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ABSTRACT

The report describes the fourth and final study in a program of research into the relationships between the characteristics of human tasks and the abilities required for task performance. The goal was to generate principles for identification of ability requirements from knowledge of the characteristics of a task and of variations in the conditions of task performance. Such knowledge has implications for selection and training of personnel. In this fourth study, possible interactions among task variations, ability profiles, and subject strategies were examined within the context of troubleshooting and problem-solving tasks previously studied. Subjects' strategies were defined in terms of their method of problem-solving under each level of task difficulty and perceptual complexity. Subgroups adopting one of several kinds of strategy were then analyzed to determine the relationships between abilities and strategies, and strategies and performance. The recurrent findings support the contention that abilities are sensitive to differences among tasks, making them more precise descriptors of performance than the broader rubrics (e.g., mental, motor; cognitive, noncognitive; etc.) which have been in vogue. In general, knowledge of a subject's problem-solving strategy was useful in obtaining a clearer understanding of ability requirements under different conditions of task performance. (Author)

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METHODS FOR PREDICTING JOB-ABILITY REQUIREMENTS:

IV. Task Characteristics, Ability Requirements, and Problem-Solving Strategies

George R. Wheaton
Andrew M. Rose
Paul W. Fingerman

FINAL REPORT

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This report describes the fourth and final 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 has been 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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20. The three previous studies examined the relationship between variations in an auditory signal identification, a troubleshooting, and a problem-solving task, and consequent changes in the abilities related to task performance. Task characteristics were generally manipulated by varying difficulty and perceptual complexity. In each study 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 performance.

The results of these studies were that complex changes in the ability requirements related to performance occurred in response to variations in task characteristics. These results suggested that certain task variations changed the nature of the task in such a way that subjects changed their approach to, or strategy for dealing with, the task.

In the fourth and final study, possible interactions among task variations, ability profiles and subject strategies were examined within the context of the troubleshooting and problem-solving tasks previously studied. Subjects' strategies were defined in terms of their method of problem solving under each level of task difficulty and perceptual complexity. Subgroups adopting one of several kinds of strategy were then analyzed to determine the relationships between abilities and strategies, and strategies and performance. In general, knowledge of a subject's problem-solving strategy was useful in obtaining a clearer understanding of ability requirements under different conditions of task performance.

ACKNOWLEDGMENTS

The authors wish to express their sincere appreciation to Dr. Edwin A. Fleishman for his guidance and support throughout the project. The research studies which were undertaken were suggested by and represent an extension of Dr. Fleishman's long-standing and programmatic investigation of human abilities and task performance.

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I. INTRODUCTION

In order to insure effective manning of newly created jobs and tasks, estimates are needed of the capabilities and skills of operator personnel together with prescriptions for the manner in which they should be trained. Similarly, as existing equipments and procedures are modified, estimates are required of the impact of such modifications on operator performance in order to update selection and training decisions. In both of these cases, accurate estimates depend upon a method for systematically translating information about the job or task to be performed into quantitative information on selection and training needs.

Traditionally, the burden of such translation has fallen upon task analysis, a general procedure typically consisting of two distinct aspects: a description of the salient characteristics of tasks and the translation of these characteristics into hypotheses stating the operator capabilities necessary for successful performance. While a variety of task-descriptive and task-analytic methods have been developed to aid in this translation, their effectiveness has been limited by the lack of task-descriptive languages which would facilitate inferences about desirable operator capabilities given information about salient features of the task.

In response to this and a series of allied problems, Fleishman and his associates undertook the development of several different but interactive taxonomies for the description and classification of tasks (e.g., Fleishman, Kinkade, & Chambers, 1968; Fleishman, & Stephenson, 1970; Fleishman, Teichner, & Stephenson, 1970; Theologus, Romashko, & Fleishman, 1970; Wheaton, Mirabella, & Farina, 1971; Levine, Romashko, & Fleishman, 1971; Farina, & Wheaton, 1971; and Wheaton, & Mirabella, 1972). While several taxonomies were investigated, the two on which most extensive research was conducted provided for detailed descriptions of tasks in terms of: human abilities hypothesized as essential to effective task performance; and salient or critical goal-, stimulus-, procedural-, and response-dimensions of tasks.

The first language uses empirically defined human abilities as its vocabulary. In this context, an ability refers to a relatively enduring characteristic of an individual which has been inferred from behavioral consistencies (e.g., correlations) on several kinds of tasks. Since the abilities are empirically defined (through factor-analytic procedures) by response consistencies on tests of known reliability, operational definitions of abilities are available. Application of these definitions in the description and classification of diverse tasks has been reasonably successful. Given verbal definitions of abilities derived from the empirical findings, Theologus, Romashko, & Fleishman (1970), Theologus, & Fleishman (1971), and Levine, Greenbaum (Kramer), & Notkin (1973) have demonstrated that experienced analysts can agree on the specification of sets of abilities presumably related to individual differences in performance on a broad cross section of tasks.

As the complement to description of relevant operator abilities, the second language--task characteristics--was designed to provide for the description of tasks in terms of intrinsic properties common to a wide variety of tasks including goals, procedures, and stimulus-response modes. The decision to attempt description in these rather morphological terms, instead of using more behavioral-, process-, or ability-oriented descriptors, stemmed from a conviction that tasks, in their own right, represented a potent class of independent variables contributing to variance in performance. This position was presented in terms of an heuristic model of performance known as POET (Farina, & Wheaton, 1971). The model simply stated that any obtained measure of performance (P) was necessarily a function of at least three major classes of variables. These included the specific operator (O) whose performance was monitored, the environmental conditions (E) under which performance occurred, and the particular task (T) on which performance was measured. The implication of the model was that if the variables comprising a task were manipulated singly or in combination (e.g., creating a number of similar but morphologically different tasks), the resultant effects on performance and on the abilities related to individual differences in performance might then be mapped systematically.

Considered jointly, therefore, the task-characteristics and abilities languages furnished a conceptual basis for translating information about the task to be performed into information about the kinds of operator capabilities and skills required for successful performance. Hypothetically, task analysts would not only be able to describe the features of a given task and to infer the kinds of abilities required, but they would also be able to specify changes in ability requirements as selected features of the task were manipulated. These kinds of specifications were viewed as central to improved selection and training decisions.

The program of research summarized in the present report was designed to investigate the task-analytic issues raised above at a more fundamental level than had been undertaken heretofore. Its goal was essentially threefold: 1) to determine whether presumably small but systematic variations in tasks were reflected in changes in ability requirements; 2) to establish whether such changes were orderly, permitting the development of principles relating task variations to ability requirements; and 3) to extend the study of basic human abilities to more cognitively-oriented tasks. In essence, therefore, the research program has been concerned with an empirical elaboration of the interplay between task demands and ability requirements conceptualized in earlier efforts.

The approach adopted to address these issues has entailed the investigation of classes of tasks both representative of those prevalent in the modern Navy and of theoretical interest. In each instance performance data are obtained for large samples of subjects who perform on systematically-induced variations of the task of interest. Empirically established ability profiles for these same subjects are then related to the performance data in a variety of ways to ascertain changes in ability requirements. The resultant patterns of changes are then interpreted for meaning.

The specific results and more general findings stemming from application of this approach to three different classes of tasks (e.g., auditory signal identification, electronic troubleshooting, and problem solving) are presented and summarized in the following sections of this report. In Section II, the basic method is elaborated and results are presented concerning: 1) the effect of task manipulations on performance; 2) the identification of operator abilities; and 3) the investigation of changing ability requirements in response to task manipulations. In Section III, intervening variables descriptive of the subjects are explored as mechanisms for consolidating and systematizing some of the complex changes in ability requirements which were demonstrated. Relevant issues include: 1) the kind of problem-solving strategies used by different subjects; 2) the relation between the kind of strategy employed and the level of performance achieved; and 3) the changes in ability requirements in response to task manipulations exhibited by the different strategy subgroups. In Section IV, conclusions and recommendations are presented.

II. TASK CHARACTERISTICS, PERFORMANCE, AND ABILITIES

Background

A recent review (Fleishman & Bartlett, 1969) indicates that laboratory studies using combinations of experimental and correlational methods to develop principles relating task dimensions to ability requirements are rare. Notable exceptions in this regard are studies described by Fleishman (1957) and Zimmerman (1954). Fleishman, for example, attempted to relate ability variables to changes in task difficulty represented by systematic alterations of control-display relations in a perceptual-motor task. The basic criterion task was a Response Orientation Task, consisting of a display panel of 16 lights in circular array and a response panel of 16 buttons similarly arranged. When a light appeared on the display panel, the subject was required to press that button on the response panel which was in a specific relative position to the light. Criterion task difficulty was manipulated by having subjects perform under eight different degrees of display rotation. A factor analysis of criterion data and reference ability measures revealed systematic changes in ability requirements as a function of display rotation and consequent task difficulty. For example, under the 0° condition where the display and response panels corresponded, individual differences in performance were primarily a function of the Perceptual Speed factor. However, as greater rotations were introduced, Perceptual Speed decreased in importance and performance increasingly became a function of two other factors--Spatial Orientation and Response Orientation.

In Zimmerman's study (1954) abilities were investigated as a function of changes in the difficulty of a paper-and-pencil perceptual task known as Visualization of Maneuvers. In this task the subject was presented with a single view of an aircraft as a starting position. An aerial maneuver was then described and the subject was to select one of five alternate pictures which correctly portrayed the airplane's position following the prescribed maneuver. Task difficulty was varied by using three forms of the task which required visualization of one, two, or three maneuvers flown in sequence. Zimmerman hypothesized that as the visualization task increased in difficulty, performance would first be a function of Perceptual Speed, then of Spatial Relations, then Visualization, and finally Reasoning factors, in that order. Factor analyses of criterion and ability reference test data obtained from large samples of Aviation Cadets tended to support the hypothesis for the first three factors. On the easiest and most speeded form of the task, performance was a function of the Perceptual Speed factor. As task difficulty increased, however, the involvement of this factor decreased and the importance of the Spatial Relations and Visualization factors increased.

Considered jointly, the Fleishman and Zimmerman studies relating abilities to changes in criterion task difficulty are of fundamental importance in understanding the interplay between task characteristics and ability requirements. Their value lies in the demonstration that manipulations of task difficulty may result in changes in the patterns of abilities accounting for individual differences in performance. Such a demonstration is all the more striking when one considers that an alternative hypothesis might predict changes in the level of involvement of a specific pattern of abilities as a function of changes in task difficulty. Clearly, the methodology for relating task characteristics to ability requirements must take the possibility of either outcome into consideration.

Within the present program three additional studies were conducted to investigate further the changes, if any, which occur in the patterns of abilities accounting for individual differences in performance under variations in the criterion task. Since Fleishman and Zimmerman had dealt with tasks in the perceptual-motor and visual-perceptual domains, criterion tasks were chosen representing more cognitive kinds of performance. These included auditory signal identification (Wheaton, Shaffer (Eisner), Mirabella, & Fleishman, 1973), fault finding (Rose, Fingerman, Wheaton, Eisner, & Kramer, 1974), and concept identification (Fingerman, Eisner, Rose, Wheaton, & Cohen, 1975).

In each case, the research was conducted in the laboratory using a combination of experimental and correlational methods. Based upon an analysis of the criterion task, a battery of reference tests was assembled which represented abilities judged to be of relevance to criterion task performance.

Subjects received the reference battery and then proceeded to perform the criterion task under different task conditions. To determine the relationship between task characteristics and ability requirements, the reference battery was factor analyzed to identify a reference ability structure. The loadings of the various criterion task conditions on that structure were then estimated. The procedures followed in each of the three studies are described below together with the major results obtained.

Auditory-Signal-Identification Task

Procedure

In this first study in the program (Wheaton, Shaffer (Eisner), Mirabella, & Fleishman, 1973), a total of 127 male college students received ten hours of testing distributed over two consecutive days. Groups of subjects were first administered a battery of 24 reference tests which were designed to tap into a number of auditory and visual abilities hypothesized as potentially relevant to auditory signal identification. Multiple marker tests were included for each of six hypothesized abilities to insure adequate factor definition. In assembling printed tests to represent the Induction, Associative Memory, Speed of Closure, Flexibility of Closure, and Perceptual Speed factors, considerable use was made of the Kit of Reference Tests for Cognitive Factors (French, Ekstrom, & Price, 1963). Tests selected from this kit were used in unmodified form, except that due to time limitations, only the first part of all two-part tests was administered. Aural tests were based primarily upon Seashore's Measures of Musical Talents (Buros, 1965) as adapted by Fleishman and Spratte (1954). The major changes made were to record standard instructions on tape, together with demonstration examples. Other aural tests were taken from among the standardized tests of auditory-perceptual abilities developed by Fleishman and Friedman (1957a, 1957b).

Upon completion of the reference battery, subjects were exposed to the criterion task, which involved the classification of relatively complex auditory stimuli into one of four ship categories--submarine, warship, cargo, and lightcraft. The stimuli came from a library of ship sounds developed by John Annett of the University of Hull. The sounds had been synthesized by electronic and mechanical means to represent realistically complex stimuli with the same general characteristics as passive sonar signals, but without any real attempt to simulate actual vessels or sonar systems. Ship sounds were comprised of several components (i.e., propeller cavitation, engine sounds, shaft squeal and hull resonance, sonar, and other mechanical ship sounds) which, when combined, constituted four broad categories of vessels. Accompanying these signals were background sea noise and assorted biological effects.

The independent variables selected for systematic manipulation of criterion task difficulty were signal duration and signal-to-noise ratio. Nine different task treatment conditions were devised according to a factorial arrangement of these two variables. Signals were presented for either 9-, 6-, or 3-second durations and at one of three signal-to-noise ratios. To create the latter, signal strength was kept constant while background noise was varied in five decibel (dB) steps--being either weaker (-5 dB), stronger (+5 dB), or of the same intensity (0 dB) as the signal. One hundred signals, comprised of 25 examples from each of the four categories of ship sounds, were presented under each of the nine different task conditions. Criterion performance was measured in terms of number of correct identifications.

Results

Criterion task performance. To assess the impact of manipulating the selected independent variables, a fully repeated measures 4 x 3 x 3 factorial design was used in which the performance of all 127 subjects was evaluated under the four signal, three duration, and three background noise level conditions. The mean percentages of correct identifications under these conditions are shown in Figure 1.

An analysis of variance revealed that performance was significantly affected by an interaction between signal category and level of background noise. In this interaction, differences in performance associated with different signal types decreased as the level of background noise increased. Under the lowest level of background noise used, each ship category differed from every other category in terms of accuracy of identification

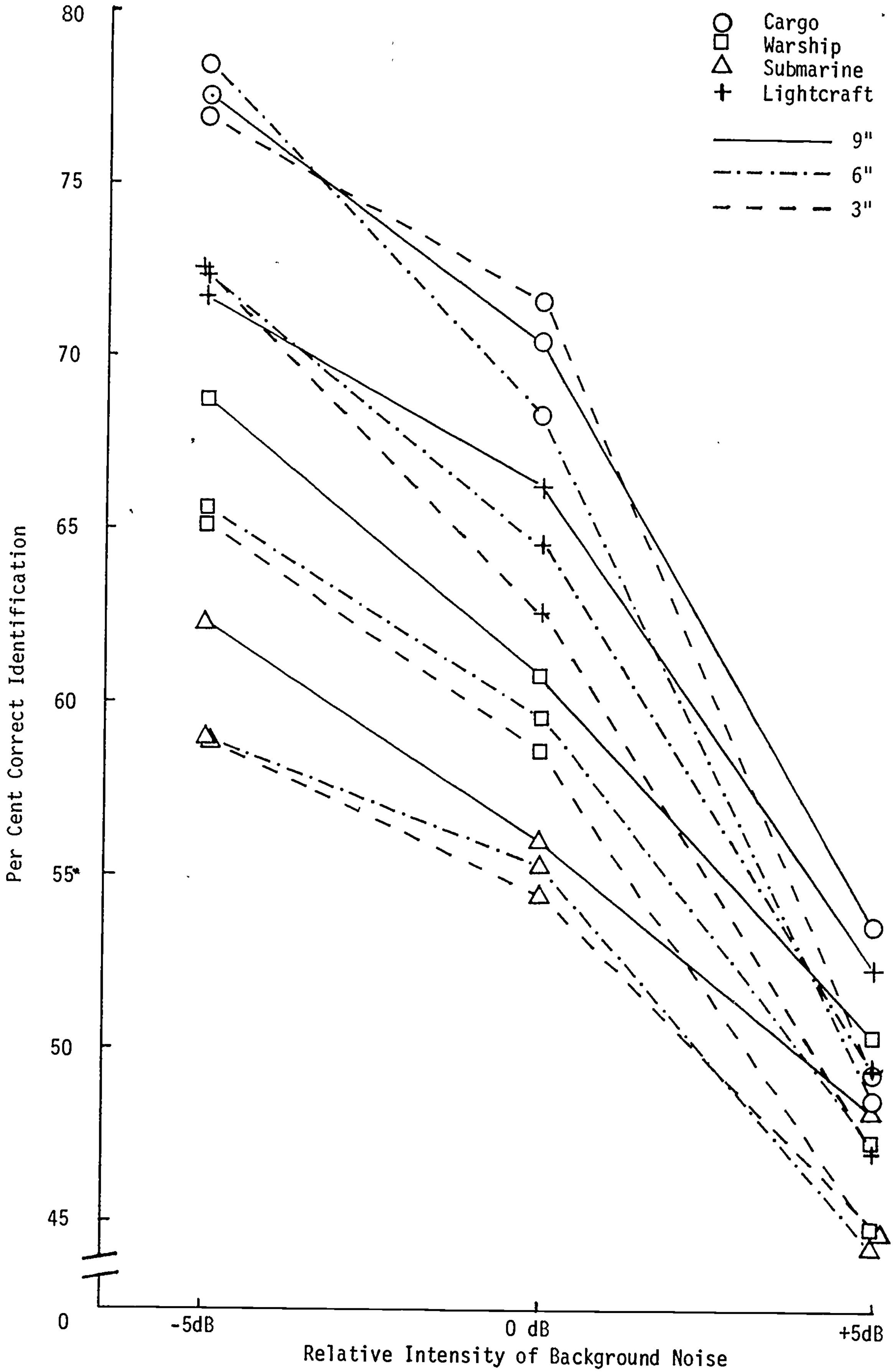

Figure 1. Identification accuracy as a function of task conditions. (From Wheaton et al., 1973.)

(e.g., cargo ships were identified more frequently, and submarines less frequently than any of the other ship types), but under the highest level of background noise, none of these distinctions was significant. Conversely, within each ship category the three levels of background noise impacted significantly on performance, identification accuracy systematically decreasing with increases in background noise. A similar systematic trend was obtained in response to the stimulus duration manipulation. The bulk of the effect, however, was confined to the difference between the nine-second and shorter intervals.

Ability structure. Data from the reference battery were intercorrelated and factor analyzed by means of a principal components solution. Table 1 presents the rotated factor loadings obtained using a varimax criterion. Of the six major factors extracted, five were tentatively identified, including: an Auditory Perceptual factor, a Flexibility of Closure factor, an Associative Memory factor, a Speed of Closure factor, and an Induction factor. The sixth factor, which had reasonably high loadings on two printed measures, could not be readily interpreted.

Ability requirements as a function of task manipulations. To determine the role played by abilities (i.e., factors) in individual differences in criterion performance, correlations were computed between the factor scores of subjects and their mean levels of criterion task performance. Of particular interest were the relationships between the various abilities (i.e., factor scores) and performance under the six variants of the criterion task attributable to the task characteristic of signal duration (i.e., 9, 6, or 3 seconds) and the task characteristic of background noise (i.e., -5, 0, or +5 dB). The obtained relationships are presented in Table 2. Only one of the six factors--Auditory Perception--was an especially significant contributor to individual differences in signal identification. As the criterion task became more difficult (i.e., when background noise increased or signal duration grew shorter), the Auditory Perceptual ability showed a corresponding, slight increase in importance. Even more interesting was the pattern of correlations between the Auditory Perceptual factor and performance under the combinations of ship category and background noise conditions which had been found to exert an interactive effect on

Table 1

Rotated Factor Matrix

	Reference Tests	I	II	III	IV	V	VI	h^2
					Factors [a]			
1.	Letter Sets	-10	16	00	16	57	43	58
2.	Locations	27	25	04	-16	58	08	50
3.	Figure Classif.	13	13	-01	09	72	-05	56
4.	Object-Number	15	12	78	11	-01	07	66
5.	Picture-Number	07	18	82	-04	09	-14	73
6.	First & Last Names	09	-04	80	18	-01	17	71
7.	Gestalt Comp.	17	10	29	62	40	-24	72
8.	Concealed Words	13	12	04	81	00	21	73
9.	4-Letter Words	00	45	24	49	-04	11	52
10.	Concealed Figs.	18	63	02	24	48	-08	72
11.	Copying	04	75	06	05	22	-13	64
12.	Designs	02	82	10	02	00	06	69
13.	Number Compar.	-03	40	07	05	-18	60	56
14.	Identical Pics.	11	68	-10	14	31	01	59
15.	Finding A's	07	53	13	02	03	17	34
16.	Pitch	70	-13	06	17	23	-10	60
17.	Loudness	-03	-12	-05	11	10	72	55
18.	Time	38	05	18	-09	17	54	51
19.	Timbre	58	18	07	05	-07	27	46
20.	Tonal Memory	79	05	-07	18	06	-12	68
21.	Rhythm	67	15	01	-21	-13	04	54
22.	Hidden Tunes	79	-04	15	05	18	05	69
23.	Code Distraction	57	07	17	02	45	20	60
24.	Kwalwasser	76	13	14	08	15	-05	64

[a] Factor loadings reflected and rounded to two places; decimals omitted.

Factors are defined as: I - Auditory Perceptual; II - Flexibility of Closure; III - Associative Memory; IV - Speed of Closure; V - Inductive Reasoning; VI - Undefined.

(From Wheaton et al., 1973.)

Table 2

Correlations Between Factor Scores and Performance Under Variations of the Criterion Task [a]

Criterion Task Variation	Factors I	II	III	IV	V	VI	h^2	R
1. 9"	35	00	-01	08	11	13	16	40
2. 6"	36	-01	07	02	18	11	18	42
3. 3"	39	-04	06	02	12	08	18	43
4. -5dB	33	-05	06	06	15	11	15	39
5. 0dB	36	00	04	06	15	11	17	41
6. +5dB	41	02	00	00	09	10	19	43

[a] Correlations rounded to two places; decimals omitted.

Factors are defined as: I - Auditory Perceptual; II - Flexibility of Closure; III - Associative Memory; IV - Speed of Closure; V - Inductive Reasoning; VI - Undefined.

(Adapted from Wheaton, et al., 1973.)

identification accuracy. As shown in Figure 2, the correlations increased across background noise conditions for two of the ship categories and decreased for the other two kinds of signals.

Implications

With respect to the general methodological issues addressed by the study, the crux of the results lay in the correlations between performance under the different criterion task conditions and individuals' factor scores. Generally speaking, changes in these correlations occurred as a function of the signal duration and signal-to-noise ratio manipulations. As either of these task characteristics was varied so as to increase task difficulty, the correlations with one set of factor scores changed accordingly.

The nature of the change in ability requirements differed from that found in the studies by Fleishman (1957) and Zimmerman (1954). In both these earlier studies specific abilities involved in criterion task performance dropped out while others came into play as a function of systematic variations in task characteristics; that is to say, the abilities contributing to performance under different versions of the task changed. In the present study, a single ability was involved under all task conditions, its importance waxing or waning slightly as a function of variations in task characteristics.

It can be argued, of course, that differential involvement of abilities in task performance is not a necessary outcome of certain kinds of task variations. As long as the same basic task is being performed, the <u>same</u> pattern of abilities can be relevant. Variations in the conditions under which that task is performed, therefore, while contributing to task difficulty, may affect only the <u>degree</u> to which the relevant pattern is involved and not the pattern itself. This suggests that it may be necessary to differentiate among two kinds of variables affecting task difficulty. For example, varying certain kinds of variables (as in the Fleishman and Zimmerman studies) may cause subtle changes in the basic task itself, resulting in changes in the pattern of abilities related to different versions of the task. Varying other kinds of variables (such as signal duration or signal-to-noise ratio in the present study) may have no

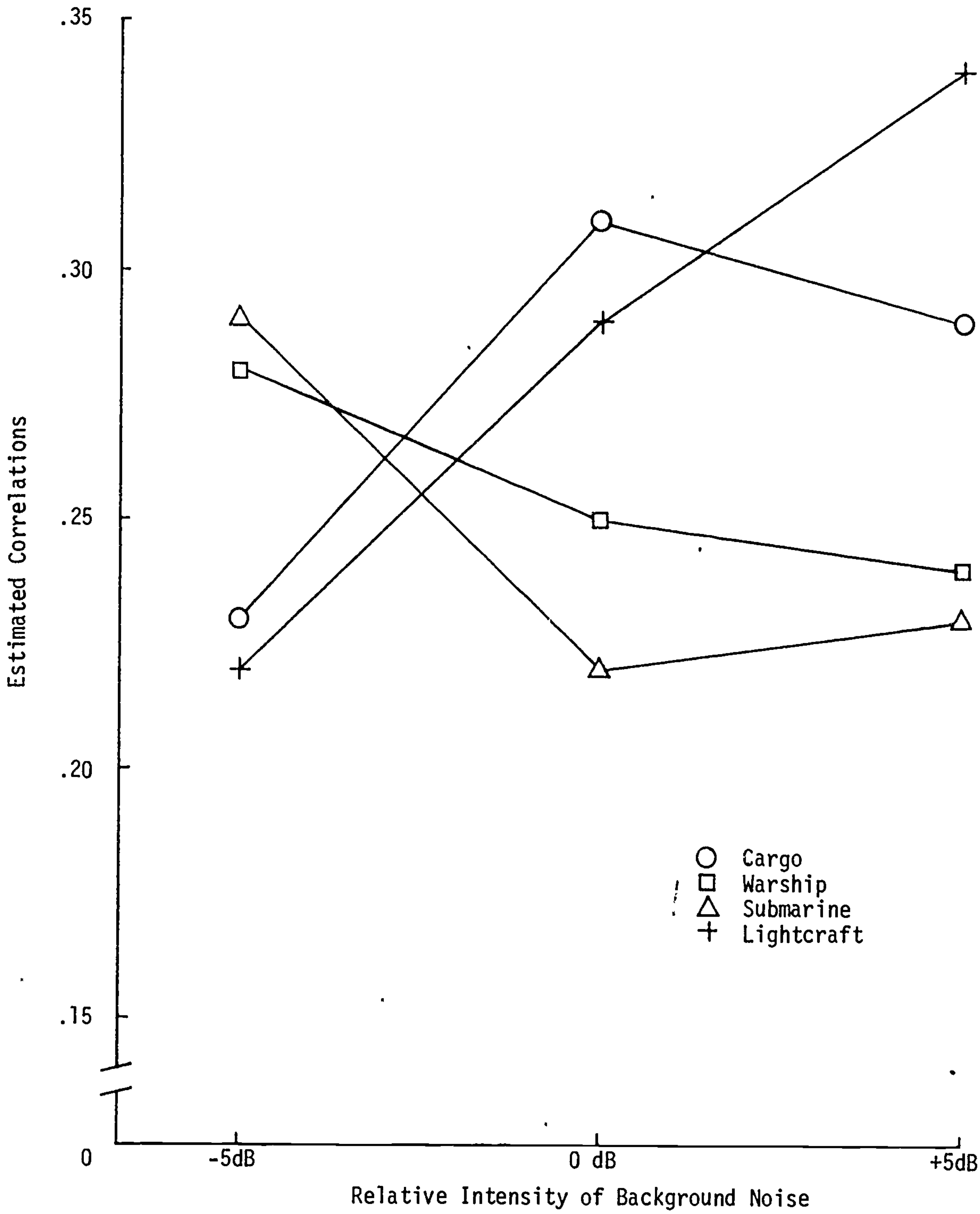

Figure 2. Estimated correlations between performance on the four signal categories and Auditory Perceptual ability as a function of background noise level.

(From Wheaton et al., 1973.)

effect on the basic nature of the task to be performed; in this case, the importance of a fixed pattern of abilities would be expected to increase or decrease as the conditions of performance became more or less demanding.

To address the issue of change-in-pattern versus change-in-degree of ability involvement a second study was conducted in which the ability requirements related to different versions of an electronic fault-finding task were investigated. This type of task was chosen because of its a priori potential for exhibiting either kind of outcome.

Electronic Fault-Finding Task

Procedure

The general procedure employed in this study was again to administer a battery of reference ability tests and several variations of a single criterion task to a large number of subjects (Rose, Fingerman, Wheaton, Eisner, & Kramer, 1974). To determine the relationships between task characteristics and ability requirements, the reference battery was factor analyzed and performance scores obtained under the various criterion task conditions were correlated with subjects' factor scores. The resultant coefficients were examined to determine whether there were any systematic relationships between changes in task dimensions and the patterns of abilities contributing to individual differences in performance.

An electronic fault-finding task (representative of situations faced by electronic troubleshooters) was employed as the criterion task. It consisted of a series of problems in which subjects were required to locate breakpoints in hypothetical electronic devices. The basic format was a current-flow diagram or digital-logic circuit in which the state of the output at any point was determined by the preceding logic gates. In each circuit a single faulty wire, or "breakpoint" was introduced. At such a point the current flow was disrupted. The subject's task was to identify the location of this break by probing the circuit at various locations while depressing different combinations of switches. The troubleshooting task was systematically varied along two dimensions. First, formal difficulty was manipulated by increasing the number of possible breakpoints and the number of logic gates in the circuit. The second manipulation was to vary the perceptual complexity of the problem by changing the configuration or layout of the circuit. Circuit diagrams were created such that different circuits were topologically equivalent, but their spatial appearances were quite varied.

Three levels of each dimension were used; thus, nine different test problems were generated. Each problem was presented twice, with different breakpoints as solutions, providing a total of eighteen experimental problems. Several dependent measures were examined, including time to solution, number of trials (probes) to solution, time per trial, efficiency (expressed in terms of the proportion of breakpoints which were eliminated by a probe relative to the maximum number which could have been eliminated on that test) on the first probe, and overall efficiency.

The reference test battery consisted of 21 tests representing six well-established factors in the cognitive, perceptual, and memorial domains of performance. The specific factors chosen were hypothesized to be relevant to criterion task performance. To insure adequate factor definition, each of these factors was represented by a minimum of three tests. A total of 135 subjects were administered the criterion problems and the reference battery.

Results

Criterion task performance. Analyses of variance conducted on the criterion task data revealed that while both task manipulations (formal difficulty and perceptual complexity) affected task performance, they did not necessarily affect the same aspects of performance (i.e., dependent measure), nor did they affect particular aspects in the same way. For example, time-to-solution and time-per-trial were both influenced strongly by both formal difficulty and perceptual complexity. Illustrative results are shown in Figure 3 for the time-to-solution measure. Trial-one efficiency was affected to a lesser degree by perceptual complexity, and almost not at all by formal difficulty. Trials-to-solution and efficiency-per-trial were more sensitive to changes in formal difficulty than to changes in perceptual complexity.

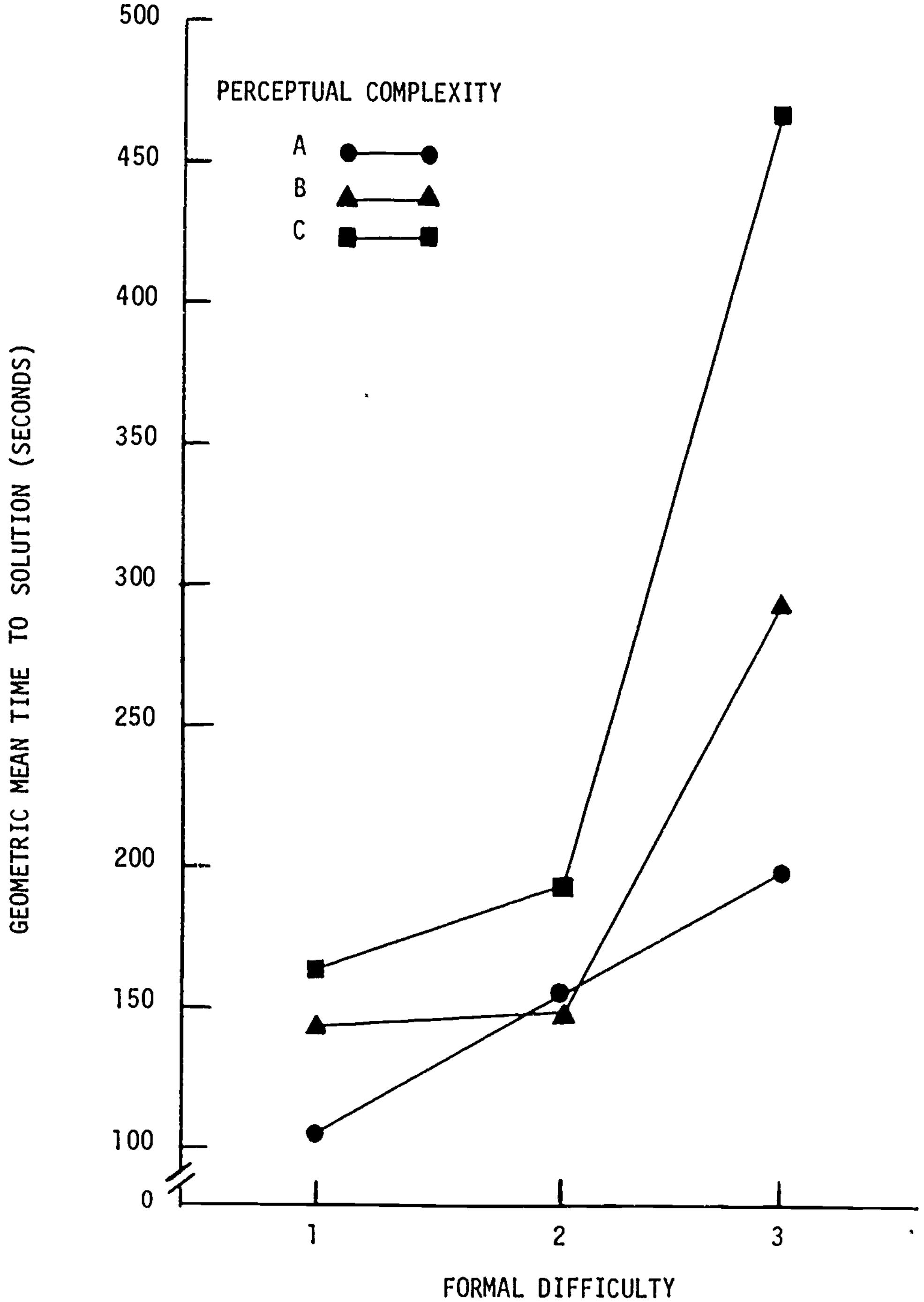

Figure 3. Geometric mean time to solution as a function of formal difficulty and perceptual complexity. (From Rose et al., 1974.)

This interplay between task manipulations and performance measures was quite important, since the different measures might be related to different sets of abilities. If this were the case, the relationship between task characteristics and ability patterns might depend upon the performance measures under consideration. Thus, different regression equations would be necessary to predict different aspects of criterion performance from abilities, over and above any changes in predictive equations made necessary by manipulations of the criterion task itself.

Ability structure. Five major factors were extracted from the intercorrelations among reference tests using a principal components solution. Orthogonal rotation of the factors was performed using a varimax criterion. Factors were interpreted for psychological meaningfulness from projections of the reference tests on the rotated axes as presented in Table 3. The five factors were as follows: Flexibility of Closure/Spatial Scanning, Syllogistic Reasoning, Associative Memory, Perceptual/Cognitive Speed, and Induction.

Ability requirements as a function of task manipulations. Relationships between ability requirements and task characteristics were again explored by correlating performance under the various task manipulations with subjects' levels of ability as reflected in their factor scores. As shown in Table 4, from 10% to 38% of the variation in the dependent measures could be accounted for by the reference factors. This common variance was primarily associated with Factors I (Flexibility of Closure/Spatial Scanning), II (Syllogistic Reasoning), III (Associative Memory), and V (Induction). The relationships between criterion performance and abilities (i.e., changes in coefficients as a function of levels of formal difficulty and perceptual complexity) were examined for each performance measure.

The general conclusion was that different abilities were involved, and at different levels of involvement, when either the task dimensions varied or different dependent measures were examined. It was found that the loadings on Factor I generally tended to increase as both formal difficulty and perceptual complexity increased. This relationship held across most performance measures. Factor II was moderately involved in all but the

Table 3

Factor Loadings [a] in Rotated Factor Matrix

Reference Tests	I	II	III	IV	V	h^2
	Factors					
1. Grammatical Reasoning	01	66	18	39	10	63
2. Maze Tracing Speed	69	-01	-01	32	00	58
3. Copying	71	08	-07	30	30	70
4. Logical Reasoning	27	63	18	-08	27	59
5. Letter Sets	18	28	15	15	52	42
6. Identical Pictures	28	13	09	62	10	49
7. First and Last Names	-07	25	77	10	-08	68
8. Locations	15	05	14	27	62	50
9. Object-Number	10	06	85	10	12	77
10. Finding A's	33	11	12	49	-10	39
11. Search (mean)	-10	-26	-04	-77	04	67
12. Number Comparison	05	-11	06	67	32	57
13. Designs	59	-01	29	51	04	70
14. Nonsense Syllogisms	00	78	08	00	08	62
15. Closure Flexibility	70	24	00	37	21	72
16. Choosing a Path	74	17	05	-20	06	63
17. Inference	05	71	02	18	06	54
18. Map Planning	53	11	07	38	30	54
19. Permutations	08	21	02	-13	69	55
20. Picture-Number	07	07	83	08	24	77
21. Figure Classification	40	61	09	01	23	60

[a] Factor loadings reflected and rounded to two places; decimals omitted.

Factors are tentatively defined as:

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

(From Rose et al., 1974.)

Table 4

Correlations Between Factor Scores and Performance Under Variations of the Troubleshooting Task [a]

Criterion Measures		Factors I	II	III	IV	V	h^2	R
Trial 1 Efficiency	1	27	18	16	09	10	15	38
	2	26	21	05	06	10	13	35
	3	33	19	21	03	07	19	44
	A	19	20	13	01	17	12	35
	B	32	25	13	03	09	19	43
	C	35	15	17	14	04	19	44
Ln Trials to Solution	1	15	20	09	-09	17	10	33
	2	30	22	09	-08	15	17	42
	3	34	12	04	-00	10	14	38
	A	19	19	12	-08	30	19	43
	B	27	17	04	-13	08	13	36
	C	34	20	07	03	07	17	41
Arcsin Square Root Efficiency per Trial	1	30	30	20	-04	12	23	48
	2	33	35	19	-02	23	32	57
	3	50	31	12	01	14	38	62
	A	34	31	30	01	28	38	61
	B	38	35	18	-04	11	31	56
	C	42	31	05	-02	14	30	54
Ln Time to Solution	1	25	14	05	-06	29	18	42
	2	25	14	-04	-04	23	13	37
	3	32	10	-08	-04	29	21	45
	A	19	11	-04	-05	31	15	38
	B	27	13	-01	-09	23	15	38
	C	41	17	-04	00	29	28	53
Ln Time per Trial	1	16	-01	-02	00	18	06	24
	2	10	03	-09	00	17	05	22
	3	08	02	-11	-04	21	07	26
	A	10	01	-12	-01	17	05	23
	B	10	03	-03	-01	18	05	21
	C	13	01	-09	-02	22	07	27

[a] Signs have been reflected to relate superior performance to superior ability; decimals omitted.

Factors are tentatively defined as:

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

(From Rose et al., 1974.)

time measures. Further, its level of involvement was fairly constant, i.e., it did not change as a function of formal difficulty or perceptual complexity. Next, the loadings on Factor V tended to decrease as a function of increasing perceptual complexity on the trials-to-solution and efficiency-per-trial measures. On the remaining measures, loadings for this same factor were moderate but constant. Finally, Factor III loadings decreased as a function of perceptual complexity for the efficiency-per-trial measure.

Implications

Given the nature of these results, one implication was clear. If one were to use ability criteria to predict who would do well on these problems, the choices would differ depending on the task characteristics and the criterion measure selected. There were, in fact, two general types of selection decisions implied by the data. One type of decision occurred when a change in task demand (due either to different criterion measures or changes within a task dimension) did not involve different abilities. In this case, a change in cut-off values would be the appropriate decision. The abilities involved were the same, but they were involved to a greater or lesser degree as the task demands changed. The second type of decision occurred when the task demands were altered and a different set of abilities was involved.. In this type of situation, since different abilities (or factors) were relevant, the implication was that entirely different selection criteria would have to be given consideration.

It would be desirable if one kind of task manipulation (or one aspect of performance) consistently implied one or the other type of decision. However, there was no consistent relationship discernable between type of manipulation (or measure) and pattern of ability requirement. It was felt, however, that such consistent relationships might emerge were more control exercised over the possible strategies subjects might utilize. The problem is that any change in a given task characteristic might be perceived as a new problem by some subjects, but as the same problem by others. To the extent that these perceptions lead the first group to adopt alternative strategies for the "new" problems, different abilities may be involved. The second group, while maintaining their strategy, would utilize the same abilities, but perhaps at different levels of involvement. An additional study was conducted, therefore, to shed light on these issues.

Concept-Identification Task

Procedure

In the third data collection effort (Fingerman, Eisner, Rose, Wheaton, & Cohen, 1975) the relationship between variations in a prototypic problem-solving task, concept identification, and consequent changes in the abilities related to problem-solving performance was investigated. A total of 128 college students participated in the experiment, which was administered in two parts--a concept-identification criterion task and a battery of 21 paper-and-pencil reference tests representing seven well-established factors in the cognitive, perceptual, and memorial domains of performance. As in the earlier studies, the specific factors chosen were hypothesized to be relevant to criterion task performance.

The simultaneous concept-identification paradigm was used for the criterion task, with the stimuli consisting of pairs of human faces. On each problem one facial characteristic (e.g., eyes) and one attribute of that feature (e.g., "squinty") were preselected by the experimenters as the solution. The subject's task was to identify that one correct facial characteristic after five consecutive trials, during which pairs of faces were projected on a screen in front of the room. For each pair of faces (or trial), the subject indicated his choice of left-hand or right-hand face, was told which face in the pair contained the solution, and was asked to indicate (on a list of all possible solutions to the problem) those facial characteristics he thought could still be the solution to the problem. The number of characteristics indicated was considered to be the number of hypotheses being entertained by or tested by the subject at that particular time. A new pair of faces was then presented to begin the next trial. Following the fifth trial, he was asked to write down the one single characteristic which he thought was the solution to the problem.

Two characteristics of the task were manipulated: (1) the number of stimulus dimensions or facial characteristics (formal difficulty), and

(2) the extent to which location of facial features varied from normal appearance (perceptual complexity). Three levels of each of the manipulations were created, and subjects were tested under all versions of the criterion task in a three-by-three, within-subjects design.

Ten problems were presented at each level of difficulty, with the first problem in each group always being a sample problem. Of the remaining nine problems at each level of difficulty, there were three problems at each level of perceptual complexity. Subjects were presented first with the set of four-dimensional problems, then with the six-dimensional problems, and finally with the eight-dimensional problems.

Results

Criterion task performance. A variety of measures of performance on the concept-identification task were available. Three representative measures were selected for use in the detailed analyses, including: (1) proportion of problems solved under each task condition; (2) an efficiency measure reflecting the number of attributes tested on each trial relative to the optimal number possible (A/B); and (3) a measure reflecting the efficiency of the set of attributes selected for testing (C^2/AB). Analyses of variance revealed strong impacts on performance due to the two task characteristics which were manipulated.

Each of the dependent measures was influenced by the stimulus-dimension variation. With respect to the proportion of problems solved, the four-dimension problems were solved significantly more often than the pooled six- and eight-dimension problems, while there was no significant difference between six- and eight-dimension problems. Similarly, with respect to either efficiency variable, subjects were significantly more efficient when solving the four-dimension problems than when solving six- or eight-dimension problems. Thus, increasing the number of dimensions from four to six or eight impaired performance across all three measures.

The impact of perceptual complexity was more complicated. Perceptual complexity did not exert any directly interpretable influence on the proportion of problems solved. However, increasing the perceptual complexity did result in different effects for the two efficiency measures. Added complexity resulted in a significant increase in processing efficiency as represented by the C^2/AB measure. This improvement is consistent with empirical findings (Postman, 1972; Tulving & Donaldson, 1972) which suggest that better recall performance is produced when the normal face presentation is altered, thereby requiring the subject to actively organize the set of facial features, rather than passively use the "natural" top-to-bottom order found in problems at the first level of perceptual complexity. Obviously, with improved recall, the subject is in a better position to use efficiently feedback information to narrow down the set of hypotheses he is considering. The effect on the A/B efficiency score, however, was moderated by level of problem difficulty. The interaction of difficulty and complexity on the A/B measure (subjects tested a more optimal number of hypotheses with increased complexity on easy problems, but tested less optimally as complexity increased on difficult problems), suggests that the strategy or approach adopted by a subject is dependent on the total cognitive load of the task. In the four-dimension problems, where the total number of hypotheses was small, subjects were able to handle the additional load imposed by increased perceptual complexity. In the eight-dimension problems, where more total possible solutions were involved, an increase in perceptual complexity required the subject to actively construct his own list organization as well as scan the increased number of relevant facial characteristics. Apparently this additional burden caused the subject to reduce his net cognitive load by decreasing the number of hypothesized solutions which he tested at any one time.

Ability structure. Six factors were extracted from the intercorrelations among reference tests using a principal components solution. Orthogonal rotation of the factors was performed using a varimax criterion. The rotated matrix of factor loadings is presented in Table 5. The factors were tentatively identified as: I - Flexibility of Closure/Spatial Scanning; II - Associative Memory; III - Perceptual Speed; IV - Syllogistic Reasoning; V - Speed of Closure; and VI - Induction.

Ability requirements as a function of task manipulations. Correlations between performance, under the difficulty (4D, 6D, 8D) and complexity (A,B,C)

Table 5

Factor Loadings [a] 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

[a] 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

(From Fingerman et al., 1975.)

conditions, and factor scores are shown in Table 6. From 15% to 45% of the variance in criterion task performance could be accounted for by individual differences on the six factor-defined abilities. Since the coefficients for the Perceptual Speed and Speed of Closure factors were uniformly low, most of the variance was accounted for by the Flexibility of Closure/Spatial Scanning, Associative Memory, Syllogistic Reasoning, and Induction factors. These four factors all showed moderate to fairly strong involvement which varied as a complex function of the task manipulations and the dependent variable considered. For example, as shown in Figure 4, the correlations between Associative Memory and proportion of problems solved varied as problem difficulty increased but remained relatively constant across levels of perceptual complexity. In a similar vein, correlations with the Flexibility of Closure/Spatial Scanning ability showed an initial increase and then a marked decrease as the number of dimensions increased; correlations with this same ability increased across levels of perceptual complexity.

Implications

Results from this study showed that as task characteristics were varied, systematic changes in performance did occur, and the abilities contributing to performance also changed. However, covariation of abilities with performance did not seem to be a simple function of task manipulations. This suggested that individual subjects may have utilized different approaches as a function of how they perceived the task to have changed. From a cognitive point of view, the way subjects view the task determines the way in which they will attempt to deal with it, and this in turn may determine which abilities are called into play in explaining individual differences in performance. If a task variation does not change the nature of the task from the subjects' point of view, then their approach should remain the same and there would be no change in the pattern of abilities contributing to individual differences in performance. If the task is viewed as a new one, then the method of attacking it may change and the abilities contributing to performance may be completely different.

Table 6

Correlations Between Factor Scores and Performance Under Variations of the Concept Identification Task [a]

Criterion Variables		Factors I	II	III	IV	V	VI	h^2
Proportion Solved:								
Perceptual Complexity	A	.14	.33	.15	.29	.11	.17	.27
	B	.27	.34	.00	.20	.12	.25	.30
	C	.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	A	.25	.28	.15	.36	.10	.25	.37
	B	.31	.26	.14	.35	.08	.28	.39
	C	.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	A	.17	.37	.15	.38	.14	.24	.41
	B	.27	.39	.07	.32	.09	.30	.43
	C	.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

[a] 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.

(From Fingerman et al., 1975.)

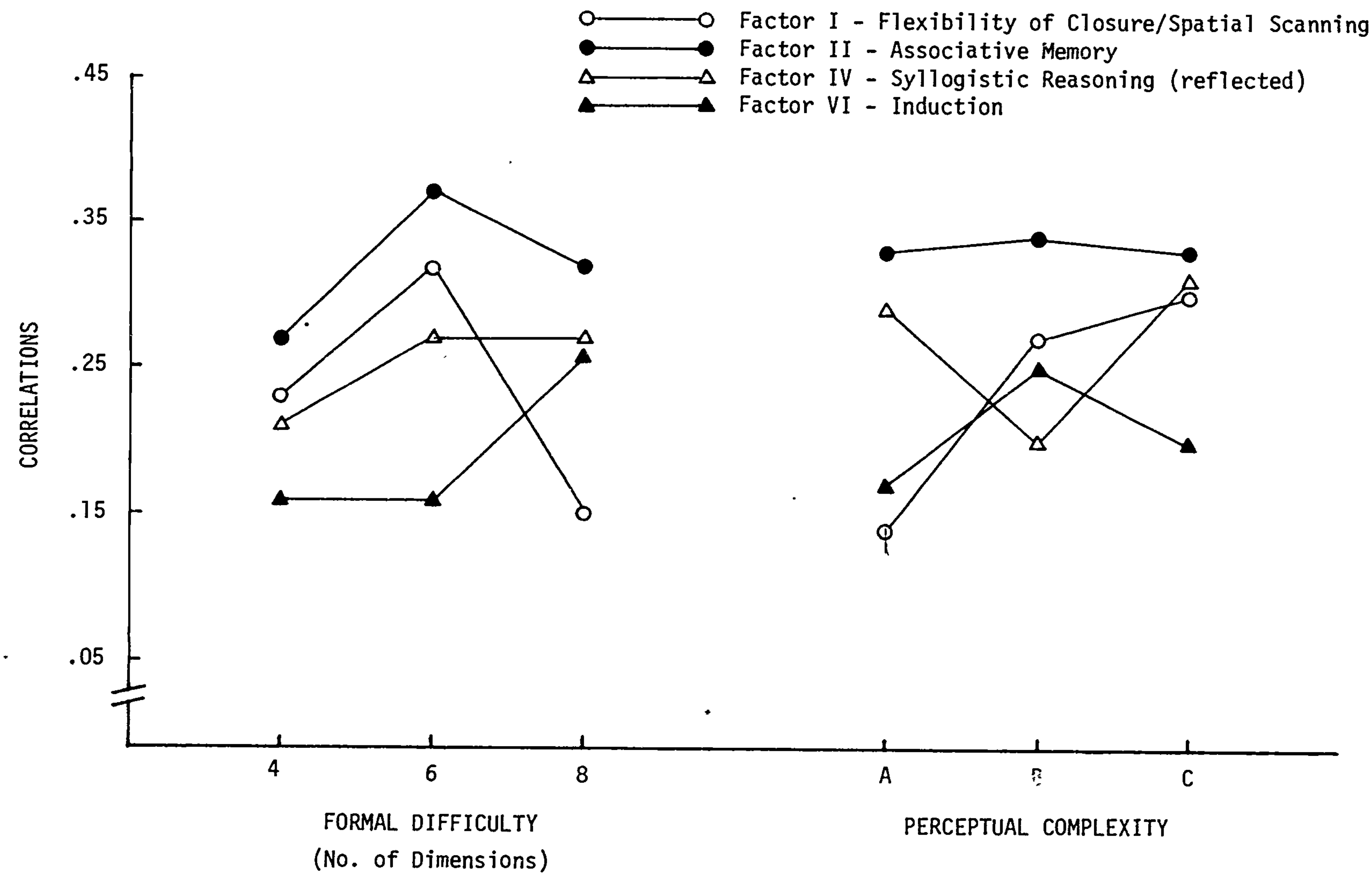

Figure 4. Proportion solved: correlations with factor scores. (From Fingerman et al., 1975.)

While the particular kinds of approaches used by subjects in concept-identification tasks are, perhaps, of limited generalizability, the implications of the research are very important. If the linkage of change in task characteristic, change in strategy, and change in individual differences can be validated, it should become possible in the short term to predict whether a new version of an old task will require revision of personnel selection or training criteria. If job incumbents were not expected to change their approach (based on empirical or theoretical analysis of the tasks involved), 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 were predicted to occur, one would then need to determine the new ability requirements after ascertaining which new approach had been adopted.

The next section of this report describes how the concept-identification and fault-finding studies were reevaluated in an attempt to address the issue of an interaction among task variations, subject strategies, and ability requirements.

III. TASK CHARACTERISTICS, STRATEGIES, AND ABILITIES

Introduction

In order to examine the hypothesized mediating role of strategies between task characteristics and abilities, it was necessary to develop a classification scheme for the different strategies used by subjects while performing on the various versions of the two cognitively-oriented criterion tasks. Fortunately, a great deal of theoretical and empirical work has been done on strategy analysis in concept-identification tasks, and the same concepts appeared applicable to the fault-finding task as well. Levine (1966, 1970) has characterized subject behavior in concept-identification problems as a series of hypothesis-testing operations. On each trial the subject chooses one or more attributes which he believes (hypothesizes) may be the solution to the problem, and attempts to test whether or not the solution is, in fact, the attribute (or one of the attributes) he has chosen. Due to the nature of the problem, he is able on each trial to eliminate or confirm part of his "working set" of attributes. He continues in this manner to the next trial with those members of the set which have been confirmed or have not yet been eliminated.

Bruner, Goodnow, and Austin (1956) distinguished two major forms of strategies in concept identification which may be cast into Levine's model as follows:

1. The wholist strategy, in which a subject takes as his working set prior to the first trial all possible attributes. Based on feedback from each trial he eliminates attributes until he has narrowed his set down to the single, correct attribute.

2. The part-scanning or part strategy, in which a subject takes as his working set prior to the first trial a subset of all the possible attributes. Based on feedback from each trial he eliminates attributes until he reaches the solution, provided the solution was originally contained in the working set, or starts over with a second sample of attributes as his new working set, from which he continues to eliminate attributes.

The wholist strategy has also been referred to as focusing, and the part strategy as subset sampling. Levine (1975) has presented an extensive model of these strategies which allowed us to develop a scheme for identifying the strategy used by a subject in attempting to solve problems posed by the concept-identification and fault-finding tasks.

The purpose in attempting to identify the strategies utilized by subjects was to determine their role in mediating the task-characteristic ability interaction. The mediational situation might be characterized as a multi-variate model which predicts performance from three variables and their interactions: task characteristics, ability profile, and strategy. The effects of the first two variables have been reported upon in the preceding chapter. In order to determine the usefulness of strategy in this system, one must look at the effect of strategy on performance (e.g., the "main effect" of the intervening variable), the interaction of strategy and task characteristics, the interaction of strategies and abilities, and finally the second-order interaction which examines the ability-task relationship for various strategies.

The extent to which groups of subjects with certain ability patterns have predictable strategy patterns represents the strategy-ability interaction. For example, one may ask whether subjects who focus under all task conditions have different ability patterns from subjects who test subsets under all conditions, and whether these two groups differ from those subjects who focus on easy problems, and turn to subset testing when the problems become more difficult.

The crucial mediating role of strategies concerns the extent to which the task-characteristic ability relationships are clarified when sets of subjects with more or less homogeneous strategies are examined, i.e., the strategy-ability-task interaction. Thus, while the task-characteristic ability correlations previously reported were highly complex when examined for all subjects combined, it might be that these patterns may be simpler to interpret when based on subjects who adopt a particular strategy.

While no thorough analysis of the abilities involved in applying each strategy under different task conditions has previously been performed, several ability-strategy relationships are strongly implied by existing models. For example, consider the subset-tester: in the unlucky event that his initial working set does not contain the solution to the problem, he must attempt to form a new set which overlaps as little as possible with the original one, i.e., which contains new attributes which he has not yet eliminated. This construction of a new and non-overlapping set is successful to the extent that he can remember the attributes previously eliminated (not a requirement if the original set contains the solution). Thus, the subsetter's performance depends to some extent on memory. The focuser's task, on the other hand, is one of attribute elimination; therefore, his memory ability should not be strongly related to performance.

Procedure

The first step in determining the role of strategies was to extract the "strategy" information from subjects' performance protocols. The method chosen was to develop criteria for the assignment of a strategy classification label to every problem attempted by each subject in both the concept-identification and troubleshooting tasks. Since strategies in the concept-identification paradigm can be unambiguously defined, labels and criteria for their assignment to protocols in that task were generated first; analogous labels and criteria were then derived for the troubleshooting task. As described in the previous report in this series (Fingerman et al., 1975), subjects were required to report which attribute(s) of the stimuli they thought were still solution possibilities after each trial. Since the stimulus sequences were orthogonal, it was possible for a subject to eliminate half of the remaining possible solutions on each trial, if a perfect focusing strategy were adopted. With respect to the protocol, this perfect focusing would appear as follows:

1. Following the first trial, exactly half of the attributes would be checked as possible solutions.

2. The number of attributes checked as possible solutions would decrease by half after each trial until the correct solution was arrived at (e.g., in the 8-dimension problems, the number of attributes checked would proceed from 8 to 4 to 2 to 1 over the first four trials).

3. Each attribute checked would be both locally consistent (consistent with feedback information from the immediately preceding stimulus presentation) and globally consistent (consistent with respect to all preceding trials, Gregg & Simon, 1967).

If these three conditions were met on any given problem protocol, it was labeled as "Excellent Focusing." However, it was possible for a subject to deviate from this ideal pattern while still attempting a focusing strategy (and, incidentally, still solving the problem). For example, a subject could simply "lose" a stimulus attribute during the course of an 8-dimension problem by forgetting one of the members of his original working set. This and other errors would produce some deviations in the problem protocols. To allow for these cases, a "Focusing with Errors" label was created by relaxing some of the above criteria as follows:

1. A full working set was still required after the first trial;

2. The number of attributes checked as possible solutions would decrease after each trial, while allowing for deviations from an orthogonal reduction (e.g., an acceptable 8-dimension protocol would be 8 to 3 to 2 to 1);

3. The locally consistent and globally consistent requirements were relaxed; most, but not all, checked attributes were required to be consistent with preceding feedback information.

The third strategy classification label, "Subsetting," was applied to protocols using the following rules:

1. Subjects took as their initial working set a number of attributes <u>less</u> than the maximum possible (e.g., fewer than eight attributes on an 8-dimension problem).

2. The working set was systematically reduced until the solution was arrived at, or in cases where the solution was not contained in the working set, a new subset was selected.

3. Each attribute checked was to be both locally and globally consistent with previous information.

Again, these criteria were modified to allow for errors, while still falling under the "subset" category; the "locally and globally consistent" requirement was relaxed, as was the "systematic reduction" criterion, yielding a "Subsetting with Errors" label.

The experimental procedures employed in the concept-identification task (i.e., having subjects list their trial-by-trial hypotheses) was an attempt to make overt the normally covert reasoning processes used by subjects. For the troubleshooting task, however, these reasoning processes could only be inferred from a more limited protocol: the ordered list of tests selected (Rose et al., 1974). It was assumed that the breakpoints actually included in each test represented the subject's working set of possible solutions. Given this assumption, strategy classifications similar to those made in the concept-identification task were made from the inferred working set of breakpoints on each trial. For example, a "split-half" technique in the troubleshooting task (wherein exactly half of the possible breakpoints are eliminated on each trial) is logically equivalent to a focusing strategy. Similarly, the troubleshooting technique of "working forward" (wherein breakpoints are eliminated in a logical order by starting with those closest to a given switch and working outward toward the terminals) is logically equivalent to subsetting.

Thus, the initial criterion for classification of protocols in the troubleshooting task as either focusing or subsetting was whether subjects attempted a "split-half" or "working-forward" approach. Through an iterative process, it was possible to develop criteria in order to distinguish between excellent, good, and poor focusing strategies and subset strategies for each protocol. In order to qualify as an excellent focusing protocol, the following rules were adopted:

1. The initial test had to include a terminal probe point.
2. All succeeding tests approximated a split-half technique (since, for the problems employed, tests of exactly half of the remaining alternatives were frequently impossible).
3. No tests were completely redundant or completely ambiguous.

The criteria for a good focusing protocol were:

1. The initial test had to include a terminal probe point.
2. All tests after the first non-erroneous negative feedback (i.e., when the probe light did not light because the breakpoint was contained

in the probe path) approximated a split-half technique.

3. Most tests (for the entire protocol) tested more than half of the breakpoints that could logically be eliminated (e.g., if it were possible to test eight potential breakpoints, four or more were tested).

Protocols wherein the first probe included a terminal point but did not meet the remainder of the criteria for good focusing were classified as poor focusing. Formal criteria for classification of subset protocols were developed; however, upon reviewing the protocols it became apparent that subsetting protocols were easily distinguishable from all others. The only criterion that was necessary was that the initial test was not at a terminal point. In all cases where protocols were classified as subsetting, it was clear that subjects had chosen not to attempt to test a full working set, but rather had chosen a particular subset of possible breakpoints to sample.

Given these criteria, project staff proceeded to classify each problem protocol for both studies. Ambiguous classifications were resolved by consensus. Once these basic data were generated, analyses were conceptualized to address the ability-strategy-task characteristic issues discussed above.

Results

Strategies and Performance

The first series of questions addressed the extent to which there were patterns of strategy utilization as a function of task manipulations across subjects. Also of interest was the degree to which there were any consistencies in the way individual subjects employed strategies.

Tables 7 and 8 show the number of subjects using each strategy as a function of the task characteristics for each of the two studies. Notice that the left margin headings, labeled Excellent, Good, or Poor Focuser, Subsetter, and Inconsistent, are designations of subgroups of subjects. After all problem protocols had been categorized, each subject was classified into one of the above subgroups for each task-characteristic marginal, as well as being assigned an overall subgroup label. On the concept-identification task (Table 7) a subject was called an Excellent Focuser in a particular marginal cell if at least six out of his nine protocols had been labeled

Table 7

Number of Subjects Using Each Strategy as a Function of Concept Identification Task Characteristic Marginals

	Task Characteristic						
	No. of Dimensions			Level of Perceptual Complexity			Overall
Strategy Classification	4	6	8	A	B	C	
Excellent Focuser	56	23	29	31	31	32	20
Good Focuser	9	14	10	17	11	22	29
Poor Focuser	43	52	44	46	49	40	44
Subsetter	16	28	37	24	24	25	22
Inconsistent	4	11	8	10	13	9	13

as perfect focusing. A Good or Poor Focuser had at least six "focusing" (either perfect or with error) protocols out of the nine. Good Focusers had a majority of perfect protocols, while Poor Focusers had mostly focusing-with-error protocols. A similar six-out-of-nine collapsing rule was used to assign subjects to the Subsetter subgroup. Subjects in the Inconsistent subgroup did not have a classifiable set of protocols (i.e., did not have either six "focusing" or six "subsetting" protocols). The "Overall" strategy subgroup assignments were based on 27 protocols; again, a two-thirds (18 out of 27) rule was used. The subgroup assignments for the troubleshooting task (Table 8) were made following the same two-thirds rule. In this case, marginal subgroup assignments were based on six protocols, the overall assignment based on 18 protocols.

The frequency distributions presented in both Tables, of course, would have been affected by the adoption of different collapsing rules. For example, if a nine-out-of-nine criterion had been adopted for the concept-identification task, the Inconsistent subgroup would have been larger. Also, the Inconsistent groups are conceptually somewhat different in the two tasks. For concept identification, an inconsistent subject had protocols distributed between focusing and subsetting. However, in the troubleshooting task, a subject could be called inconsistent if his protocols were evenly split between "good focusing" and "poor focusing" as well as between focusing and subsetting. Despite these limitations on interpretation, several interesting points can be abstracted from these Tables.

For subjects in the concept-identification task (Table 7), the manipulation of perceptual complexity did not affect the frequency of occurrence of different strategies. However, the number-of-dimensions manipulation substantially reduced the number of Excellent Focusers, while the number of Subsetters increased. Although not discernable from the data presented in Table 7, strategy "shifts" by individual subjects occurred for the most part in the expected direction: some Excellent Focusers moved to Good or Poor Focusers, and some Good and Poor Focusers moved to subsetting. Subsetters were very consistent; that is, very few subjects shifted from subsetting to a different strategy.

Table 8

Number of Subjects Using Each Strategy as a Function of Troubleshooting Task Characteristic Marginals

	Task Characteristic						
	Level of Difficulty			Level of Perceptual Complexity			Overall
Strategy Classification	1	2	3	A	B	C	
Excellent/Good Focuser	78	44	20	52	48	26	33
Poor Focuser	3	26	50	19	22	25	56
Subsetter	20	22	29	21	24	25	22
Inconsistent	34	43	36	43	41	59	24

Similar trends can be observed for the troubleshooting data shown in Table 8. In this case, both task-characteristic manipulations reduced the number of Excellent and Good Focusers. (Frequencies for these two groups were combined due to the low incidence of subjects meeting the Excellent-Focuser criteria for the more difficult problems.) The number of Poor Focusers increased dramatically across the formal difficulty manipulation. Again, Subsetters were very consistent across both task-characteristic manipulations.

Attention was next directed toward whether strategies had any impact on performance. In the concept-identification task, this question was addressed directly by comparing the proportion of problems solved using a focusing strategy to the proportion solved using a subsetting strategy. These proportions are presented in Table 9 as a function of task-characteristic marginals. As in apparent from these data, a focusing strategy was far more effective than a subsetting strategy for the solution of the problems at all levels of task characteristics. This result conforms to both theoretical expectations and previous empirical findings (e.g., Wandersman & Wandersman, 1973). Likewise (although not presented here), focusing was superior to subsetting on the other performance measures obtained in the study.

A more detailed examination of the impact of strategies on performance was undertaken for the troubleshooting task. In this case, it was not obvious what strategy was "better" for the dependent variables obtained. Similarly, this detailed examination was important to "validate" the procedure for generalizing concept-identification strategies to a different task. The method chosen for this analysis was to compare performance of subgroups of subjects using different strategies on two dependent variables: mean log time to solution and arcsin, square root efficiency per trial. Mean performance for each strategy subgroup on these variables as a function of task-characteristic marginals is presented in Table 10. Tests of the statistical significance of between-subgroup contrasts are presented in Table 11.

Table 9

Proportion of Concept Identification Problems Solved as a Function of Task Characteristic and Strategy

Strategy Classification	No. of Dimensions			Level of Perceptual Complexity		
	4	6	8	A	B	C
Focusing	.887	.750	.818	.810	.837	.819
Subsetting	.785	.515	.476	.540	.584	.528

Table 10

Performance on the Troubleshooting Task as a Function of Strategy Employed and Task Characteristic

Strategy Classification	Task Characteristic					
	Level of Difficulty			Level of Perceptual Complexity		
	1	2	3	A	B	C
	Mean Log Time to Solution					
Excellent/Good Focuser	4.896	5.038	5.637	4.958	5.220	5.440
Poor Focuser	5.347	5.366	5.911	5.243	5.487	5.737
Subsetter	5.000	5.219	5.782	5.142	5.301	5.567
Inconsistent	5.100	5.153	5.716	5.079	5.264	5.568
	Arcsin, Square Root Efficiency Per Trial					
Excellent/Good Focuser	1.092	1.091	1.011	1.071	1.083	1.059
Poor Focuser	.785	.825	.760	.830	.851	.812
Subsetter	.879	.854	.780	.866	.842	.800
Inconsistent	.929	.969	.881	.926	.935	.906

Table 11

Contrasts Between Troubleshooting Subgroup Performance for Each Task Characteristic Marginal Condition

Task Characteristic	Contrast [a]					
	FXG-FP	FXG-SS	FXG-I	FP-SS	FP-I	SS-I
	Mean Log Time to Solution					
Level of Difficulty						
1	-1.61(79)	-1.23(96)	-3.89(110)**	1.20(21)	.88(35)	-1.12(52)
2	-3.64(68)**	-1.95(64)	-1.63 (85)	1.39(46)	2.43(67)*	.73(63)
3	-3.60(68)**	-1.74(47)	-1.02 (54)	1.89(77)	3.21(84)**	.95(63)
Level of Perceptual Complexity						
A	-2.85(69)**	-1.97(71)	-1.96 (93)	.81(38)	1.61(60)	.65(62)
B	-3.62(68)**	-1.06(70)	- .70 (87)	1.97(44)	2.66(61)**	.42(63)
C	-4.40(49)**	-1.84(49)	-2.16 (83)*	2.45(48)*	2.77(82)**	-.04(82)

[a] Cell entries are in the form: obtained t-value (degrees of freedom) level of significance. Symbols used include:

- **: $p < .01$
- *: $p < .05$
- FXG: Excellent/Good Focuser
- FP: Poor Focuser
- SS: Subsetter
- I: Inconsistent

Table 11 (Continued)

Contrasts Between Troubleshooting Subgroup Performance
for Each Task Characteristic Marginal Condition

Task Characteristic	Contrast [a]					
	FXG-FP	FXG-SS	FXG-I	FP-SS	FP-I	SS-I
	Arcsin, Square Root Efficiency Per Trial					
Level of Difficulty						
1	-6.08(79)**	4.90(96)**	7.54(110)**	-1.53(21)	-2.78(35)**	-1.21(52)
2	7.23(68)**	5.96(64)**	3.43 (85)**	- .87(46)	-4.93(67)**	-3.49(63)**
3	11.20(68)**	7.16(47)**	4.76 (54)**	- .64(77)	-4.63(84)**	-2.89(63)**
Level of Perceptual Complexity						
A	10.06(69)**	6.58(71)**	6.14 (93)**	-1.11(38)	-3.78(60)**	-1.86(62)
B	7.53(68)**	7.45(70)**	5.49 (87)**	.25(44)	-2.66(61)**	-2.18(63)**
C	9.28(49)**	7.22(49)**	5.82 (83)**	.32(48)	-3.48(82)	-2.93(82)**

[a] Cell entries are in the form: obtained t-value (degrees of freedom) level of significance. Symbols used include:

**: $p < .01$
*: $p < .05$

FXG: Excellent/Good Focuser
FP: Poor Focuser

SS: Subsetter
I: Inconsistent

These analyses produced some surprising results. For example, it was not anticipated that Poor Focusers would be the slowest and least efficient subgroup; one might have expected a speed-accuracy trade-off to have operated (i.e., the subjects who were most accurate, the Excellent and Good Focusers, could have sacrificed speed in order to locate logically efficient tests). Despite this and other unanticipated findings, the general picture provided by these analyses was that the level of performance achieved on a given problem by subgroups of subjects was clearly related to the kind of strategy employed. Furthermore, this influence was moderated by the dependent variable examined and by the task-characteristic manipulations. For example, Inconsistents did not differ from Subsetters with respect to the time-to-solution or efficiency-per-trial measures for the easiest problems. However, the Subsetters were significantly less efficient than Inconsistents on the more difficult problems (see Table 11).

Summary. Although interesting in themselves and worth pursuing in their own right, these particular strategy-performance analyses will not be discussed further in the present report. The purpose of these analyses was to demonstrate that a strategy-performance relationship existed, the precise nature of the relationship being a subsidiary issue. Likewise, the nature of the relationship could have been modified by different subgroup-assignment rules. As will be described below, subgroups were reconstituted during the course of further analyses. Therefore, the main conclusions to be drawn from these strategy-performance analyses are, first, that the labeling scheme could be effectively used to assign strategy codes to individual protocols, and second, that choice of strategy certainly impacts on performance. Accordingly, the next issue addressed was the relationship between strategy and ability. Are subjects who employ a particular strategy discriminable on the basis of their ability profiles from subjects who adopt alternative problem-solving approaches?

Strategies and Abilities

To address the strategy-ability relationship a stepwise discriminant analysis was performed. Factor scores for each subject in the various strategy subgroups (defined independently for each task characteristic level) served as predictors in the discriminant analyses. Again, despite the level of detail of the analysis, the basic question was straightforward: can subgroups of subjects categorized on the basis of strategy usage be discriminated on the basis of their factor scores? Tables 12 and 13 present the results of the discriminant analyses for the two experiments. These tables provide, for the overall strategy classification and for each task characteristic subgroup, the following information: the abilities which significantly differentiated subgroups, Wilks' lambda (the multivariate analogue to an *F*-ratio), the proportion of classification variance accounted for, and the between-groups discrimination matrix.

For the most part, subgroups were discriminable on all versions of the two tasks. Discrimination was greater in the concept-identification study than in the troubleshooting case, as indicated by the greater proportion of variance accounted for in the former.

An example will serve to demonstrate the type of information obtained and the inferences that can be drawn. Consider the discriminant analysis predicting the overall classification in the concept-identification task. Table 12 shows that when the Syllogistic Reasoning, Associative Memory, Flexibility of Closure/Spatial Scanning, and Speed of Closure factors are included in the discriminant function, Excellent Focusers are discriminable from Subsetters. In fact, the Excellent Focusers have substantially higher mean factor scores on all four factors; however, this directional consistency was not always the case. That is, the Subsetter and Inconsistent subgroups are also discriminable on the basis of these four factors; however, Subsetters have higher mean factor scores on Syllogistic Reasoning and Associative Memory, lower scores on Speed of Closure, and practically identical scores on Flexibility of Closure/Spatial Scanning.

Summary. The primary purpose of these analyses was to demonstrate that the subgroups were discriminable. As was the case in the strategy-performance analyses, these discriminant analyses are interesting in their own right, but further discussion is not warranted at this time. Again, the specific relationships uncovered may vary as a function of the rules used to generate the subgroups. While the present subgroups were interesting from a theoretical and methodological perspective, other possible subgroupings

Table 12

Stepwise Discriminant Function Analyses of Strategy Subgroup

Membership Predicted from Ability-Factor Scores:

Concept Identification Experiment

Task Characteristic	Abilities in the Order Entered in Solution [a]	Wilks' Lambda (Degrees of Freedom)	Corrected W^2 [b]		Univariate Discrimination Matrix [c]			
					FX	FG	FP	SS
Overall	SYLREA	.606*	.320	FG				
	ASCMEM	(4,4,123)		FP				
	FC/SS			SS	*	*	*	
	SPCLOS			I	*	*	*	*
No. of Dimensions								
4	SYLREA	.700*	.229	FG				
	ASCMEM	(3,4,123)		FP	*	*		
	FC/SS			SS	*	*		
				I	*	*		
6	FC/SS	.688*	.241	FG				
	SYLREA	(3,4,123)		FP	*			
	ASCMEM			SS	*	*	*	
				I	*			
8	ASCMEM	.610*	.324	FG	*			
	SYLREA	(3,4,123)		FP				
	SPCLOS			SS	*	*	*	
				I				*

[a] FC/SS: Flexibility of Closure/Spatial Scanning
SYLREA: Syllogistic Reasoning
IND: Induction
ASCMEM: Associative Memory
PERCSP: Perceptual Speed
SPCLOS: Speed of Closure

*Statistically significant, $p < .05$.

[b] Proportion of variance accounted for, using Tatsuoka's correction for bias.

[c] FX: Excellent Focuser; FP: Poor Focuser; SS: Subsetter; I: Inconsistent; FG: Good Focuser

Table 12 (Continued)

Stepwise Discriminant Function Analyses of Strategy Subgroup Membership Predicted from Ability-Factor Scores: Concept Identification Experiment

Task Characteristic	Abilities in the Order Entered in Solution [a]	Wilks' Lambda (Degrees of Freedom)	Corrected W^2 [b]		Univariate Discrimination Matrix [c] FX	FG	FP	SS
Level of Perceptual Complexity								
A	SYLREA	.611*	.326	FG				
	ASCMEM	(3,4,123)		FP		*		
	FC/SS			SS	*	*	*	
				I	*	*		
B	SYLREA	.592*	.336	FG				
	ASCMEM	(4,4,123)		FP	*			
	FC/SS			SS	*	*	*	
	PERCSP			I	*			*
C	SYLREA	.591*	.336	FG	*			
	FC/SS	(4,4,123)		FP				
	ASCMEM			SS	*	*	*	
	SPCLOS			I	*		*	

[a] FC/SS: Flexibility of Closure/Spatial Scanning; SYLREA: Syllogistic Reasoning; IND: Induction; ASCMEM: Associative Memory; PERCSP: Perceptual Speed; SPCLOS: Speed of Closure

*Statistically significant, $p < .05$.

[b] Proportion of variance accounted for, using Tatsuoka's correction for bias.

[c] FX: Excellent Focuser; FP: Poor Focuser; SS: Subsetter; I: Inconsistent; FG: Good Focuser

Table 13

Stepwise Discriminant Function Analyses of Strategy Subgroup Membership Predicted from Ability-Factor Scores: Troubleshooting Experiment

Task Characteristic	Abilities in the Order Entered in Solution [a]	Wilks' Lambda (Degrees of Freedom)	Corrected W^2 [b]		Univariate Discrimination Matrix [c] FXG	FP	SS
Overall	FC/SS	.821*	.131	FP	*		
	SYLREA	(2,3,131)		SS	*		
				I	*		
Level of Difficulty							
1	FC/SS	.899*	.056	FP			
		(1,3,131)		SS			
				I	*		
2	IND	.759*	.197	FP	*		
	FC/SS	(3,3,131)		SS			
	SYLREA			I	*	*	
3	FC/SS	.687*	.273	FP	*		
	SYLREA	(3,3,131)		SS	*		
	IND			I		*	*

a FC/SS: Flexibility of Closure/Spatial Scanning; SYLREA: Syllogistic Reasoning; ASCMEM: Associative Memory; PERCSP: Perceptual Speed; IND: Induction

b Proportion of variance accounted for, using Tatsuoka's correction for bias.

c FXG: Excellent/Good Focuser; FP: Poor Focuser; SS: Subsetter; I: Inconsistent

* Statistically significant, $p < .05$ by the *t*-test.

Table 13 (Continued)

Stepwise Discriminant Function Analyses of Strategy Subgroup Membership Predicted from Ability-Factor Scores: Troubleshooting Experiment

Task Characteristic	Abilities in the Order Entered in Solution [a]	Wilks' Lambda (Degrees of Freedom)	Corrected W^2 [b]		Univariate Discrimination Matrix [c] FXG	FP	SS
Level of Perceptual Complexity							
A	FC/SS	.669*	.271	FP	*		
	SYLREA	(4,3,131)		SS	*		
	IND			I	*		
	PERCSP						
B	FC/SS	.814*	.139	FP	*		
	SYLREA	(2,3,131)		SS	*		
				I	*	*	
C	FC/SS	.821*	.138	FP	*		
		(1,3,131)		SS	*		
				I	*	*	

a FC/SS: Flexibility of Closure/Spatial Scanning; SYLREA: Syllogistic Reasoning; ASCMEM: Associative Memory; PERCSP: Perceptual Speed; IND: Induction

b Proportion of variance accounted for, using Tatsuoka's correction for bias.

c FXG: Excellent/Good Focuser; FP: Poor Focuser; SS: Subsetter; I: Inconsistent

* Statistically significant, $p < .05$ by the t-test.

are more important for the purposes of subsequent analyses. Several sortings and reanalyses of the resulting subgroups were conducted during the course of the project. One of these was used to investigate, in detail, the task characteristic-ability-strategy relationship. Results from this central analysis are presented and discussed in the following section.

Abilities, Strategies, and Task Characteristics

To recapitulate briefly, the analytical steps employed in order to establish the role of strategy as a mediator between abilities and task characteristics were as follows. First, a priori criteria were established to classify subjects into strategy subgroups. Second, it was determined that the constitution of the subgroups impacted on performance. Third, it was determined that this strategy subgroup sorting was related to abilities. In light of these prior outcomes, the final step is to determine the correlations between the ability-factor scores and performance as a function of variations in task characteristics for each strategy subgroup. This analytical procedure was performed for both the concept-identification and the troubleshooting tasks.

Concept-Identification task. On the basis of the analyses presented above, six strategy subgroups of subjects were established. These six subgroups consisted of Good Focusers, Fair Focusers, Poor Focusers, Partial Subsetters, Subsetters, and Inconsistent. The criteria for subject assignment were similar to those previously discussed; the primary difference was the creation of a subgroup of subjects who attempted a subset strategy at some point in the experiment but did not maintain it over a sufficient number of problems to be categorized as Subsetters.

Tables 14 and 15 present, respectively, the mean proportion of problems solved by each subgroup as a function of task characteristics, and the performance discrimination matrices. It is clear that the subgroups could be discriminated in terms of performance.

Tables 16 and 17 present, respectively, the mean factor scores and the factor-score discrimination matrices for the strategy subgroups. Although there are few obvious subgroup mean differences, some general trends can

Table 14

Mean Proportion of Problems Solved as a Function of Task Characteristic for Strategy Subgroups in the Concept Identification Experiment

	Task Characteristic					
	No. of Dimensions			Level of Perceptual Complexity		
Strategy Group (N)	4	6	8	A	B	C
Good Focusers (23)	.976	.889	.961	.942	.947	.937
Fair Focusers (10)	.967	.767	.822	.889	.867	.800
Poor Focusers (32)	.851	.677	.733	.719	.757	.785
Subsetters (15)	.711	.504	.437	.496	.637	.519
Part Subsetters (13)	.863	.616	.547	.684	.675	.667
Inconsistent (18)	.852	.580	.617	.661	.691	.698

Table 15

Performance Discrimination Matrices: Differences in Proportion of Problems Solved Among Strategy Subgroups as a Function of Task Characteristics in Concept Identification [a]

Task Characteristic	Comparison Subgroup	Strategy Subgroup				
		FG	FF	FP	SS	PS
No. of Dimensions						
4	FF	.46				
	FP	3.95**	3.36**			
	SS	3.65**	3.46**	1.79		
	PS	2.35**	2.08*	.22	1.77	
	I	3.41**	2.96**	.02	1.76	.19
6	FF	1.79				
	FP	5.79**	1.26			
	SS	5.48**	2.82**	2.36*		
	PS	5.40**	1.90	1.11	1.38	
	I	5.17**	2.18*	1.53	.87	.50
8	FF	2.72*				
	FP	5.37**	1.38			
	SS	8.32**	4.83**	3.98**		
	PS	5.93**	3.23**	2.32*	1.19	
	I	5.46**	2.57*	1.59	2.05*	.75

[a] Subgroup Abbreviations are:

FG: Good Focuser SS: Subsetter
FF: Fair Focuser PS: Part Subsetter
FP: Poor Focuser I: Inconsistent

Table entries are _t_-values.

* $p \leq .05$
** $p \leq .01$

Table 15 (Continued)

Performance Discrimination Matrices: Differences in Proportion of Problems Solved Among Strategy Subgroups as a Function of Task Characteristics in Concept Identification [a]

Task Characteristic	Comparison Subgroup	Strategy Subgroup FG	FF	FP	SS	PS
Level of Perceptual Complexity						
A	FF	1.93				
	FP	5.72**	3.98**			
	SS	7.44**	6.30**	3.27**		
	PS	5.91**	4.36**	.64	2.65*	
	I	5.48**	4.21**	.95	2.17*	.33
B	FF	1.59				
	FP	6.43**	1.97			
	SS	4.03**	2.54*	1.49		
	PS	4.31**	2.43*	1.21	.39	
	I	4.89**	2.49*	1.14	.59	.20
C	FF	2.50*				
	FP	4.09**	.24			
	SS	7.26**	3.71**	4.15**		
	PS	4.33**	1.68	1.72	1.82	
	I	4.78**	1.46	1.51	2.47**	.41

[a] Subgroup Abbreviations are:

FG: Good Focuser
FF: Fair Focuser
FP: Poor Focuser
SS: Subsetter
PS: Part Subsetter
I: Inconsistent

Table entries are t-values.

* $p \leq .05$
** $p \leq .01$

Table 16

Mean Ability-Factor Scores for Strategy Subgroups in the Concept Identification Experiment

	Ability Factors [a]					
Strategy Subgroup	FC/SS	ASCMEM	PERCSP	SYLREA	SPCLOS	IND
Good Focusers	.509	.204	.029	.287	.141	.374
Fair Focusers	.212	-.051	-.251	.590	.330	.276
Poor Focusers	-.184	.151	.114	.106	.074	-.037
Subsetters	-.466	-.642	.571	-.682	.113	-.001
Part Subsetters	.014	-.276	-.132	-.123	-.596	-.108
Inconsistent	-.340	.118	-.336	-.209	-.098	-.169

[a] Abbreviations for ability factors:

FC/SS: Flexibility of Closure/Spatial Scanning
ASCMEM: Associative Memory
PERCSP: Perceptual/Cognitive Speed
SYLREA: Syllogistic Reasoning
SPCLOS: Speed of Closure
IND: Induction

Table 17

Ability Discrimination Matrices: Differences in Factor Scores Among Strategy Subgroups in Concept Identification [a]

Factor	Comparison Subgroup	Strategy Subgroup FG	FF	FP	SS	PS
Flexibility of Closure/Spatial Scanning	FF	.76				
	FP	2.61*	1.01			
	SS	3.45**	1.68	.99		
	PS	1.31	.42	.52	1.22	
	I	3.02**	1.37	.55	.42	.90
Associative Memory	FF	.58				
	FP	.22	.47			
	SS	2.94**	1.29	2.90**		
	PS	1.15	.41	1.05	.84	
	I	.30	.37	.12	2.40**	.90
Perceptual/ Cognitive Speed	FF	.73				
	FP	.30	.99			
	SS	1.67	2.07*	1.52		
	PS	.52	.31	.86	2.17*	
	I	1.06	.21	1.39	2.54*	.59

[a] Subgroup abbreviations are:

FG: Good Focuser — SS: Subsetter
FF: Fair Focuser — PS: Part Subsetter
FP: Poor Focuser — I: Inconsistent

Table entries are t-values.

* $p \leq .05$
** $p \leq .01$

Table 17 (Continued)

Ability Discrimination Matrices: Differences in Factor Scores Among Strategy Subgroups in Concept Identification [a]

Factor	Comparison Subgroup	Strategy Subgroup				
		FG	FF	FP	SS	PS
Syllogistic Reasoning	FF	.70				
	FP	.82	1.17			
	SS	3.19**	2.75*	2.91**		
	PS	1.49	1.61	.97	1.77	
	I	1.54	1.68	1.08	1.32	.25
Speed of Closure	FF	.53				
	FP	.28	.73			
	SS	.07	.47	.10		
	PS	2.07*	2.11*	1.91	1.52	
	I	.82	1.10	.60	.50	1.28
Induction	FF	.26				
	FP	1.39	.97			
	SS	1.19	.81	.15		
	PS	1.22	.92	.21	.30	
	I	1.57	1.21	.46	.55	.16

[a] Subgroup abbreviations are:

FG: Good Focuser
FF: Fair Focuser
FP: Poor Focuser
SS: Subsetter
PS: Part Subsetter
I: Inconsistent

Table entries are t-values.

* $p \leq .05$
** $p \leq .01$

be discerned. Good and Fair Focusers are superior to all other subgroups on most factors. Subsetters are substantially below the other subgroups on several factors, as is the Inconsistent subgroup.

Correlations between factor scores and performance for each of the strategy subgroups as a function of task characteristics are presented in Table 18. These correlations are analogous to those shown in Table 6 above; however, since that analysis was performed on the entire pool of subjects rather than on smaller (and presumably more homogeneous) subgroups, the magnitude of the correlations is not comparable.

There are several trends indicated by these data that may help in explaining why ability-task characteristic relationships previously reported were difficult to interpret. At the most general level, it is clear that different abilities correlated with performance for the various subgroups. For example, Flexibility of Closure/Spatial Scanning (FC/SS) correlated highly with performance for the Subsetters, but not for other subgroups. Likewise, Induction was important for Fair Focusers but not for anyone else. Hence, if all subgroups were combined, one would expect ambiguous results. Similarly, even for abilities predicting performance for different subgroups, the pattern of involvement across task manipulations differs for the different strategies. For example, Associative Memory (ASCMEM) has high correlations with performance for Fair Focusers, Part Subsetters, and Subsetters across the "number-of-dimensions" task manipulation. However, the correlations increase consistently for the Fair Focusers; the ability "drops out" for the Subsetters at the most difficult problem level; while for the Part Subsetters it increases dramatically at the most difficult level. Again, pooling these three subgroups would result in a possibly misleading pattern of involvement which would not reflect any of the subgroup patterns. To further illustrate this last point, consider the Inconsistent subgroup. These subjects (by definition) did not use a strategy consistently from one problem to the next. As might be expected, there are no consistent patterns of correlations across either task manipulation.

Another outcome from these correlations that would limit the interpretability of correlations obtained from pooled subjects is that abilities

Table 18

Correlations Between Ability-Factor Scores and Concept Identification Performance as a Function of Variations in Task Characteristics for Each Strategy Subgroup [a]

Strategy Subgroup [b]	Ability-Factor	Task Characteristic: No. of Dimensions 4	6	8	Level of Perceptual Complexity A	B	C
Good Focusers	FC/SS	-08	25	-20	-05	14	09
	ASCMEM	23	-58	17	10	-29	-41
	PERCSP	-34	16	-12	-20	-19	23
	SYLREA	-37	07	03	-08	02	-04
	SPCLOS	-11	-18	14	-25	-04	07
	IND	05	25	08	24	07	12
Fair Focusers	FC/SS	-35	-08	-23	-20	-28	-08
	ASCMEM	11	33	49	29	68	16
	PERCSP	39	57	17	14	44	52
	SYLREA	15	-20	-51	01	-44	-30
	SPCLOS	-11	47	07	42	-03	48
	IND	37	67	21	42	30	71
Poor Focusers	FC/SS	22	32	-11	-16	24	34
	ASCMEM	03	22	-03	00	08	12
	PERCSP	36	02	15	02	33	24
	SYLREA	-08	11	02	-14	05	24
	SPCLOS	13	-14	04	-01	09	-01
	IND	-01	-20	31	08	-02	13

[a] Correlations rounded to two places, decimals omitted.

[b] Abbreviations for Ability-Factors:

FC/SS: Flexibility of Closure/Spatial Scanning
ASCMEM: Associative Memory
PERCSP: Perceptual/Cognitive Speed
IND: Induction
SYLREA: Syllogistic Reasoning
SPCLOS: Speed of Closure

Table 18 (Continued)

Correlations Between Ability-Factor Scores and Concept Identification Performance as a Function of Variations in Task Characteristics for Each Strategy Subgroup [a]

Strategy Subgroup [b]	Ability-Factor	Task Characteristic: No. of Dimensions 4	6	8	Level of Perceptual Complexity A	B	C
Subsetters	FC/SS	53	64	74	53	79	64
	ASCMEM	44	65	-10	32	31	48
	PERCSP	-47	-24	-42	-25	-49	-44
	SYLREA	-01	-24	07	13	-26	00
	SPCLOS	32	26	07	44	10	20
	IND	-13	-11	-02	-09	-15	-04
Part Sub-setters	FC/SS	-20	10	-23	-59	07	-01
	ASCMEM	49	47	74	53	55	66
	PERCSP	-37	07	-02	-17	03	-18
	SYLREA	47	10	16	26	15	29
	SPCLOS	54	08	53	50	49	24
	IND	17	25	10	-03	36	10
Inconsistent	FC/SS	10	-14	-10	16	-16	-22
	ASCMEM	05	45	20	36	28	16
	PERCSP	-27	25	28	-14	19	40
	SYLREA	01	04	21	00	24	06
	SPCLOS	-25	-49	-37	-31	-46	-43
	IND	-16	19	15	02	27	00

[a] Correlations rounded to two places, decimals omitted.

[b] Abbreviations for Ability-Factors:

FC/SS: Flexibility of Closure/Spatial Scanning
ASCMEM: Associative Memory
PERCSP: Perceptual/Cognitive Speed
IND: Induction
SYLREA: Syllogistic Reasoning
SPCLOS: Speed of Closure

apparently operate differentially for different subgroups within a given task characteristic level. For example, consider the Perceptual Speed (PERCSP) factor for the 4-dimensional problems. Correlations are substantial for all subgroups; however, these correlations are positive for the Fair Focusers and Poor Focusers, but negative for the other groups. The net result upon combining subgroups (Table 6) was that this factor had an essentially zero correlation with performance. A final outcome which would limit the interpretability of pooled results is that even for subgroups using the same general strategy, different abilities were related to performance at different levels of the task-characteristic manipulations. For example, consider the Good, Fair, and Poor Focusers and their correlational patterns at the "C" level of perceptual complexity. Clearly, the patterns of correlations are different, although the same general strategy was used. Thus, there is no single expected pattern of correlations for the general strategy of focusing; if one knew that a given subject was a focuser (or even that he was a Good Focuser) on the 4-dimension problems, one could not predict his performance on a variant of the task. It might be possible to predict from his ability profile that he would likely continue to be a Good Focuser (or change to a Fair or Poor Focuser) and, from the predicted strategy, predict performance on the modified task. Similarly, one could not predict performance simply from a knowledge of a subject's ability without knowing which strategy he used in other versions of the task.

Troubleshooting. The analytic procedures described above for the concept-identification study were carried out for the troubleshooting task. There were three principal reasons why this was done. First, it was an attempt to validate the methodological and analytic procedures developed to ascertain the mediational role of strategy for ability-performance relationships. The second reason was to gain support for the general conclusions drawn from the concept-identification analyses. Finally, there were several specific issues related to strategy types, dependent variables, and task characteristics which could be addressed directly through these analyses.

The first step was again to generate subject subgroups on the basis of their protocol strategies. The subgroups selected for these analyses were as follows:

1. Focusers (F): subjects who had mostly excellent or good focusing protocols for each level of task manipulation.
2. Good-to-Poor Focusers (GPF): subjects who were classified as Excellent/Good Focusers on the easiest problems, but became Poor Focusers on the more difficult problems.
3. Early-to-Inconsistent Focusers (EIF): subjects who were classified as Excellent/Good Focusers on the easiest problems, but could not be classified as Good or Poor Focusers thereafter.
4. Change Focusers (CF): a pooling of the GPF and EIF subgroups.
5. Subsetters: subjects who had mostly subset protocols for all levels of task manipulations.
6. Inconsistent (I): subjects who were unclassifiable by the preceding criteria (typically, I subjects had several subset protocols randomly distributed across task dimensions).

The next steps were to assess the impact of this categorization upon performance and ability profiles. Two performance measures were selected for analysis: mean log time to solution, and arcsin, square-root efficiency per trial. These measures were chosen because they were basically independent of the protocol classification rules. Mean levels of performance for each subgroup as a function of task characteristics are presented in Table 19. Subgroup pairwise contrasts of these means were performed for each cell. (A table of these comparisons will not be presented due to the large number of t-values that would have to be presented.) As was true for the concept-identification task, most strategy subgroups differed from one another on performance, with the exceptions of the "A" level of perceptual complexity on the time-to-solution measure, and scattered subgroup combinations within each cell. The mean ability scores for each subgroup are presented in Table 20. Subgroup pairwise contrasts of these means were performed. Again, subgroups were found to differ on several factors. Thus, the two necessary conditions to establish "strategy" as a mediator have been met; strategies are related to performance and abilities.

Table 19

Mean Performance as a Function of Task Characteristic and Strategy in Troubleshooting

Strategy Classification (Group size)	Task Characteristic: Level of Difficulty 1	2	3	Level of Perceptual Complexity A	B	C
Log Time to Solution						
Focusers (21)	4.89	5.03	5.67	4.98	5.20	5.41
Good-to-Poor Focusers (14)	4.99	5.46	6.02	5.23	5.52	5.71
Early-to-Inconsistent Focusers (27)	4.85	5.14	5.74	5.00	5.22	5.52
Change Focusers (41)	4.90	5.25	5.84	5.08	5.33	5.58
Subset (20)	5.09	5.21	5.77	5.13	5.29	5.65
Inconsistent (40)	5.05	5.14	5.80	5.04	5.31	5.64
Arcsin, Square Root Efficiency Per Trial						
Focuser	1.10	1.15	.98	1.09	1.09	1.05
Good-to-Poor Focuser	1.04	.82	.74	.89	.87	.84
Early-to-Inconsistent Focuser	1.11	1.02	.90	1.04	1.02	.97
Change Focuser	1.08	.95	.85	.99	.97	.93
Subset	.90	.86	.76	.87	.85	.79
Inconsistent	.92	.92	.76	.90	.89	.81

Table 20

Mean Ability-Factor Scores for Strategy Subgroups in the Troubleshooting Experiment

Strategy Subgroup	Ability Factors [a]				
	FC/SS	SYLREA	ASCMEM	PERCSP	IND
Focusers	.432	.304	-.094	-.425	.436
Good-to-Poor Focusers	-.242	-.486	.505	-.434	-.273
Early-to-Inconsistent Focusers	.330	.410	.253	.315	-.173
Change Focusers	.135	.104	.339	.059	-.207
Subsetters	-.132	-.203	-.322	.237	.112
Inconsistent	-.445	-.112	-.124	-.020	-.140

[a] Abbreviations for Ability Factors:

FC/SS: Flexibility of Closure/Spatial Scanning
SYLREA: Syllogistic Reasoning
ASCMEM: Associative Memory
PERCSP: Perceptual Speed
IND: Induction

Table 21 presents the correlations between factor scores and performance for each subgroup as a function of variations in task characteristics. For the most part, the general conclusions reached from the parallel concept-identification analysis are supported in the troubleshooting task. First, different abilities correlated with performance for the various subgroups, although there was more consistency in this study than in the concept-identification study. For example, Induction was correlated with the time measure for all subgroups except the Focusers and Inconsistents. Also, a given ability had different patterns of involvement for different subgroups, which when combined, could lead to ambiguous or misleading conclusions. For example, the Associative Memory factor had substantial negative correlations with the time measure for the GPF and CF groups, but high positive correlations for the Subsetters. Similarly, FC/SS correlations with the time measure increase across the difficulty manipulation for the EIF and CF subgroups, stays high and positive for the F, SS, and I subgroups, and is basically uncorrelated with the GPF subgroup. These differential outcomes are totally obscured when correlations are examined across all subjects (Table 4).

An additional interesting result is that the abilities correlate differently with the time and efficiency measures for each subgroup. For example, Induction, while not correlated with the time measure for the I subgroup, is highly related to their efficiency scores; the opposite is true for the Subsetters (i.e., correlated with time but not with efficiency). Perhaps more impressively, Syllogistic Reasoning is in general negatively related to the time measure for Subsetters, but has high positive correlations with efficiency. If Table 21 is compared to Table 4, one can see that the overall correlations are a function of the combination of the subgroup correlations for each cell. Therefore, the interpretation of the overall results must be modified by consideration of subgroup membership and hence of strategy employed.

Table 21

Correlations Between Factor Scores and Troubleshooting Performance as a Function of Variations in Task Characteristics for Each Strategy Subgroup [a]

		Mean Log Time to Solution [c]						Arcsin, Square Root Efficiency Per Trial					
Strategy Subgroup	Ability Factor [b]	Difficulty 1	Difficulty 2	Difficulty 3	Perceptual Complexity A	Perceptual Complexity B	Perceptual Complexity C	Difficulty 1	Difficulty 2	Difficulty 3	Perceptual Complexity A	Perceptual Complexity B	Perceptual Complexity C
Focusers	FC/SS	28	26	24	23	09	42	07	05	13	23	-05	02
	SYLREA	18	05	00	02	12	10	06	12	-27	-07	-03	01
	ASCMEM	-01	-03	-04	14	-15	-11	23	32	14	44	06	09
	PERCSP	12	-03	01	16	-02	-08	15	16	13	38	04	-08
	IND	06	16	22	09	06	28	16	-06	18	07	13	07
Good-to-Poor Focusers	FC/SS	10	28	-02	15	-06	43	36	33	12	16	12	40
	SYLREA	-13	09	-37	-08	-20	07	16	41	06	04	09	37
	ASCMEM	-34	-43	-27	-36	-19	-58	15	-28	26	02	48	-38
	PERCSP	-26	-40	02	-25	-22	-28	-06	-32	29	-14	01	08
	IND	43	32	43	48	39	16	03	32	01	45	21	-33
Early-to-Inconsistent Focusers	FC/SS	-07	17	42	08	24	29	09	34	59	10	41	57
	SYLREA	08	14	16	05	23	14	13	20	44	31	28	19
	ASCMEM	-12	-20	-21	-11	-25	-22	34	32	15	48	26	00
	PERCSP	04	-06	-01	-25	33	-11	-07	-03	08	-31	32	-03
	IND	48	34	29	49	32	36	13	10	-03	38	-20	00

[a] Correlations rounded to two places, decimals omitted.

[b] Same as footnote [a], Table 20.

[c] All correlations with the time measure of performance have been reflected since decreases in this measure correspond to improved performance.

Table 21 (Continued)

Correlations Between Factor Scores and Troubleshooting Performance as a Function of Variations in Task Characteristics for Each Strategy Subgroup [a]

Strategy Subgroup	Ability Factor [b]	Mean Log Time to Solution [c]						Arcsin, Square Root Efficiency Per Trial					
		Difficulty 1	Difficulty 2	Difficulty 3	Perceptual Complexity A	Perceptual Complexity B	Perceptual Complexity C	Difficulty 1	Difficulty 2	Difficulty 3	Perceptual Complexity A	Perceptual Complexity B	Perceptual Complexity C
Change Focusers	FC/SS	06	29	35	18	22	39	25	40	49	23	38	55
	SYLREA	11	26	21	13	26	24	24	42	48	40	37	38
	ASCMEM	-21	-30	-25	-22	-26	-34	23	06	09	25	22	-15
	PERCSP	04	-01	17	-09	29	00	05	17	31	-01	36	18
	IND	46	32	31	46	33	29	11	14	01	36	-05	-07
Subsetters	FC/SS	35	27	36	36	24	36	28	30	35	40	38	20
	SYLREA	04	-24	-24	-02	-25	-17	62	32	32	48	42	48
	ASCMEM	37	49	49	30	50	56	-03	11	04	00	05	04
	PERCSP	34	20	15	20	13	38	16	26	05	04	10	31
	IND	38	31	48	49	44	10	02	-03	-04	12	-07	-06
Inconsistent	FC/SS	35	31	28	17	44	41	09	26	41	27	26	19
	SYLREA	05	09	21	11	15	11	22	19	34	09	35	24
	ASCMEM	-11	-05	-18	-22	-02	-10	12	35	26	36	20	18
	PERCSP	-03	13	02	14	02	-04	15	02	-11	07	-04	05
	IND	21	05	19	19	06	21	31	33	29	39	19	36

[a] Correlations rounded to two places, decimals omitted.

[b] Same as footnote [a], Table 20.

[c] All correlations with the time measure of performance have been reflected since decreases in this measure correspond to improved performance.

IV. CONCLUSIONS

The experimental-correlational studies described in the present report, together with those reported upon previously by Zimmerman (1954) and Fleishman (1957), were conducted to explore ability-task interactions in situations representing a spectrum of human performance. The earlier studies, involving visualization-of-maneuver and response-orientation tasks, investigated the visual-perceptual and perceptual-motor domains. The later studies, concerned with auditory target identification, electronic troubleshooting, and problem solving, have delved into auditory-perceptual and perceptual-cognitive tasks of current interest to the Navy.

In each of these investigations the general approach was to vary tasks along one or two specified physical dimensions and to administer these task variations to groups of subjects who also received a battery of reference tests known to sample certain more general abilities (e.g., syllogistic reasoning, associative memory, perceptual speed, etc.). Correlations between these ability constructs and measures of performance on variations of the criterion task serve to specify the ability requirements, and changes in these requirements, as a function of criterion task variations.

Considered jointly, these experimental-correlational studies have provided convincing support for the validity of the ability constructs sampled during the course of the various studies. Ability scores do correlate with criterion task performance and do account for sizeable portions of the variance in those measures--variance which is typically ascribed to individual differences among operators. Furthermore, those abilities accounting for individual differences in performance on one task are not necessarily the same as those involved in other, obviously dissimilar tasks. This recurrent finding supports the contention that abilities are sensitive to differences among tasks, making them more precise descriptors of performance than the broader rubrics (e.g., mental, motor; cognitive, noncognitive; etc.) in vogue not so long ago.

In many respects, the current program of research assumed these outcomes from the start. If personnel requirements are to be stated in terms of abilities, such constructs must in fact contribute to the prediction of operator performance. Similarly, to the extent that diverse tasks (as defined in terms of ability requirements) are considered, differential ability-task relationships must be demonstrable. Given these assumptions, therefore, the basic thrust of the research program was to test their limits. Interest lay in exploring how the ability requirements associated with a given task might change as physical "stimulus" features of the task were varied in small and systematic increments. One of four outcomes was theoretically possible:

1. no change in ability requirements, either in terms of those involved in the original version of the task (i.e., those exceeding a specific correlational value), or in terms of their degree of involvement (i.e., an increase or decrease in the correlation coefficient);
2. a systematic change (increase or decrease) in the involvement of the relevant ability(ies);
3. a systematic increase in the involvement of one or more abilities and a simultaneous decrease in the importance of others; or
4. changes in involvement which did not appear to be systematic over incremental task variations.

The Zimmerman (1954) and Fleishman (1957) studies demonstrated the third kind of outcome, the Wheaton et al. (1973) passive-sonar study yielded the second kind of outcome, while the Rose et al. (1974) troubleshooting and Fingerman et al. (1975) concept-identification studies yielded the fourth type of outcome.

Failure to produce the first outcome was, of course, primarily due to the experimenters' ingenuity in selecting task characteristics and incremental values which would impact on task performance and upon ability requirements. For purposes of the research such variations were desirable since they served to demonstrate that an effective incremental change had in fact occurred.

The second outcome, as demonstrated in the Wheaton et al. study, has implications for ability assessment techniques (Theologus et al., 1970) as well as for personnel decisions based on such assessments. It suggests that there are certain kinds of task variations which simply influence what might be termed the conditions of performance rather than the nature of the performance itself. The abilities contributing to individual differences in performance on the original task continue to do so, but become more important as the conditions under which performance occurs become more demanding. Such a possibility must be kept in mind by the abilities analyst who attempts to determine the ability requirements for the task variation based upon his knowledge of the requirements for the original version. Similarly, the personnel decision maker, given certain other constraints, should be prepared to retain his selection instruments but to raise his cutoff criterion.

The third outcome, as demonstrated in the Fleishman and Zimmerman studies has important and different implications. These studies demonstrate that subtle variations can be induced which actually change the nature of the task, such transformations being defined in terms of new ability requirements. Again, ability analysts must be sensitive to such variations if they are to avoid erroneous extrapolations from the ability requirements associated with base-line task conditions. Individuals responsible for selection will have to modify their instruments.

Given these outcomes the issue becomes one of differentiating between two general kinds of task variation. One, which seems extrinsic to the task itself, serves to change conditions under which the task is performed without altering the set of abilities contributing to individual differences in performance. The other, which appears to be an integral part of the task, serves to modify those abilities accounting for individual differences. The Rose et al. and Fingerman et al. studies included task-characteristic manipulations believed to represent both extrinsic and intrinsic task variations. Levels of difficulty, as defined in those studies, entailed an intrinsic variation while perceptual complexity represented a background or extrinsic variation.

Unfortunately, both of these studies produced the fourth outcome. Changes in ability requirements were manifest, but these changes were not of the systematic variety anticipated (second and third outcomes). Thus, it became apparent that intrinsic and extrinsic variations could not be defined in terms of morphological features of a task. Rather, the distinction between an intrinsic and extrinsic variation must be a function of the subject's perception of the change in a physical task characteristic. If the subject perceives such a change as representing a change in the way he must now perform the task, that change can be said to represent an intrinsic task variation. Conversely, if the task manipulation is not so perceived, it represents an extrinsic variation. This reasoning was explored on a post hoc basis by examining the relationship between task variations and the problem-solving strategies employed by individual subjects.

Reanalysis of the Rose et al. and Fingerman et al. studies in terms of these concepts served to clarify the circumstances which produced the fourth type of outcome. In light of these findings, the implications for ability assessment and for personnel decision making are significant. In situations potentially representing intrinsic variations in a task, estimates of the ability profiles associated with different problem-solving approaches or strategies will be required. Furthermore, methods will be needed in order to identify individuals who will adopt one of several strategies as well as those who will change their strategy in response to a change in the task. The goal of future research will be to supply such methods.

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