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AUTHOR Rose, Andrew M.; And Others

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ABSTRACT

The relationships between the characteristics of human tasks and the abilities required for task performance are investigated. The goal of the program is to generate principles which can be used to identify ability requirements from knowledge of the characteristics of a task and of variations in the conditions of task performance. Such knowledge has important implications for both selection and training of personnel. The relationship between variations in an electronic fault-finding task and consequent changes in the abilities related to fault-finding performance was investigated. Characteristics of the fault-finding task were manipulated by varying formal difficulty and perceptual complexity. Subjects received a battery of reference ability tests and then proceeded to perform the criterion task under the different experimental 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 various criterion task conditions on that structure were then estimated. Five separate ability factors were identified. Four were found to be related to criterion task performance. One seemed to be involved to the same extent across alternative versions of the task, while others increased or decreased as the task characteristics were manipulated. (Author/SM)

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METHODS FOR PREDICTING JOB-ABILITY REQUIREMENTS:

II. Ability Requirements as a Function of Changes in the Characteristics of an Electronic Fault-Finding Task

Andrew M. Rose
Paul W. Fingerman
George R. Wheaton
Ellen Eisner
Gloria Kramer

TECHNICAL REPORT

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George R. Wheaton
Edwin A. Fleishman

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

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As the second step in this program, the present study investigated the relationship between variations in an electronic fault-finding task and consequent changes in the abilities related to fault-finding performance. Characteristics of the fault-finding task were manipulated by varying formal difficulty and perceptual complexity. Subjects received a battery of reference ability tests and then proceeded to perform the criterion task under the different experimental 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.

Five separate ability factors were identified. Four were found to be related to criterion task performance. One seemed to be involved to the same extent across alternative versions of the task, while others increased or decreased as the task characteristics were manipulated.

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INTRODUCTION

Various personnel decisions are based on prediction of success in a given task. To the degree that this prediction can be achieved, the accuracy of personnel selection, classification, and placement, and the design of training programs would improve. Unfortunately, the procedures required to insure a satisfactory level of prediction are arduous and time-consuming. These procedures consist of the following necessary stages: 1) task or job analysis, to form a hypothesis as to what characteristics make for success or failure; 2) choice of possibly useful tests to measure these characteristics; 3) administration of tests to an experimental group of workers; 4) collection of criterion data that show how these workers succeeded on the job; 5) analysis of the relation between test score and success on the job, and installation of the most effective selection plan; and 6) periodic validity studies to check on the continuing soundness of the plan (Cronbach, 1970, p. 407).

Of these stages, one of the most crucial and certainly one of the most difficult to conduct is task or job analysis. The difficulty inherent in task analysis is apparent when one reviews the tremendous variety of methods and the sheer number of different schemes proposed for accomplishing it (see Smith, 1965). In effect, task analysis consists of two distinct aspects: a description of the salient characteristics of the tasks, and the translation of these characteristics into hypotheses stating the operator characteristics necessary for successful performance. In terms of the accuracy and efficiency of such an analysis, it is desirable to have a common "language" to describe both the task and operator characteristics. Furthermore, it is important that the common language consists of constructs having a high degree of reliability and validity. That is, the vocabulary should include only those terms which can be used consistently and which have been empirically demonstrated to be effective predictors of performance.

In addition to being able to describe both the task and the operator, a powerful task-analytic language must also satisfy other requirements. First, as implied by Cronbach's list of stages, the constructs comprising the vocabulary must be operationally defined, typically through a reliable test or set of tests. Practically, these tests must be amenable to administration to groups of operators, have easily interpretable scores, etc. Second, the constructs or their defining tests must predict performance in a selected criterion task. Minimally, this prediction must differentiate good operators from poor operators. Other predictions and differentiations are also desirable; e. g., predicting who will be good learners and poor learners of the criterion task, or who will better retain the training. Third, the constructs must be valid and reliable over time. For example, a test which differentiates good and bad operators might not be useful if, after some experience on the task, the test becomes irrelevant to performance.

In order to address these requirements, Fleishman and his co-workers have focused on the development of 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; Wheaton & Mirabella, 1972; and Wheaton, Shaffer (Eisner), Mirabella, & Fleishman, 1973). One of the taxonomic languages investigated by these researchers for the description of tasks and operators uses empirically defined human abilities as its vocabulary. In this context, ability refers to a characteristic trait of an individual which has been inferred from behavioral consistencies (e.g., correlations) on several kinds of tasks. It has been found that this ability language meets several of the requirements discussed above. Since the abilities are empirically defined (through factor-analytic procedures) by response consistencies on tests of known reliability, operational definitions of abilities are available. The application of an abilities language to the classification of tasks has been moderately successful. Given verbal definitions of abilities derived from empirical findings, Theologus, Romashko, & Fleishman (1970), Theologus & Fleishman (1971), and Levine, Greenbaum (Kramer), & Notkin (1973) demonstrated that a set of observers could consistently select a defining set of abilities for several different tasks.

However, it soon became apparent that a different set of considerations was involved when attempting to predict level of criterion task performance, as opposed to merely describing tasks in terms of ability requirements. One consideration is that in order to make a prediction, one must discover not only which abilities are involved in task performance, but also their relative levels of involvement. A second consideration is that for any task, either the descriptor abilities or their relative weights may vary from one specific configuration to another. For example, assume that it is possible to describe the task of a passive sonar operator in terms of an abilities language. Assume also that the specific abilities selected to describe this task may differ as a function of changes in the specific characteristics of the task. For example, the sonar signals might appear in a low-noise background, in which case they would be easily discriminable, or a high-noise background in which case they would not be easily discriminable. As the "discriminability" characteristic of the task varies, there might be a corresponding change in the abilities required for satisfactory performance. "Pitch discrimination" would probably not be an important predictor ability in the low-noise, high discriminability case. However, it might be important if the signals were embedded in high-background noise and, therefore, were not easily distinguishable. Similarly, "memory" would not be important if only two different signals were presented, but might be crucial if several different signals were to be discriminated.* To state the problem in terms of a constraint on the methodological language, it is important that the language and its constructs be sensitive to changes in task characteristics when in fact these changes alter the demands paced on the operator and thus require different operator aptitudes. On the other hand, certain changes in task characteristics, while affecting level or variability of task performance, might not require different operator aptitudes. A powerful task-analytic language should be sensitive to either of these relationships.

Thus, there is a need for systematic investigation of the types and

*Wheaton, Shaffer (Eisner), Mirabella, & Fleishman (1973) actually studied hypothetical sonar tasks in this way. Their report (first in this series) describes their actual findings.

magnitudes of changes in task characteristics, and the role each plays in determining necessary operator abilities.

> "As new systems, jobs, and tasks are developed, forecasts are needed regarding the kinds of personnel who will be required in order to perform effectively at these positions. Similarly, as existing equipment and procedures are updated, estimates are needed of the expected impact of such modifications on performance (Wheaton, Shaffer (Eisner), Mirabella, & Fleishman, 1973, p. 1)."

The general goal of the current research is to develop principles relating task characteristics to ability requirements. More specifically, this phase of the program addresses the following issues:

1. Can an abilities vocabulary adequately relate operator and task characteristics by means of a common language?
2. Do ability constructs predict performance in a range of different criterion tasks?
3. Is the ability structure for a <u>given</u> task sensitive to changes in task performance demands?
4. How does this "sensitivity" manifest itself?

The strategy adopted to investigate these issues was discussed more fully in the previous report in this series (Wheaton, et al., 1973). In essence, Cronbach's stages of test establishment were applied to classes of tasks representative of the kinds of tasks prevalent in the modern Navy and of theoretical interest. Using this strategy, an early study investigated a psychomotor task (Fleishman, 1957); the current series initially focused on an auditory signal identification task representing the duties performed by a passive sonar operator (Wheaton, et al., 1973). Thus, previous research in this area has focused mainly on less cognitive tasks. In order to determine whether or not the same proposed methodology would be useful in "higher-order" reasoning tasks, the current study examined an electronic fault-finding task, representative of situations faced by electronic troubleshooters.

The troubleshooting task was carefully analyzed, and abilities hypothetically contributing to criterion performance were selected. Next, a series of manipulations of the basic fault-finding task was introduced. These manipulations were assumed to affect the conditions of task performance by making the task more demanding while maintaining the basic performance requirements. These manipulations will be discussed further in the method section. The criterion task and the reference battery were then administered to a large group of subjects. To determine the relationship between task variations and ability requirements, several statistical analyses were then performed, including a factor analysis of the reference battery to establish an empirical ability structure, and an analysis to estimate the loadings of the various task criterion conditions on that structure.

These procedures permitted a direct examination of several of the issues discussed above. First, the effect of changes in criterion task conditions on performance could be assessed. Second, the degree to which the set of ability factors predicts performance could be directly estimated. Third, the effect of the task variations on the efficacy of the predictions could be demonstrated. Finally, the nature of any systematic relationship between changes in task parameters and changes in the relevance of different abilities could be examined.

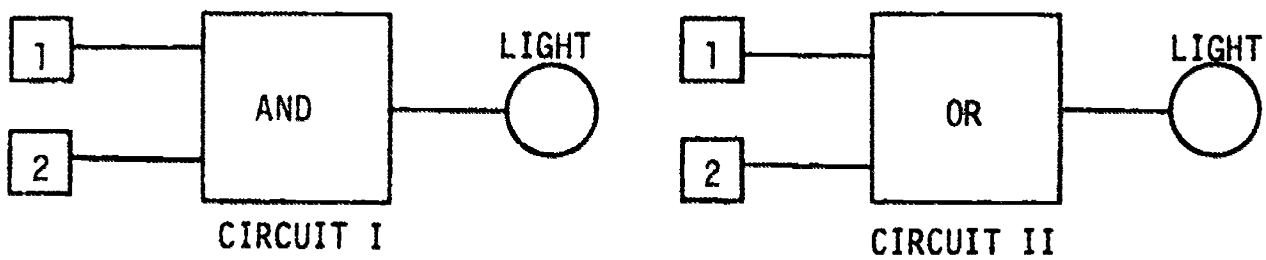
METHOD

Subjects

The subjects employed in this study were 141 male college students with normal color vision recruited from universities in the metropolitan Washington, D. C. area. They were paid $18.00 for their participation upon completion of a single day of testing. Six subjects were dismissed when they failed to understand the experimental criterion task after receiving standard training.

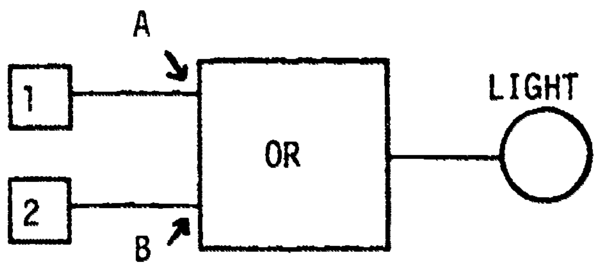
Experimental Criterion Task

The criterion task consisted of a series of problems in which subjects were required to locate broken wires 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. For example, in circuit I below,



the light will not go on unless switches 1 and 2 are both depressed, allowing current to flow through the AND logic gate. In circuit II, the light will light if either switch 1 or switch 2 (or both) is depressed, since only one switch is necessary to permit current through the OR logic gate. Each fault-finding problem was constructed with a number of such AND and OR gates in the circuit.

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. For example, consider circuit III below.



CIRCUIT III

A and B represent the locations of potential breakpoints. If switch 1 is depressed and the light goes on, a break cannot exist at point A. If switch 2 is depressed and the light fails to go on, point B must be faulty. In the experimental problems (paper-and-pencil representations of the circuits), subjects had the opportunity to place a probe (a "light bulb") at various designated points ("sockets") in the circuit diagram in order to find which of the possible breakpoints was, in fact, faulty. Thus, each problem contained exactly one true breakpoint which the subject had to identify from among several potential breakpoints. In circuit III above, only one test was necessary to locate the actual breakpoint, since if A was not faulty, B must be, and vice versa.

The troubleshooting task was varied in two ways. First, formal difficulty was manipulated by increasing the number of possible breakpoints and the number of gates in the circuit. The effect of this manipulation was to increase the "depth" of the necessary search. In the more complex circuits it was necessary to trace back through as many as four gates in order to test a potential breakpoint.

Three levels of formal difficulty were used. The first level was represented by problems with four gates and nine possible breakpoints; the second level contained five gates and sixteen possible breakpoints; and the third and most complex level had a total of six gates and twenty-four breakpoints.

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. This simulated the real-world situation where troubleshooters are often faced with perceptually confusing diagrams, in which it is neither immediately apparent how the circuit is organized, nor obvious how troubleshooting should proceed.

Three levels of perceptual complexity were designed. The first level of perceptual complexity was an uncomplicated left-to-right, switch-gate-light circuit diagram. In the second level, the locations of switches and gates remained the same but particular connections between switches and gates were interchanged so that proximal switches and gates were not necessarily interconnected, and wires from one switch crossed over wires from another. In the third and most complex level of perceptual complexity, positions of the switches and gates were changed, and the general left-to-right organization was disrupted.

Nine different paper-and-pencil test problems were generated from this 3 x 3 (formal difficulty by perceptual complexity) design. Each problem was presented twice, with different breakpoints as solutions, providing a total of eighteen experimental problems. The nine test circuits presented to subjects are included in Appendix I.

The order of presentation was counterbalanced by use of a Greco-Latin square, to control for practice effects. In addition, each problem used different letters to label light socket probe points, and different numbers to label the possible breakpoints. Three problems at the beginning and two problems at the end of the test session were added as buffer problems to insure that subjects understood the mechanics involved and to reduce any endspurt effect.

Procedure

Upon arriving, subjects filled out a brief biographical questionnaire. Next, subjects received training on the troubleshooting task. This consisted of instruction on six sample circuits which illustrated the mechanics of probing for the faulty breakpoint; i.e., identifying the true breakpoint from among the potential breakpoints. This training period usually took 30 to 45 minutes.

Subjects were told that each problem in the testing session would have exactly one breakpoint and their task was to discover this breakpoint. Instructions emphasized that subjects would be scored in terms of speed (how fast they performed) and efficiency (number of breakpoints eliminated from consideration with each test of the circuit performed). A complete set of instructions is presented in Appendix II.

After training, twenty-three problems (18 test problems and 5 buffers) were administered to each subject. In order to locate the breakpoint each subject formulated a troubleshooting test, writing down on a small card the switch (or switches) he wished to depress and the letter of the light he wished to test. This card was given to the experimenter who sat directly in front of the subject's desk. Feedback from the experimenter as to whether the light did or did not light was provided through a visual display. This display consisted of a green "yes" light indicating that the light being tested would light, a red "no" light indicating the light would not light, and a yellow "error" light indicating the subject had performed a test for which there was no pathway connecting the switch and light, or a test in which the switches did not provide sufficient current through an AND gate to light a light. After feedback, the subject formulated his next test.

The subject continued to write and submit test cards, one at a time, until he thought he had located the breakpoint. He then wrote this breakpoint number on a card. If he was correct, the experimenter confirmed his answer, and introduced the next problem. If the subject wrote down the wrong breakpoint, he was told to continue testing in order to determine the correct breakpoint. In this manner, the subject attempted to solve each of the 23 problems. Short rest breaks occurred after problems 3, 7, and 19. Subjects took one and a half to three hours to complete this phase.

For each problem, a complete record of the subject's tests was made from the cards he submitted. The experimenter also recorded the time in seconds from the beginning of each problem to the first "negative test" (i.e., the first nonerroneous test on which the probe light failed to light), as well as the total time to solution of the problem.* If the subject had not solved a problem at the end of 15 minutes, he was told that his time limit was up and to proceed to the next problem.

Reference Test Battery

Staff members reviewed definitions of many empirically determined abilities, and independently selected sets of abilities judged as relevant to the criterion task. Interjudge agreement was quite high. The tests defining the selected abilities were then combined to form a reference battery for administration to subjects.

A battery of 21 tests was administered to all subjects following their participation in the fault-finding task. The tests represented 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.

In assembling the battery, considerable use was made of the Kit of Reference Tests for Cognitive Factors prepared by French, Ekstrom, and Price (1963). While each test taken from the kit had two equivalent parts, only one part of each test was administered due to time limitations. Three other tests from a set of tests developed by Rose (1974) were also included in the battery because of their judged relevance to criterion task performance. The entire test battery was composed of group tests of the paper-and-pencil variety.

Brief descriptions of the reference tests are given below with references to further sources of information. The reliability reported for each test is shown in Table 1. In cases where this information was unavailable, reference is made either to the original test from which the present version came or to a similar test. The order in which the tests were administered is shown in the second column.

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* Data on time to the first negative test are not discussed in this report. They essentially parallel total time data.

TABLE 1

RELIABILITIES OF REFERENCE TESTS[1]

Induction Factor	Order	r	Source
Letter Sets Test	5	.64	Lemke et al. (1967)
Locations Test	8	.82	Lemke et al. (1967)
Figure Classification	21	.94	Pemberton (1952)
Associative Memory Factor			
Picture-Number Test	20	.76	Duncanson (1966)
Object-Number Test	9	.79	Duncanson (1966)
First and Last Names Test	7	.81	Duncanson (1966)
Flexibility of Closure Factor			
Copying Test	3	.88[2]	Thurstone (1938)
Closure Flexibility (Concealed Figures)	15	.78	Buros (1965)
Designs Test	13	.94	Pemberton (1952)
Perceptual Speed Factor			
Finding A's Test	10	.81	Duncanson (1966)
Number Comparison Test	12	.79	Duncanson (1966)
Identical Pictures Test	6	.88	Duncanson (1966)
Syllogistic Reasoning Factor			
Nonsense Syllogisms Test	14	.88[3]	Lemke, et al. (1967)
Logical Reasoning Test	4	.72[3]	Lemke, et al. (1967)
Inference Test	17	.53	Guilford, et al. (1952)
Spatial Scanning Factor			
Maze Tracing Speed Test	2	.94	Frederiksen (1965)
Choosing a Path Test	16	.77	Frederiksen (1965)
Map Planning Test	18	.79	Frederiksen (1965)
Other Reference Tests			
Grammatical Reasoning (A-B) Task	1	.80[4]	Baddeley (1968)
Neisser Search Task	11	.80[4]	Rose (1974)
Permutations Task	19	.83[4]	Rose (1974)

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

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

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

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

Figure Classification Test--Each item presents two or three reference groups, each containing three geometrical figures that are alike in accordance with some rule. The second row of each item contains eight test figures. The task is to discover the rules and then to assign each test figure to one of the groups. There are 14 problems containing eight test figures (eight mins.). Score is the number correct minus a fraction of the number incorrect (French, et al., 1963).

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

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

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

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

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

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

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

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

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

Finding A's Test--In each of several columns of 41 words, the task is to draw a line through the five words containing the letter "a". Score is the number of words correctly found in two minutes (French, et al., 1963).

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

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

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

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

Logical Reasoning Test--In this test developed by Guilford, the subject's task is to choose the correct conclusion that can be drawn from two given statements. The test is composed of 20 formal syllogisms, each with four response choices (10 mins.). Score is number correct minus a fraction of the number incorrect (French, et al., 1963).

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

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

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

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

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

Three additional tests were administered. While not used frequently as marker tests, they were presumed to reflect various aspects of human information processing. These tests are:

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

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

Permutations Task--In this task, developed by Leskow and Smock (1970) and adapted by Rose (1974), the subject is asked to write down on separate slips of paper (which he then turns face down) as many different license plate numbers containing only the digits 1, 2, 3, and 4 as he can think of (3 mins.). Scores are: 1) the total number of

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

correct new permutations, and 2) a frequency count of numbers held constant from one trial to the next in the first position, and a similar count for the second position, given the first was held constant.*

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

RESULTS

The results of three sets of analyses are presented below. The first set deals with the impact of criterion task manipulations on a variety of performance measures. The second set is concerned with the factor structure of the reference battery. The third and final set examines the relationship between ability factors and criterion task performance.

Criterion Task

The proportions of fault-finding problems solved under each of the nine (3 x 3) experimental conditions for each replication are presented in Table 2. A problem was defined as solved if the subject named the correct breakpoint within the 15 minutes allotted. From the proportions shown in Table 2, it is clear that the problems were generally soluble within the time limit provided. The most conspicuous cells are those representing the highest level of formal difficulty and perceptual complexity (3C). Approximately half of the subjects failed to solve this problem on their first encounter (Replication 1), but after continued exposure to the test problems almost all subjects solved it during Replication 2.

As part of a more detailed analysis of how the task manipulations affected various aspects of performance on the criterion task, a number of dependent measures were examined. Total time to solution (maximum = 15 minutes) and number of trials to solution were the most basic.* Both measures were transformed to normalize their distributions using natural logarithms. The geometric means collapsed across replications are presented in Figures 1 and 2 for time to

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* For problems which were not solved, the maximum time score (15 minutes) was assigned, and the number of trials completed at that time was used as the trial score.

TABLE 2

PROPORTIONS OF PROBLEMS SOLVED WITHIN 15 MINUTES (N=135)

	Replications					
	1			2		
Formal Difficulty	1	2	3	1	2	3
Perceptual Complexity A	1.000	.925	1.000	1.000	1.000	.985
B	1.000	.993	.926	1.000	1.000	1.000
C	1.000	.993	.542	1.000	1.000	.993

solution and number of trials to solution respectively.* An analysis of variance performed on the time-to-solution data (see Appendix III) revealed significant main effects for difficulty (D), complexity (C), and replications (R). All interaction terms were also significant. The main effect of replication and its interactions with the other independent variables were, in general, significant for all of the dependent measures; however, the replication variable was of peripheral interest in the present report, and will not be considered further.

Time to solution did increase as a function of both difficulty and complexity. A more detailed analysis of the D x C interaction showed that the differences between the A (lowest) and C (highest) levels of perceptual complexity were significant at each level of formal difficulty ($P < .01$, Scheffe, 1959). Further, the size of the A-C difference (See Figure 1) varied significantly as a function of difficulty ($p < .001$, Myers, 1972, p. 368), so that, while the effect of perceptual complexity is in general significant, its impact is largest on problems at the highest level of formal difficulty.

The analysis of variance of trials-to-solution data indicated a significant main effect of formal difficulty, but no significant main effect for perceptual complexity (see Appendix III). The D x C interaction was significant; further, there was a significant interaction (see Figure 2) between A-C and difficulty ($p < .001$). The A-C difference was significant only at the highest level of difficulty ($p < .01$). Thus, the significant D x C interaction is accounted for by the fact that perceptual complexity impacts on trials-to solution only for the highest level of formal difficulty.

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* Geometric mean = $e^{n^{-1}} \left\{ \frac{\sum_{i=1}^{N} (\ln X_i)}{N} \right.$

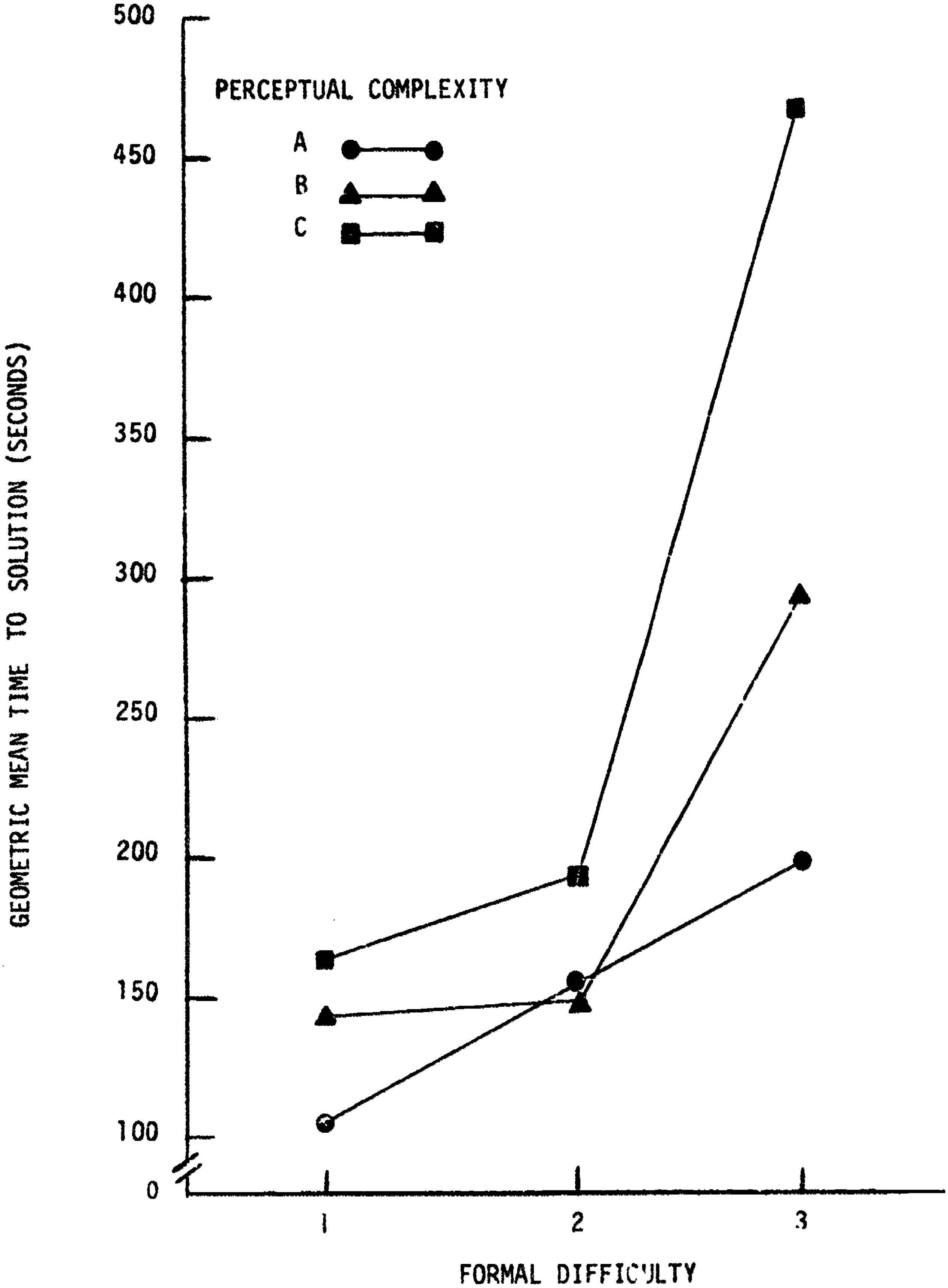

Figure 1. Geometric mean time to solution as a function of formal difficulty and perceptual complexity.

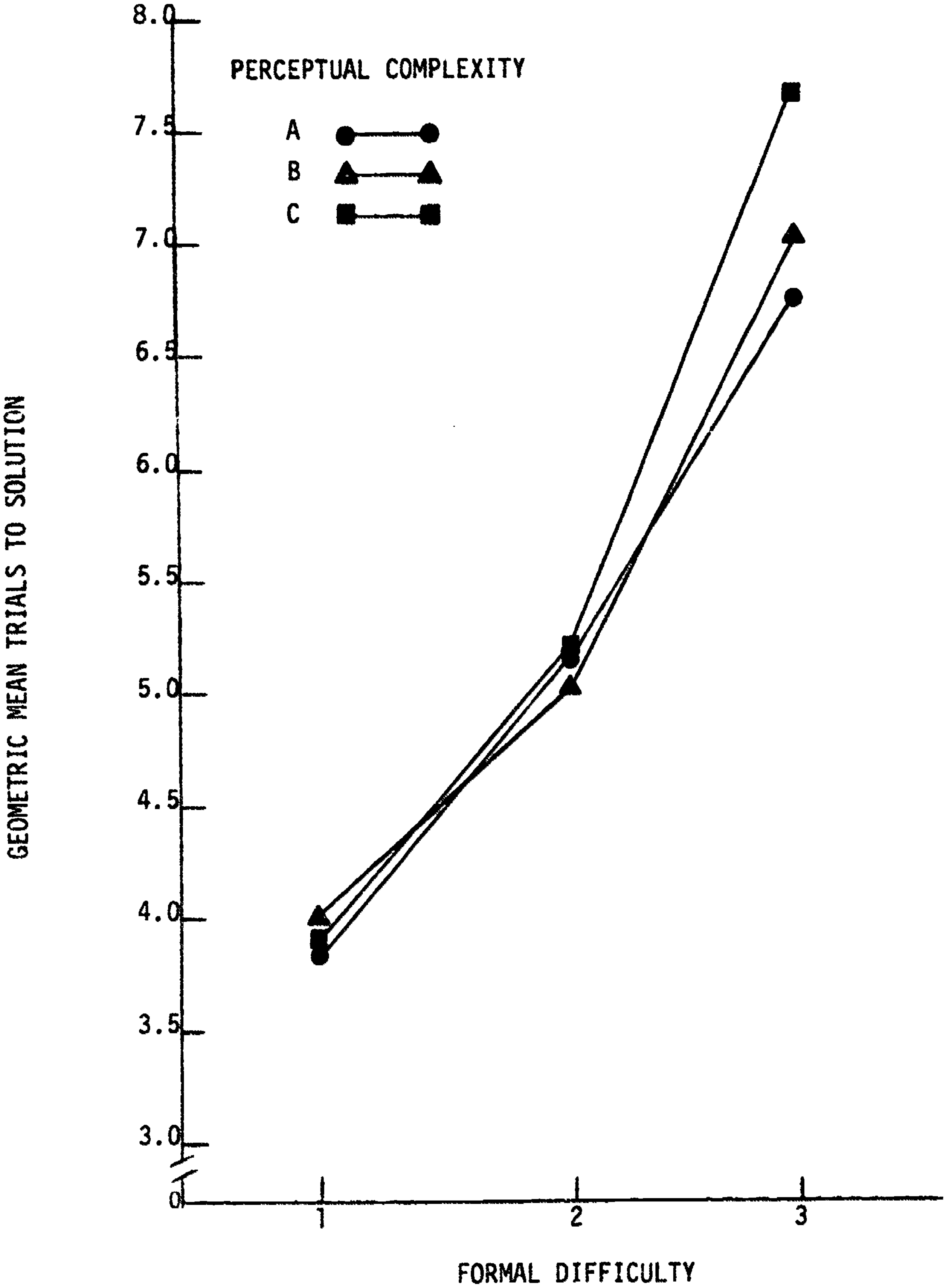

Figure 2. Geometric mean trials to solution as a function of formal difficulty and perceptual complexity.

From these two analyses, it is clear that both independent variables impact upon criterion task performance, but their impact differs as a function of the dependent measure considered. In particular, while complexity strongly affects time to solution at all levels of formal difficulty, it only affects trials to solution on the most difficult problems.

Another dependent measure of interest is time per trial. For each problem, the subject's time to solution was divided by his total number of trials, and the resulting scores were normalized using natural logarithms. The geometric means collapsed across replications are presented in Figure 3. An analysis of variance of the time-per-trial data showed all main effects and interactions to be significant (see Appendix III). The differences between the A and C levels of perceptual complexity were significant at all levels of formal difficulty (p .01) the A-C by difficulty interaction was also significant (p .005); perceptual complexity again had its greatest impact at the highest level of difficulty (see Figure 3).

The final two dependent variables are measures of the efficiency of the fault-finding tests conducted by subjects. Efficiency was expressed in terms of the proportion of breakpoints which were eliminated by each test a subject used relative to the maximum number which could have been eliminated on that test. Efficiency was scored for trial one (the first test) as well as averaged over trials. A more detailed discussion of the derivation of these measures is presented in Appendix IV.

Mean trial-one efficiencies are presented in Figure 4 as a function of formal difficulty and perceptual complexity. An analysis of variance (see Appendix III) of these data showed a significant main effect for complexity, but not for difficulty. The D x C interaction was significant, so once again this interaction was analyzed in more detail. The A-C by difficulty interaction was significant ($p<.01$).

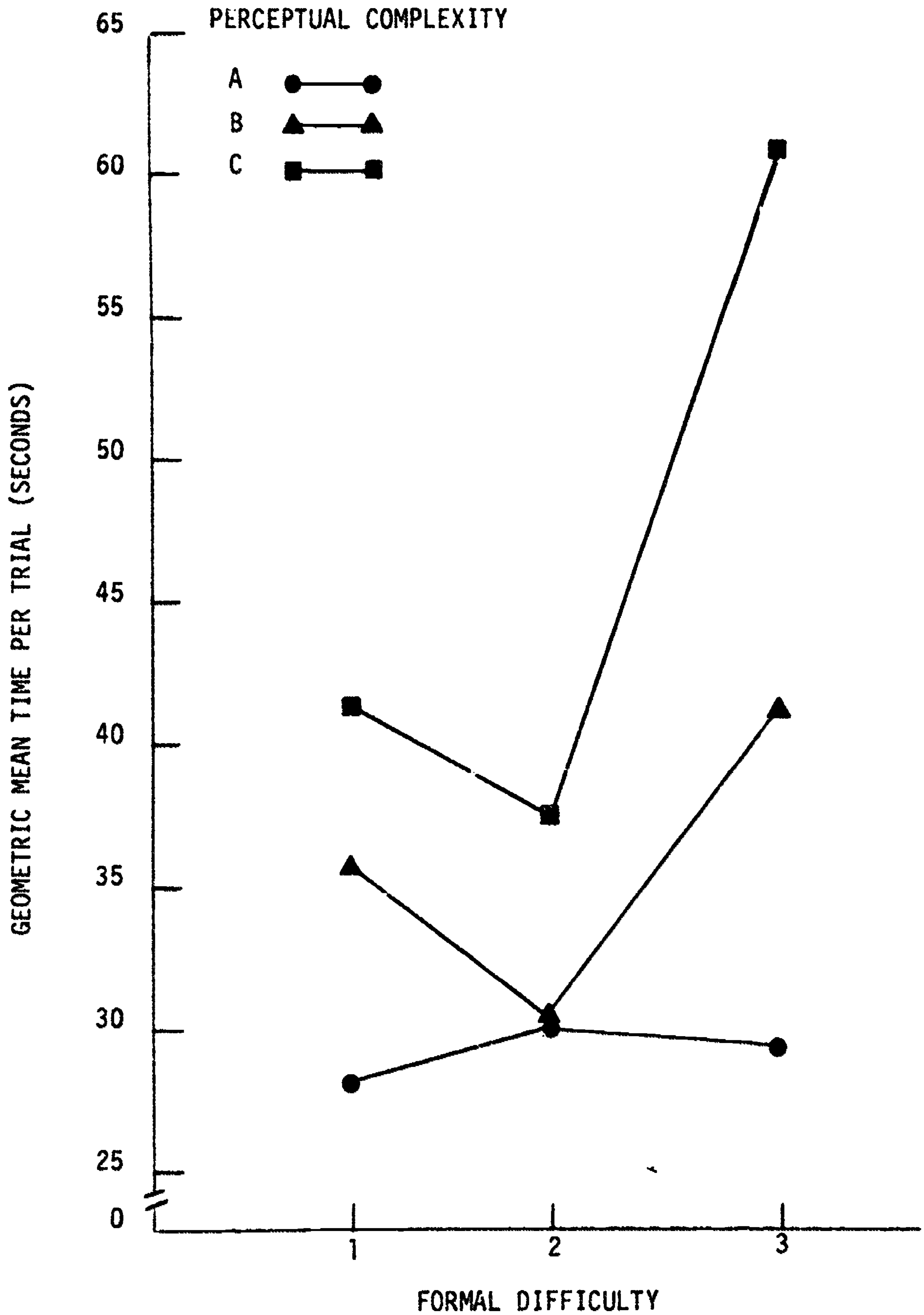

Figure 3. Geometric mean time per trial as a function of formal difficulty and perceptual complexity.

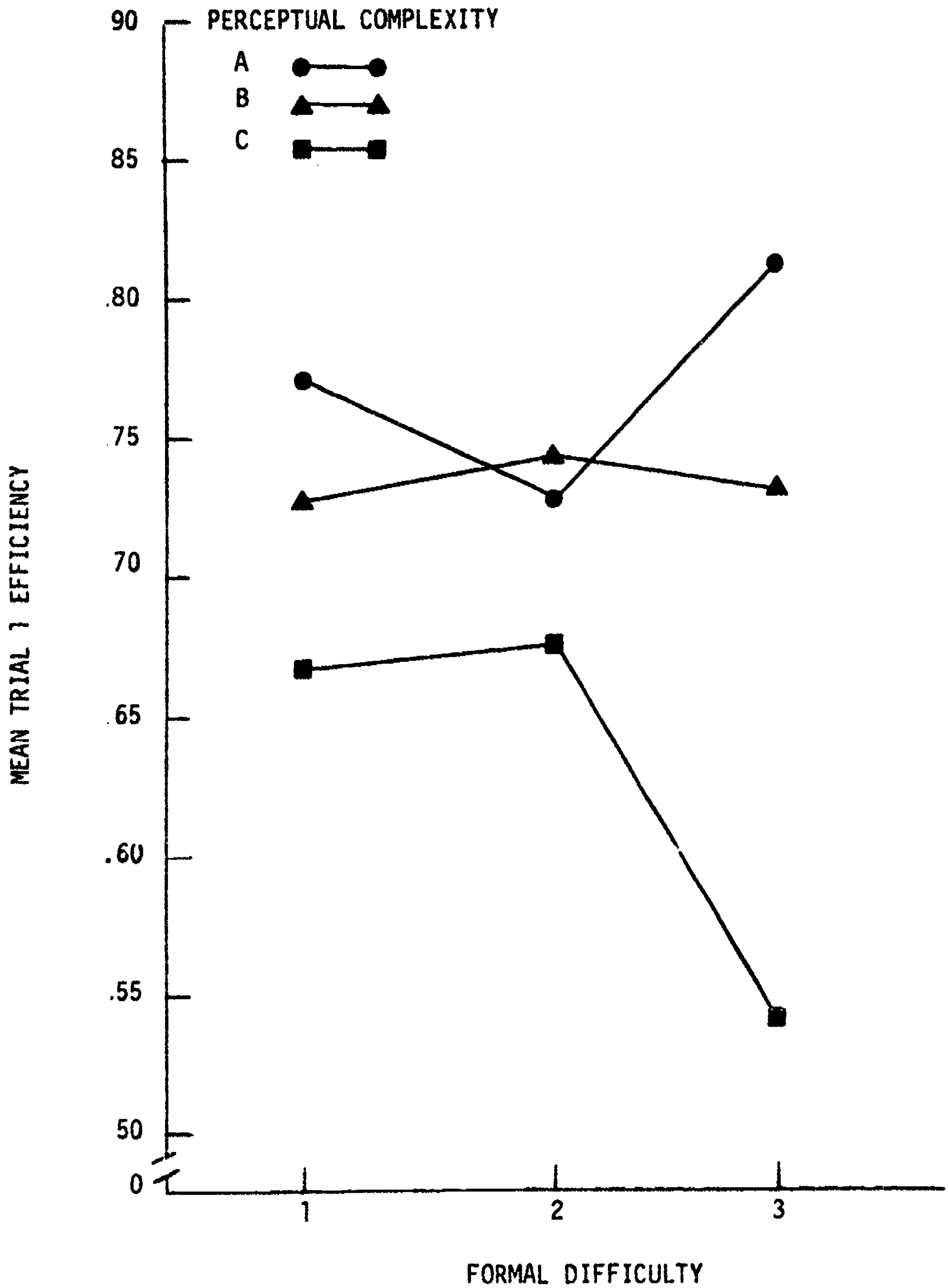

Figure 4. Mean trial-one efficiency as a function of formal difficulty and perceptual complexity.

The A-C complexity contrast was significant at both the 1 and 3 levels of difficulty (p .01), but neither the A-C nor the B-C contrast was significant at the intermediate difficulty level. The interaction cannot be explained parsimoniously, but to speculate, it appears that the 1A and 1C values are spuriously far apart. Both are within the 99% confidence interval around the 1B value; thus, it may be that perceptual complexity impacts on trial-one efficiency primarily, once again, at the highest level of formal difficulty.

An arcsin square root transformation was applied to the efficiency-per-trial data. The means are presented in Figure 5 as a function of perceptual complexity and formal difficulty. An analysis of variance (see Appendix III) showed that the main effects of difficulty and complexity, as well as the D x C interaction, were significant. The significant interaction appears once again to be due to a strong complexity effect at the highest level of difficulty. The A-C by difficulty interaction contrast was significant, and the A-C contrast was significant only at the highest level of difficulty. it seems from these final two analyses that perceptual complexity has its greatest impact on fault-finding efficiency when the formal difficulty of the problems is high.

The analyses of the five dependent measures show that, while both difficulty and complexity affect the performance of subjects in the criterion task, they do not necessarily affect the same aspects of performance, nor do they affect particular aspects in the same way. Table 3 presents η^2 for each independent-dependent variable pair.*

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* According to Fleiss (1969), ω^2 is the preferred statistic for estimating the proportion of variance in Y accounted for by X. It was not convenient to estimate ω^2 in the present study; however, η^2 and ω^2 differ only in the extent to which the numerators and denominators are unbiased. Furthermore, the values for the two statistics differ only slightly when F values are high and when there is a large number of independent observations of each experimental factor. Both these conditions were met in the present study.

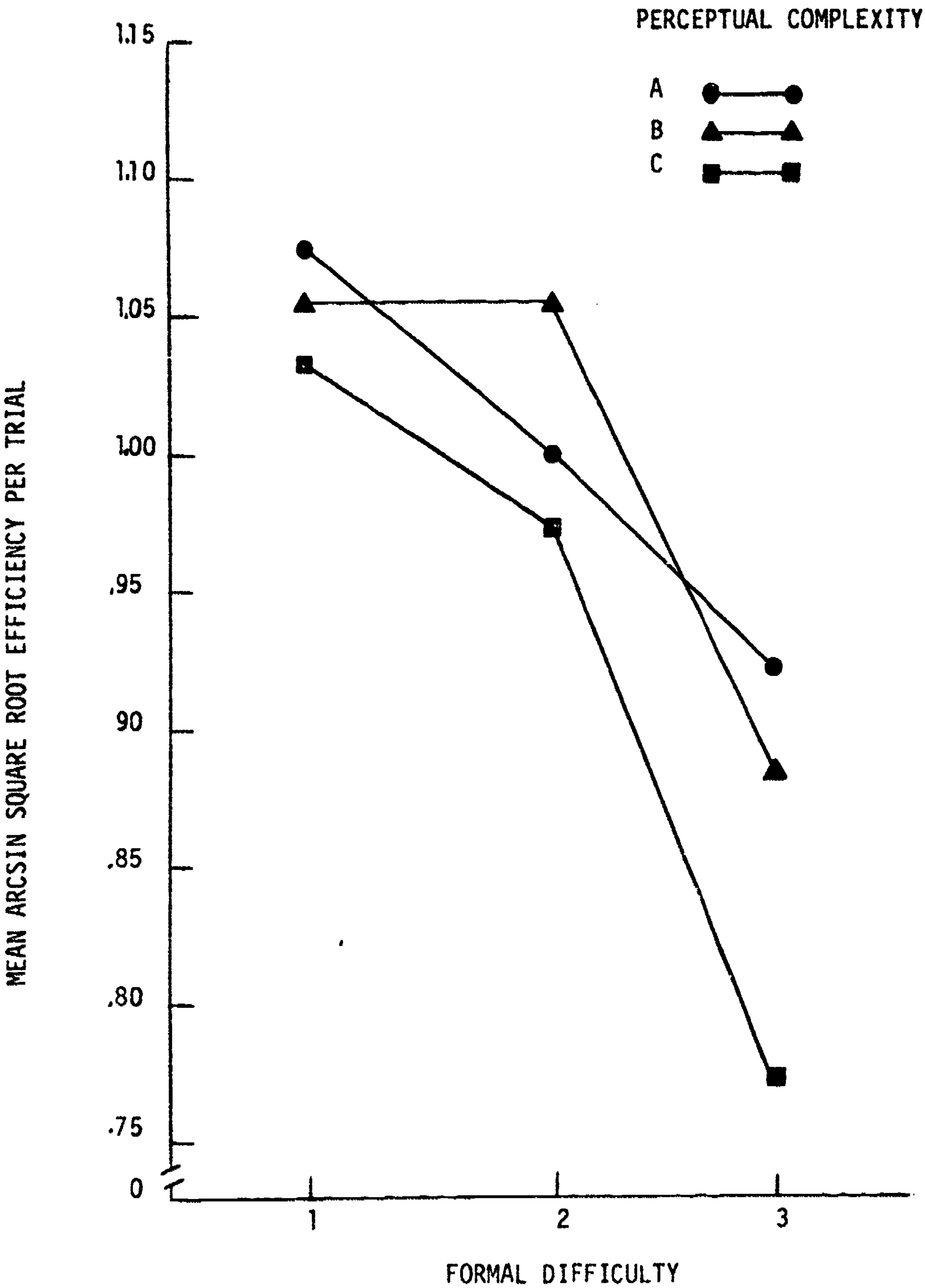

Figure 5. Mean arcsin square root efficiency per trial as a function of formal difficulty and perceptual complexity.

TABLE 3

RELATIVE SENSITIVITY OF DEPENDENT VARIABLES TO DIFFICULTY AND PERCEPTUAL COMPLEXITY IN TERMS OF η^2

Experimental Manipulations	Dependent Measures				
	Time	Trials	Time/Trial	Trial 1 Efficiency	Efficiency/Trial
Formal Difficulty	.82	.79	.60	.04	.52
Perceptual Complexity	.70	.03	.84	.30	.18

Time to solution and time per trial are influenced strongly by both difficulty and complexity, while trial-one efficiency is affected to a lesser degree by perceptual complexity, and almost not at all by difficulty. Trials to solution and, to a lesser extent, efficiency per trial are more sensitive to changes in difficulty than to changes in complexity. The only impact of perceptual complexity on trials to solution or efficiency per trial appears to occur at the highest level of formal difficulty.

The interplay between task manipulations and performance measures is quite important, since the different measures may be related to different (sets of) abilities. If this is the case, the relationship between task characteristics and ability patterns may depend upon the performance measures under consideration. Thus, different regression equations might 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.

Reference Battery

The intercorrelations among reference tests are presented in Table 4. Five major factors were extracted from this matrix using a principal components solution. Orthogonal rotation of the factors was performed using a varimax criterion. Table 5 presents the rotated factor loadings; the algebraic signs for Factor IV have been reflected for convenience. Factors were interpreted for psychological meaningfulness from the projections of the reference tests on the rotated axes.

Factor I is defined in terms of the high loadings exhibited by six of the reference tests. Three of the tests, Copying, Closure Flexibility, and Designs have previously been used as marker tests for a Flexibility of Closure factor (see Table I above and French, et al., 1963). Although French et al.,designate the same three measures as the best definers of a Flexibility of Closure factor, substantial loadings of other tests suggest that the obtained factor may be broader than

TABLE 4

MATRIX OF INTERCORRELATIONS* AMONG REFERENCE TESTS

	Reference Tests 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Grammatical Reasoning	-																				
2. Maze Tracing Speed	13	-																			
3. Copying	17	51	-																		
4. Logical Reasoning	48	22	24	-																	
5. Letter Sets	30	10	29	31	-																
6. Identical Pictures	30	42	39	21	18	-															
7. First and Last Names	25	00	-02	25	16	23	-														
8. Locations	14	22	33	25	31	25	08	-													
9. Object-Number	26	09	13	21	20	14	53	20	-												
10. Finding A's	19	26	31	03	26	31	08	17	17	-											
11. Search (mean)	-37	-30	-31	-14	-21	-43	-17	-23	-13	-44	-										
12. Number Comparison	29	29	26	08	17	34	03	28	19	25	-39	-									
13. Designs	26	43	56	16	26	46	20	31	35	41	-44	35	-								
14. Nonsense Syllogisms	43	05	14	44	18	12	26	20	15	13	-20	-07	02	-							
15. Closure Flexibility	32	49	73	30	32	50	06	34	15	33	-39	23	66	22	-						
16. Choosing a Path	10	38	38	37	24	08	-04	13	10	21	-07	10	29	11	38	-					
17. Inference	42	10	20	39	25	15	15	14	14	12	-30	10	17	41	26	13	-				
18. Map Planning	38	52	55	30	32	36	10	30	17	29	-30	35	48	09	53	28	19	-			
19. Permutations	12	04	26	29	24	14	05	16	13	01	-03	06	03	24	23	14	15	19	-		
20. Picture-Number	27	10	07	25	24	14	52	30	67	17	-14	16	29	12	14	12	15	20	19	-	
21. Figure Classification	42	22	34	43	38	23	16	30	17	28	-16	06	28	43	48	36	42	32	27	20	-

r>.228,p<.01

* Rounded to two places, decimals omitted

TABLE 5

FACTOR LOADINGS* 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

*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

originally defined. The other tests with high loadings are Maze Tracing Speed, Choosing a Path, and Map Planning. These are the three marker tests originally chosen for the proposed Spatial Scanning factor. Royce (1973), in his recent review of cognitive factors, has argued that both of these factors--Flexibility of Closure and Spatial Scanning--may be components of a second-order Visualization factor. Although the evidence is incomplete, the first factor obtained in the present study is tentatively interpreted as a combined Flexibility of Closure/Spatial Scanning factor.

Factor II is defined primarily from high loadings of the Nonsense Syllogisms, Logical Reasoning, and Inference tests. These are the marker tests for a Syllogistic Reasoning factor. Further support for this interpretation is the high loading of the Grammatical Reasoning test, which clearly involves "ability in formal reasoning from stated premises to rule out nonpermissible combinations and thus to arrive at necessary conclusions (Ekstrom, 1973)."

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

Factor IV is defined by the high loadings of the Finding A's, Number Comparison, and Identical Pictures tests as the Perceptual Speed factor. French et al.,defined this factor as "speed in finding figures, making comparisons, and carrying out other very simple tasks involving visual perception." In an attempt to add support to this interpretation, an adaptation of one of Neisser's search tasks, presumably measuring some aspects of visual memory and perceptual speed, was included in the present battery. This test (Neisser Search Task) had a high loading on this factor.*

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* The measure of performance on this task was a time-per-item measure; a lower score indicated better performance. This scoring rule explains why the test has a negative loading on Factor IV.

Factor V is defined primarily by the high loadings of the Letter Sets, Locations, and Permutations tests. French, et al., have designated the first two of these measures as two of the best definers of a cognitive factor known as Induction. It is defined as the ability to find and test out hypotheses which will explain sets of data. The same type of reasoning (as distinct from syllogistic reasoning) was discussed by Leskow and Smock (1970) in terms of Piaget's stage of formal operations. Leskow and Smock devised a test which confirmed some of Piaget's postulations about this type of reasoning. This same test was adapted for use in the present battery (Permutations test) and as expected, loaded quite highly on this factor.

Projection of Criterion Data on Reference Factors

The purpose in conducting this final set of analyses was to relate the two basic criterion task characteristics to the pattern(s) of abilities contributing to performance under the various experimental conditions. While an analysis of the abilities related to performance under each of the (3x3x2) 18 conditions would have been of interest, the most direct way of relating task dimensions to ability requirements was to focus on the marginals. Specifically, the marginals for formal difficulty (1, 2, 3, as difficulty increased) and perceptual complexity (A, B, C, as complexity increased) were used. This approach was preferred to that of using the 18 interactive marginals since the latter could not be ordered a priori. Without such ordering, interpretation of the pattern of loadings on the ability structure would be difficult at best.

A Stoloff regression procedure (Stoloff, 1973) was performed to obtain coefficients representing the estimated loadings of the criterion measures on the factor structure underlying the reference battery. Table 6 presents the intercorrelations of the ability reference tests with the five performance measures for each level of formal difficulty and perceptual complexity. The coefficients estimated by the Stoloff pro-

TABLE 6

MATRIX OF INTERCORRELATIONS* AMONG REFERENCE TESTS AND CRITERION MEASURES N=(135)

Criterion Measure	Ln Total Time						Ln Total Trials					
Task Condition	1	2	3	A	B	C	1	2	3	A	B	C
Reference Tests												
1. Grammatical Reasoning	-16	-18	-16	-10	-20	-24	-14	-18	-14	-10	-17	-21
2. Maze Tracing Speed	-12	-16	-12	-04	-11	-30	-04	-21	-17	00	-11	-28
3. Copying	-30	-29	-33	-27	-26	-43	-14	-23	-25	-23	-17	-23
4. Logical Reasoning	-23	-25	-21	-23	-18	-32	-24	-34	-19	-30	-20	-28
5. Letter Sets	-05	-11	-19	-11	-08	-19	-04	-21	-15	-17	-08	-16
6. Identical Pictures	-10	-08	-10	-15	-01	-12	03	00	-04	-11	13	-02
7. First and Last Names	-01	07	12	04	08	07	-11	-09	-03	-17	-01	-06
8. Locations	-20	-28	-20	-25	-17	-29	-06	-17	18	-22	09	-08
9. Object-Number	-07	00	-00	01	-07	-01	-04	-05	-08	-06	-06	-06
10. Finding A's	-08	-11	-14	-11	-04	-18	-07	-14	-19	-14	-05	-21
11. Search (mean)	01	00	03	-02	01	05	-05	00	06	-08	-04	12
12. Number Comparison	-05	04	-04	03	-02	-08	-08	00	-14	-03	-07	-13
13. Designs	-16	-09	-13	-09	-11	-19	-15	-18	-19	-19	-16	-20
14. Nonsense Syllogisms	-22	-15	-11	-16	-19	-14	-16	-08	-01	-15	-09	-03
15. Closure Flexibility	-33	-26	-38	-29	-30	-41	-19	-21	-29	-28	-21	-23
16. Choosing a Path	-25	-18	-32	-15	-30	-33	-16	-25	-33	-15	-28	-33
17. Inference	-03	-03	-01	02	00	-11	-18	-19	-13	-15	-12	-25
18. Map Planning	-13	-18	-21	-08	-17	-33	-10	-24	-29	-13	-21	-30
19. Permutations	-39	-16	-29	-33	-26	-25	-30	-12	-20	-34	-22	-11
20. Picture-Number	-19	-10	-05	-09	-12	-14	-19	-18	-11	-21	-11	-17
21. Figure Classification	-22	-21	-20	-17	-19	-30	-27	-38	-29	-35	-27	-34

* Rounded to two places; decimals omitted.

TABLE 6 (Cont'd)

MATRIX OF INTERCORRELATIONS* AMONG REFERENCE TESTS AND CRITERION MEASURES N=(135)

Criterion Measure	Ln Time/Trial Total						Trial 1 Efficiency					
Task Condition	1	2	3	A	B	C	1	2	3	A	B	C
Reference Tests												
1. Grammatical Reasoning	-06	-10	-06	-05	-10	-07	14	12	22	14	16	18
2. Maze Tracing Speed	-10	-06	01	-04	-04	-07	19	16	24	13	20	26
3. Copying	-22	-19	-16	-18	-16	-23	17	22	14	16	16	22
4. Logical Reasoning	-06	-03	-07	-07	-06	-09	26	34	32	36	35	26
5. Letter Sets	-02	-01	-08	-02	-03	-06	16	18	15	17	20	14
6. Identical Pictures	-15	-09	-07	-11	-10	-09	13	10	16	11	21	09
7. First and Last Names	08	13	14	15	09	11	21	04	14	14	15	12
8. Locations	-17	-21	-21	-16	-23	-21	09	18	13	25	08	11
9. Object-Number	-05	04	05	06	-03	04	17	10	25	10	16	25
10. Finding A's	-02	-04	00	-04	-02	-02	15	20	[illegible]	06	19	20
11. Search (mean)	05	00	-02	03	03	-04	-22	-14	-16	-12	-17	-23
12. Number Comparison	01	04	06	06	02	02	21	12	16	12	12	26
13. Designs	-04	01	01	02	-01	-03	25	18	25	16	21	31
14. Nonsense Syllogisms	-11	-12	-10	-10	-14	-10	14	14	08	16	18	06
15. Closure Flexibility	-21	-16	-17	-16	-18	-21	28	21	27	18	26	32
16. Choosing a Path	-15	006	-08	-08	-12	-07	32	30	40	27	42	35
17. Inference	12	07	08	12	08	08	15	24	17	16	19	22
18. Map Planning	-06	-07	00	-01	-04	-08	26	24	26	16	26	34
19. Permutations	-19	-11	-15	-17	-13	-15	18	05	09	10	20	05
20. Picture-Number	-05	-01	02	04	-06	-01	18	11	24	20	15	19
21. Figure Classification	-01	-02	00	02	-02	-03	29	22	32	26	30	29

* Rounded to two places; decimals omitted.

TABLE 6 (Cont'd)

MATRIX OF INTERCORRELATIONS* AMONG REFERENCE TESTS AND CRITERION MEASURES N=(135)

Criterion Measure		Sin^{-1} Square Root Efficiency/Trial Total					
Task Condition		1	2	3	A	B	C
Reference Tests	1. Grammatical Reasoning	19	27	23	22	27	22
	2. Maze Tracing Speed	17	22	27	15	24	26
	3. Copying	16	30	36	30	22	32
	4. Logical Reasoning	37	51	45	53	42	42
	5. Letter Sets	16	23	30	29	23	19
	6. Identical Pictures	02	14	16	18	07	08
	7. First and Last Names	18	17	14	30	16	05
	8. Locations	11	27	12	33	07	14
	9. Object-Number	19	23	18	28	22	12
	10. Finding A's	21	17	24	28	16	20
	11. Search (mean)	-10	-15	-18	-14	-13	-16
	12. Number Comparison	12	08	15	12	12	12
	13. Designs	26	21	31	31	25	22
	14. Nonsense Syllogisms	22	21	19	23	25	15
	15. Closure Flexibility	29	30	45	38	34	33
	16. Choosing a Path	34	36	54	37	43	45
	17. Inference	24	30	30	24	30	32
	18. Map Planning	20	34	40	29	33	33
	19. Permutations	25	24	22	30	22	20
	20. Picture-Number	26	28	18	35	25	15
	21. Figure Classification	42	44	42	43	42	44

* Rounded to two places; decimals omitted.

cedure are presented in Table 7. The communalities (h^2) in Table 7 show that very little of the time per trial variation was accounted for by the reference factors ($h^2 = .08$, N = 135, $p < .01$); thus, this measure was excluded from further analysis. From 10% to 30% of the variation in the other dependent measures was accounted for. Further, this common variance was primarily associated with Factors I, II, III, and V; all but two of the Factor IV coefficients were approximately zero. Generally small correlations were also found between the reference tests defining Factor IV and the criterion conditions (as shown in Table 6).

The relationships between criterion performance and abilities are clarified in Figures 6 through 9. These figures show the changes in loadings as a function of levels of formal difficulty and perceptual complexity, for each performance measure except time per trial. In each plot, any factor which had at least one coefficient greater than .20 was included.

Certain patterns are apparent from these figures. First, the loadings on Factor I (Flexibility of Closure/Spatial Scanning) generally tended to increase as both formal difficulty and perceptual complexity increased. This relationship held across all four performance measures. Second, Factor II (Syllogistic Reasoning) was moderately involved in all but the time to solution measure. 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 (Induction) 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 insignificant, or moderate but constant. Finally, Factor III (Associative Memory) appeared in only two plots, where its loadings

* Recall that the confidence intervals for regression coefficients are quite broad as the coefficients approach zero (cf. Hays, 1963, p. 522). Thus, the notion of "constant" is appropriate, even though not apparent in the Figures.

TABLE 7

ESTIMATED FACTOR LOADINGS* OF CRITERION VARIABLES ON REFERENCE FACTOR STRUCTURE

Criterion Measures		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

*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

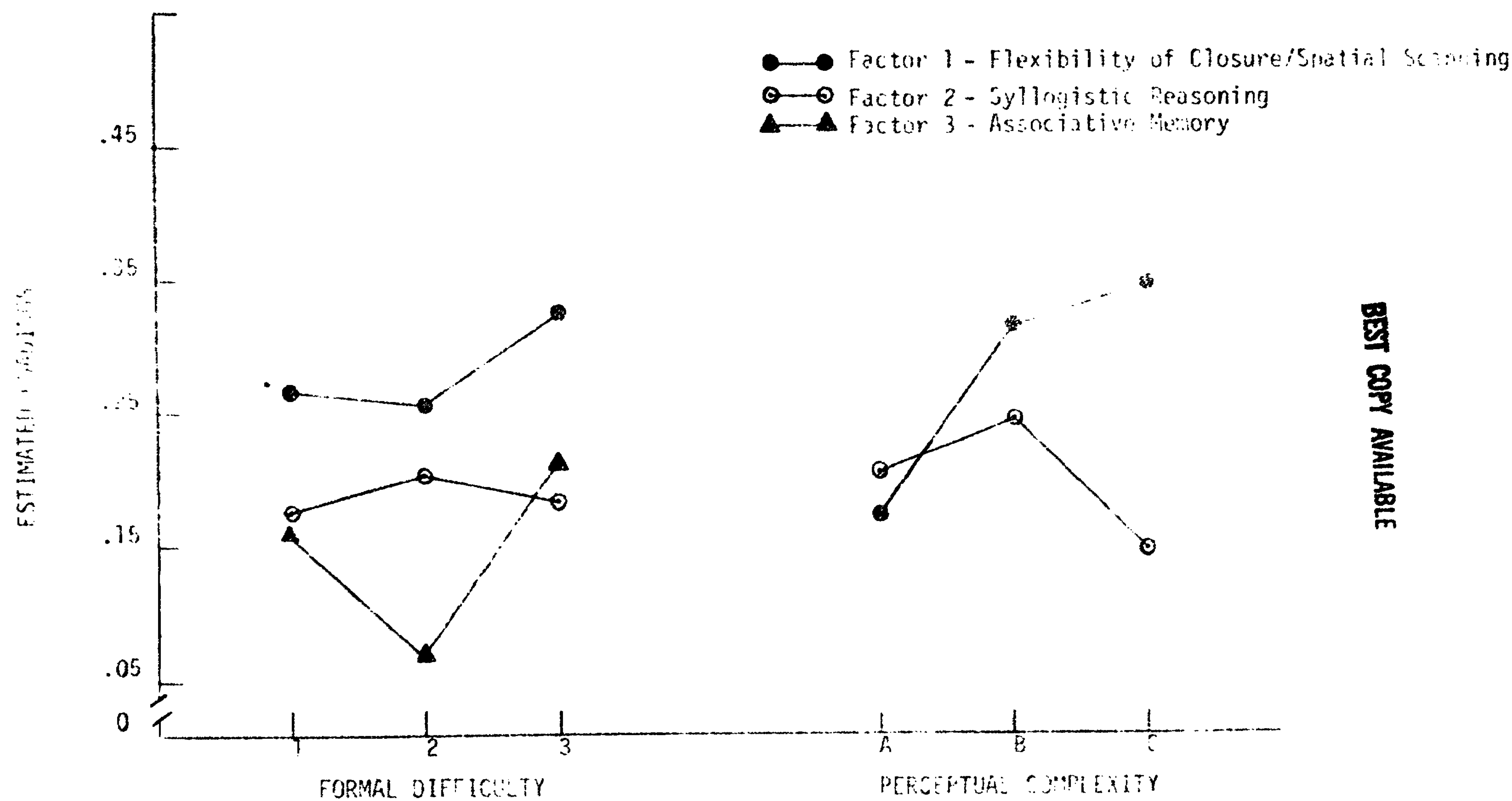

Figure 6. Trial 1 Efficiency: estimated loadings.

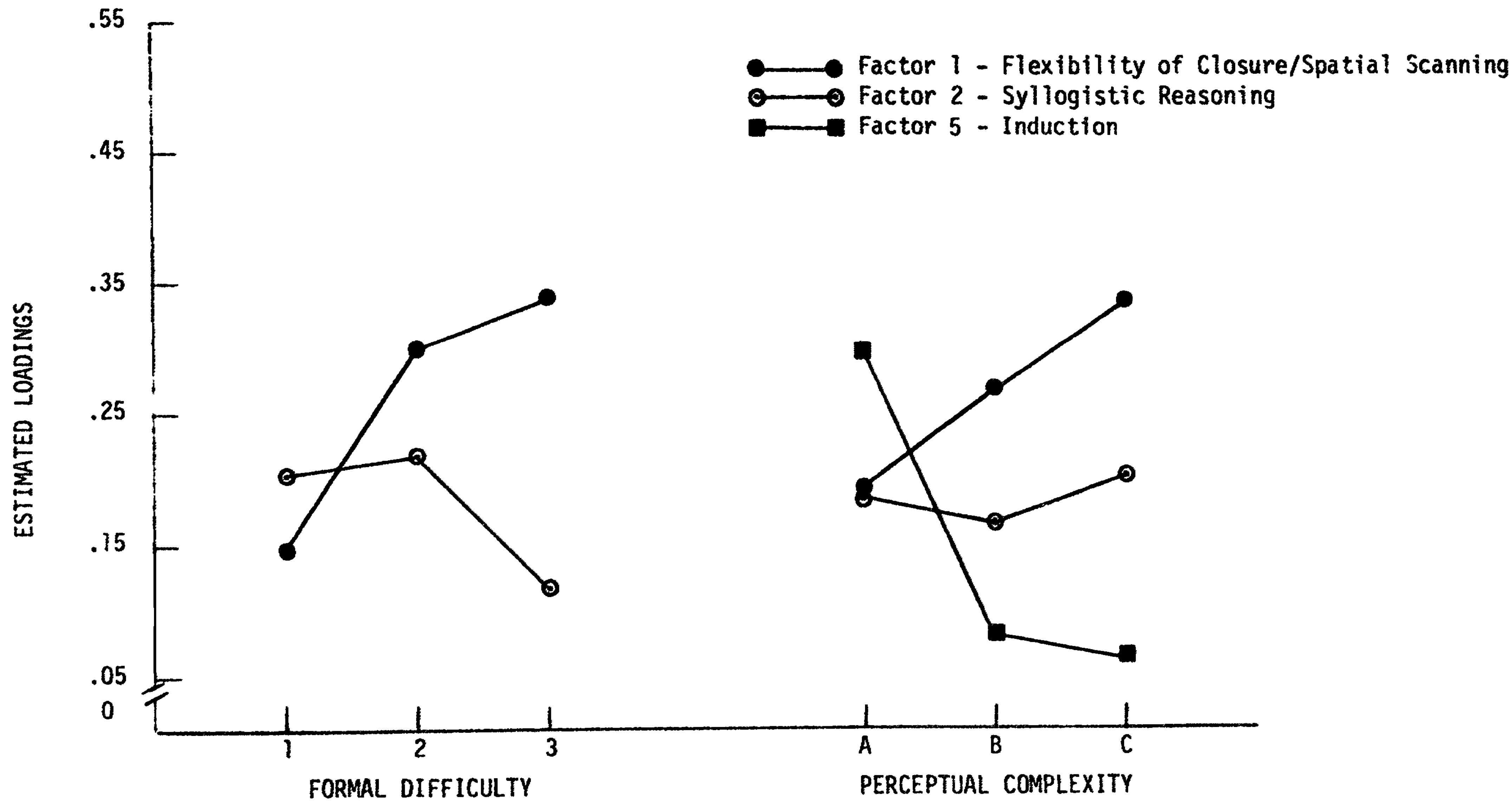

Figure 7. Geometric mean trials to solution: estimated loadings.

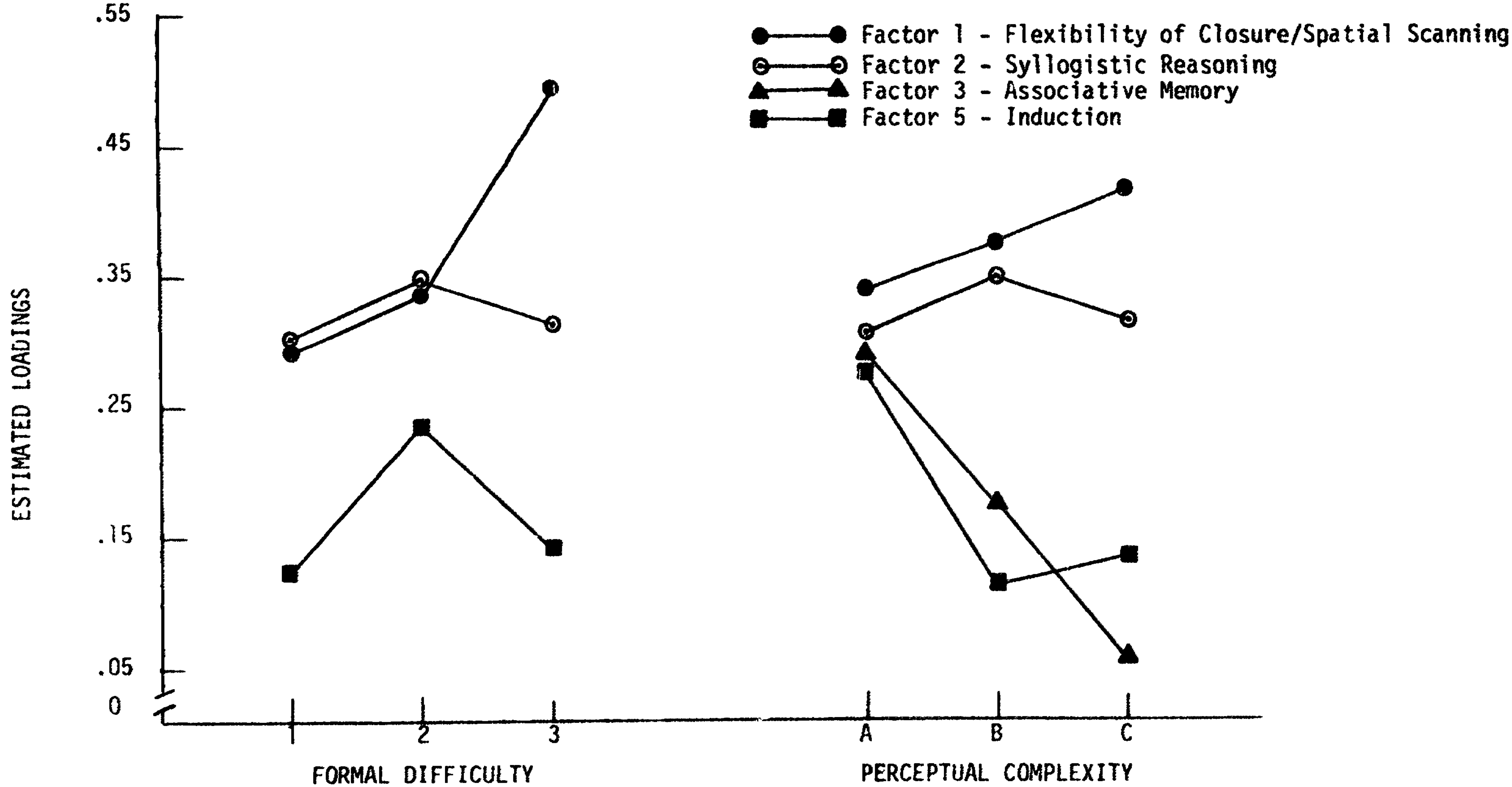

Figure 8. Arcsin square root efficiency per trial: estimated loadings.

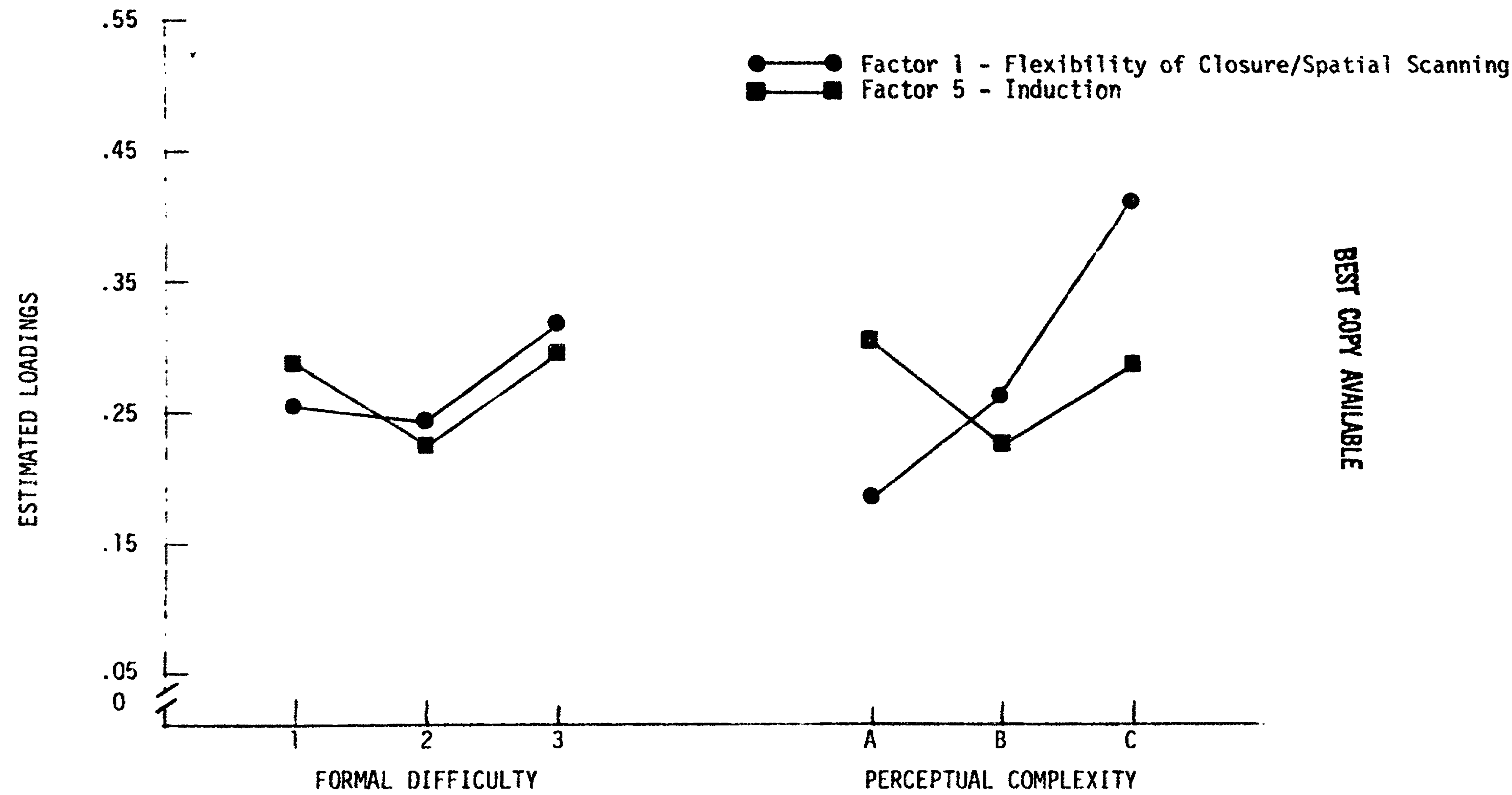

Figure 9. Geometric mean time to solution: estimated loadings.

decreased as a function of perceptual complexity for the efficiency-per-trial measure and were small and constant as a function of formal difficulty on the trial-one-efficiency measure.

DISCUSSION

The two task manipulations, formal difficulty and perceptual complexity, strongly and systematically affected performance. The effect was in the expected direction; as formal difficulty and perceptual complexity increased, performance deteriorated. However, various aspects of performance were affected differentially by the task manipulations. This is reflected by the relative sensitivity of the dependent variables in terms of Υ^2 (Table 3 above). Trials to solution and time to solution were both influenced to a large degree by formal difficulty. This effect was almost "forced" by the problem construction; an ideal troubleshooter would have to use more trials (and consequently more time), since he had to test more breakpoints as formal difficulty increased. Perceptual complexity, on the other hand, would be expected to influence time to solution, and to have little effect on number of trials. This expectation stems from the topological equivalence of the problems. To the extent that subjects noticed this equivalence, perceptual complexity should have no effect on the number of trials, since each test is logically independent of the circuit configuration. However, time to solution should increase, since the subject must sort out test paths from increasingly confusing circuit diagrams. In fact, time to solution did increase across levels of perceptual complexity, while trials to solution did not, except at the highest level of formal difficulty. This last finding probably indicates that topological equivalence is harder to detect in the most difficult problems.

The results for the other measures are not so easily interpreted, mainly because assumptions concerning subjects' strategies or information processing skills are necessary. For example, trial 1 efficiency is affected considerably more by perceptual complexity than by formal difficulty. It could be hypothesized that subjects develop some low-level tactic for deciding what the first test should be (e.g., "look for the longest circuit of OR gates", or more simply, "test the top-most terminal path"). These tactics could be maintained across the formal difficulty dimension; however, they might be more difficult to implement for the more perceptually confusing problems, when, for example, the longest circuit of "OR" gates is difficult to locate. Similarly, any other strategy making use of the configurational properties of the diagrams would probably be altered when the perceptual complexity is changed.

On the other hand, efficiency per trial is affected more by formal difficulty than by perceptual complexity. This finding could be accounted for by assuming that subjects were choosing a strategy which did not depend on the configurational properties of the problems but which was sensitive to changes in formal difficulty. Such would be the case, for example, if subjects chose a strategy of testing a constant number of breakpoints.

The time-per-trial measure is particularly difficult to interpret. This may be due to the inherent confounding it represents between trials (sensitive to difficulty) and time (sensitive to both difficulty and complexity).

While there are no straightforward ways of confirming or disconfirming these "strategy" hypotheses in the present experiment, there is another way of viewing these results. It is possible to examine the abilities contributing to performance on each dependent measure under the different task conditions. Hopefully, ability requirements can be formulated for various task demands. Such a formulation has direct bearing on several types of personnel decisions, especially those involving training and selection.

One general question implied by a consideration of personnel selection problems is the following: given the ability requirements for one form of a criterion task, what will the requirements be if the task is altered in some way? In the present context, this question can be reformulated to ask several particular questions. Are the same abilities involved as a task is varied across a single dimension, or are other abilities "brought into play"? For example, are the abilities which covary with performance on the 4-gate problems (formal difficulty, level 1) the same abilities that covary with performance on the 6-gate problems (formal difficulty, level 3)? Similarly, can abilities predict between dimensions (e.g., are the abilities which covary with formal difficulty the same as those which covary with perceptual complexity)? Furthermore, given the state of affairs discussed above, namely that different aspects of performance are measured by the different dependent variables, a similar set of questions could be posed for the different measures. Can a single set of abilities predict several different performance measures? For example, do the abilities which covary with trial 1 efficiency also covary with total time to solution?

Answers to these questions have both theoretical and practical importance. From a theoretical perspective, the answers might give a clearer indication of the strategies subjects used than could be inferred from the dependent measures alone. This might enable a better understanding of the kinds of task variations or performance demands that would produce changes in ability requirements. Practically, answers would provide information as to the relationship between task characteristics and ability requirements for use in personnel decision procedures. Ideally, one would like the following kind of statements: "Given that task A will be performed under conditions 1, 2, and 3, personnel selection (or training) would be different for each condition. Furthermore, people with ability profile X will perform well on 1 and 2, but not 3, etc."

The results presented in Table 7 and Figures 6 through 9 deal directly with the above questions. On a conceptual level, there are several possible patterns of factor loadings that could have resulted. Of interest here are: 1) abilities that have a relatively constant pattern of loadings across both task dimensions; 2) abilities whose loadings increase or decrease consistently within one dimension but not the other; and 3) abilities that "appear" for only certain of the dependent measures. In fact, examples of such patterns did emerge. Loadings on Factor I (Flexibility of Closure/Spatial Scanning) consistently increased as perceptual complexity increased; this held for all of the dependent measures. Likewise, as formal difficulty increased, the loadings on Factor I tended to increase. The loadings on Factor II (Syllogistic Reasoning) in general remained constant across all measures (except total time) and both task dimensions. Factor III (Memory) showed decreasing loadings as formal difficulty and complexity increased on the efficiency-per-trial measure, but generally the reverse on trial 1 efficiency, and only small loadings on the other measures. Factor IV (Perceptual Speed) was unrelated to any of the measures of criterion performance. Factor V (Induction) showed decreasing loadings on the trials-to-solution and trial-1-efficiency measures, as both difficulty and complexity increased, and reasonably high loadings with no consistent patterns on the other dependent measures.

Thus, it can be concluded that different abilities are involved, and at different levels of involvement, when either the task dimensions vary or different dependent measures are examined. If one were to use ability criteria to pre-select who would do well on these problems, the choices would differ depending on the task characteristics and the criterion measure selected. As an illustration of possible personnel decisions, consider, for example, Figure 8, the loadings for the efficiency-per-trial measure. If we were to select a group to solve "A" configuration problems efficiently, independent of formal difficulty or speed, we would pick those subjects who had fairly high scores on Factors I, II, III and V. Furthermore, each of these abilities would be given approximately equal importance (in other words, the cutoff value would be comparable across each of the factors). Now suppose we had a suspicion that the task might be performed under more perceptually complex circumstances (the "C" configuration). In that case, we would select subjects with high scores on Factor I and II while the requirements for good scores on Factors III and V would no longer be appropriate. Further, Factors I and II would not receive equal weight in the decision; Factor I would be weighted more heavily. If another criterion of performance were considered desirable, for example, total time to solution (Figure 9), different standards would be necessary.

There are two general types of training or selection decisions implied by the data. One type of decision, typified by the pattern of loadings on Factor I, occurs when a change in task demand (due either to different criterion measures or changes within a task dimension) does not involve different abilities. Rather, a change in cut-off values is the appropriate decision. The abilities involved are the same, but are involved to a greater or lesser degree as the task demand changes. The second type of decision occurs when the task demand is altered and when a different set of abilities are involved, as occurred in the efficiency example (Figure 8). In this type of situation, since different abilities (or factors) are relevant, the implication is that different subjects should be selected.

It would be desirable if one kind of task manipulation (or one aspect of performance) consistently implied one or the other type of decision. There was no consistent relationship between type of manipulation (or measure) and pattern of ability requirement in the present study. It may be that such consistent relationships could be explored when more control is 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 adapt 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. Hopefully, further investigations, using the experimental-correlational approach employed in the present study, will shed further light on these issues.

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APPENDIX I

CIRCUIT DIAGRAMS

This appendix contains black and white renditions of the actual circuit diagrams used in the experiment. _Formal difficulty_ is coded by numbers, and _perceptual complexity_ by letters, in order of increasing difficulty or complexity. Thus, problem 3C is the most difficult and most complex, while 1C is the least difficult and most complex. In the actual diagrams of problems involving the B and C levels of _perceptual complexity_, wire segments were represented in randomly chosen colors (blue, green, red, black) to further influence _perceptual complexity_.

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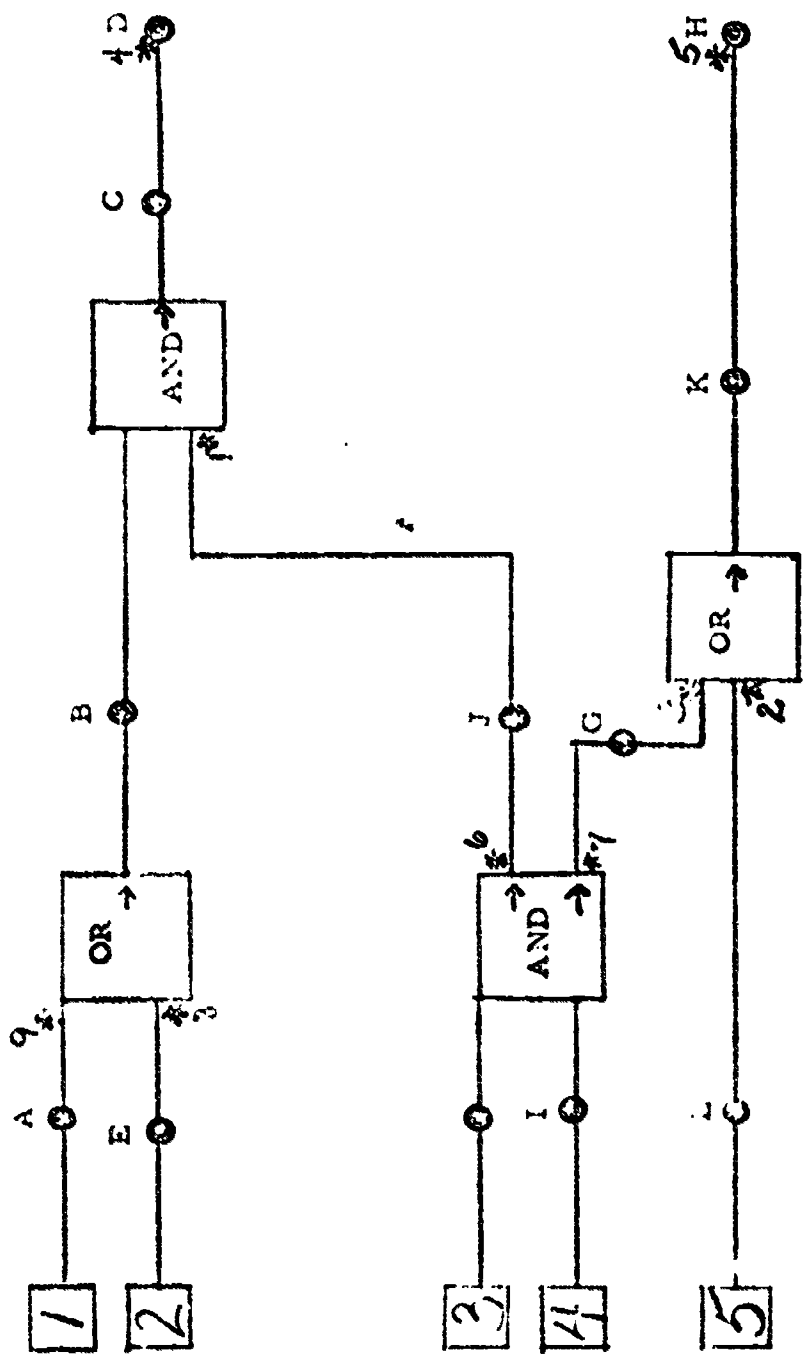

DIAGRAM 1[illegible]

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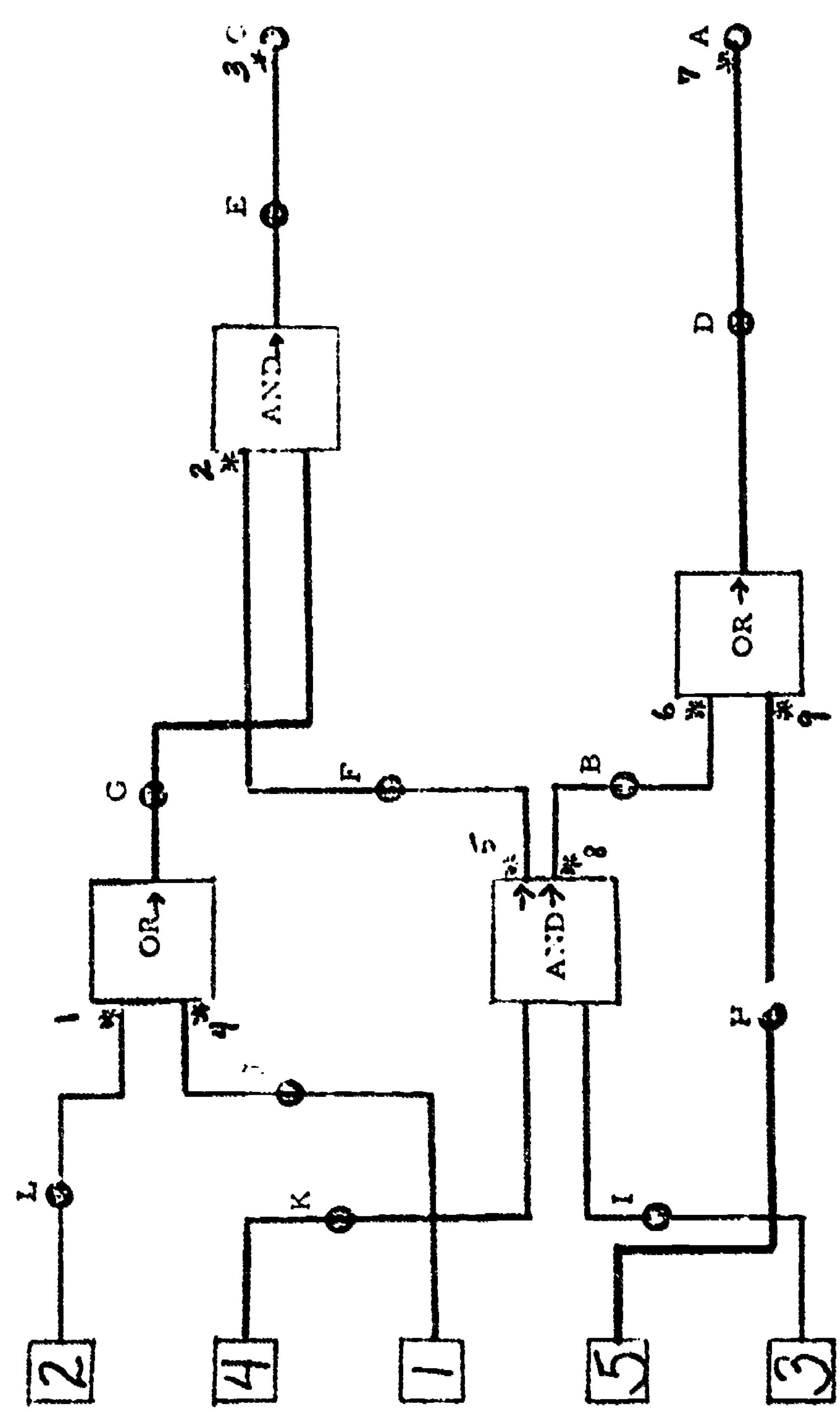

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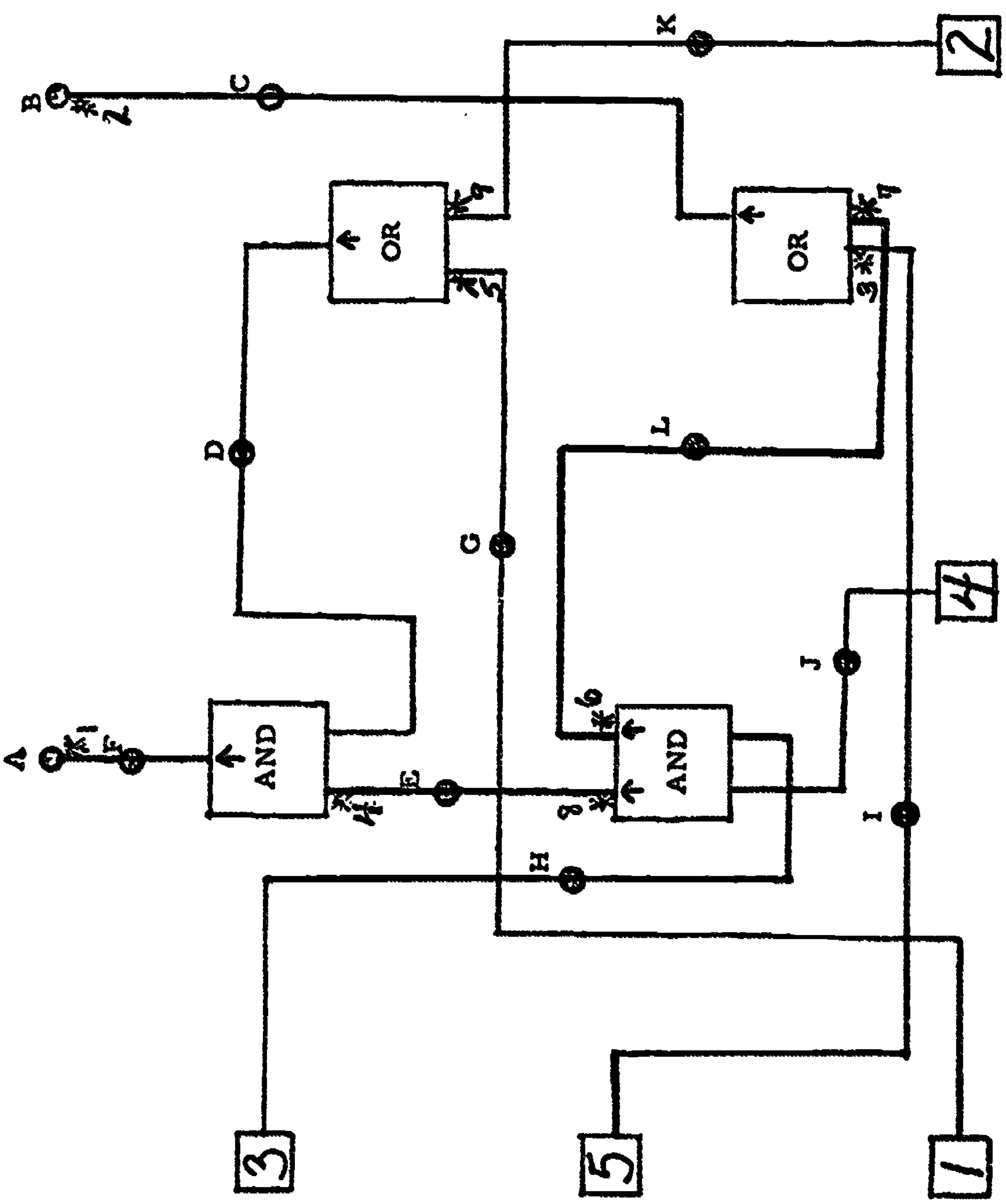

DIAGRAM 1C

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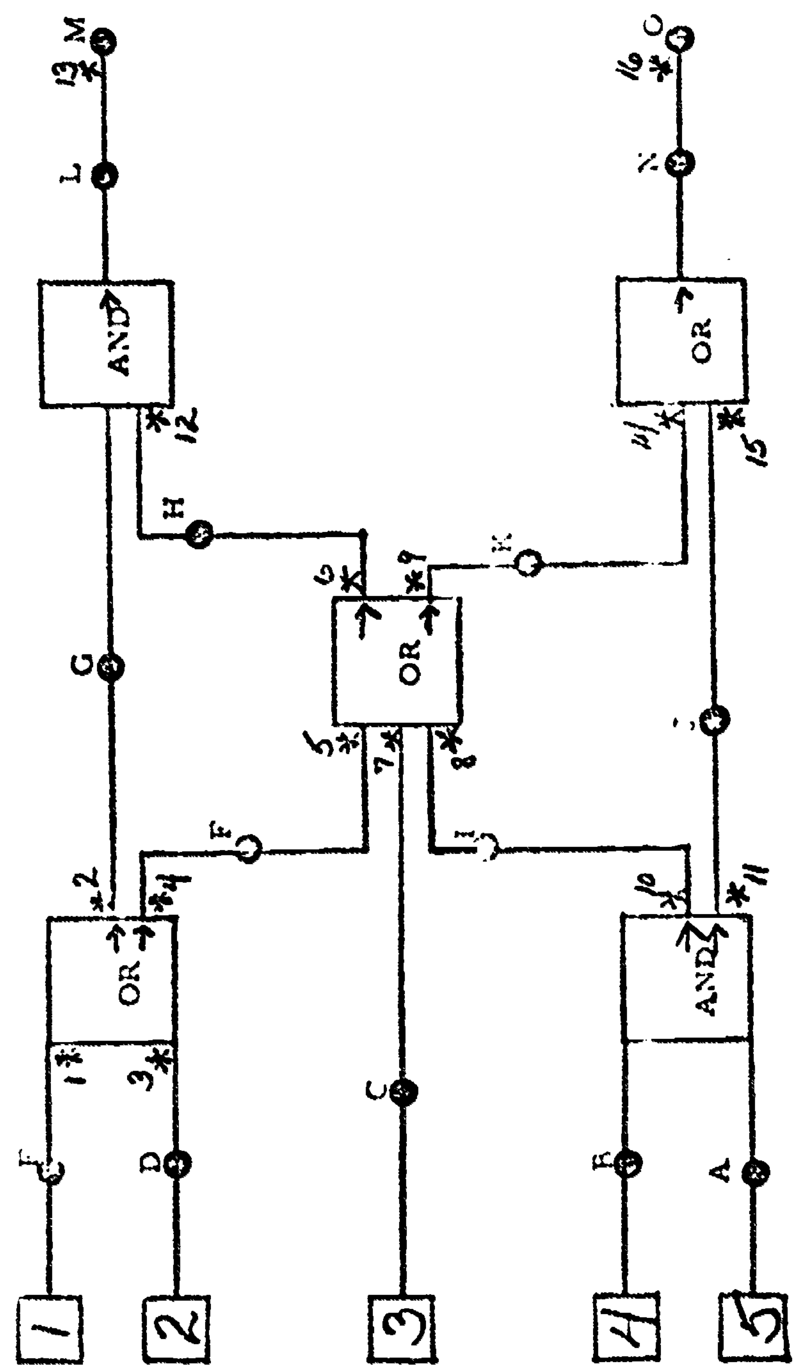

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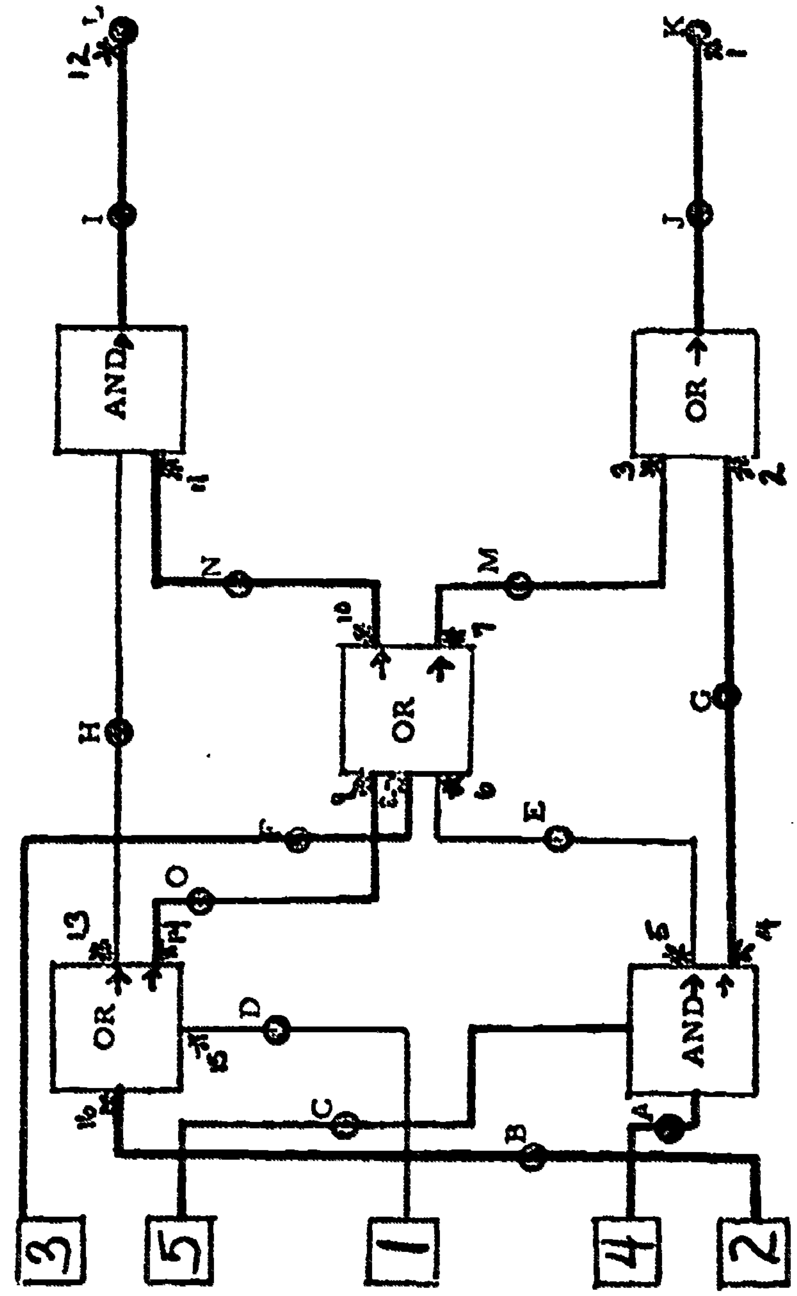

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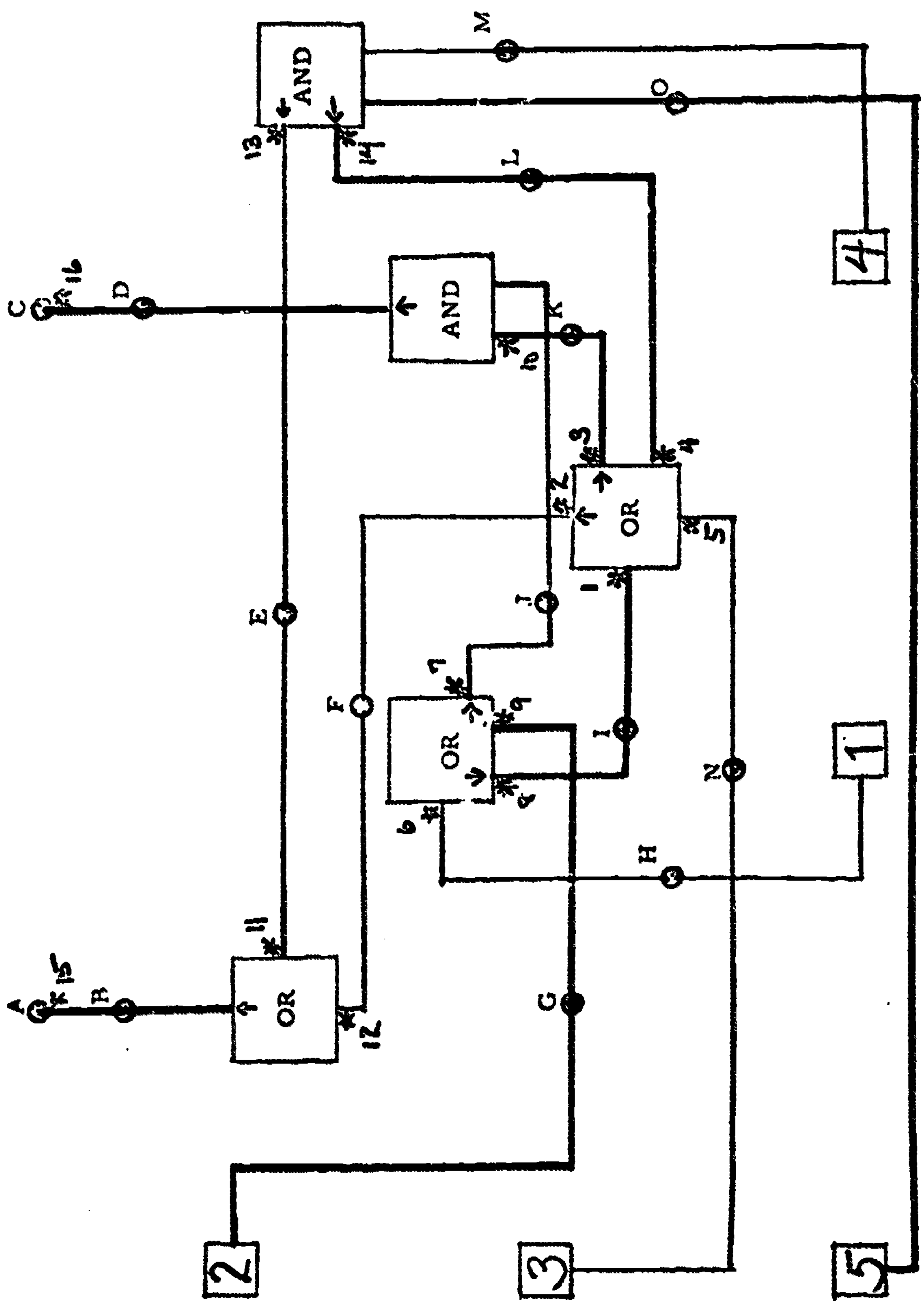


DIAGRAM 2C

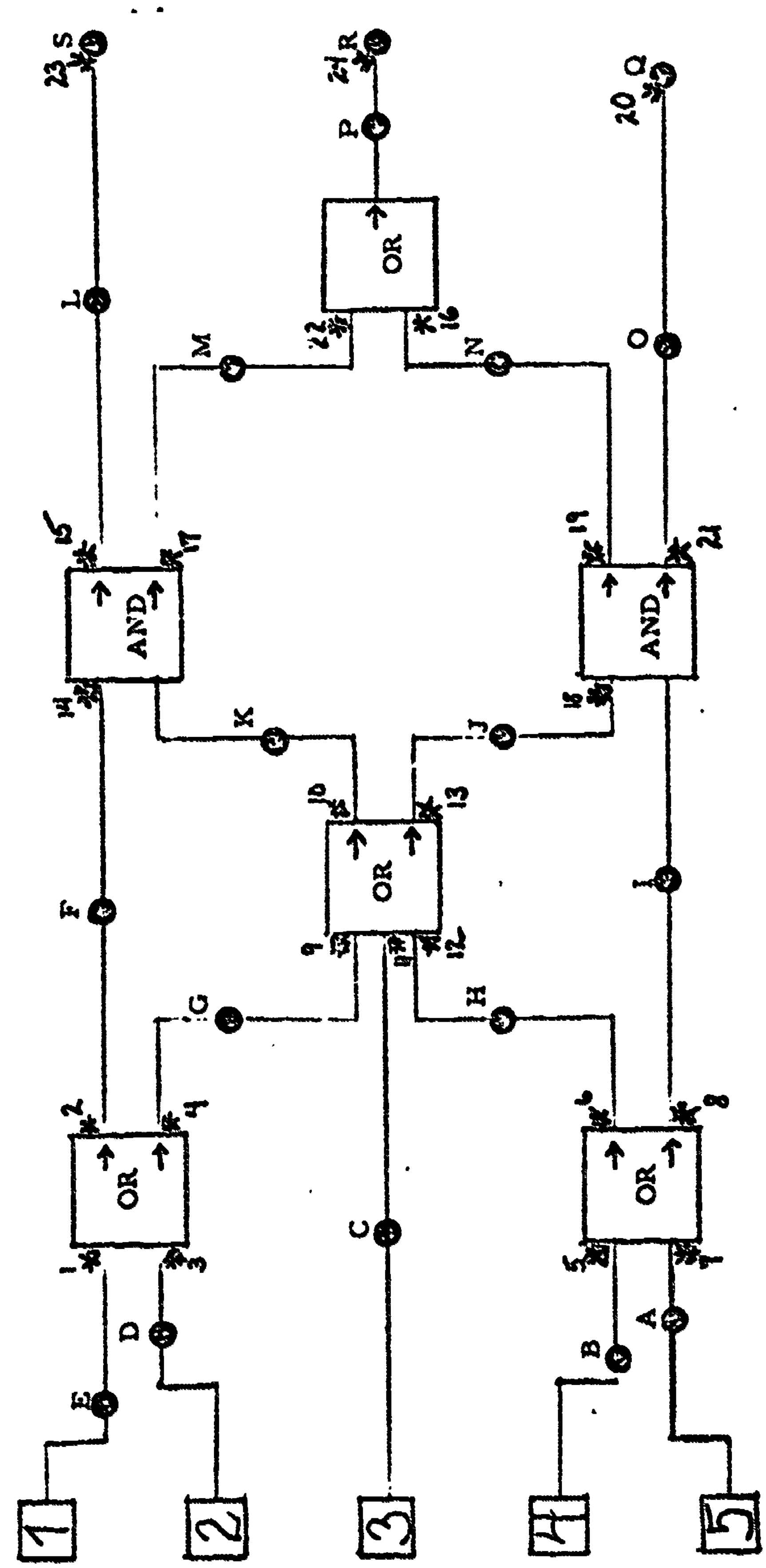
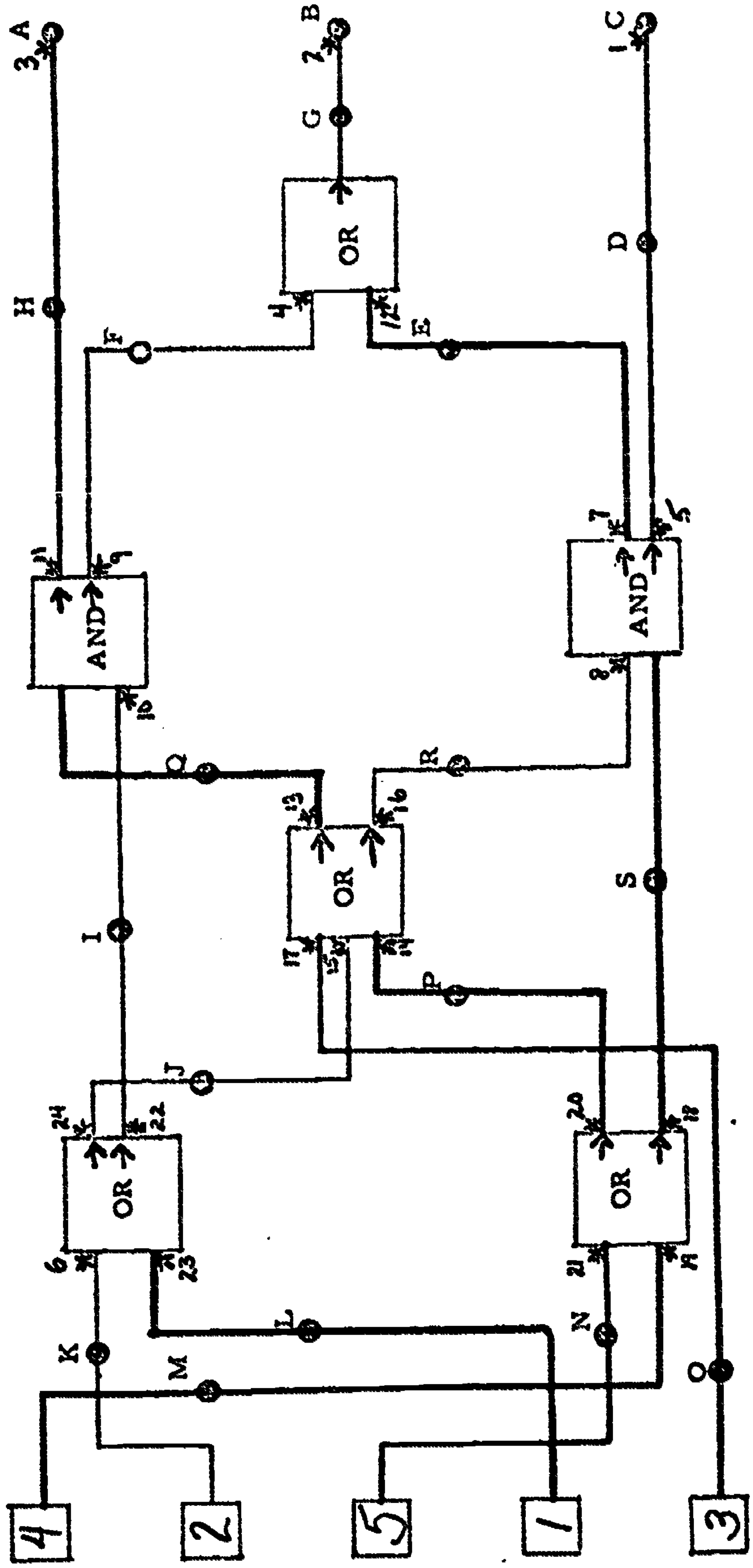


DIAGRAM 3A



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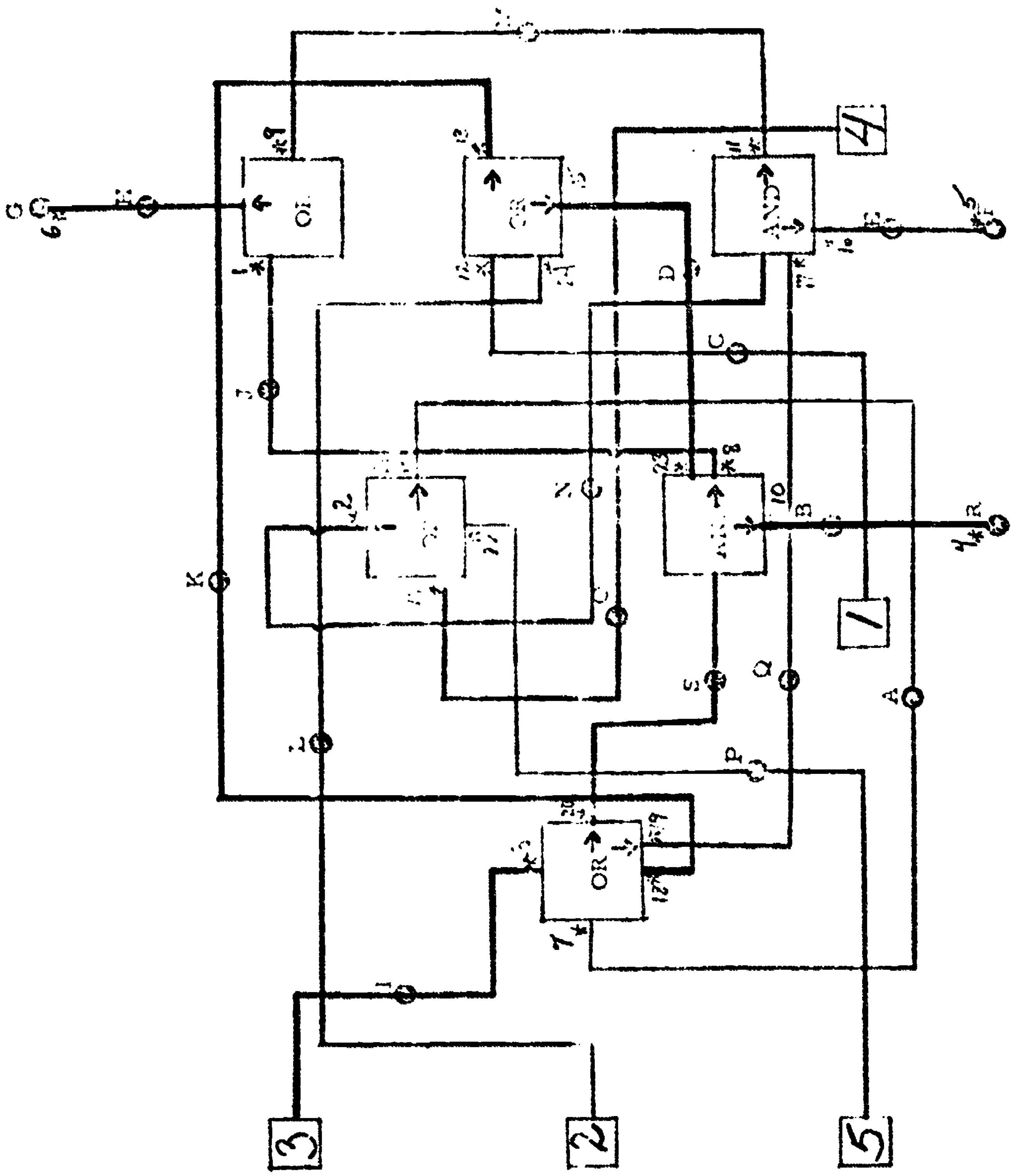


DIAGRAM 3C

APPENDIX II

INSTRUCTIONS

Welcome to the American Institutes for Research. I am ______________, and will be working with you during the course of this experiment. Before we get down to work this morning, I'd like to take care of a few administrative details and then give you a brief overview of what it is you'll be doing today. First of all, I need to know your name; then I'd like you to tell me whether or not you are color blind or have had experience with computers or symbolic logic. Could you also give me your age, the title of the last course you've taken in mathematics (note whether course was taken in high school or college), and your college major.

As you know the experiment in which you are taking part today is concerned with problem solving--specifically with how well you can locate breakpoints (or points of malfunctioning) in problems involving electrical circuits. In the real world, people who perform such tasks are called troubleshooters. The data which you help us generate will aid in answering several research questions. For instance, if some people are better at troubleshooting than others, we would like to find out why in terms of individuals' basic aptitudes or abilities. We would also like to find out what happens to performance as variations in the task are introduced, making the task easier or more difficult.

In a few minutes we will begin training you for the troubleshooting task. First we will acquaint you with some of the basic concepts and terminology which efficient troubleshooters use, and then familiarize you with the techniques of troubleshooting. Following the training session, you will be presented with a set of troubleshooting problems to solve. We will then take a rest break. After the break you will be taking 21 paper-and-pencil tests covering many aspects of human ability. These tests were selected because they are either known or hypothesized to be related to performance on the problem-solving task. We think you'll find this test battery to be both interesting and fun. "Pass" and "Fail" have no meaning on these tests, so relax and enjoy them, and simply try to do your best. We anticipate finishing by about 3:30 p.m. You will be paid for your participation at that time.

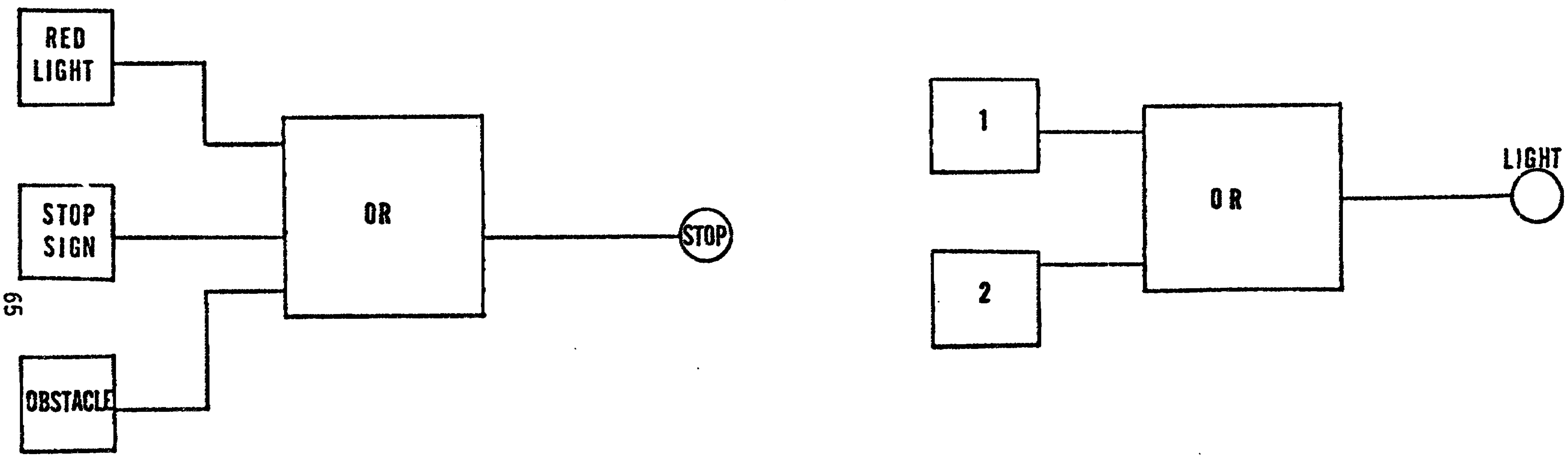
We are now ready to begin. Any questions at this point? Please stop me at any time in the instructions if something is not clear.

Now, if you will please give me your attention at the front of the room (E stands by easel where a variety of circuit diagrams are presented).

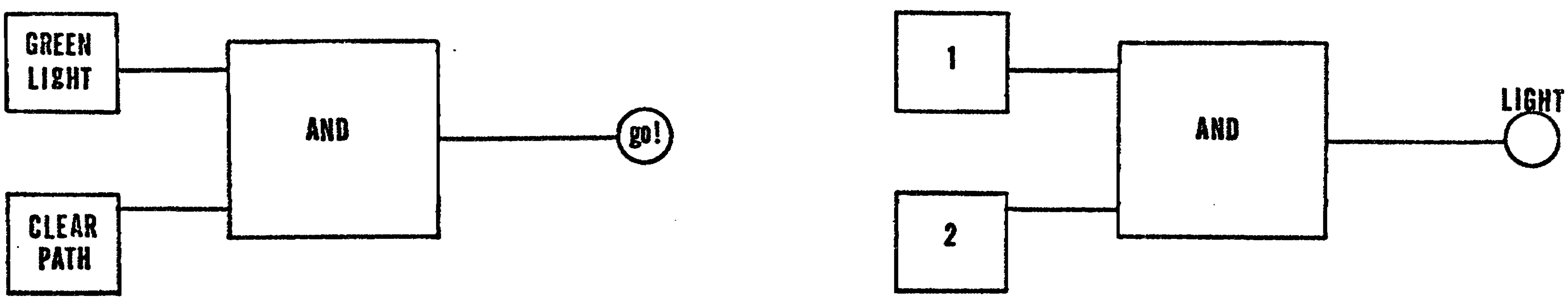
In the real world, we often make decisions based on certain conditions which must be met. For example, if a driver sees either a red light OR a stop sign OR an obstacle, he must stop. This situation can also be depicted symbolically as an electrical diagram (Picture 1). The light in this picture (point) will go on if either switch 1 "or" switch 2 is depressed, since electrical current will flow from either switch on the left through the OR box and enable the light on the right to light. Decisions can also involve a number of "AND" conditions--for instance, if a driver arrives at an intersection when the traffic light is green AND the path is clear, the driver can then go through the intersection (Picture 2). Here, the light will only go on if--and only if--both switch 1 and switch 2 are depressed since current must flow from both wires on the left through the AND box in order for the light on the right to light. It is important that you understand how these AND - OR conditions operate in order to solve the troubleshooting problems which you will be working on a little later.

We will now go into the mechanics of what you will be doing. Please open your notebooks to Example 1. Before you is a simple electrical diagram with two OR boxes. By depressing any one of the numbered switches on the left, you initiate current through the wires. The circles which are labeled A - F represent light sockets. The numbered stars indicate points at which breaks in the circuit may occur. In each problem there will be one, and only one, point where a break exists--all other points are in good working order. Your task will be to locate the one point which is not working.

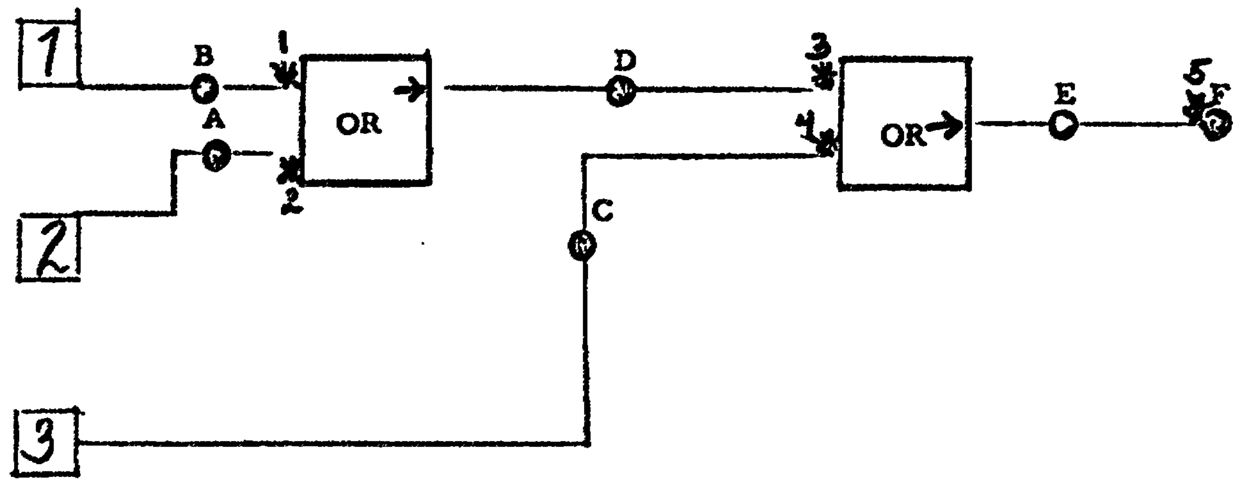
Now, let's assume for a moment that all points in the system are working, and you have an imaginary light bulb. How would you get light A to go on? B? C? D? E? and F? Notice you cannot light "D" by



PICTURE 1



PICTURE 2



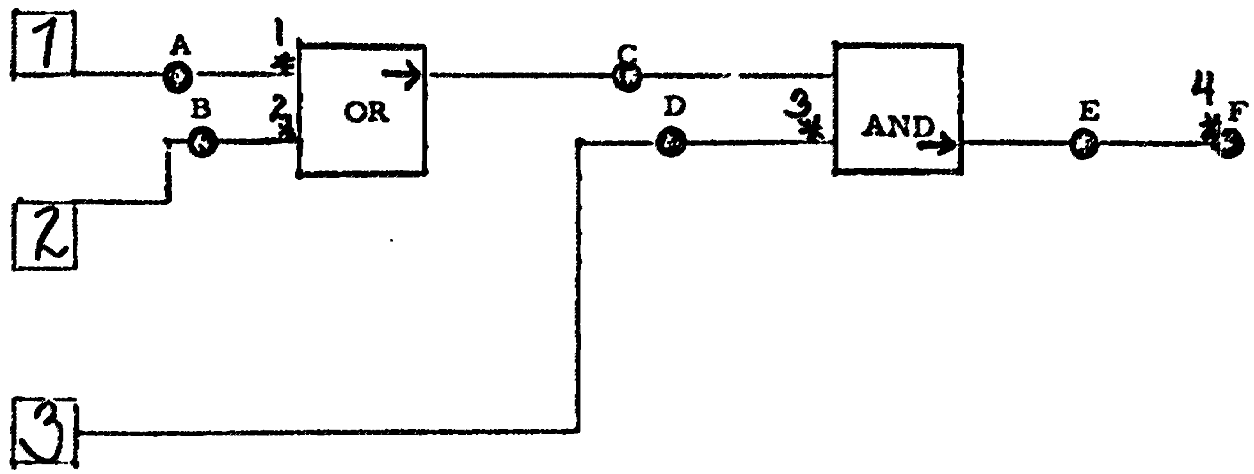
EXAMPLE #1

depressing switch 3. The reason for this is that current cannot flow backwards. Notice the arrows inside the OR boxes; they will tell you the direction of current going out of the boxes. All other wires coming in contact with the box are input wires.

Now let's look at the consequences of there being a break at some point in the circuit. Looking at the diagram before you, if the break point were at *4, and you put a lightbulb in socket F and depressed switch 3, would the light go on? (Pause.) The reason it would not go on is because current cannot continue to flow through a wire beyond the break point. In this example, therefore, current cannot get through the OR box to light the light. In the same diagram, if there were a break at *5, could "E" light by depressing switch 1? (Yes.) How about "F"? (No.)

Now turn to Example 2. Here we encounter one OR box and one AND box. What would you do to light "F"? (#1, #3F or #2, #3F). Do you see that if you put a light at F, and simply depress switch 1, F could not light? (The AND box needs two inputs.) Remember, your task during testing will be to discover at which of the possible break points in each problem a break actually occurs. In order to locate this breakpoint you will be checking different pathways by inserting a light bulb in one of the indicated sockets and depressing the proper switch or switches in order to turn the light on. If a light in a circuit doesn't work, you would know that the breakpoint is somewhere in that circuit and in no others; on the other hand, if a bulb lights, all points tested along that pathway must be working.

For example, if this were a real test problem, you would know that one, and only one, out of the 4 points was broken. Your task is to find out which one. Let's say you start by putting a bulb at E and pressing switches 1 and 3. If E lights, which points would you know are good and can be eliminated? (No break at *1 or *3.) However, if E doesn't light, you would know the break must be at *1 or *3. Notice that you gain information if the light lights or if it doesn't light. Now, what do you do from here? Let's assume now that E doesn't light, and that we know the break is at either *1 or *3. To determine at which of the two



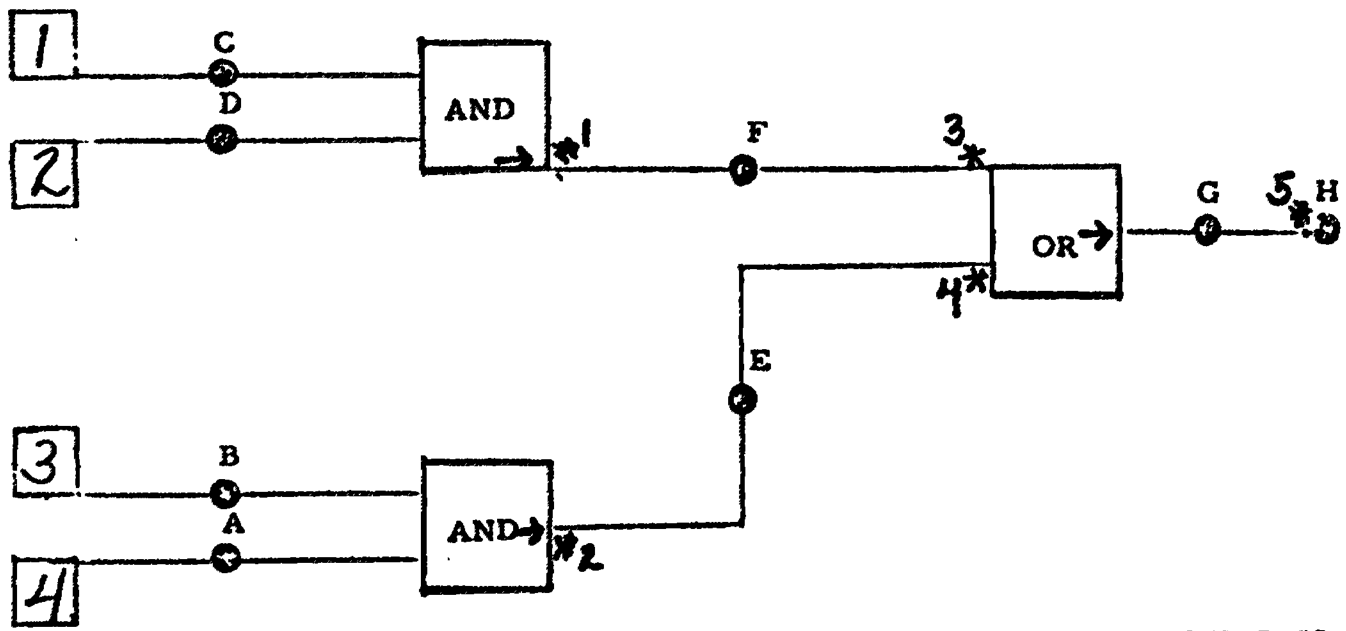
EXAMPLE #2

points the break exists, we could try putting our bulb at C and depressing switch 1. If C lights we would know *1 was not the break. Therefore it must be at *3. However, if C did not light, the break would be at *1.

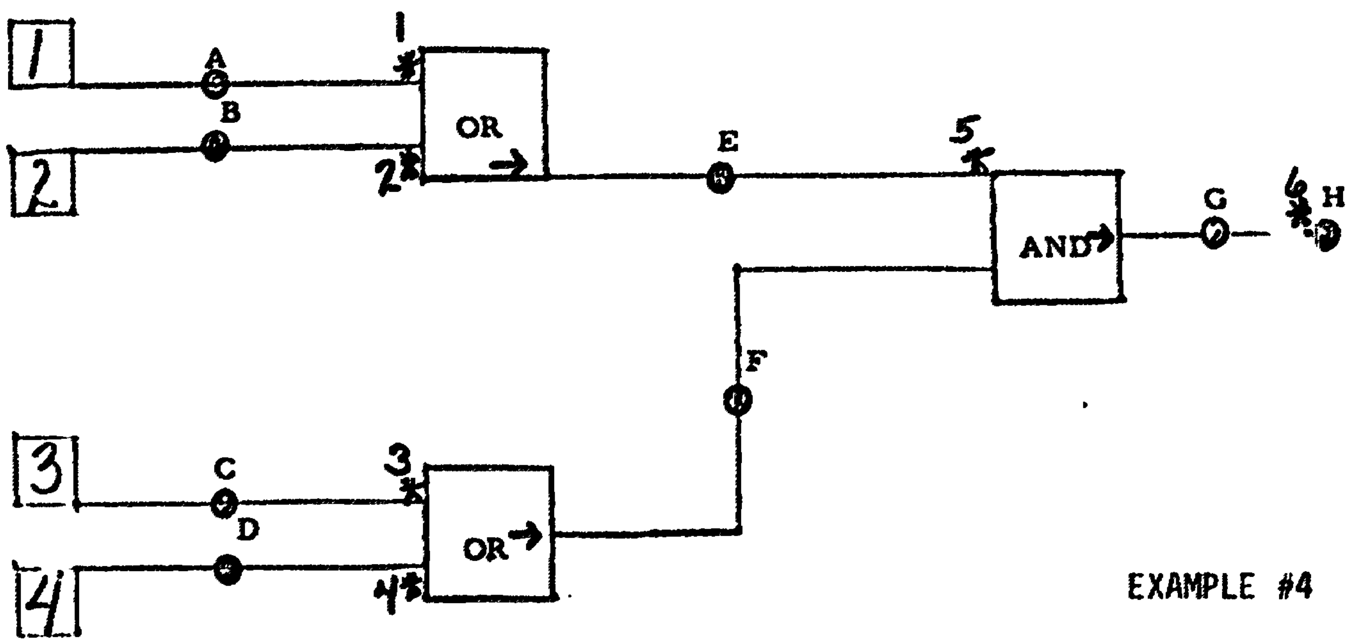
Turn to Example 3. The problems you will be doing will vary in complexity. All problems, however, will still involve only "or" - "and" conditions and will contain only one breakpoint. Your task will be to discover the breakpoint in the most efficient manner possible. This means that it is important for you to work as quickly as possible and perform the least number of tests possible. You will be scored in comparison with an optimal troubleshooter whose tests always gain him the maximum amount of information. . . . .Looking now at the third sheet, how would you light G? (1, 2G; 3, 4G). If there were a break at one of the five points in this problem, how would you begin to locate this breakpoint? (Which points can be eliminated? Which points are suspicious now?)

Turn to your fourth example. How would you turn on the light at G? (1, 3G or 1, 4G; 2, 3G or 2, 4G) How would you go about locating a break in this problem? (Points eliminated? Points suspect?)

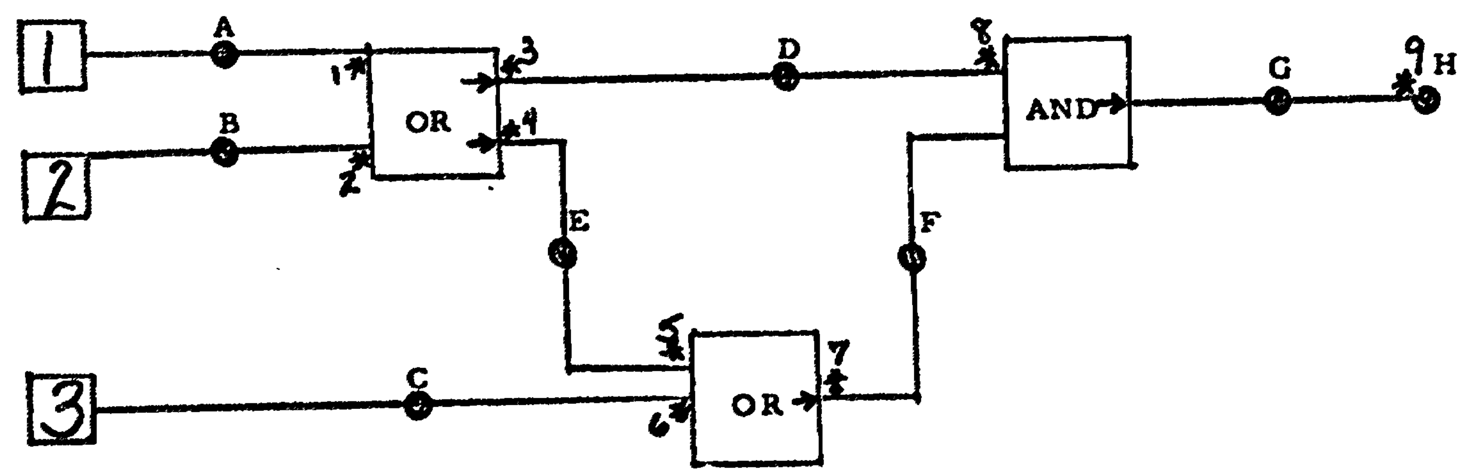
Turn now to the fifth example. In this training problem, we will consider some special properties of the boxes. Notice an OR box has two outputs. An AND box may also have two outputs. If you press switch 1, assuming all points are in working order, could you light D, E, F, and what about H? (Yes.) Why? The OR box has two separate outputs which both send current through the AND box. Switch 2 will light H in the same manner. However, switch 3 alone will not light G or H. Let's consider what would happen if we depressed switches 1 and 2 and put a lightbulb at D. If there were a break at *1 or *2, would D light? (Yes.) Why? If I told you the light doesn't go on, where does the break have to be? So by depressing both switches 1 and 2, no information is gained concerning *1 or *2. Similarly, if you were to depress switches 1 and 3 and place a bulb at H, you would receive no information about points *4, *5, *6 since current can travel through the bottom OR box via the circuit from switch 1 or from switch 3. What would your first test be in this problem to locate the break? (Points eliminated? Points suspect?)



EXAMPLE #3



EXAMPLE #4

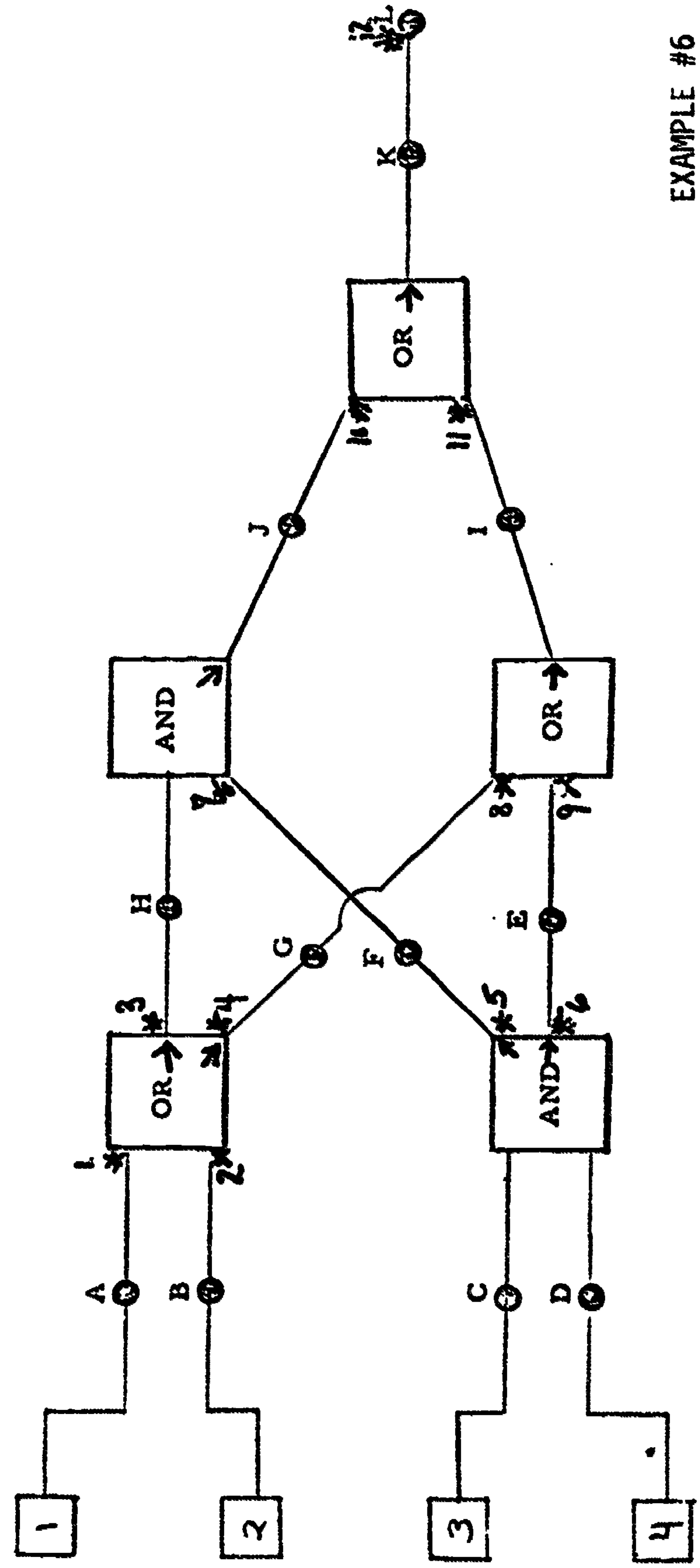


EXAMPLE #5

Turn to Example 6, your last training problem. This problem is similar to those you will see during testing. How would you light J? (1, 3, 4J or 2, 3, 4J.) How would you light K? (1K, 2K, 3, 4K.) Let's find the break in this problem. How would you begin? (Points eliminated? Points suspect?) Any questions or comments?

We are now ready to begin the testing session. There are a total of 23 test problems. Each problem has only one breakpoint and it is your task to discover this breakpoint. In order to locate it, you will perform tests one at a time in the same manner we have been doing. You will write down each test on a card indicating which switch (or switches) you wish to depress and the letter of the light you wish to test. (For example, in the last training problem, if you wished to put a light at J and press 1, 3, & 4, we want you to write "1, 3, 4J" on your card. Or if you wished to test for a break at *1 or *4, you would write 1G on your card.) Please write as legibly as possible. Give this card to the experimenter who will inform you if the light will light (your green "yes" light will light) or if the light will not light (your red "no" light will go on.) If you have made an erroneous test--such as a test for which there is no pathway connecting the switch and light indicated on your card--the yellow "error" light will go on. For example, in the last training problem, if you depressed switch 1 and put a light at E, E could not light. (Do you see what's wrong?) Another error would occur if you did not have sufficient current through an AND box to light the light--for example, if you depressed switch 3 and put a light at E, E would not light.

You will continue to write test cards and give them to the experimenter until you have found the breakpoint. Make tests until you know where the breakpoint is. Then write the breakpoint number on a card, and the experimenter will confirm the correct answer. Remember you will be scored in terms of speed (how fast you perform) and efficiency (how much information you gain by each test). Please do not guess where the breakpoint lies, as this will lower your efficiency considerably.



EXAMPLE #6

Is everyone ready to begin? Feel free to smoke during the session if you wish. Please do not make any notations in your book about the tests you have made. During breaks, do not discuss these problems among yourselves.

APPENDIX III

ANALYSIS OF VARIANCE TABLES

TABLE III-1

ANALYSIS OF VARIANCE OF CRITERION DATA
(Ln Time to Solution)

Source	df	MS	F
S (Subjects)	134	1.324	
C (Complexity)	2	50.064	318.364**
D (Difficulty)	2	139.940	632.738**
R (Replications)	1	90.956	356.306**
SC	268	.157	
SD	268	.221	
SR	134	.255	
CD	4	8.499	52.607**
RD	2	2.884	16.507**
RC	2	3.656	18.694**
SCD	536	.162	
SRD	268	.175	
SRC	268	.196	
RCD	4	.806	3.699*
SRCD	536	.218	

* p .01

** p .001

TABLE III-2

ANALYSIS OF VARIANCE OF CRITERION DATA
(Ln Trials to Solution)

Source	df	MS	F
S (Subjects)	134	.398	
C (Complexity)	2	.470	4.390
D (Difficulty)	2	73.828	503.950**
R (Replications)	1	6.912	55.710**
SC	268	.107	
SD	268	.147	
SR	134	.124	
CD	4	.480	4.709*
RD	2	1.703	14.070**
RC	2	1.248	9.327**
SCD	536	.102	
SRD	268	.121	
SRC	268	.134	
RCD	4	2.037	14.353**
SRCD	536	.142	

* p .01

** p .001

TABLE III-3

ANALYSIS OF VARIANCE OF CRITERION DATA
(Ln Time Per Trial)

Source	df	MS	F
S (Subjects)	134	1.432	
C (Complexity)	2	41.017	683.078**
D (Difficulty)	2	15.543	198.656**
R (Replications)	1	47.690	323.130**
SC	268	.600	
SD	268	.782	
SR	134	.148	
CD	4	5.149	88.484**
RD	2	2.062	37.600**
RC	2	2.463	47.054**
SCD	536	.582	
SRD	268	.548	
SRC	268	.523	
RCD	4	2.227	35.626**
SRCD	536	.625	

** p .001

TABLE III-4

ANALYSIS OF VARIANCE OF CRITERION DATA (TRIAL 1 EFFICIENCY)

Source	df	MS	F
S (Subjects)	134	.324	
C (Complexity)	2	4.402	56.946***
D (Difficulty)	2	.176	1.865
R (Replications)	1	1.386	20.927***
SC	268	.773	
SD	268	.946	
SR	134	.662	
CD	4	.931	12.678***
RD	2	.158	2.377
RC	2	.542	.979
SCD	536	.734	
SRD	268	.666	
SRC	268	.554	
RCD	4	.115	1.662
SRCD	536	.693	

*** p .0005

TABLE III-5

ANALYSIS OF VARIANCE OF CRITERION DATA
(Arcsin Square Root Efficiency Per Trial)

Source	df	MS	F
S (Subjects)	134	.337	
C (Complexity)	2	1.400	29.450**
D (Difficulty)	2	8.260	144.909**
R (Replications)	1	1.034	21.961**
SC	268	.475	
SD	268	.570	
SR	134	.471	
CD	4	.407	10.216**
RD	2	.294	5.941*
RC	2	1.385	27.374**
SCD	536	.399	
SRD	268	.495	
SRC	268	.506	
RCD	4	.598	11.125**
SRCD	536	.537	

* p .01

** p .001

APPENDIX IV

DERIVATION OF EFFICIENCY MEASURES

Efficiency was defined as the number of breakpoints eliminated by a test divided by the number of breakpoints which could be eliminated by the optimum test on that trial. For each trial, the scorer determined the breakpoints which might still be faulty (i.e., about which the subject could have had no definite information). The subject's test eliminated some number of these breakpoints; this number was less than or equal to the number of breakpoints which could be eliminated by the best available test. The efficiency for that trial was the ratio of these two numbers.

For example, on the first trial of the simplest problem (1A), there are nine breakpoints, exactly one of which is known to be faulty. The optimal first test in this situation would eliminate four breakpoints from further consideration (if the probe light lights), or five breakpoints (if the probe light fails to light). If the probe light fails to light, a test is available for two of the five remaining breakpoints, and so on, following an appropriate split-half technique. Thus, on trial one, the optimal test eliminates either 4/9 or 5/9 of the breakpoints, and the optimal score is defined as the value less than or equal to 1/2 (in this case 4/9). A subject might perform a trial-one test which eliminates n breakpoints (if the light lights), or 9 - n breakpoints (if the light doesn't light). The subject's efficiency value is n/9 or 9 - n/9, whichever is less than or equal to 1/2. His trial-one efficiency score is defined as his efficiency value divided by the optimal score, e. g., $\frac{n}{9}/\frac{4}{9}$ or $\frac{9-n}{9}/\frac{4}{9}$. On scoring trial two, the scorer determined the breakpoints which were still possibly faulty, as a result of the subject's preceding test. The optimal test for these remaining breakpoints was then determined and the optimal score was calculated. On this and subsequent trials the obtained efficiency value was the number of remaining breakpoints eliminated by the subject's test, divided by the number of possibly faulty breakpoints before the test; the <u>efficiency score</u> is the efficiency value divided by the optimal score. Thus, at each trial, the number of breakpoints which are logically tenable are used to examine a subject's performance. He deviates from perfect scores to the extent that he retests breakpoints already logically eliminated, or fails to find the most efficient test based on all logically available information.

TABLE IV-1

HYPOTHETICAL PROTOCOLS

Subject #1

Trial #	Breakpoints 1	2	3	4	5	6	7	8	Optimal Score	Bulb	Efficiency Value	Efficiency Score
1	?	?	?	?	?	?	?	?	4/8	0	4/8	1.0
2	?	?	?	?	+	+	+	+	2/4	1	2/4	1.0
3	+	+	?	?	+	+	+	+	1/2	1	1/2	1.0

Faulty breakpoint is #4

Trial 1 efficiency = 1
Average efficiency/trial = 3/3 = 1

Subject #2

Trial #	Breakpoints 1	2	3	4	5	6	7	8	Optimal Score	Bulb	Efficiency Value	Efficiency Score
1	?	?	?	?	?	?	?	?	4/8	1	1/8	.25
2	+	?	?	?	?	?	?	?	3/7	1	2/7	.66
3	+	?	?	?	?	+	+	?	2/5	0	1/5	.50
4	+	?	?	?	?	+	+	+	2/4	1	1/4	.50
5	+	?	?	?	+	+	+	+	1/3	1	0/3	.00
6	+	?	?	?	+	+	+	+	1/3	0	1/3	1.0
7	+	+	?	?	+	+	+	+	1/2	0	1/2	1.0

Faulty breakpoint is #4

Trial 1 efficiency = .25
Average efficiency/trial = 3.31/7 = .559

Two hypothetical protocols are presented in Table IV-1. Assume an eight-breakpoint problem, where split-half or nearly split-half tests are always available. A "?" represents a potential breakpoint which has not yet been shown to be either faulty or non-faulty, a "+" is a breakpoint logically shown to be non-faulty, the underlined breakpoints are those under test, and "1" indicates the light lit, while "0" indicates the bulb failed to light. Subject #1 is an ideal troubleshooter, while #2 is not.

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