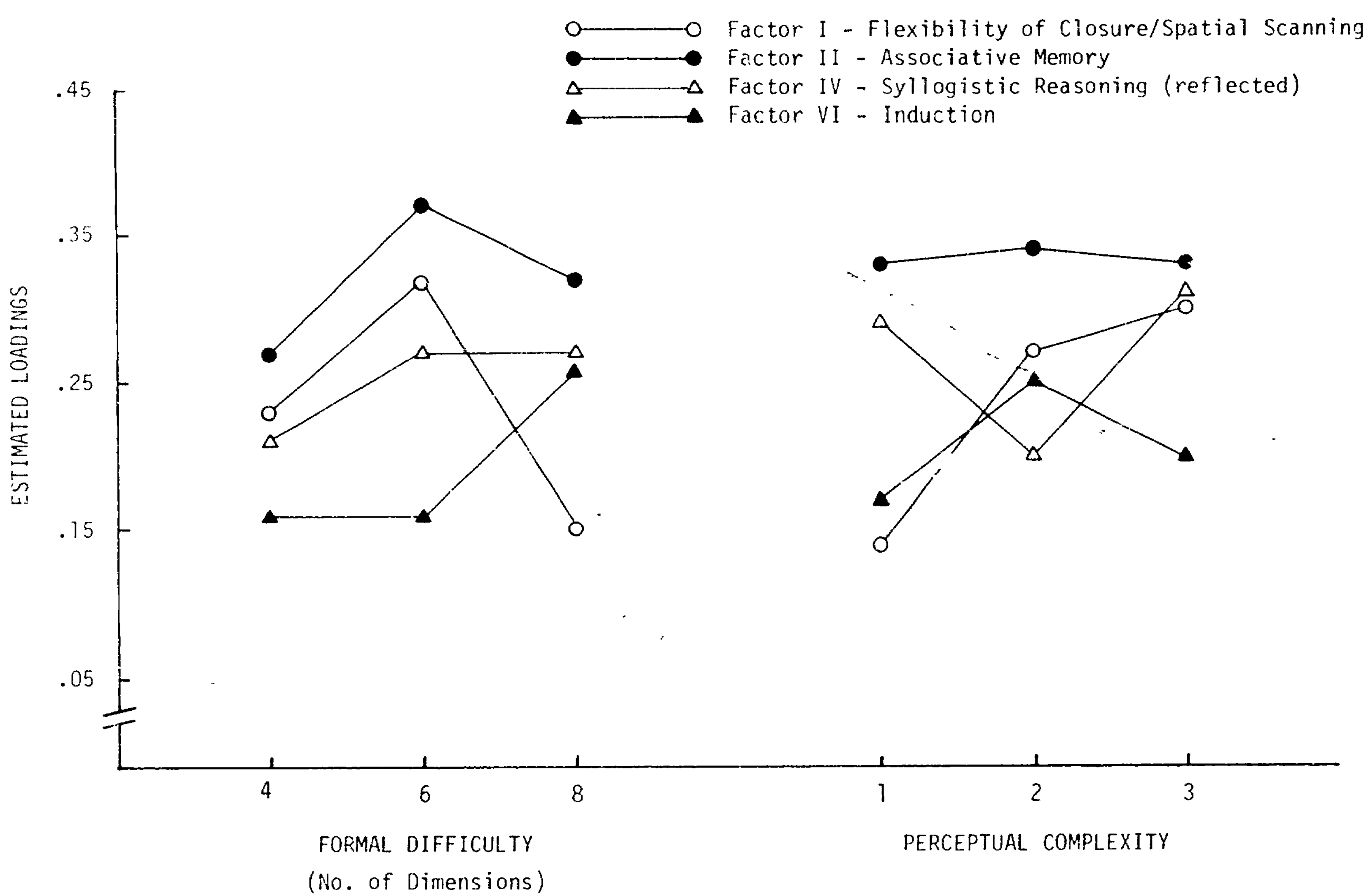

Figure 3. Proportion solved; estimated loadings on marginals.

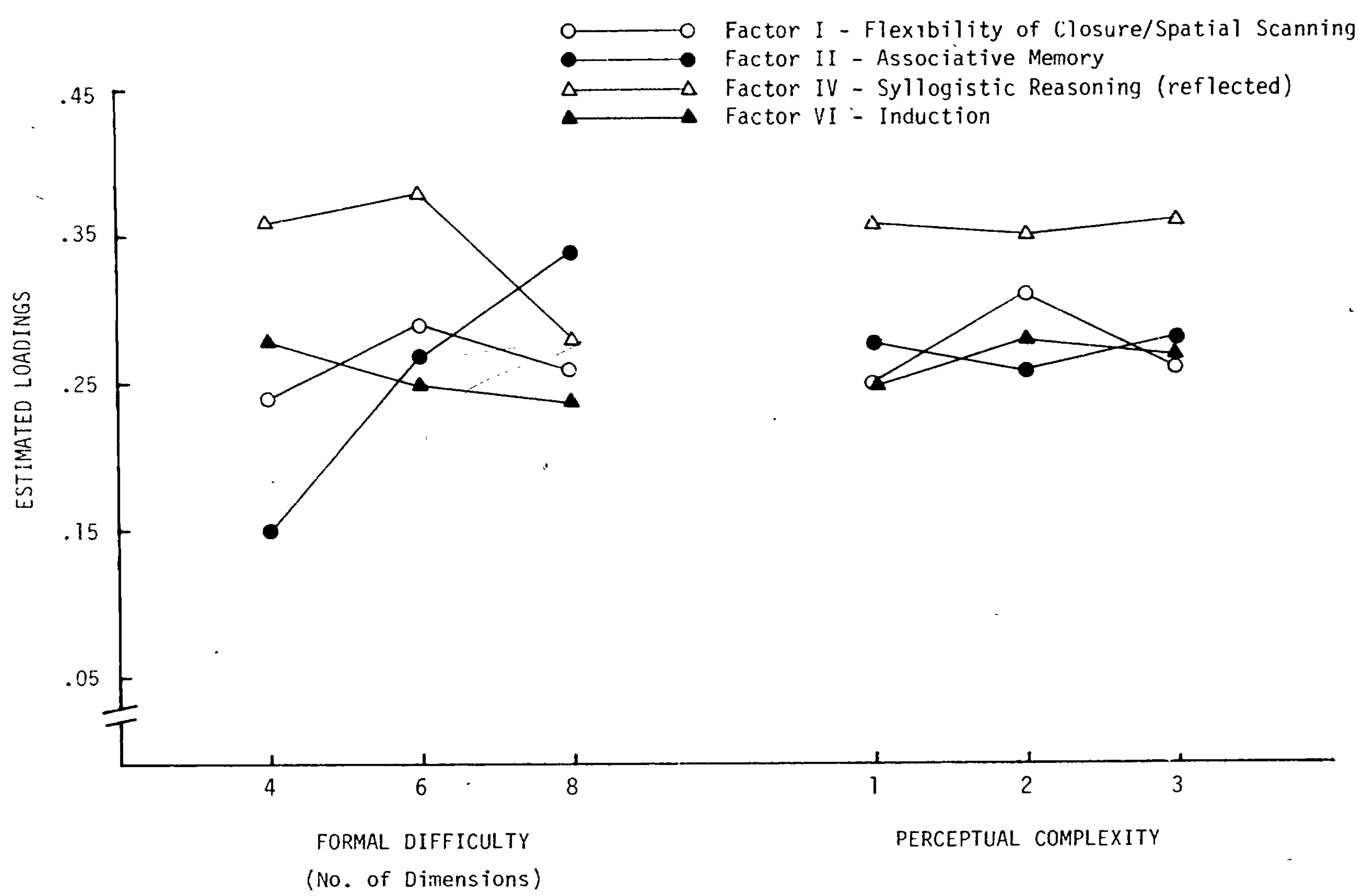

Figure 4. Number of hypotheses (A/B): estimated loadings on marginals.

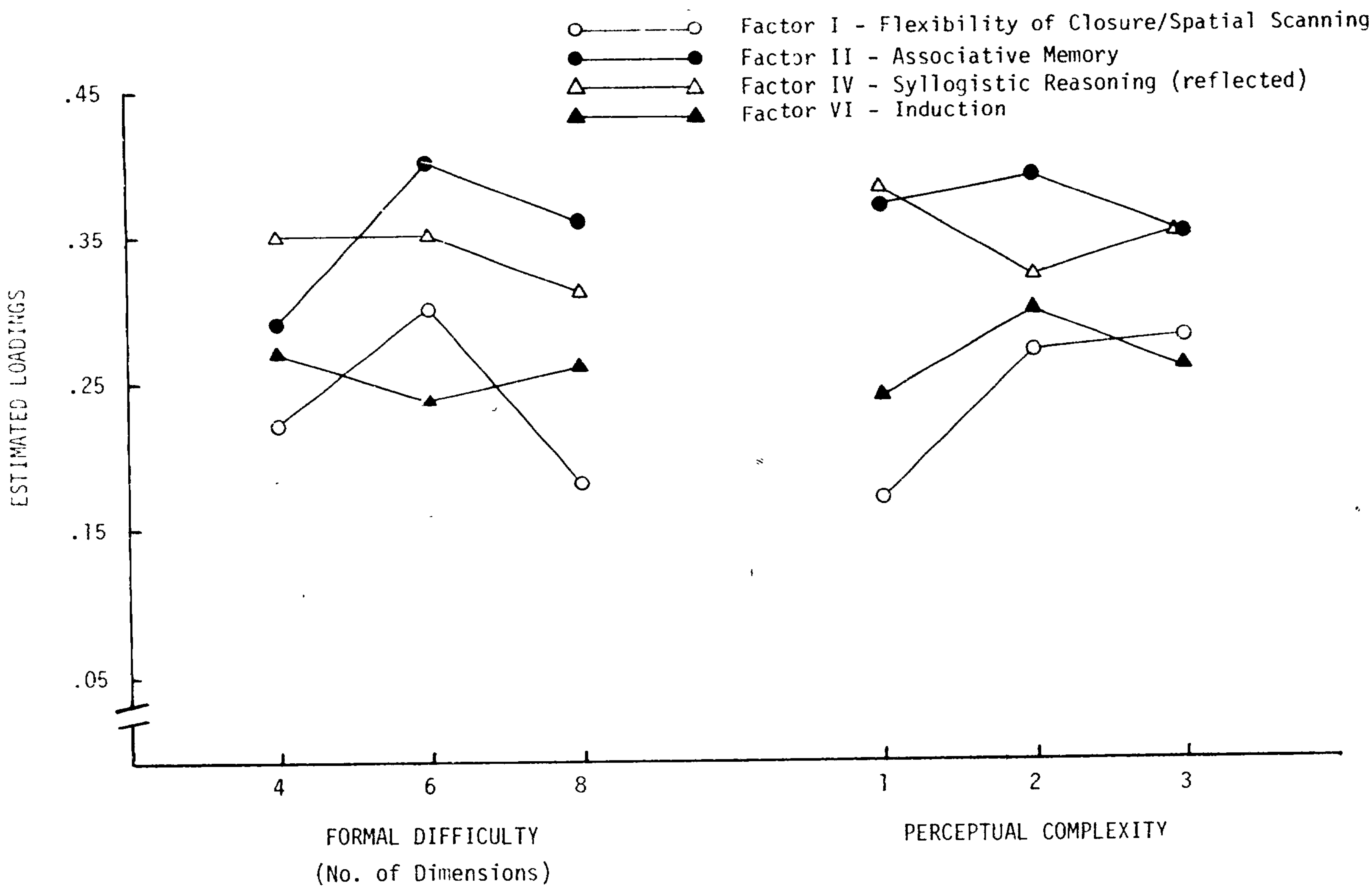

Figure 5. Efficiency (C^2/AB): estimated loadings on marginals.

Since the analyses of variance revealed interactions between the two task characteristics, Stoloff loadings were obtained to measure the relationship between performance in each of the nine D x P cells and the factor structure unc lying the reference battery. The communalities for these regressions are presented in Table 9. The loadings are presented for the proportion-solved measure in Figures 6a through 6f (one for each factor), for A/B in Figures 7a through 7f, and for C^2/AB in Figures 8a through 8f.

The communalities in Tables 8 and 9 indicate that while the proportion of variance accounted for is somewhat less for the interaction than for the main-effect loadings, they are still reasonably high, ranging from 15% to 41%. In addition, Figures 6, 7, and 8 indicate that the cell loadings follow the marginal loadings for the most part, but some deviations do occur.

Cell loadings on the dependent variable proportion solved (Figure 6) may be compared with the marginal loadings shown in Figure 3. The cell loadings for Factor I (Figure 6a) follow the marginals quite closely, rising and then falling as a function of difficulty, and rising as perceptual complexity increases. The one exception is the six-dimension, level-three loading, which is lower than might be expected from the marginal pattern. The cell loadings for Factor II (Figure 6b) also follow the difficulty marginal loading pattern, with the exception of the six-dimension, level-three cell. They do, however, seem more variable across levels of perceptual complexity. The loadings for Factor III (Figure 6c) are still low, but an interesting pattern may be present. The cell loadings for Factor IV (Figure 6d) are considerably more variable than is suggested by the marginal loadings, indicating that the D x P interaction strongly influences the degree of involvement of this factor. The cell loadings for Factor V (Figure 6e) are low, as were the marginal loadings, but there is a hint that this factor may be involved in very easy problems, or hard and complex problems, but not otherwise. Factor VI cell loadings (Figure 6f) suggest a moderate rise in loading as difficulty increases for the intermediate level of perceptual complexity.

TABLE 9

COMMUNALITIES (h^2) OF ESTIMATED REGRESSION EQUATIONS FOR D x P INTERACTION MATRIX

Criterion Variable	Level of Perceptual Complexity	Number of Dimensions (Formal Difficulty)		
		Four	Six	Eight
Proportion Solved	1	.15	.20	.20
	2	.20	.25	.26
	3	.24	.24	.17
A/B	1	.34	.33	.25
	2	.33	.35	.28
	3	.22	.33	.41
C^2/AB	1	.30	.35	.28
	2	.36	.37	.34
	3	.29	.33	.32

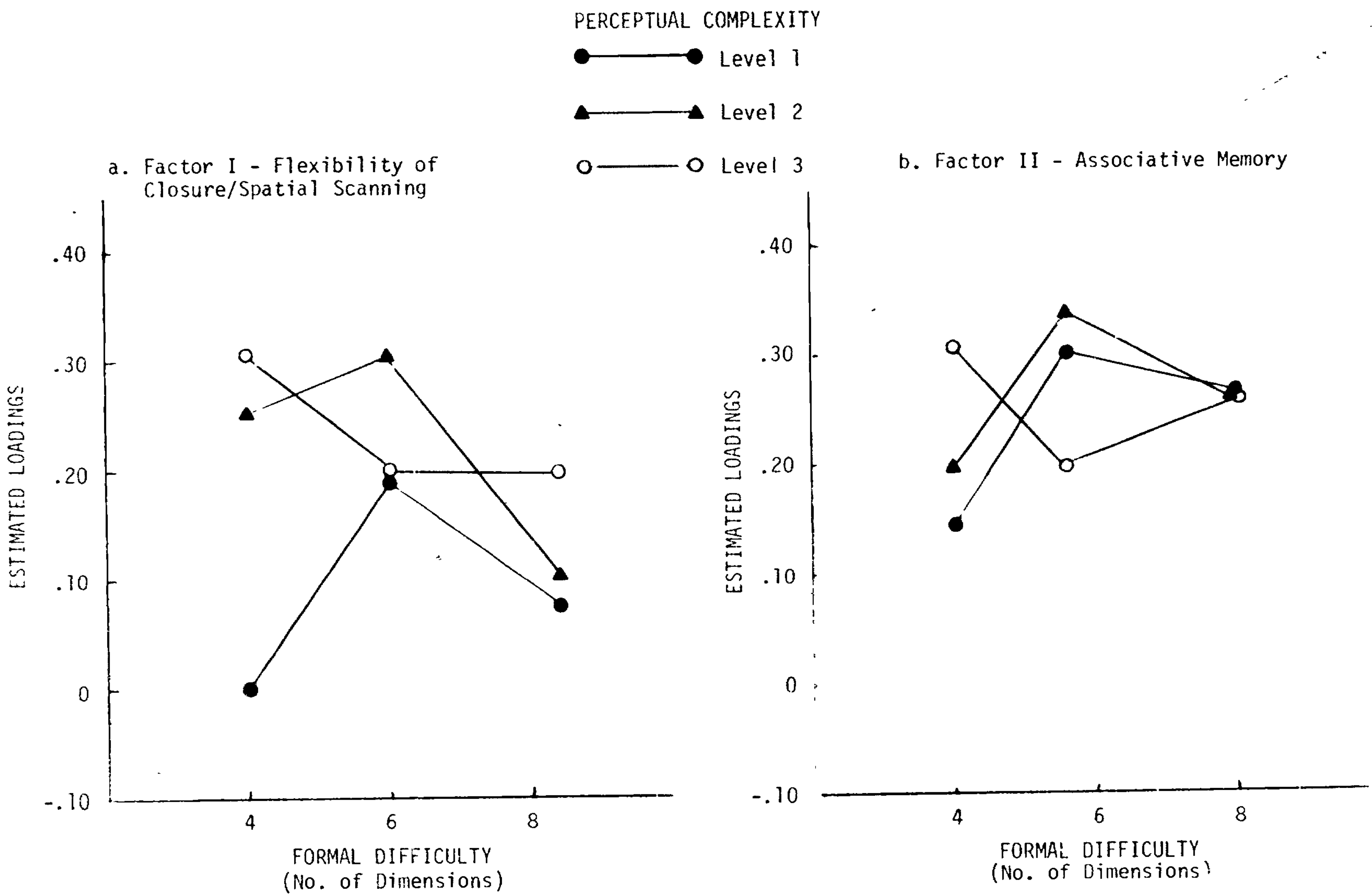

Figure 6. Proportion solved: estimated loadings on the D x P interaction.

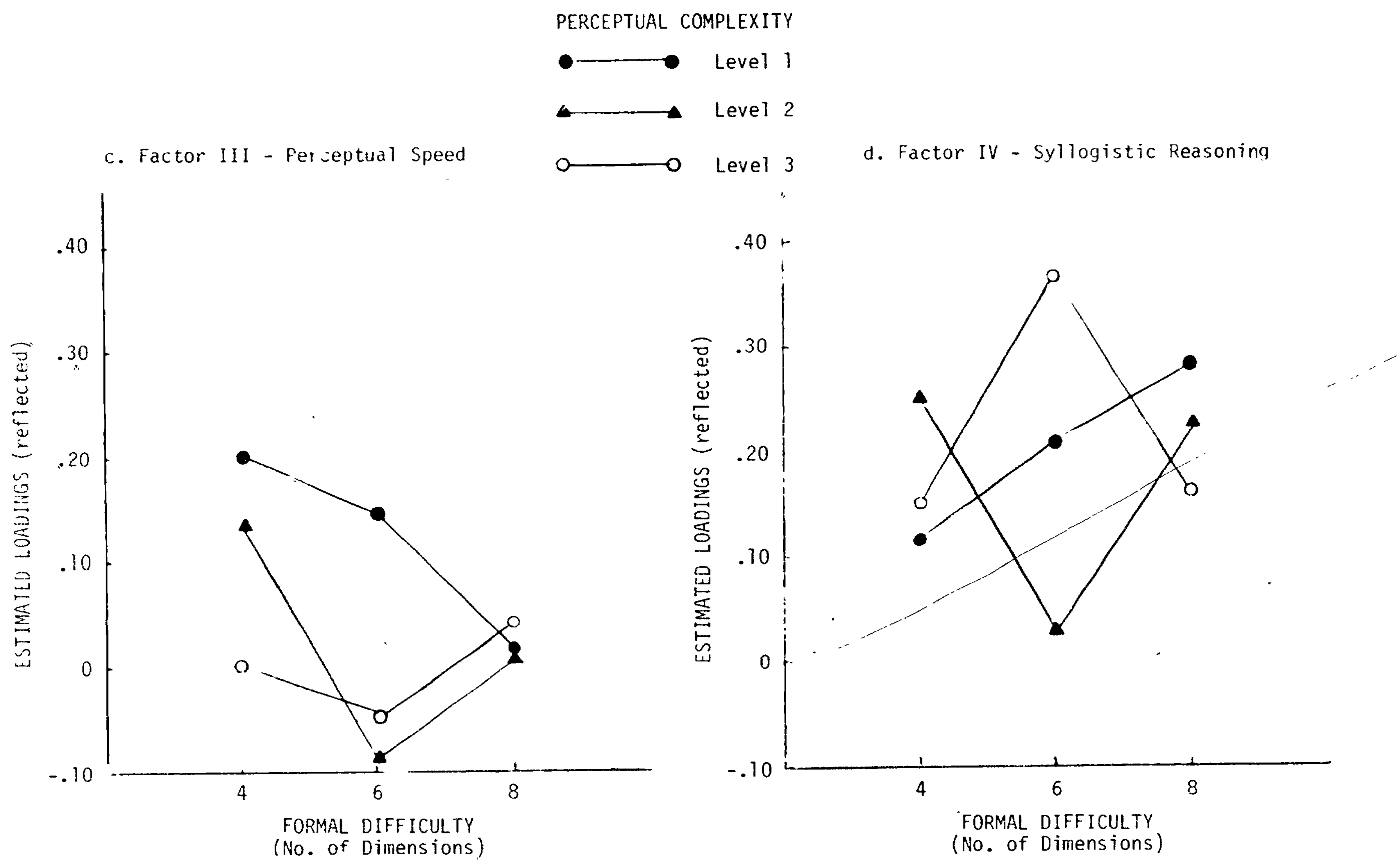

Figure 6. Proportion solved: estimated loadings on the D x P interaction. (Cont.)

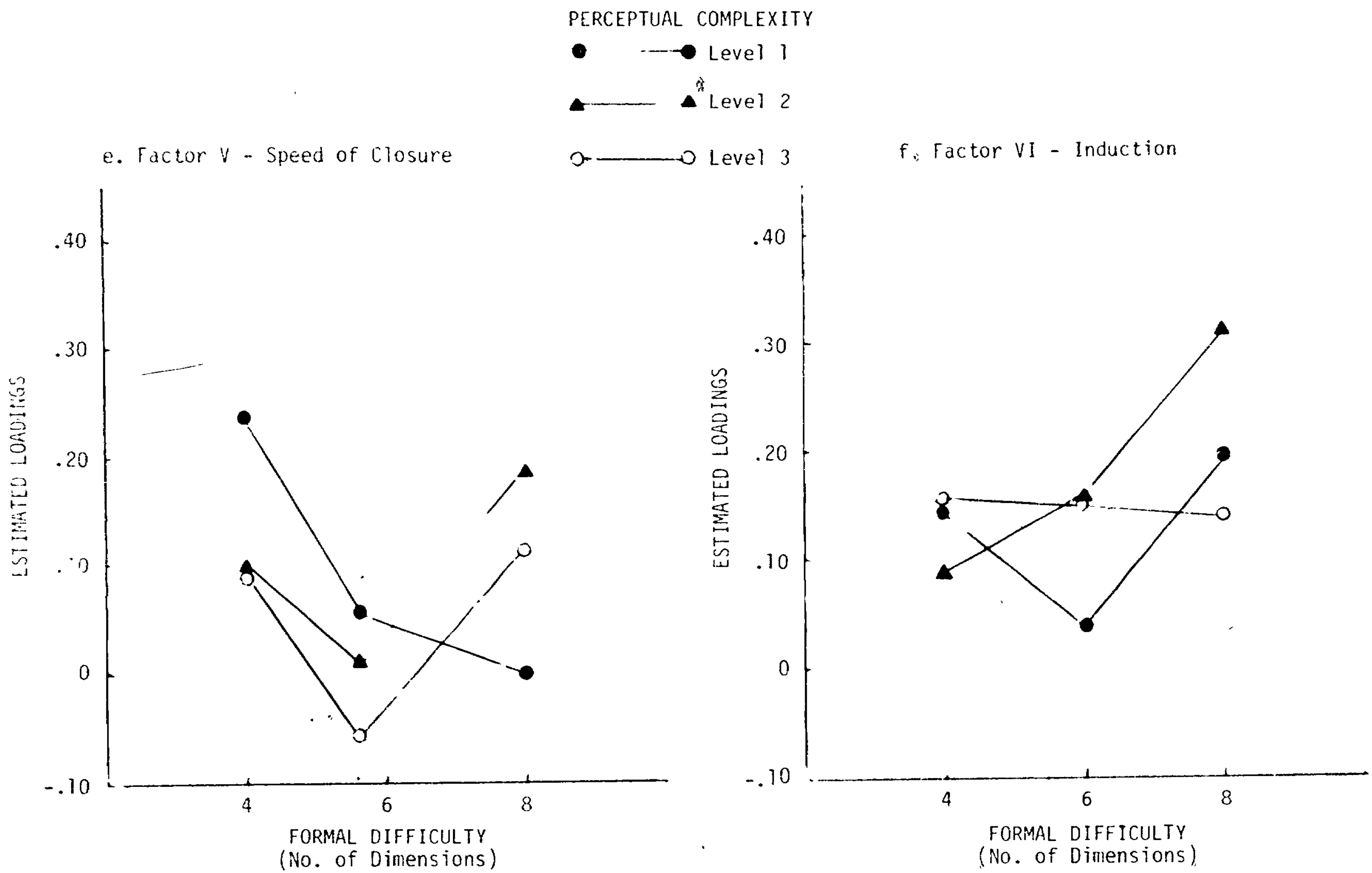

Figure 6. Proportion solved: estimated loadings on the D x P interaction. (Cont.)

The cell loadings for the dependent measure A/B (Figure 7) follow the marginal loading patterns almost exactly. This might seem somewhat surprising, as it was this measure of performance which was sensitive to the D x P interaction (cf. Figure 1). However, it is important to note that the analysis of variance is sensitive to group performance, while the Stoloff regressions describe the relationship between individual abilities and performance.

As shown in Figure 8, the cell loadings for the third performance measure, C^2/AB, are almost identical in pattern to those for the first performance measure, proportion solved, and all of the comments applied to Figure 6 apply to this one as well. One exception is Factor VI, which has moderate and generally constant loadings for all cells.

While the proportion of variance accounted for in this study is relatively substantial, the patterns which emerge in the loadings are not easily summarized. Perceptual Speed and Speed of Closure (Factors III and V) show very little relationship to performance on the criterion task, while the other factors all show moderate to fairly strong involvement which varies as a complex function of the task manipulations.

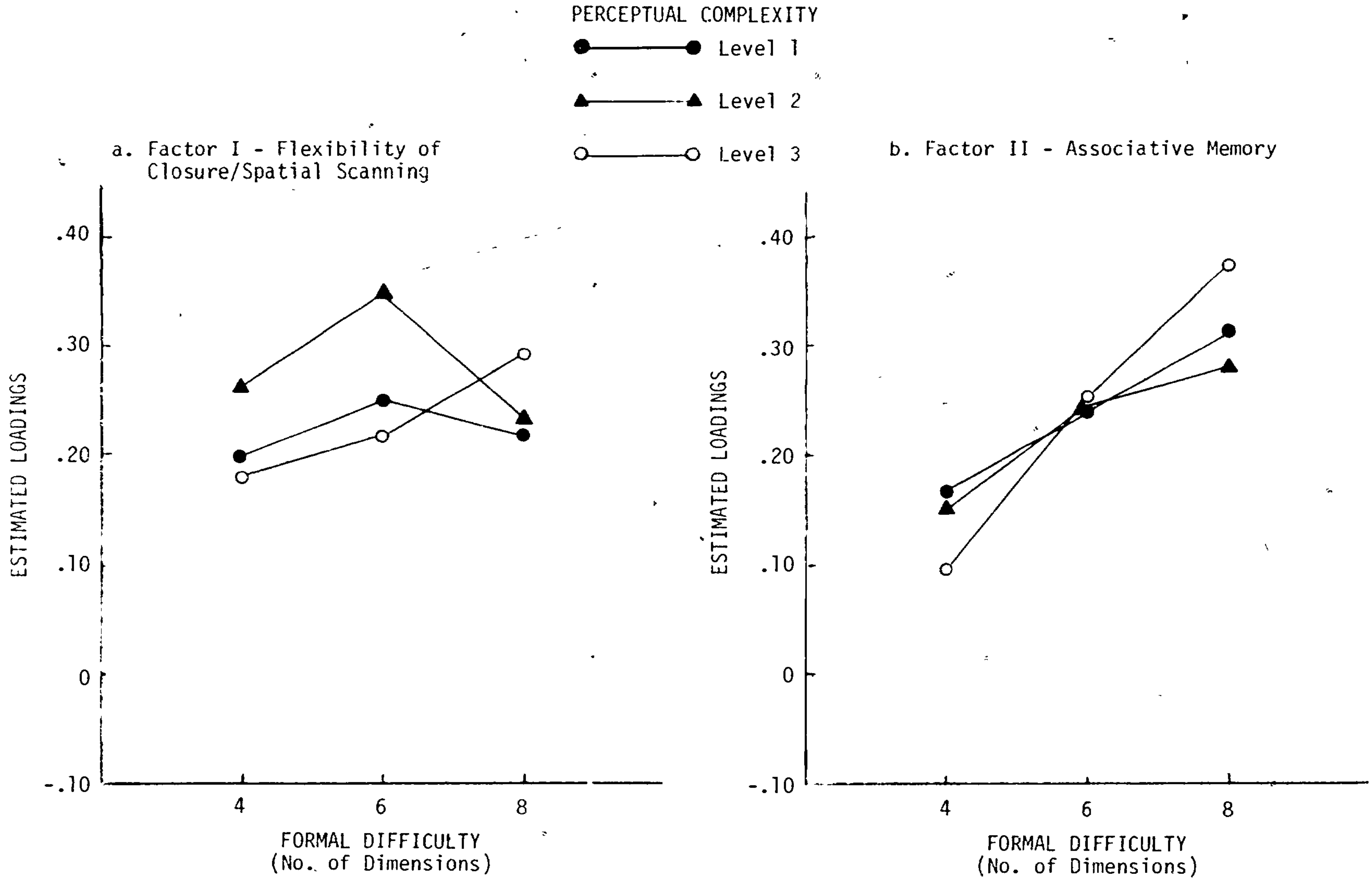

Figure 7. Number of hypotheses (A/B): estimated loadings on the D x P interaction.

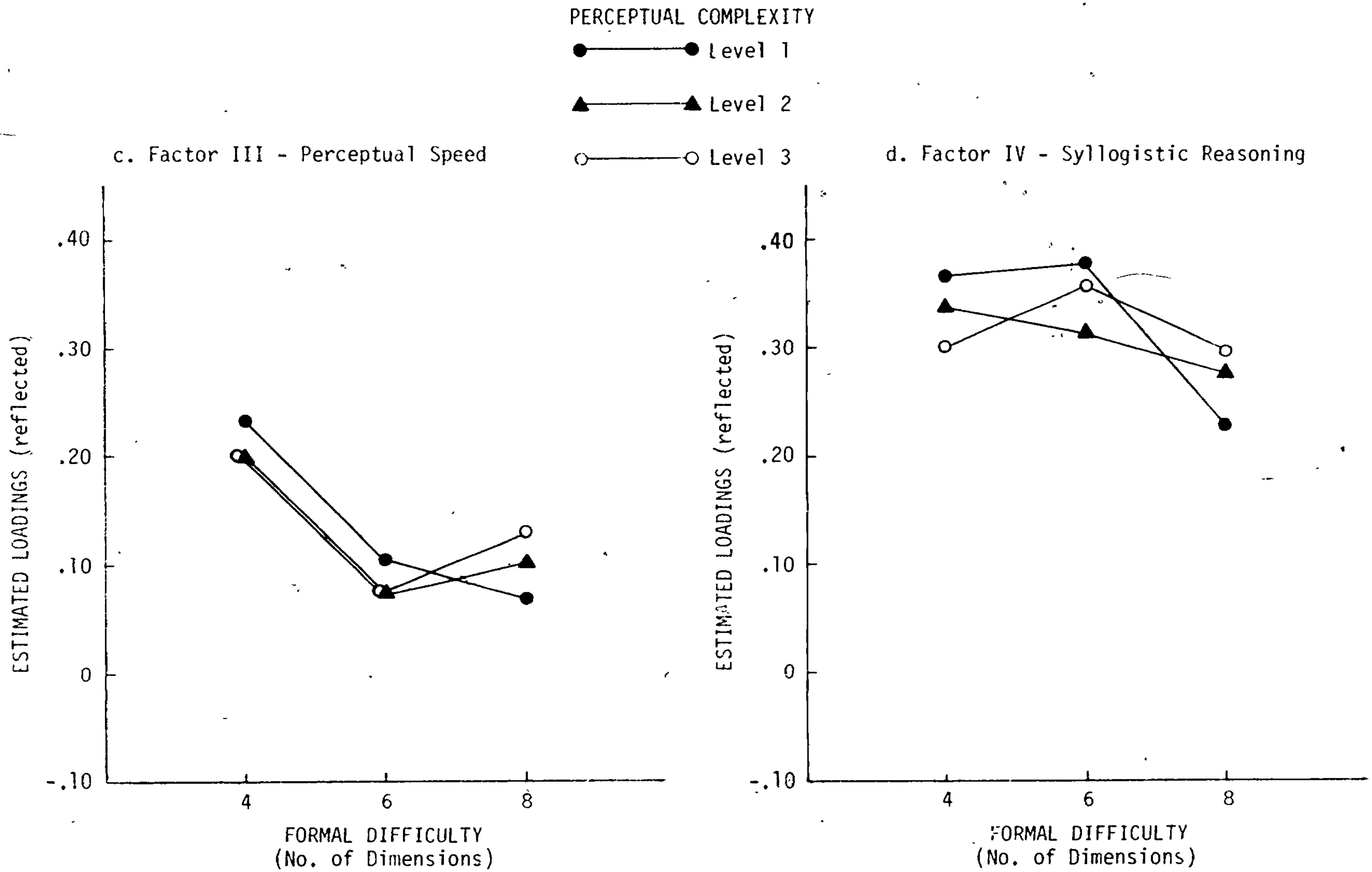

Figure 7. Number of hypotheses (A/B): estimated loadings on the D x P interaction. (Cont.)

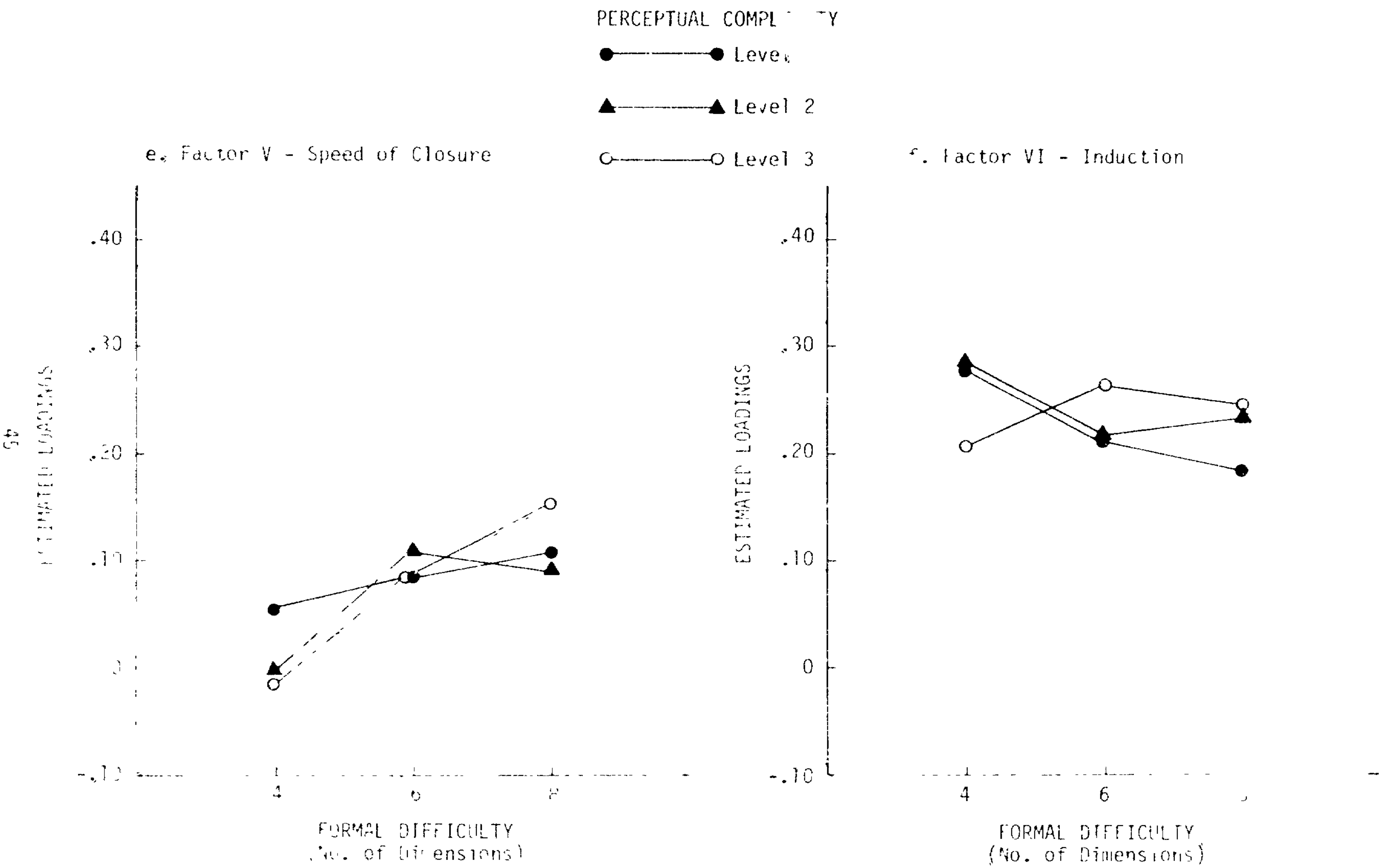

Figure 7. Number of hypotheses (A/B) estimated loading on the D x P interaction. (Cont.)

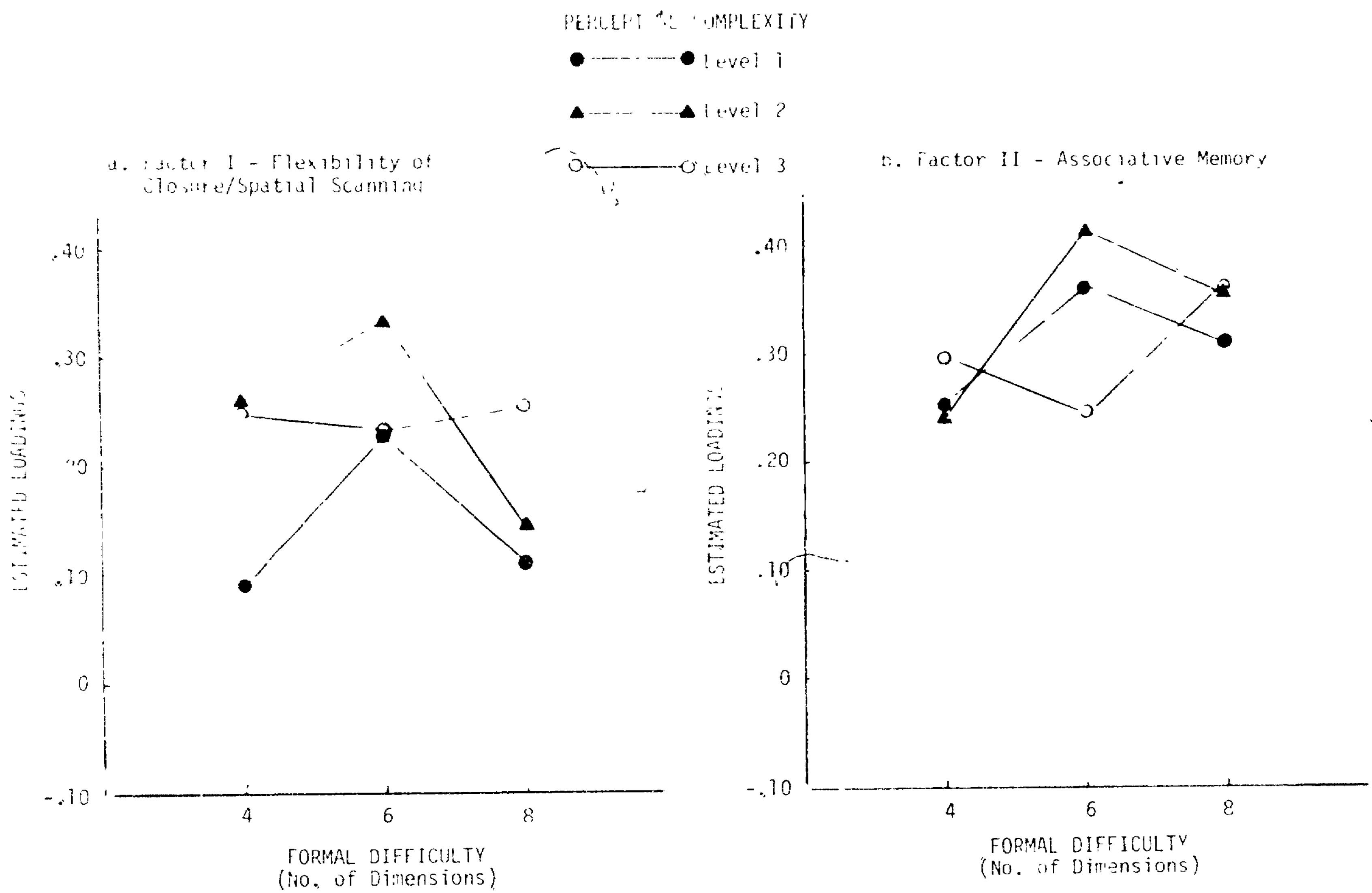

Figure 8. Efficiency (C^2/AB): estimated loadings on the D x P interaction.

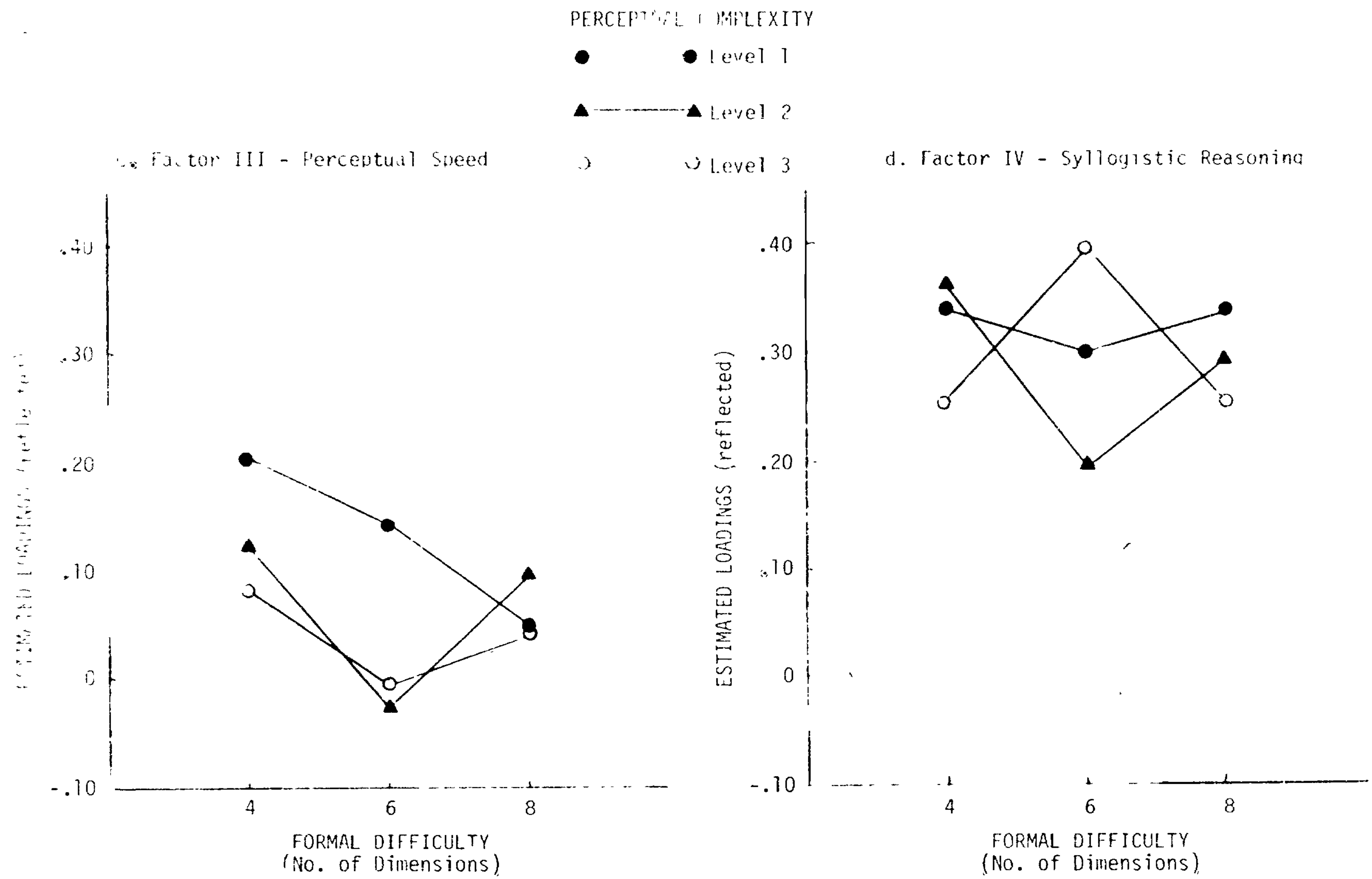

Figure 8. Efficiency (C^2/AB): estimated loadings on the D x P interaction. (Cont.)

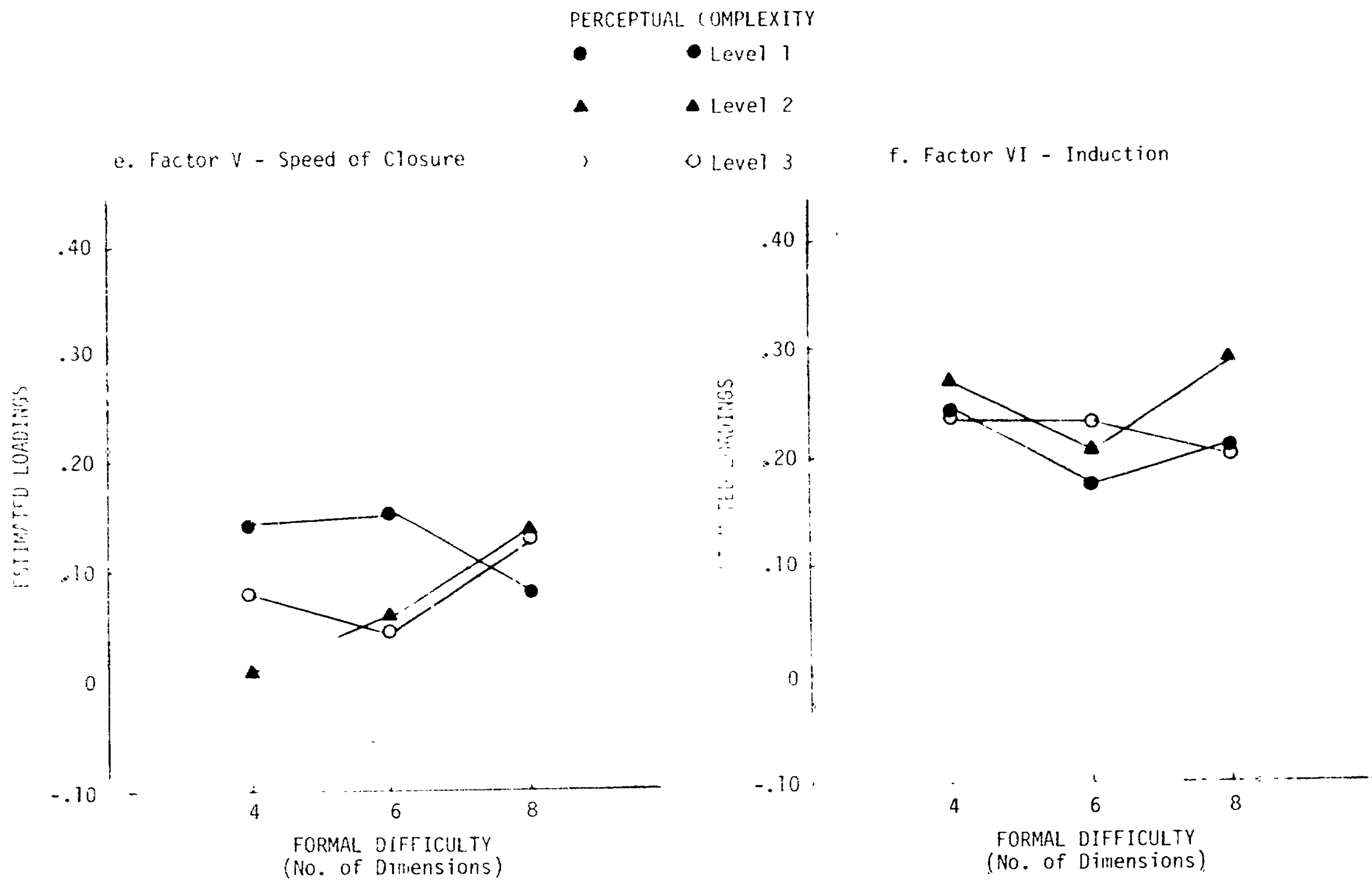

Figure 8. Efficiency (C^2/AB): estimated loadings on the D x P interaction. (Cont.)

DISCUSSION

Formal difficulty strongly and systematically influenced performance on the criterion task. In general, performance on each of the three dependent measures deteriorated as the number of dimensions was increased from four to six. The expected impact of eight dimensions was apparently offset by practice; subjects had almost twice as much experience with the task when they began the eight-dimension problems as when they began the six-dimension problems. The perceptual complexity task characteristic also impacted on criterion performance, but its influence was more subtle. On the number-of-hypotheses measure (A/B) subjects did better with increased complexity on easy problems, and worse as complexity increased on difficult problems. An improvement in performance was found for the efficiency measure (C^2/AB) as perceptual complexity increased regardless of problem difficulty. No simple effect of perceptual complexity on the proportion-solved measure was found.

While a general decrement in performance as number of dimensions increases is a consistent finding in concept identification research (cf. Bourne, et al., 1971), the impact of perceptual complexity has not been studied extensively. A hypothesis to explain the present results can be developed based on theoretical work which has been done in concept identification tasks (Bruner, et al., 1956; Levine, 1969). Subjects sample a subset of the possible solutions, and test this subset using information from successive feedback trials. This subset may include one or more hypothesized solutions, and is known as the focus set. The optimal focus set size (all of the attributes on the first trial, half on the second, one-fourth on the third, and so on) serves as a baseline for the A/B performance measure used in the current study. This measure reflects the actual size of a subject's focus set (A) relative to the optimal set size (B). According to Levine (1970), subjects test the hypotheses in their focus set, and thus narrow it down, in the following fashion. On each trial, the subject chooses one side of the stimulus, and codes those facial attributes which are in his focus set and on the chosen side. If his choice response is correct, he retains the coded attributes in his focus set, and eliminates the uncoded attributes; if his choice response is incorrect, he eliminates the coded attributes and retains the others as his updated focus set. The performance measure C^2/AB indicates the number of attributes that are consistent with all preceding feedback information and which the subject has correctly retained (C), relative to the total number which he has retained (A) and the number which he should optimally have retained (B).

Thus, A/B measures the size of a subject's focus set, while C^2/AB measures how well he uses feedback information to correctly narrow down his set to the solution to the problem. The number of problems solved depends on the size of the focus set <u>and</u> the proper elimination of incorrect attributes from the focus set; thus the proportion-solved measure is partially dependent on the other two measures. When a subject codes the intersection of his focus set and the chosen face, he must find the attributes of interest and remember them as distinct from his total focus set so that he may properly apply the feedback information. In the easiest and least complex problems, it seems reasonable to suppose that finding the attributes in the normal face is quite simple, and that they are remembered (or rehearsed) in accordance with the order in the face itself, e.g., top-to-bottom. While the normal face presentation does not explicitly require that the list of attributes be remembered in top-to-bottom order, the subject may feel compelled to do so since it seems more 'natural.' As the perceptual complexity increases, this natural ordering is lost. It is generally held (e.g., Postman, 1972) that when no list ordering is imposed by the experimenter, the subject organizes the list himself so that it is more easily remembered. According to Postman, "The organization imposed by the learner on a set of items depends on his perception of the structure of the list... For any list of items presented to a <u>particular</u> subject there is an optimal organization that will maximize recall" (p. 5, emphasis added). Thus, when the naturally ordered face is disrupted, subjects are free to (or forced to) actively organize the list themselves. Empirical findings (Tulving & Donaldson, 1972) suggest that this active involvement in problems with high perceptual complexity produces better recall than does the passive use of the top-to-bottom organization provided in problems at level one of perceptual complexity.

Obviously, the more attributes remembered, the more likely that feedback would be used correctly to narrow down the focus set. This is reflected in improved performance on the C^2/AB measure.

In order to account for the results on the A/B measure, one additional assumption is necessary: the subject's approach to the problem (i.e., the number of hypotheses he chooses to test simultaneously in his focus set) is dependent on the total cognitive load imposed by the task. When the number of total hypotheses is small, as in the four-dimension problems, the added load of finding the desired attributes and constructing a list organization is easily borne, and recall of the attributes is made easier due to the subject-generated list organization. The net cognitive load is decreased, thus allowing the subject to attempt to handle a larger focus set. When more total possible solutions are involved, as in the eight-dimension problems, the burden of constructing a list organization plus finding the attributes causes the subject to reduce his net load by reducing the size of his focus set. This would account for the observed changes in performance on the A/B measure.

There is some support for these hypotheses in the Stoloff relationships between abilities and performance as task characteristics are varied. The ability to scan and process complex visual fields (Factor I) becomes more predictive of overall performance (proportion solved) as perceptual complexity increases. However, it does not become more predictive of the focus-set measure (A/B) as complexity increases, either for the complexity marginal, or for complexity at individual levels of difficulty. This suggests that the added load of memory organization construction is more important in accounting for the D x P interaction for the A/B measure. Factor I does increase its relationship with the C^2/AB measure as complexity is increased, suggesting that subjects have difficulty processing attributes as they become more difficult to find, but that they do not change their approach when this occurs.

In accordance with these hypotheses, the Associative Memory factor (II) does become more predictive of the size of the subject's focus set as well as of his processing efficiency as formal difficulty increases. Thus, it becomes increasingly involved in both the approach the subject adopts, and how well he executes that approach. The non-monotonic relation of Factor II with proportion of problems solved over levels of formal difficulty is not understood at present.

While the ability data may be helpful in understanding the effects of the task-characteristic changes on performance, the goal of the study is to examine the effects of task-characteristic changes on the ability requirements. Thus, as task characteristics were varied, systematic changes in performance were noted, and the ability patterns predicting performance also changed. Are these changes in ability patterns systematic, and does it seem (at least ultimately) that they would be predictable from knowledge of the task characteristic manipulations?

In order to examine the results of this study from this point of view, it will be useful to review the possible relationships which might be found between changes in task characteristics and changes in degree of involvement of one or more abilities. One such relationship occurs when, as a result of a task characteristic change, a new task is created which requires abilities entirely different from those required by the original task. In this case one or more abilities which predicted performance in the old task would have essentially zero loadings in the new one, while others which were uninvolved in performance on the original task would predict performance in the new version. Examples from the current study might include Associative Memory, which has a very low loading on A/B performance for four-dimension problems, but which has moderate loadings for six- and eight-dimension problems. As another example, the loading for Flexibility of Closure/ Spatial Scanning on the proportion-solved and C^2/AB measures is very low for problems at the lowest level of perceptual complexity, but rises for more complex problems.

Another pattern of relationship between task characteristics and abilities occurs when, as a characteristic is manipulated, one or more abilities gradually rise or fall in importance. This pattern is essentially indistinguishable from the first, since a true zero correlation (indication of non-involvement) is empirically most unlikely. However, the distinction is theoretically important, since the first pattern implies that a threshold has been crossed, and the new task is truly different from the old, while a more gradual change implies a continuity between versions of tasks. As long as one uses a heterogeneous population of subjects and several levels of each task characteristic, an abrupt change in loadings is empirically unlikely, since all subjects would simultaneously have to reach the implied threshold, with corresponding identical changes in task characteristics.

A third pattern of relationship between characteristics and abilities occurs when, as the task is manipulated, one or more abilities change non-monotonically. One need only glance through Figures 3 through 8 of the current study to find many such instances of this kind of characteristic-ability pattern. For example, the loadings of Factor I on all three performance measures rise and then fall as difficulty increases. Such patterns, of course, might arise were the task characteristics in fact not correctly ordered; in our case this might be reasonable for the perceptual manipulation, but probably not for difficulty.

Wheaton, et al. (1973) invoke the concepts of intrinsic and extrinsic task variations in an attempt to explain different ability-task characteristic loading patterns. Given a set of abilities which are involved in a task, an extrinsic variation produces monotonic variations in the set of abilities; whether the loadings increase or decrease, they change in a similar fashion for all abilities in the set. Extrinsic variations may also produce more complex patterns, when the variations are improperly ordered, or when the range of variation is very great. "Under the simplest conditions, all subjects might perform relatively well, despite different levels of ability. Under the most difficult conditions, performance would be generally poor, no matter how much ability a given subject possessed. Between these extremes the advantage would be with those subjects possessing the greatest amount of the relevant abilities" (p. 35).

While extrinsic variations may produce similar changes in loadings for an entire set of abilities, intrinsic variations produce different changes for different abilities in the set. Intrinsic variations are hypothesized to produce this kind of change because the task, from the subjects' point of view, has changed. Subjects may then apply a new approach to this new and different task, which calls a new set of abilities into play. In the present study, therefore, both formal difficulty and perceptual complexity seem to represent intrinsic task variations, since the set of abilities do not covary consistently. Rose, et al. (1974) reported similar findings for a fault-finding task; as formal difficulty and perceptual complexity were varied, no consistent covariation of ability loadings on performance were observed. Wheaton, et al. found only one ability related to the performance of the tasks they examined, and so were precluded from examining covariation in a set of abilities.

Rose, et al. made an additional finding which bears on this discussion. They found, as did the present study, that different measures of performance on the criterion task showed different effects of varying task characteristics, and led to different characteristic-ability interactions. Any description of changes in ability loadings as a task characteristic varied depended upon the measure of performance which was used to estimate the loading. They suggested that the different measures of performance represent different aspects of a subject's approach to the problem. As a task characteristic varied, one aspect of the subject's approach might change, leading to new ability requirements. Those same task variations need not have changed other aspects of that subject's approach, leaving other ability requirements unchanged. It is even possible to imagine a case in which two independent aspects of a subject's approach might change in response to a particular task variation so as to create completely contradictory loading changes on the same set of abilities for two different measures of performance. The picture becomes even more complicated when one allows for two task variables which interact, or when the changes in a particular subject's approach depend on the actual amounts of various abilities which he possesses.

Rose, et al. suggest that the proper mediator of task-ability relationships is the subject's approach. From a cognitive point of view, the way he views the task determines the way in which he will attempt to deal with it, and this in turn will determine the abilities which are called into play. If a task variation does not change the nature of the task from the subject's point of view, no change in the set of ability requirements will be observed, although this set may become more or less predictive; if the task is seen as a new one, the set of abilities required by the approach adopted for this new task may be entirely different. For example, one would expect abilities related to speed of processing to be related to performance in a task where the subject's approach included an emphasis on speed. In the present study, no need for speed was imposed, and no relation to Perceptual Speed or Speed of Closure factors was found. Suppose that, in the present study, another version of the task were used which required that subjects work as quickly as possible. In this case one might expect Factors III and V to predict some aspect of performance on this version of the criterion task.

The admittedly speculative analysis presented at the beginning of this section is another example of this kind of analysis. That explanation supposes that certain combinations of task variations cause subjects (on the average) to change their approach. As aspects of their approach change, changes appear in the loadings of relevant abilities on the dependent measures which, in part, reflect those hypothesized changes in approach.

Actually, a much more efficient way of examining the validity of this kind of analysis is available for the data collected in the current study. A great deal of theoretical and empirical work exists regarding the behavior of subjects in solving concept identification tasks (e.g., Bruner, et al., 1956; Gholson, Levine, & Phillips, 1972; Gholson, Phillips, & Levine, 1973; Levine, 1969, 1970; Restle, 1962; Wandersman & Wandersman, 1973; Wickens & Millward, 1971). Researchers have described various ways in which subjects code the members of their focus sets, process feedback information, and remember information from preceding trials. Perhaps the most extensive work has been done in describing what happens when subjects select focus sets of various sizes, how sets are narrowed down, and the kinds of strategies used to locate the solution.

From the data available in the present study, it is possible to identify when subjects might have used one or another of these strategies, and how these might have changed for individual subjects as the task variations were introduced. Based on this data it should be possible to ascertain more precisely what happens when a task variation causes a subject to change his approach. In addition, it may be possible to relate both theoretically and empirically the ability requirements of several of the approaches adopted by subjects.

The following kinds of analyses are planned in the next phase of this project to attempt to validate the change-of-task, change-of-approach, change-of-ability model. One technique will be to stratify subjects on the basis of their approach to various versions of the task to determine if changes in ability loadings on performance coincide with changes in approach. Subjects will also be stratified on the basis of certain ability patterns, to examine the way that abilities which subjects possess might influence their choice of approach. Subjects may also be stratified based on their performance on one or more of the dependent variables; these samples would then be examined for approaches used and abilities possessed.

While the particular kinds of approaches used by subjects in concept identification tasks are of limited generalizability to tasks in the Navy, two very important outcomes are expected. If the importance of change of approach to change in ability requirements can be validated, it may become possible in the short term to predict whether a new version of an old Navy task will require revision of personnel decision-making criteria. Based on empirical and theoretical analysis of the tasks involved, it may be possible to determine if, for example, job incumbents would view a variation in the old task to have changed its nature, and thus change their approach. If incumbents were not expected to change their approach, no new selection instruments or training courses would be required (although performance criteria in selection or training might require change).

If a change in approach is predicted to occur, the problem becomes much more difficult. While personnel planners would know that their current procedures were inadequate, determining new requirements would depend on ascertaining which new approach would be employed, and analyzing that approach for ability requirements. This process would seem to require a great deal of additional research before it could be realized.

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APPENDIX

This appendix contains three items to further document the procedure used in administering the concept identification criterion task. First, a detailed description of the procedure, including complete instructions, is presented. Next, a table is provided which indicates the order in which subjects received problems, and the solutions to those problems. Finally, several pages from a subject answer booklet are included. Subjects solved up to six problems per booklet, and responses for each of these were recorded in a different column. Thus, on each trial the subject turned to a new page; for each new problem he returned to the front of the booklet and used the next column. Included are a sample choice response page, a sample probe page, and a sample trial-five probe page, which includes space for writing the solution. The samples provided are for eight-dimension problems. Others would be identical, except that fewer attributes would be listed on the probe pages.

PROCEDURE: EXPERIMENTAL CRITERION TASK

Subjects were held in a waiting area until the whole group was assembled. They then entered the laboratory where the experimenters introduced themselves. The following instructions were read aloud. Questions were answered by repeating or rephrasing appropriate sections from the instructions.

Instructions

You are about to participate in one phase of a continuing research effort designed to help us understand the relationships between various tasks and the abilities necessary to perform these tasks. As you know, the experiment in which you are taking part today is concerned with problem solving. Your morning session will consist of a series of these problem solving tasks with several rest breaks interspersed. Then you will have a lunch break after which you will be taking 21 paper-and-pencil tests covering many aspects of human ability. These tests were selected because they are either known or hypothesized to be related to performance on the problem solving task.

We anticipate finishing by about 5:00 p.m. You will be paid $20.00 in cash at that time for your participation. Are there any questions? We are now ready to begin the problem solving task. Please stop me at any time if something is not clear. In front of you is your first answer booklet, marked "3-0." First, write your sex, "male" or "female," on the front page of the booklet.

Before you on the screen are two faces. Faces can vary across a number of dimensions - such as texture of the hair, size of the lips, denseness of the eyebrows and so on - and it is possible to classify faces by describing these characteristics.

Let's suppose that the Earth has been invaded by creatures from another planet. Further, suppose that these creatures looked exactly like human beings. Therefore, it would be almost impossible to distinguish these creatures from earthlings should you happen to meet one on the street. However, these creatures do have an interesting feature--all of them have one identical facial characteristic. Your task is to discover which facial characteristic these creatures have in common. Looking at the two faces on the screen I will tell you now that one of these faces is that of a creature from outer space and one of his facial features is common to all of these creatures. It could be any one of the following:

ALL CREATURES HAVE STRAIGHT HAIR OR
ALL CREATURES HAVE CURLY HAIR OR
ALL CREATURES HAVE BUSHY EYEBROWS OR
ALL CREATURES HAVE SPARSE EYEBROWS OR
ALL CREATURES HAVE FULL LIPS OR
ALL CREATURES HAVE THIN LIPS

ANY ONE of these six characteristics could be the one characteristic that all the alien creatures have in common. You must determine which of the six characteristics is the correct one.

In order to discover the correct facial feature, we will present you with a series of five slides showing pairs of faces similar to the pair before you now. Using your first answer booklet, 3-0, turn to the first page containing problem A and problem B. Each problem has five trials. Under problem A, trial numbers are listed on the left hand side and two circles are present for each trial - labeled left and right. On each slide or trial you will check the corresponding left or right circle to indicate which face you believe belongs to the creature from another planet. After you have checked the appropriate circle, you will raise your pencil to show me you are ready. After everyone has responded, we will remove the slide and tell you which one was the creature's face. Then we will present the slide for trial #2 and you will again check the circle corresponding to the face which you believe belongs to the creature, and raise your pencil. Again we will tell you which side actually was the creature, and so on. After everyone has marked his choice for trial #5, raised his pencil and feedback has been given, you will write down what one single facial characteristic you think all the creatures possess, in the space provided at the bottom.

Let's review the characteristics again. It could be STRAIGHT hair or CURLY hair or BUSHY eyebrows or SPARSE eyebrows or FULL lips or THIN lips.

One and only one of these is the characteristic that all creatures have in common. Remember after each slide is presented, you will check the circle corresponding to the face which you believe belongs to the creature, raise your pencil to indicate you have responded, and, after everyone has responded, we will remove the slide, tell you which was the creature's face and then present the next slide. Are there any questions? All right, let's try a problem. Notice the trial number is shown in the middle of each slide. This will help you to mark your choice for each trial in the correct answer space. Okay, mark your first choice and raise your pencil.

(At the end of problem A) That's the end of this problem. Don't forget to write what you think the solution was - what one, single characteristic was common to all the creatures. Is everybody finished? Okay, the solution was straight hair. Everytime you picked the face with straight hair your response was correct.

Let's take a look at problem B. Notice how the facial features are switched around in this problem. We have again chosen one particular characteristic as the solution to the problem, that is, one feature which all "creatures" have in common. Your task is the same - you have five trials to determine which characteristic all creatures have in common. Remember, it could be FULL lips or THIN lips or BUSHY eyebrows or SPARSE eyebrows or STRAIGHT hair or CURLY hair. All right, let's try problem B. . . Mark your choice and raise your pencil. . . That's the end of problem B. Don't forget to write what you think the solution was. . .Is everyone finished? Okay, the solution was full lips. The rest of the problems will continue in much the same way--we will think of a feature and you will have five trials to figure out what it is. Your job is to figure out what one feature we have in mind on each problem. Any questions?

While the rest of the problems will be similar, the procedure we will follow will be a little different. Since we are interested in learning how people go about solving the problems, we are going to use a device to "get inside your heads"; that is, to find out what you are thinking as you solve the problems. Please turn to the next page of your answer booklet. On this page, labeled "Trial #1," you can see space for recording a "choice response" for the first slide for problem 1. If you turn over the two pages glued together you will see a space for recording your choice response for the second slide, or trial 2. This pattern continues throughout the rest of the book. Turn 2 more glued-together pages and you'll find trial 3, and so on. Thus, every other page provides space for recording your choice response for the five trials of problem 1 and similarly for problem 2. These pages will be referred to as choice response pages. You probably have noticed that another kind of page has been inserted between each choice response page. Turn back to the trial 2 choice response page. The facing page is what we will refer to as the probe page, for it is the information you provide on this kind of page that will enable us to probe the way in which you solve the problems. Notice in the column for problem 1 there is a list (in alphabetical order) of the possible solutions we have gone over before--BUSHY eyebrows, CURLY hair, FULL lips, SPARSE eyebrows, STRAIGHT hair, and THIN lips. Next to each possible solution is a space for you to make a check mark. On this page you will show us what you are thinking, by checking those solutions you think could still be correct. For example, if you think the solution could be either bushy eyebrows or curly hair, you would check both bushy and curly. Is this clear? Fine. We'll go through problem 1 like this.

We'll show you the first slide, and you check the side you think is correct on the Trial 1 choice response page. After you have marked your choice, you will raise your pencil. When everyone has responded and raised his pencil, we will remove the slide and tell you which side was correct. You will then turn over two pages to the Trial 1 probe page, and put a check by any of the facial characteristics you think could still be the solution to the problem. After you have finished, fold the pages on the left under the rest of the book. Make sure you fold the probe page over after you have marked it. When everyone has finished, we'll show you the second slide. You'll mark your choice on the trial 2 choice response page, and raise your pencil. We will remove the second slide and tell you which side was correct. You will then turn two pages to the trial 2 probe page and mark those features you still think could be the solution. We continue like this through trial 5. At the bottom of the trial 5 probe page there is a space for you to write down the one characteristic you think is the solution to the problem. If you're not sure, give your best guess.

Remember to mark on each probe page: BUSHY, if you think bushy eyebrows could still be the solution, CURLY, if you think curly hair could still be the solution, FULL, if you think full lips could still be the solution, SPARSE, if you think sparse eyebrows could still be the solution, STRAIGHT, if you think straight hair could still be the solution, and THIN, if you think thin lips could still be the solution. These are listed on the poster on the front wall to help you remember. You may check as many characteristics as you like on the probe pages, but only write one characteristic in the solution box at the end of each problem.

Turn back now to the trial #1 choice response page. For Problem #1, notice the facial features again have been moved around. Let's begin the problem. Check the corresponding left or right circle to indicate which face you believe is correct. Raise your pencil when you have done this. The correct side is____. Turn the choice response page over. On the trial #1 probe page, check the characteristics you think could still be the solution. When you're finished, fold the pages on the left underneath.

Turn to the trial 2 choice page. Check the corresponding left or right circle to indicate which face you believe belongs to the creature. Raise your pencil when you have done this. The correct side is____. Turn the choice response page over. On the trial 2 probe page check the characteristics you think could still be the solution. When you finish, fold the pages underneath. We'll continue just like this through trial 5. As soon as you have completed the trial 5 probe page and written your solution, turn back to the trial 1 choice response page, and raise your pencil. The solution to problem 1 was sparse eyebrows. Whenever you picked the face with sparse eyebrows you were correct. Any questions?

Is everybody on the trial 1 choice response page for problem 2? Here is a slide of two new faces in an even more scrambled order. Notice the features have not changed. The faces still have CURLY or STRAIGHT hair, or BUSHY or SPARSE eyebrows, or FULL or THIN lips, but they are jumbled around. Your task is the same as before - to identify the one characteristic that I have in mind, that is the solution to the problem. Let's begin. . . .

(Prompting as necessary.) Okay, the solution is thin lips. Put your 3-0 booklet under the brown file and take the 4-1 booklet out of the file.

All right, open your 4-1 booklet to the trial 1 choice response page. All booklets will now list six problems on each choice response page, and the six corresponding problems on each probe page.

The first pair of faces you see on the screen has another possible facial dimension that you must consider - eyes. The possible solutions now include WIDE eyes or SQUINTY eyes. There are now eight possible solutions to each problem. Turn to the probe page for trial 1. The possible solutions are STRAIGHT hair or CURLY hair, or BUSHY eyebrows or SPARSE eyebrows, or FULL lips or THIN lips, or WIDE eyes or SQUINTY eyes. Notice all these solutions are in the probe page in alphabetical order.

Ready for problem #1. . .(Prompting only if necessary). . .The solution is curly hair. Before beginning the next problem, we want to remind you that the facial features may also be scrambled like this. Notice the facial features are moved around but once again the characteristics have not changed. They are BUSHY eyebrows or SPARSE eyebrows, or FULL lips or THIN lips, or STRAIGHT hair or CURLY hair, or WIDE eyes or SQUINTY eyes. Remember, one and only one feature is the solution to each problem. Remember also that features could be scrambled like this. Any questions? Okay. Please don't make any notations in your booklets other than checkmarks in the circles provided. Also, please do not turn back any pages through your book, except when we're all ready to begin a new problem. (Go through all four-dimension problems.

(After all four-dimension problems):

We'll now take a short break. Please do not discuss the problems during the break.

(After break):

All right, open your 6-1 booklet to trial 1 choice response page. The pairs of faces are slightly more complex now. Two more possible facial dimensions must be considered - glasses and noses. The solution could be either round or square glasses. Also, it could be either a long or a short nose. So there are now 12 possible solutions to the problem. Turn to the trial 1 probe page. The solution could be STRAIGHT hair or CURLY hair, or BUSHY eyebrows or SPARSE eyebrows, or FULL lips or THIN lips, or WIDE eyes or SQUINTY eyes, or ROUND glasses or SQUARE glasses, or LONG nose or SHORT nose. Remember, one and only one feature is the solution to any one problem.

Ready for problem 1. . .The solution is long nose. Before we begin the next problem, I want to remind you that the facial features may also be scrambled like this. Notice the facial features are moved around again; however, the characteristics are the same--STRAIGHT hair or CURLY hair, or BUSHY eyebrows or SPARSE eyebrows, or FULL lips or THIN lips, or WIDE eyes or SQUINTY eyes, or ROUND glasses or SQUARE glasses, or LONG nose or SHORT nose. Remember also that features could be scrambled like this. Any questions? Okay, let's begin problem 2. . ..

(After all six-dimension problems):

We'll now take a short break. Please do not discuss the problems during the break.

(After break):

All right, open your 8-1 booklet to trial 1 choice response page. On the next pair of faces, two new possible facial dimensions have been added - facial hair and scar. The solution now could be either a mustache or a beard or scar on the right side of the face or on the left side of the face. Determine the side of the scar as you view it.

So there are now 16 possible solutions to the problem. Turn to the trial 1 probe page. The solution could be STRAIGHT hair or CURLY hair, BUSHY eyebrows or SPARSE eyebrows, FULL lips or THIN lips, WIDE eyes or SQUINTY eyes, ROUND glasses or SQUARE glasses, LONG nose or SHORT nose, BEARD or MUSTACHE, RIGHT or LEFT SCAR. Remember, one and only one feature is the solution to each problem.

Ready for problem 1?. . .The solution is round glasses. Before we continue, remember that the facial features may be scrambled like this. Notice the facial features are switched again. However, the characteristics are the same--STRAIGHT hair or CURLY hair, BUSHY eyebrows or SPARSE eyebrows, FULL lips or THIN lips, WIDE eyes or SQUINTY eyes, ROUND glasses or SQUARE glasses, LONG nose or SHORT nose, BEARD or MUSTACHE, RIGHT or LEFT SCAR. Remember, they could appear like this, too; the scar, however, will always be on the left or right. Let's begin problem 2. . .(continue with remaining eight-dimension problems).

Appendix Table 1

Presentation Order of Experimental Problems

Problem No.	No. of Dimensions (Formal Difficulty)	Degree of Disorganization (Perceptual Complexity)	Solution (Value, Dimension)
1	4	1	curly, hair (Sample)
2	4	1	wide, eyes
3	4	3	bushy, eyebrows
4	4	2	thin, lips
5	4	2	squinty, eyes
6	4	1	sparse, eyebrows
7	4	2	curly, hair
8	4	3	straight, hair
9	4	1	full, lips or squinty, eyes*
10	4	3	sparse, eyebrows
Break			
11	6	1	long, nose (Sample)
12	6	3	bushy, eyebrows
13	6	1	straight, hair
14	6	2	short, nose
15	6	1	full, lips
16	6	3	sparse, eyebrows
17	6	1	wide, eyes
18	6	2	square, glasses
19	6	2	thin, lips
20	6	3	curly, hair
Break			
21	8	1	round, glasses (Sample)
22	8	3	square, glasses
23	8	2	left, scar
24	8	2	curly, hair
25	8	1	squinty, eyes
26	8	3	round, glasses
27	8	1	full, lips
28	8	2	short, nose
29	8	3	mustache, facial hair
30	8	1	bushy, eyebrows

* This problem had two solutions due to an error made in constructing the problem.

TRIAL #1

PROBLEM #1		PROBLEM #2		PROBLEM #3		PROBLEM #4		PROBLEM #5		PROBLEM #6	
LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT

TRIAL #1

PROBLEM #1		PROBLEM #2		PROBLEM #3		PROBLEM #4		PROBLEM #5		PROBLEM #6	
BEARD	○	BEARD	○	BEARD	○	BEARD	○	BEARD	○	BEARD	○
BUSHY	○	BUSHY	○	BUSHY	○	BUSHY	○	BUSHY	○	BUSHY	○
CURLY	○	CURLY	○	CURLY	○	CURLY	○	CURLY	○	CURLY	○
FULL	○	FULL	○	FULL	○	FULL	○	FULL	○	FULL	○
LEFT	○	LEFT	○	LEFT	○	LEFT	○	LEFT	○	LEFT	○
LONG	○	LONG	○	LONG	○	LONG	○	LONG	○	LONG	○
MUSTACHE	○	MUSTACHE	○	MUSTACHE	○	MUSTACHE	○	MUSTACHE	○	MUSTACHE	○
RIGHT	○	RIGHT	○	RIGHT	○	RIGHT	○	RIGHT	○	RIGHT	○
ROUND	○	ROUND	○	ROUND	○	ROUND	○	ROUND	○	ROUND	○
SHORT	○	SHORT	○	SHORT	○	SHORT	○	SHORT	○	SHORT	○
SPARSE	○	SPARSE	○	SPARSE	○	SPARSE	○	SPARSE	○	SPARSE	○
SQUARE	○	SQUARE	○	SQUARE	○	SQUARE	○	SQUARE	○	SQUARE	○
SQUINTY	○	SQUINTY	○	SQUINTY	○	SQUINTY	○	SQUINTY	○	SQUINTY	○
STRAIGHT	○	STRAIGHT	○	STRAIGHT	○	STRAIGHT	○	STRAIGHT	○	STRAIGHT	○
THIN	○	THIN	○	THIN	○	THIN	○	THIN	○	THIN	○
WIDE	○	WIDE	○	WIDE	○	WIDE	○	WIDE	○	WIDE	○

TRIAL #5

PROBLEM #1

PROBLEM #2

PROBLEM #3

PROBLEM #4

PROBLEM #5

PROBLEM #6

[illegible] what you [illegible] on to this problem was, i.e. what one characteristic [illegible] the correct face [illegible] not sure, [illegible] one last [illegible]

[illegible] #1 | [illegible] #2 | [illegible] #3 | [illegible] #4 | [illegible] #5 | [illegible] #6

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