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ABSTRACT

The relationship between variations in an auditory signal identification task and consequent changes in the abilities related to identification performance was investigated. Characteristics of the signal identification task were manipulated by varying signal duration and signal-to-noise ratio. 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. The Auditory Perceptual ability was found most related to criterion task performance and increased in importance as background noise increased and signal duration decreased. Thus, these variations in task conditions produced changes in the degree of involvement but not in the patterning of the abilities required. Implications for predicting task performance are discussed. (Author/EH)

# Methods for Predicting Job Ability Requirements:

## I. Ability Requirements as a Function of Changes in the Characteristics of an Auditory Signal Identification Task

George R. Wheaton
Ellen L. Shaffer
Angelo Mirabella
Edwin A. Fleishman



Technical Report
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13. ABSTRACT

This report describes the first 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.

As the first step in this program, the present study investigated the relationship between variations in an auditory signal identification task and consequent changes in the abilities related to identification performance. Characteristics of the signal identification task were manipulated by varying signal duration and signal-to-noise ratio. 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.

Of the five separate ability factors which were identified, the Auditory Perceptual ability was found most related to criterion task performance and increased in importance as background noise increased and signal duration decreased. Thus, these variations in task conditions produced changes in the degree of involvement but not in the patterning of the abilities required. Implications for predicting human performance are discussed.

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| Signal Duration | | | | | | |
| Signal-to-Noise Ratio | | | | | | |
| Factor Analysis | | | | | | |

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# METHODS FOR PREDICTING JOB-ABILITY REQUIREMENTS:

## I. ABILITY REQUIREMENTS AS A FUNCTION OF CHANGES IN THE CHARACTERISTICS OF AN AUDITORY SIGNAL IDENTIFICATION TASK

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TABLE OF CONTENTS

## LIST OF TABLES

LIST OF FIGURES

## INTRODUCTION

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 equipments and procedures are updated, estimates are needed of the expected impact of such modifications on performance. In both cases, accurate forecasting of manpower and training requirements is necessary to insure effectiveness at the task, job, or system level.

The accuracy with which such forecasts can be made depends upon: (a) detailed and reliable information describing salient characteristics of the tasks to be performed; and (b) a method for systematically translating these descriptions into quantitative information about the basic human abilities and knowledge required for successful task performance. While a variety of task-descriptive and task-analytic procedures have been employed for these purposes, their effectiveness has often been limited. Task description, even at the detailed subtask or task-element level, has been qualitative rather than quantitative, attributive rather than parametric. Similarly, the translation of this information into personnel requirements data has depended upon highly subjective methods involving judgments about the abilities required and the extent of their involvement.

In an attempt to deal with these and similar problems, the work of Fleishman and his associates appears to offer several promising lines of research. In a series of recent studies supported by the Advanced Research Projects Agency, the Department of the Army, and the Naval Training Equipment Center, these investigators have focused on the development of systems (taxonomies) for the description and classification of tasks (e.g., Fleishman, Kinkade, & Chambers, 1968; Fleishman & Stephenson, 1970; Fleishman, Teichner, & Stephenson, 1970; Theologus, Romashko, & Fleishman, 1970; Wheaton, Mirabella, & Farina, 1971; Levine, Romashko, & Fleishman, 1971; Farina & Wheaton, 1971; and Wheaton & Mirabella, 1972). While several such systems were investigated, the two on which most extensive research was conducted provide for detailed description of tasks in terms of the (a) salient or critical display, procedural, and control dimensions of tasks; and (b) human abilities hypothesized as essential to effective task performance. Considered jointly, these two descriptive languages furnish a conceptual basis for translating information about salient dimensions of tasks into statements about the patterns of abilities required for effective performance.

Given these conceptual bases, attention has turned to uncovering those principles which may govern the interplay between task demands and consequent ability requirements. If a set of such principles were available, it might then be feasible to translate information about the physical dimensions of task complexity or difficulty into forecasts about the aptitude requirements for performing such tasks. However, in spite of the potential importance of such a methodology for personnel selection and training, relatively little research of this type has been conducted.

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

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

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

These issues bear directly on the goal of the long-range research program, which is to develop principles relating task characteristics to ability requirements. The approach which has been adopted to uncover such principles entails the investigation of classes of tasks which are of theoretical interest and which are representative of the kinds of tasks prevalent in the modern Navy. The ability requirement and performance data obtained, following manipulation of the characteristics of such tasks, can be used to address issues of both theoretical and practical concern.

The present study was conducted to further investigate the changes, if any, which occur in patterns of abilities accounting for individual differences in performance under variations in the criterion task. Since Fleishman and Zimmerman already dealt with tasks in the perceptual-motor and visual perceptual domains, respectively, a criterion task was chosen from the auditory perceptual domain. The task selected was one of auditory signal identification in which subjects were required to identify one of four types of ships. It had the added virtue of high face validity, inasmuch as it closely resembled the task of a passive sonar operator in the form in which it was presented. Criterion task difficulty was manipulated by systematically varying two task characteristics: signal duration and signal-to-noise ratio.

The research was conducted in the laboratory using a combination of experimental and correlational methods. Based upon an analysis of the criterion task, a battery of reference tests was assembled which represented abilities judged to be of relevance to criterion task performance. Subjects received the reference battery and then proceeded to perform the criterion task under different signal duration and signal-to-noise ratio 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.

## METHOD

### Subjects

The subjects employed in this study were 127 male college students recruited from universities in the metropolitan Washington, D. C. area. They were paid for their participation in the study upon completion of the second of two days of research activities. All subjects were screened for hearing defects at the time of scheduling.

### Reference Test Battery

A battery of 24 specifically selected tests was administered to all subjects prior to their involvement in the auditory signal identification criterion task. The battery contained tests representing a variety of well-established factors in the cognitive, perceptual, and memorial domains of performance. The specific factors chosen for representation had been hypothesized as relevant for criterion task performance. Both printed and aural tests were used. In addition to representing cognitive and memory abilities, printed tests were included to determine whether any of the abilities previously identified in visual perception (e.g., speed of closure) might extend to the auditory domain. The aural tests were included to provide detailed data on the relationship between an individual's auditory ability (ies) and his skill in performing different versions of the auditory criterion task.

Each ability or factor of interest in the present study was represented by a minimum of three tests to insure adequate factor definition. In assembling the printed tests considerable use was made of the Kit of Reference Tests for Cognitive Factors (French, Ekstrom, & Price, 1963). Tests selected from this kit were used in unmodified form, except that due to time limitations, only the first part of all two-part tests was administered. Aural tests were based primarily upon Seashore's Measures of Musical Talents (Buros, 1965), particularly as adapted by Fleishman and Spratte (1954). The major changes made were to record standard instructions on tape, together with demonstration examples. Other aural tests were taken from among the standardized tests of auditory-perceptual abilities developed by Fleishman and Friedman (1957a, 1957b).

Brief descriptions of the tests comprising the reference battery are given below with references to additional sources of information. The reliability reported for each of the tests is shown in Table 1. In cases where this information is unavailable, reference is made either to the original test from which the version used in the present study came or to a similar test.

## Printed Tests

Tests (1), (2), and (3) are measures of the Induction factor which is defined as the ability to find general concepts that will fit sets of data. It involves the formulation and testing out of hypotheses.

1. 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).

2. Locations Tests--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).

3. 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).

Tests (4), (5), and (6) are measures of the Associative Memory factor, which is defined as the ability to remember bits of unrelated material.

4. 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 numbers 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).

5. 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).

TABLE 1

RELIABILITIES OF REFERENCE TESTS

| | | |
|---|---|---|
| **Printed Tests:** | | |
| Induction Factor | | |
| 1. Letter Sets Test | .64* | Lemke *et al.* (1967) |
| 2. Locations Test | .82* | Lemke *et al.* (1967) |
| 3. Figure Classification | .94* | Pemberton (1952) |
| Associative Memory Factor | | |
| 4. Picture-Number Test | .76* | Duncanson (1966) |
| 5. Object-Number Test | .79* | Duncanson (1966) |
| 6. First and Last Names Test | .81* | Duncanson (1966) |
| Speed of Closure Factor | | |
| 7. Gestalt Completion Test | .62* | Guilford *et al.* (1952) |
| 8. Concealed Words Test | .80* | Guilford *et al.* (1952) |
| 9. Four Letter Words Test | .92* | Pemberton (1952) |
| Flexibility of Closure Factor | | |
| 10. Copying Test | .88** | Thurstone (1938) |
| 11. Closure Flexibility (Concealed Figures) | .78* | Buros (1965) |
| 12. Designs Test | .94* | Pemberton (1952) |
| Perceptual Speed Factor | | |
| 13. Finding A's Test | .81* | Duncanson (1966) |
| 14. Number Comparison Test | .79* | Duncanson (1966) |
| 15. Identical Pictures Test | .88* | Duncanson (1966) |
| **Aural Tests:** | | |
| Seashore Measures of Musical Talent (tests 16-20) | | |
| 16. Pitch Discrimination Test | .86* | Fleishman and Friedman (1957b) |
| 17. Loudness Test | .63* | Fleishman and Friedman (1957b) |
| 18. Time Test | .73* | Fleishman and Friedman (1957b) |
| 19. Timbre Test | .79* | Fleishman and Friedman (1957b) |
| 20. Tonal Memory Test | .88* | Fleishman and Friedman (1957b) |
| 21. Rhythm Test | .90* | Fleishman and Friedman (1957a) |
| 22. Code Distraction Test | .92* | Fleishman and Friedman (1957b) |
| 23. Hidden Tunes Test | .78* | Fleishman and Friedman (1957b) |
| 24. Kwalwasser Music Talent Test | .54* | (From present study) |

*Split-half reliability coefficient corrected for full length with the Spearman-Brown formula.

**Reliability estimated by the tetrachoric correlation of odd and even items.

6. 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).

Tests (7), (8), and (9) represent a Speed of Closure factor, which is described as the ability to unify a complex perceptual field of apparently disparate elements.

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

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

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

Tests (10), (11), and (12) were included to represent a Closure Flexibility factor. Broadly defined, this factor represents the ability to retain a complex idea in spite of distraction.

10. 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).

11. 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 49 problems (10 mins.). Score is the number correct minus the number incorrect.

12. 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.

Tests (13), (14), and (15) represent a Perceptual Speed factor, which is described as the ability to compare visual configurations and identify two figures as similar or identical.

13. 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).

14. 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).

15. 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).

<u>Aural Tests</u>

16. Pitch Discrimination (subtest of the Seashore Measures of Musical Talents)--A series of 50 pairs of tones differing in pitch is presented, and the subject indicates whether the second tone in each pair is higher or lower in pitch than the first. Administration time is 7 1/2 minutes. Score is the number correct (Fleishman & Friedman, 1957b; Fleishman & Spratte, 1954).

17. Loudness (subtest of the Seashore Measures of Musical Talents)--A series of 50 pairs of tones differing in loudness is presented, and the subject indicates if the second tone in each pair is stronger or weaker than the first. Administration time is 7 1/2 minutes. Score is the number correct (Fleishman & Friedman, 1957b; Fleishman & Spratte, 1954).

18. Time (subtest of the Seashore Measures of Musical Talents)--A series of 50 pairs of tones differing in duration is presented, and the subject indicates if the second tone in each pair is longer or shorter than the first. Administration time is 6 minutes. Score is the number correct (Fleishman & Friedman, 1957b; Fleishman & Spratte, 1954).

19. Timbre (subtest of the Seashore Measures of Musical Talents)--A series of 50 pairs of tones differing in timbre or tonal quality is presented, and the subject indicates if the tones in each pair are the same or different. Administration time is 6 minutes. Score is the number correct. (Fleishman & Friedman, 1957b; Fleishman & Spratte, 1954).

20. Tonal Memory (subtest of the Seashore Measures of Musical Talents)--A series of 30 pairs of tone patterns is presented, with one note changed in the second pattern of each pair. The subject indicates on an answer sheet which note in the second pattern is changed (e.g., the first, second, etc.). Administration time is 7 1/2 minutes. Score is the number correct (Fleishman & Friedman, 1957b; Fleishman & Spratte, 1954).

21. Rhythm Test--A modified version of the Rhythm subtest of the Seashore battery, using the first 50 pairs of rhythmic patterns from Form D of the Fleishman and Friedman revision (1957a). The subject indicates whether the second pattern in each pair is the same as or different from the first. Administration time is approximately 11 minutes. Score is the number correct.

22. Code Distraction Test--This is a shortened version of a test developed by Fleishman and colleagues (Fleishman & Spratte, 1954; Fleishman & Friedman, 1957b), using Morse Code signals presented against background noise. The first 50 stimulus-items (in a set of 120) were used. The subject's task is to determine how many dots are contained in each signal. Because the test reflects the ability of a subject to ignore distracting auditory stimuli (i.e., dashes and background noise), it was hypothesized that this test might relate to the Speed of Closure or Perceptual Speed factors identified in the visual mode. Administration time is approximately 5 minutes. Score is the number correct.

23. Hidden Tunes Test--Originally described by White (1954) this test consists of 50 pairs of short tunes. The subject indicates whether the first melody in each pair is contained within the second melody. Closure ability was also hypothesized to play a part in this test. Administration time is 12 minutes. Score is the number correct (Fleishman & Friedman, 1957b).

24. Kwalwasser Music Talent Test (Form A)--Fifty items are presented, each consisting of a 3-tone pattern which is repeated with a change in either pitch, time, rhythm, or loudness. The subject must determine which of these variables was changed, selecting between the two choices provided for each item on the answer sheet. Administration time is 10 minutes. Score is the number correct (Buros, 1965).

Criterion Task

The basic criterion condition used in this study consisted of an auditory signal identification task similar, for instance, to that confronting a passive sonar operator. Before performing on the criterion task, however, subjects were first trained under optimum conditions to classify relatively complex auditory sitmuli into one of four categories. Upon completion of this training the same subjects were then required to identify similar kinds of stimuli presented under nine different criterion conditions representing varying degrees of task difficulty. More detailed information about salient features of the criterion task is presented in the following sections.

Auditory Stimuli. The stimulus materials used to prepare both training and testing tapes were taken from stimuli developed originally by Annett (1971) under contract to the U.S. Naval Training Equipment Center. Annett's stimuli were synthesized by electronic and mechanical means to represent realistically complex sounds with the same general characteristics as passive sonar signals, but without any real attempt to simulate actual vessels or sonar systems. Stimuli in Annett's library of ship sounds consist of several components, each component being recorded on one channel of an eight-track tape. Included among the stimulus components are propellar cavitation, engine sounds, shaft squeal and hull reasonance, echo ranging signals and other mechanical ship sounds. These components, when played in combination, represent four broad categories of vessels including cargo, warship, submarine, and lightcraft. Accompanying these signals on additional tracks are "sea noise" and assorted biological effects. (See Annett [1971] for a complete description of his signals and the manner in which they were developed.)

Arrangements were made to copy Annett's basic library of 120 ship sounds with the provision, however, that selected channels be deleted. The "sea noise" and biological effects channels were eliminated in order to present subjects with relatively clear, unmasked sounds during training. Similarly, two other sound components, namely echo ranging and mechanical ship sounds, were eliminated in an attempt to remove cues highly diagnostic of any particular ship category. The resultant 120 stimuli consisted of three component sounds--propellar cavitation, engine sounds, and shaft squeal and hull reasonance.

Signals within a given ship type possessed a characteristic propeller cavitation rate. Cargoships ranged between 60 and 100 r.p.m. while submarines varied between 100 and 200 r.p.m. Warships and lightcraft had higher cavitation rates, the former ranging between 200 and 300 r.p.m., and the latter between 300 and 450 r.p.m. Propeller cavitation pitch also varied systematically among the classes of signals. Cargoships were lowest in pitch, lying between 355 and 710 Hz. Warships and submarines were intermediate, falling between 710 and 1400, and 1400 and 2800 Hz., respectively. Lightcraft were highest, lying between 2800 and 5600 Hz. Engine sounds consisted of a variety of whines, buzzes, rumbles, and roars, some of which were pulsed while others were either rhythmic or continuous. There was considerable overlap among ship categories with respect to engine sounds. Finally, some of these basic signals were also accompanied by shaft squeal or hull reasonance.

Construction of training and test tapes. Twenty-five signals from each of the four ship categories were selected from Annett's library of 120 sounds. An attempt was made to include a broad representation of the range of sounds comprising each category and to eliminate any signals whose class membership seemed ambiguous. With but few exceptions, within any of the four ship categories no two sounds were precisely the same. Using this core of 100 signals, one training tape and nine test tapes were generated.

The training tape consisted of 20 trials, each trial containing eight ship sounds. Items within each trial were presented for 10 seconds followed by an interval of five seconds. Prior to presentation each item was announced by trial number and item number. All non-essential background noise was eliminated from the tape in an attempt to maximize the nature of the differences among signal categories. Signals were recorded randomly on the training tape with the restriction that each trial was to contain two examples of each ship type.

The independent variables selected for manipulation of task difficulty were signal duration and signal-to-noise ratio. Nine different task conditions were generated according to a factorial arrangement of these two variables. Stimuli were presented for either nine, six, or three seconds, and under one of three signal-to-noise ratios. Background noise was set at -5 dB, 0 dB, or +5 dB, referenced to the intensity of the signal alone. Each of the nine different task conditions generated in this manner was represented by a test tape containing 100 signals, 25 for each ship category. To simplify the task of recording, only the first and last set of 15 items were randomized on each tape. The remaining 70 intermediate items appeared in a random order which was the same across all nine test tapes.

The original signals provided by Annett were played on a Magnecord Tape Recorder (Model 728) and re-recorded onto high quality tape using a Viking Tape Recorder (Model 96). A Lafayette Instrument Company Noise Generator (Model 15012) was used to produce background masking noise. The output from the noise generator was passed through a filter network consisting of a

100 K resistor and a .075 microfared capacitor to roll off the high end of the white noise. This procedure resulted in a noise which subjectively appeared to provide better masking of the signals used and to be less harsh over prolonged test periods. The output from this circuit was mixed with the signals and fed to the Model 96 recorder. Differential loudness between signal and background noise was controlled with the aid of a VU meter. Stimulus and noise onset was controlled by a sound activated relay. Termination of signal and noise were controlled manually in response to a sweep second hand.

During playback the recorded signals with their background noise were routed through a Bogen Amplifier (Model AP-250) to two Electro-voice loudspeakers (Model EV-2) centered at the front of the laboratory where testing was conducted. Stimuli were presented at an intensity representing a comfortable listening level as determined in earlier pilot work. A voltmeter across one of the speakers was used to insure constant signal intensity across tapes having the same signal-to-noise characteristics, as well as to permit calibration of the system for each test session.

The intensity of the stimuli impinging upon the subjects was checked with a General Radio sound-level meter (Model 1565-A). The mean decibel level for tapes on which the background noise was five decibels less than signal strength was 64.0 dB. When the background noise and signals were of equal strength, intensity was at 67.4 dB. Finally, when background noise was five decibels greater than the signal, overall output was at 69.6 dB. The highest level recorded (73.5 dB) is approximately the level produced by heavy street traffic and does not pose a threat to normal hearing.

Procedure

The ability reference tests, training sequence, and criterion task conditions were administered to subjects in small groups averaging approximately 10 subjects each. The testing for each group extended over two consecutive days, with each day's session beginning at about 9:00 a.m. and lasting approximately five hours. Testing took place in AIR's Auditory-Perceptual Laboratory, which is equipped with ten semi-private listening booths and easily accommodates five to six additional student desks.

At the start of the first session, subjects were given a brief overview of what the study involved. Each group then received the battery of fourteen printed tests in a fixed order, with a five-minute break coming midway through. Following the printed tests, and after a ten-minute break, subjects received the auditory portion of the reference battery, also in a fixed order. Upon completion of the battery and after a fifteen-minute break, the experimenter introduced the main task of the study and explained the ship sound training regimen. A demonstration tape, containing two examples of each ship type, was then played. Subjects were instructed to listen carefully and to try to determine what sounds in the same category had in common. After the demonstration tape, the experimenter suggested types of cues that might be useful in distinguishing one category from another (e.g., continuity of sounds, frequency, presence of a ping or squeal).

Subjects then proceeded through the first fifteen of the twenty trials on the training tape in the following manner. On odd-numbered trials, all eight signals within the trial were presented after a cue as to the signal's identity had been given. This cue was in the form of a capital letter appearing on the answer sheet for that trial and item number which corresponded to the correct ship class (i.e., "W" for warship, "S" for submarine, "LC" for lightcraft, and "C" for cargo).

The purpose of these trials was to give subjects ample opportunity to refine the methods of classification which they had established for themselves. On even-numbered trials, subjects listened to each signal and then identified it by circling the appropriate letter on the answer sheet. Four choices were always provided and subjects were instructed to guess when unsure of their answer. The purpose of these trials was to obtain a series of acquisition measures during the course of learning. No feedback was provided to subjects during the even-numbered trials.

Upon completion of the fifteenth trial, subjects were given a short break, and then returned for the remaining trials (16 through 20). All five of these trials were administered in the manner described for the even-numbered trials above, thus providing an overall measure of training effectiveness. This concluded the activities for Day 1, and subjects were dismissed.

Day 2 began with a refresher tape, consisting of four examples of each ship category played in a randomized order. Each signal was identified by the announcer prior to commencement of the signal. Subjects were then presented with the series of nine criterion tapes. The order of tapes was randomized for each group of subjects, with the restriction that each tape appeared in first and last (i.e., ninth) position at least once. Subjects were given a twenty-minute break after completing the first set of three tapes and also after the second set of three. Prior to starting each tape, the experimenter informed the group whether the signals would contain "some," "quite a bit," or an "extreme amount" of noise and also whether the duration of the signals would be "long," "moderately long," or "relatively short." This step seemed advisable in as much as subjects had not been given examples of the background noise or the stimulus durations with which they would be working. Upon completion of these instructions testing began. The testing format was the same as employed during acquisition testing on the preceding day. At the conclusion of the session subjects were paid for their services and debriefed.

Data Analysis

Three sets of analyses were performed on data obtained from the reference battery and criterion conditions. Criterion performance was measured in terms of number of correct identifications. These data were examined by means of analysis of variance procedures to first assess the impact of task parameter manipulations on task difficulty. A fully repeated measures 4 x 3 x 3 factorial design was used in which the performance of all 127 subjects was evaluated under the four signal, three duration, and three background noise level conditions.

Data from the reference battery of 24 ability tests were intercorrelated and factor analyzed by means of a principal components solution. Those components whose eigenvalues were greater than one ($> 1$) were then subjected to orthogonal rotation according to a varimax criterion.

To determine the role played by abilities in the individual differences observed in criterion performance, the loadings of various criterion conditions were then estimated on the rotated factor structure defined by the reference battery. Projections were obtained following procedures developed by Dwyer (1937) and extended by Mosier (1938) and Stoloff (1973).

## RESULTS

### Criterion Data

The mean percentage of signals correctly identified by all subjects during the training session is shown in Figure 1 as a function of trial block. Each block consists of two test trials, eight signal presentations occurring within each trial. In the first trial block (2+4) 55.6% of the signals were classified correctly, while by the end of training (block 14+16) accuracy had improved to 70.3%. This level of proficiency was maintained in the 5-trial test following training (Mean = 71.2%) and a similar level (Mean = 70.1%) was obtained on the following day under the task condition most closely resembling that used during training (i.e., nine seconds, -5dB). In this respect the training regimen served its purpose. Subjects attained an average level of proficiency which was judged high enough to permit subsequent evaluation of performance under degraded task conditions. Annett (1971) reports similar improvements in a group of British university students who received longer training under slightly more difficult conditions.

The degradation in performance which occurred under various task conditions is shown in Figure 2. Performance ranged from 78.4% during the identification of cargoship signals presented for six seconds under minimal background noise, to 44.3% for submarine signals presented for six seconds against high background noise.

Results of an analysis of variance conducted on the performance criterion data are summarized in Table 2. The analysis indicates that the signal duration and signal-to-noise ratio parameters which were manipulated, as well as the signal categories, had an interactive effect upon identification accuracy. Performance was significantly affected by an interaction between signal category and level of background masking noise (df = 6,756; $f = 14.62$; $p < .0005$). It was also affected marginally by an interaction between signal duration and background noise intensity (df = 4,504; $f = 2.59$; $p < .05$).

The "signal category by masking noise" interaction is portrayed in Figure 3. Post hoc Tukey tests conducted on these data indicate that differences in performance associated with different signal types decrease as the level of background noise increases. Under the lowest level of masking noise used (i.e., -5dB) each signal category differed from every other category in terms of accuracy of identification. Cargoships were identified

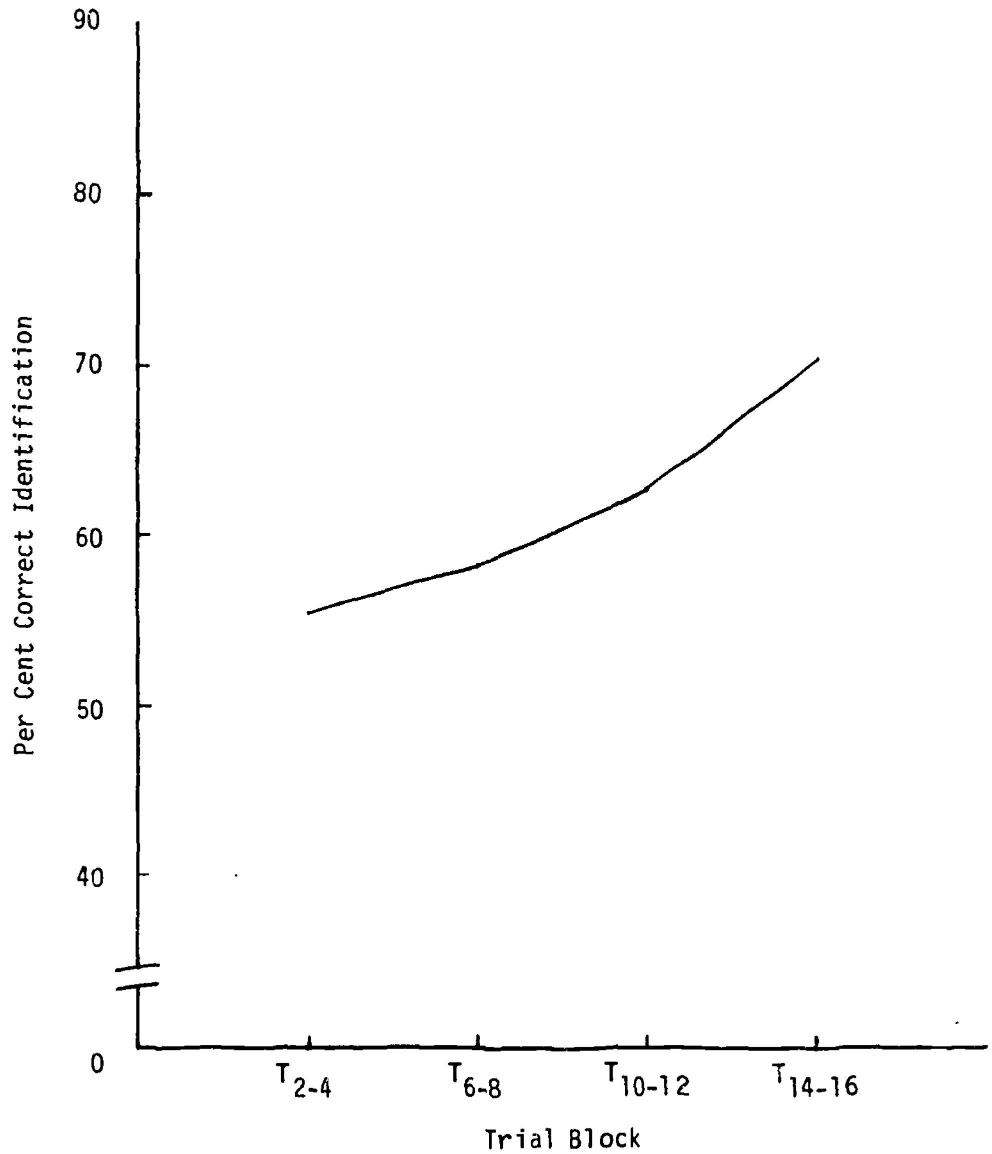


Figure 1. Signal identification accuracy during training as a function of trial block.

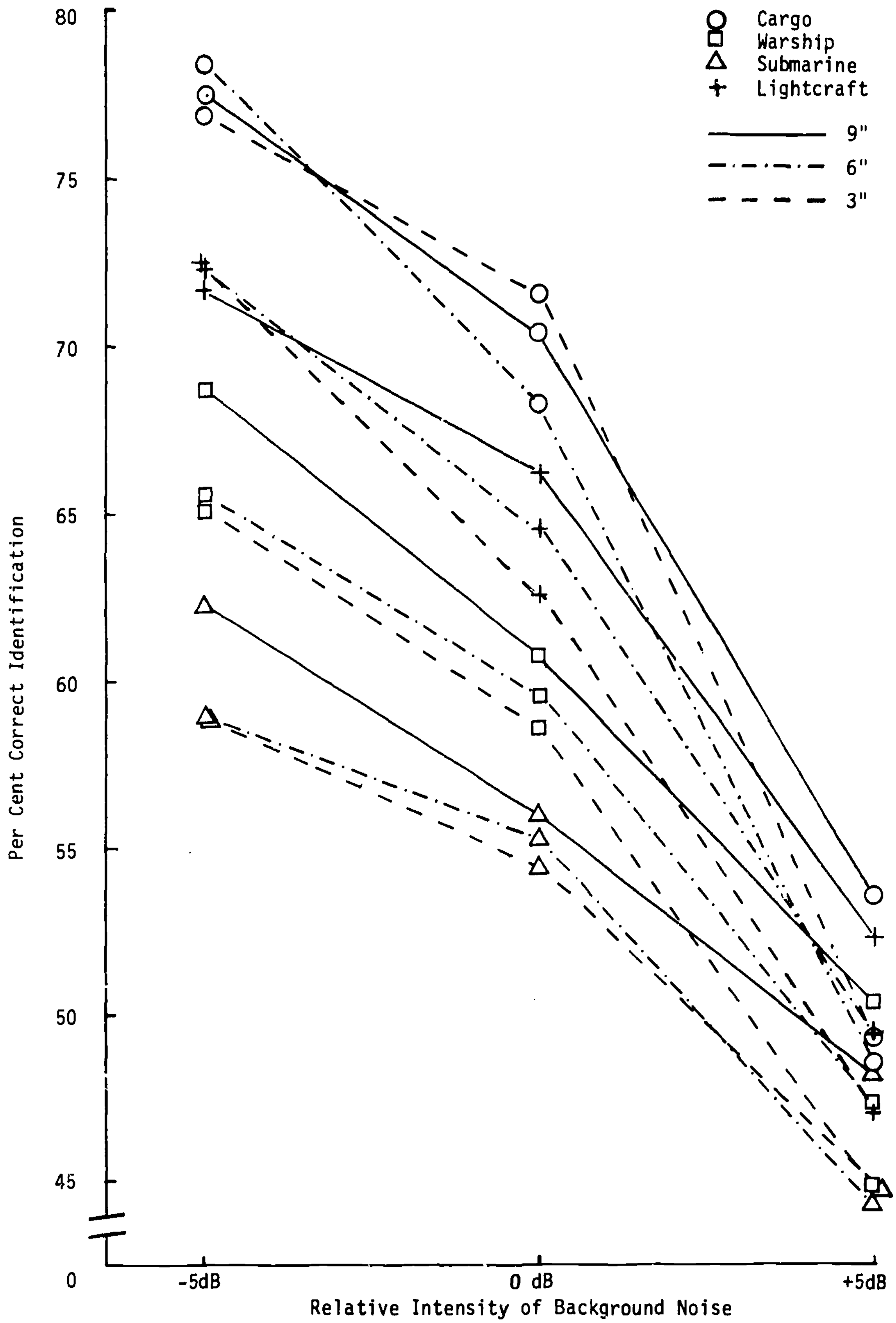


Figure 2. Identification accuracy as a function of task conditions.

TABLE 2

ANALYSIS OF VARIANCE OF CRITERION DATA

| Source | Sum of Squares | df | Mean Square | F |
|---|---|---|---|---|
| Subjects | 53092.00 | 126 | 421.36 | |
| C(signal categories) | 6113.67 | 3 | 2037.89 | 19.67* |
| Cxsubjects | 39160.89 | 378 | 103.60 | |
| D(signal durations) | 380.72 | 2 | 190.36 | 20.38* |
| Dxsubjects | 2354.33 | 252 | 9.34 | |
| N(noise levels) | 21297.11 | 2 | 10648.55 | 493.10* |
| Nxsubjects | 5442.02 | 252 | 21.60 | |
| CxD | 61.95 | 6 | 10.32 | 1.59 |
| CxDxsubjects | 4920.12 | 756 | 6.51 | |
| CxN | 1194.54 | 6 | 199.09 | 14.62* |
| CxNxsubjects | 10293.51 | 756 | 13.62 | |
| DxN | 107.66 | 4 | 26.92 | 2.59+ |
| DxNxsubjects | 5239.97 | 504 | 10.40 | |
| CxDxN | 139.47 | 12 | 11.62 | 1.70 |
| CxDxNxsubjects | 10358.73 | 1512 | 6.85 | |
| TOTAL | | 4571 | | |

* $p < .0005$

+ $p < .05$

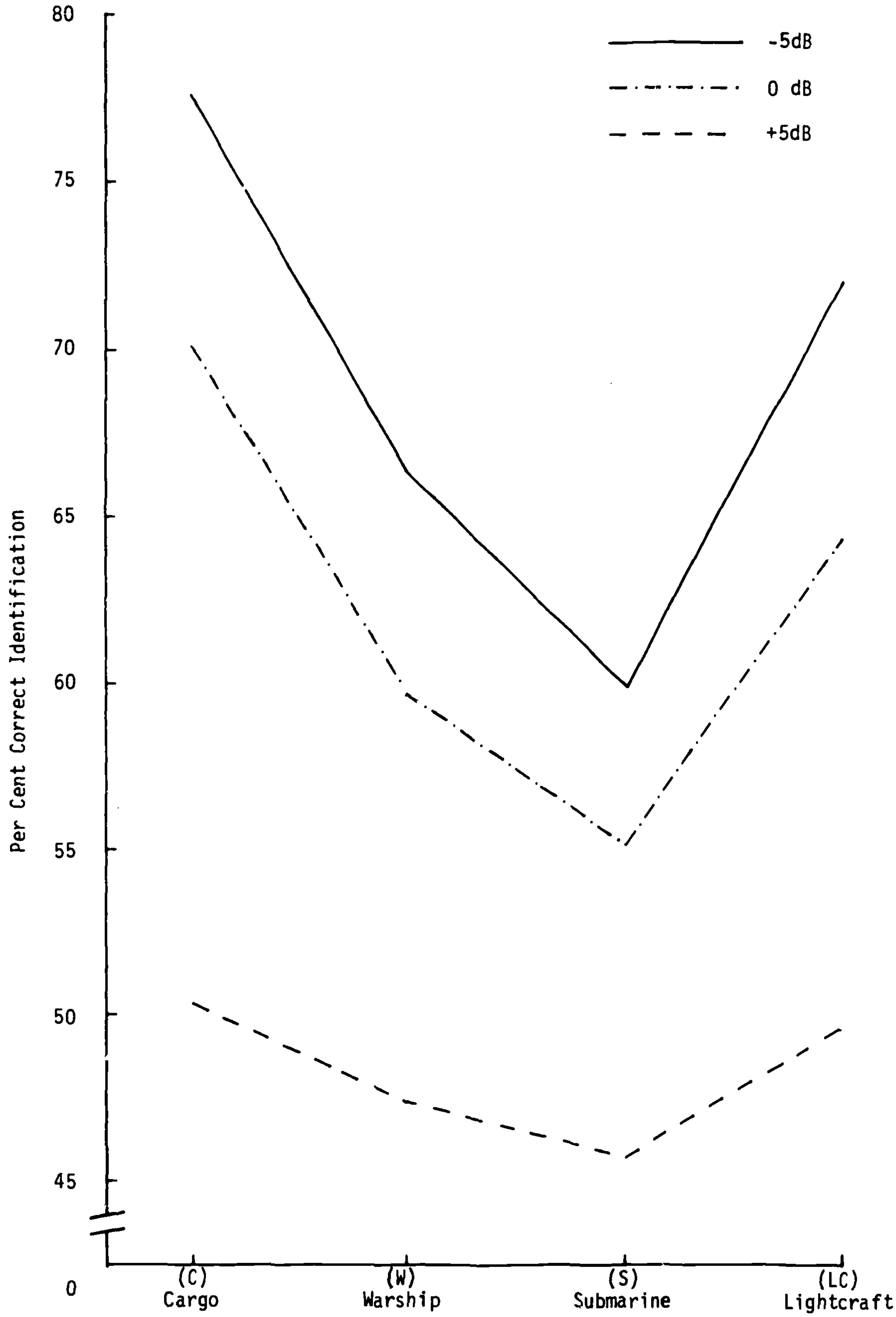


Figure 3. Interactive effect of signal category and background noise on identification performance.

more often than lightcraft ($p < .05$) or warships and submarines ($p < .01$). Lightcraft were identified more frequently than warships ($p < .05$) or submarines ($p < .01$), and warships were in turn identified with greater accuracy than submarines ($p < .01$). Under the highest level of background noise, however, none of these distinctions was significant ($p > .05$). Within each category the three levels of background noise had significantly different effects upon identification performance ($p < .01$).

Effects of the "stimulus duration by background noise" interaction on signal identification are shown in Figure 4. Tukey tests performed on these data tend to indicate that longer signal durations may promote increasingly better identification performance as background noise increases in intensity. Specifically, under high background noise (i.e., +5dB) identification of signals presented for nine seconds was significantly better than for those lasting for six or three seconds ($p < .01$). The more salient aspect of these data, however, is the general ordering of performance in terms of signal duration. Single degree-of-freedom F-tests conducted on the duration main effect show performance to be generally better for nine-second signals as opposed to those of shorter duration ($p < .0005$). Differences between six- and three-second data were not significant ($p > .05$).

In summary, subjects learned to discriminate the four kinds of signals used in this study with a reasonable degree of accuracy when the signals were presented under optimum conditions. Manipulation of task parameters degraded criterion task performance. Task difficulty was increased when signals were presented for durations shorter than nine seconds. Difficulty also varied as a function of the type of signal presented and the amount of background noise in that presentation.

Reference Battery Data

The intercorrelations among reference tests are presented in Table 3. Intercorrelations among the printed tests (1-15) are fairly modest, while those among the aural tests (16-24) appear to be somewhat more substantial. Correlations between the two subsets of measures are generally low, although the Locations (2) and Concealed Figures (10) tests covary significantly with several of the auditory measures.

Six major factors were extracted from the reference battery matrix using a principal components solution. Orthogonal rotations of the vectors

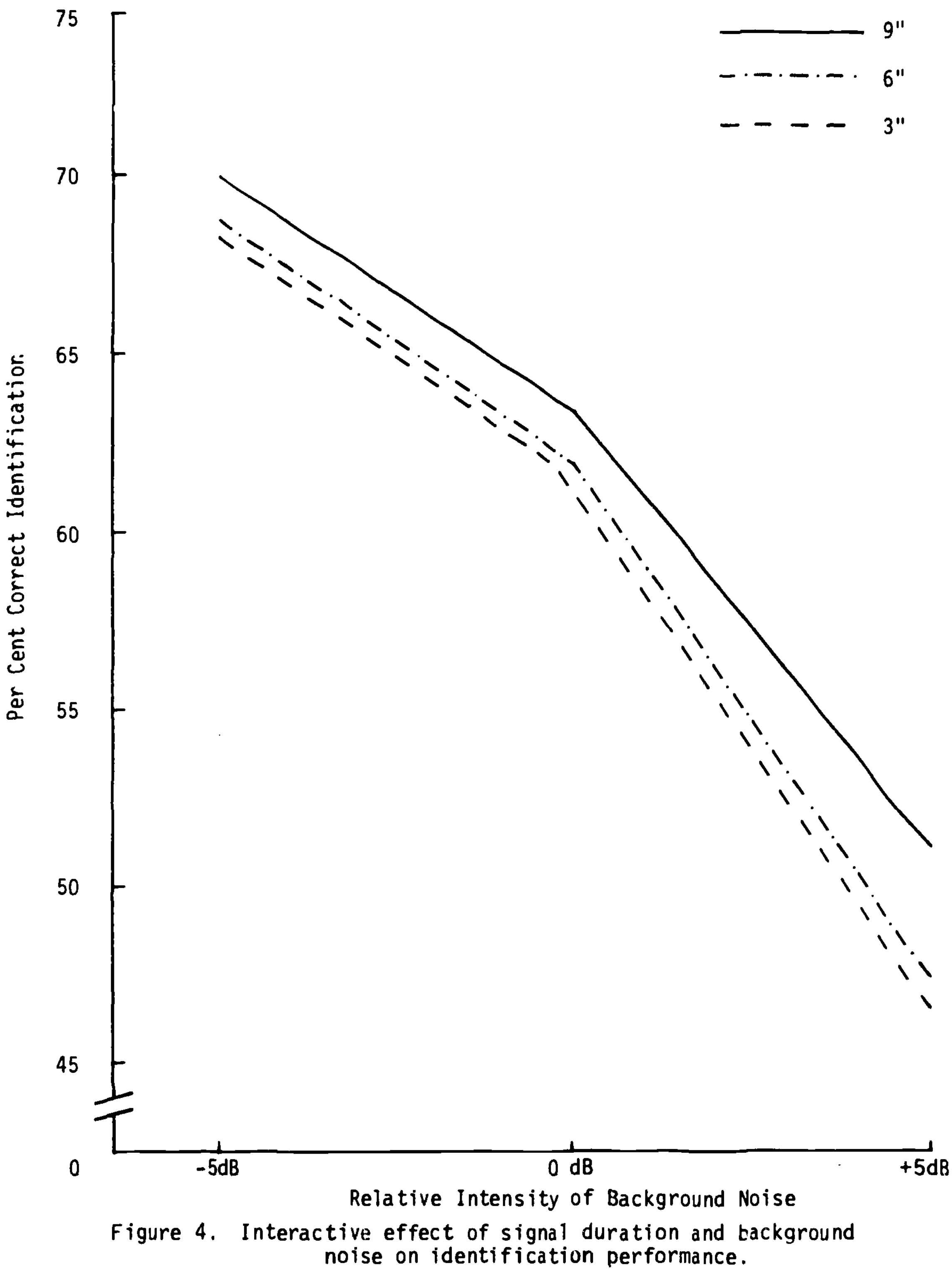


Figure 4. Interactive effect of signal duration and background noise on identification performance.

TABLE 3

MATRIX OF INTERCORRELATIONS* AMONG REFERENCE TESTS
(N = 127)

| | Reference Tests 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Letter Sets | - | | | | | | | | | | | | | | | | | | | | | | | |
| 2. Locations | 22 | - | | | | | | | | | | | | | | | | | | | | | | |
| 3. Fig. Classif. | 33 | 40 | - | | | | | | | | | | | | | | | | | | | | | |
| 4. Object-Number | 02 | 08 | 05 | - | | | | | | | | | | | | | | | | | | | | |
| 5. Picture-Number | 01 | 13 | 07 | 53 | - | | | | | | | | | | | | | | | | | | | |
| 6. First & Last Names | 12 | 03 | 04 | 54 | 52 | - | | | | | | | | | | | | | | | | | | |
| 7. Gestalt Completion | 17 | 21 | 34 | 25 | 29 | 28 | - | | | | | | | | | | | | | | | | | |
| 8. Concealed Words | 18 | 07 | 11 | 16 | 05 | 23 | 40 | - | | | | | | | | | | | | | | | | |
| 9. 4-Letter Words | 16 | 10 | 15 | 29 | 25 | 19 | 31 | 32 | - | | | | | | | | | | | | | | | |
| 10. Concealed Figs. | 30 | 37 | 39 | 16 | 20 | 04 | 39 | 29 | 25 | - | | | | | | | | | | | | | | |
| 11. Copying | 21 | 21 | 24 | 15 | 29 | -04 | 21 | 10 | 33 | 59 | - | | | | | | | | | | | | | |
| 12. Designs | 22 | 20 | 08 | 15 | 18 | 13 | 11 | 18 | 30 | 51 | 55 | - | | | | | | | | | | | | |
| 13. Number Comparison | 24 | 04 | 01 | 15 | 05 | 13 | -13 | 17 | 25 | 09 | 15 | 28 | - | | | | | | | | | | | |
| 14. Identical Pics. | 22 | 31 | 26 | 09 | 09 | -07 | 29 | 14 | 34 | 58 | 50 | 45 | 21 | - | | | | | | | | | | |
| 15. Finding A's | 16 | 21 | 11 | 12 | 12 | 18 | 16 | 10 | 27 | 35 | 25 | 37 | 25 | 26 | - | | | | | | | | | |
| 16. Pitch | 09 | 20 | 19 | 12 | 12 | 16 | 24 | 11 | 01 | 24 | 04 | -06 | -08 | 07 | 00 | - | | | | | | | | |
| 17. Loudness | 20 | 03 | 01 | 02 | -04 | 03 | -07 | 17 | 04 | -02 | -02 | -07 | 19 | 02 | 05 | -05 | - | | | | | | | |
| 18. Time | 20 | 25 | 05 | 20 | 11 | 21 | 12 | 08 | 10 | 17 | 04 | 14 | 21 | 13 | 10 | 24 | 25 | - | | | | | | |
| 19. Timbre | 06 | 24 | 11 | 18 | 09 | 18 | 14 | 16 | 15 | 19 | 14 | 16 | 09 | 17 | 12 | 31 | 16 | 35 | - | | | | | |
| 20. Tonal Memory | -01 | 23 | 17 | 12 | 02 | 07 | 22 | 16 | 07 | 24 | 14 | 06 | -02 | 14 | 06 | 61 | -07 | 23 | 34 | - | | | | |
| 21. Rhythm | -09 | 19 | 18 | 07 | 08 | 08 | 00 | 06 | -02 | 04 | 06 | 14 | 01 | 06 | 12 | 24 | -03 | 20 | 41 | 37 | - | | | |
| 22. Hidden Tunes | 06 | 28 | 20 | 23 | 24 | 13 | 25 | 13 | 07 | 21 | 05 | -06 | 06 | 13 | 12 | 54 | 07 | 26 | 35 | 58 | 47 | - | | |
| 23. Code Distraction | 24 | 31 | 33 | 25 | 18 | 19 | 21 | 18 | 11 | 37 | 18 | 14 | -01 | 26 | 14 | 43 | 13 | 42 | 26 | 39 | 29 | 57 | - | |
| 24. Kwalwasser | 07 | 26 | 22 | 22 | 20 | 15 | 31 | 14 | 13 | 29 | 16 | 15 | 01 | 20 | 15 | 52 | -05 | 31 | 38 | 53 | 44 | 62 | 51 | - |

r ≥.174, p ≤.05
r ≥.206, p ≤.01
r ≥.228, p ≤.005

*Rounded to two places, decimals omitted.

defining these components were made. Table 4 presents the rotated factor loadings obtained using a varimax criterion. Factors were interpreted for psychological meaningfulness from the projections of the reference tests on the rotated axes. The algebraic signs of loadings for factors II, V, and VI have been reflected to aid in interpretation.

Factor I is defined readily from its high loadings on the aural tests as an Auditory Perceptual factor. It is defined by both basic perceptual (e.g., Pitch) and more complex auditory measures (e.g., Hidden Tunes). The factor seems to involve the ability to make auditory discriminations between pairs of tones or tonal patterns. Best definers of Factor I were tests called Hidden Tunes, Tonal Memory, Kwalwasser, and Pitch. The lower loadings on the Time and Loudness tests suggest that the factor may not extend to tests requiring comparative judgments about stimulus intensity or duration.

Factor II is defined primarily from its high loadings on the Concealed Figures, Copying, and Designs tests as a Flexibility of Closure factor. It seems to involve the ability to identify specific configurations in a complex perceptual field containing irrelevant or distracting material. Although French, et al. (1963) designate the same three measures as the best definers of a Flexibility of Closure factor, the substantial loadings of the Number Comparison, Identical Pictures, and Finding A's tests (often used to define a Perceptual Speed factor) suggest that Factor II may be somewhat broader than that defined by French, et al.

Factor III is readily defined from high loadings on the Object-Number, Picture-Number, and First & 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 in terms of its loadings on the Gestalt Completion, Concealed Words, and 4-Letter Words tests. It is the Speed of Closure factor as defined by French, et al., and it represents the ability to unify a complex perceptual field.

Factor V is defined primarily in terms of reasoning tests. Tests having the highest loadings are Letter Sets, Locations, and Figure Classification. French, et al. have designated these same three measures as 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.

TAPLE 4

ROTATED FACTOR MATRIX

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

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

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

Factor VI is not readily interpretable. It has reasonably high loadings on two printed tests (i.e., Letter Sets and Number Comparison) and on two auditory measures (i.e., Loudness and Time). It is the only factor which has substantial loadings on tests from both the printed and aural subsets, making it of particular interest. For the present, however, it must remain undefined.

Projection of Criterion Data on Reference Factors

Intercorrelations of the ability reference tests with the acquisition and performance measures are presented in Table 5. With few exceptions the printed reference tests (1-15) do not correlate significantly with the acquisition data (1-5). One notable exception is the Gestalt Completion test (7). The aural reference tests (16-24) show more frequent and stronger zero-order correlations with these same learning data. The same general patterns hold true for the performance measures representing the nine experimental conditions and also for the summary measures, summed across durations or noise levels. Among the printed tests only the Gestalt Completion (7) and Concealed Figures (10) tests bear a strong and consistent relationship to these measures. Again, aural tests appear to be of greater relevance. This is particularly true of the Timbre (19), Hidden Tunes (22), and Code Distraction (23) tests. These relationships become clearer upon examination of the projected loadings of the acquisition and performance measures on the factor structure underlying the reference battery.

Estimated Loadings for Acquisition Data. As shown in Table 6 the most general finding with respect to the acquisition measures (variables 1-5) is the rather small percentage of variance ($h^2$) which is accounted for by the set of reference factors. Even with such small communalities, however, trends are evident across acquisition trials. The clearest of these is the increasing contribution of the Auditory Perceptual factor (I) to individual differences in the acquisition of signal identification skill. The increase is from an estimated loading of 0.16 ($p < .10$) at $T_{2-4}$, to a loading of 0.25 ($p < .01$) at $T_{14-16}$. Contributions of the remaining five factors to individual differences in skill acquisition are rather small but stable across trial blocks. There is no evidence of a change in the pattern of abilities related to identification performance across training trials.

TABLE 5

MATRIX OF INTERCORRELATIONS* AMONG REFERENCE TESTS AND CRITERION VARIABLES
(N = 127)

| Criterion Variables | Reference Tests | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 1. Trial 2-4 | -01 | -09 | 04 | 10 | -07 | 15 | 21 | 07 | -06 | 04 | -17 | -10 | -05 | -05 | -02 | 10 | 12 | 08 | 14 | 14 | 06 | 19 | 07 | 08 |
| 2. Trial 6-8 | 14 | 02 | 14 | 12 | -01 | 13 | 20 | 17 | 03 | 15 | -03 | -06 | -06 | 12 | 05 | 04 | 00 | 24 | 13 | 19 | 03 | 18 | 27 | 16 |
| 3. Trial 10-12 | 02 | 09 | 02 | 13 | 09 | 13 | 21 | 12 | -01 | 15 | -06 | -09 | -03 | 08 | 08 | 12 | 12 | -03 | 20 | 16 | 03 | 24 | 23 | 18 |
| 4. Trial 14-16 | -02 | 04 | -07 | 01 | -04 | 02 | 12 | 08 | -09 | 07 | -07 | -13 | -07 | 03 | -05 | 05 | 12 | 07 | 17 | 23 | 15 | 26 | 24 | 13 |
| 5. Test (T16-20) | 03 | 08 | 01 | 14 | 05 | 06 | 23 | 11 | 01 | 20 | 08 | -03 | 02 | 14 | 04 | 10 | 16 | 12 | 28 | 21 | 16 | 33 | 29 | 22 |
| 6. 9", -5dB | 11 | 16 | 02 | 15 | 01 | 02 | 20 | 15 | -04 | 23 | -02 | -07 | 01 | 13 | 01 | 18 | 21 | 13 | 31 | 21 | 14 | 36 | 29 | 25 |
| 7. 9", 0dB | 11 | 08 | -04 | 17 | 02 | 03 | 19 | 10 | -11 | 25 | 04 | 02 | -02 | 07 | 06 | 21 | 11 | 18 | 28 | 20 | 12 | 34 | 32 | 27 |
| 8. 9", +5dB | 06 | 07 | -02 | 00 | -02 | -03 | 15 | 12 | -11 | 19 | 06 | 07 | -05 | 08 | 17 | 16 | 16 | 18 | 32 | 21 | 24 | 32 | 25 | 30 |
| 9. 6", -5dB | 05 | 21 | 09 | 19 | 12 | 06 | 19 | 06 | -05 | 24 | 03 | -03 | -09 | 14 | 04 | 18 | 19 | 15 | 25 | 21 | 14 | 37 | 32 | 27 |
| 10. 6", 0dB | 09 | 16 | 07 | 15 | 08 | 06 | 17 | 12 | -08 | 27 | 09 | -01 | -01 | 14 | 06 | 16 | 22 | 14 | 36 | 19 | 20 | 32 | 31 | 31 |
| 11. 6", +5dB | 09 | 11 | -01 | 14 | 09 | 01 | 25 | 04 | -07 | 18 | -01 | -04 | -06 | 07 | 13 | 21 | 13 | 25 | 31 | 21 | 24 | 34 | 32 | 31 |
| 12. 3", -5dB | 06 | 09 | -03 | 16 | 11 | 06 | 16 | 09 | -10 | 14 | -01 | -08 | -07 | 05 | 01 | 14 | 17 | 13 | 27 | 19 | 22 | 36 | 30 | 24 |
| 13. 3", 0dB | 06 | 15 | 07 | 14 | 05 | 02 | 22 | 09 | -06 | 21 | 01 | -09 | -04 | 17 | 07 | 24 | 18 | 14 | 33 | 24 | 19 | 41 | 33 | 35 |
| 14. 3", +5dB | 08 | 12 | 04 | 10 | 10 | 00 | 14 | -03 | -07 | 20 | 05 | 00 | -03 | 07 | 08 | 25 | 08 | 21 | 38 | 29 | 27 | 32 | 25 | 32 |
| 15. 9" | 10 | 12 | -01 | 12 | 01 | 01 | 19 | 13 | -09 | 24 | 02 | 00 | -02 | 10 | 08 | 20 | 17 | 17 | 32 | 22 | 18 | 37 | 31 | 29 |
| 16. 6" | 09 | 18 | 06 | 17 | 10 | 05 | 22 | 08 | -07 | 25 | 04 | -03 | -06 | 13 | 08 | 20 | 21 | 19 | 34 | 22 | 21 | 37 | 35 | 32 |
| 17. 3" | 07 | 13 | 02 | 15 | 09 | 03 | 20 | 07 | -08 | 20 | 02 | -07 | -05 | 10 | 05 | 22 | 16 | 17 | 35 | 25 | 24 | 40 | 32 | 33 |
| 18. -5dB | 08 | 16 | 03 | 17 | 08 | 05 | 19 | 11 | -06 | 21 | 00 | -06 | -05 | 11 | 02 | 17 | 20 | 14 | 29 | 21 | 17 | 38 | 31 | 26 |
| 19. 0dB | 09 | 14 | 04 | 16 | 05 | 04 | 21 | 11 | -09 | 26 | 05 | -03 | -03 | 13 | 07 | 21 | 18 | 16 | 34 | 22 | 18 | 38 | 34 | 33 |
| 20. +5dB | 08 | 12 | 00 | 08 | 05 | -01 | 20 | 05 | -09 | 21 | 03 | 01 | -06 | 07 | 15 | 23 | 13 | 23 | 36 | 26 | 28 | 36 | 30 | 34 |
| 21. TOTAL | 08 | 13 | 02 | 14 | 04 | 01 | 19 | 08 | -10 | 21 | 01 | -07 | -06 | 09 | 03 | 22 | 19 | 20 | 34 | 23 | 22 | 38 | 33 | 32 |

*Rounded to two places; decimals omitted; $r \geq .174$, $p \leq .05$; $r \geq .228$, $p \leq .01$.

TABLE 6

ESTIMATED FACTOR LOADINGS* OF CRITERION VARIABLES ON REFERENCE FACTOR STRUCTURE

| Criterion Variable | I | II | III | IV | V | VI | $h^2$ | R |
|---|---|---|---|---|---|---|---|---|
| | | | Factors | | | | | |
| 1. T2-4 | 16 | -17 | 05 | 16 | 01 | 06 | 09 | 29 |
| 2. T6-8 | 17 | -05 | 06 | 16 | 17 | 08 | 09 | 31 |
| 3. T10-12 | 19 | -06 | 10 | 14 | 09 | 02 | 08 | 28 |
| 4. T14-16 | 25 | -11 | -04 | 07 | 03 | 05 | 09 | 29 |
| 5. Test (T16-20) | 29 | 03 | 05 | 11 | 08 | 09 | 11 | 33 |
| 6. 9", -5dB | 31 | -04 | 01 | 12 | 14 | 14 | 16 | 39 |
| 7. 9", 0dB | 32 | 00 | 04 | 06 | 11 | 09 | 13 | 36 |
| 8. 9", +5dB | 35 | 05 | -07 | 03 | 04 | 11 | 15 | 39 |
| 9. 6", -5dB | 30 | -02 | 09 | 02 | 21 | 06 | 15 | 39 |
| 10. 6", 0dB | 33 | 03 | 05 | 04 | 15 | 13 | 15 | 39 |
| 11. 6", +5dB | 36 | -03 | 06 | 01 | 12 | 10 | 16 | 40 |
| 12. 3", -5dB | 32 | -07 | 09 | 03 | 08 | 09 | 13 | 36 |
| 13. 3", 0dB | 39 | -03 | 02 | 07 | 16 | 08 | 19 | 43 |
| 14. 3", +5db | 40 | 03 | 03 | -06 | 09 | 06 | 18 | 42 |
| 15. 9" | 35 | 00 | -01 | 08 | 11 | 13 | 16 | 40 |
| 16. 6" | 36 | -01 | 07 | 02 | 18 | 11 | 18 | 42 |
| 17. 3" | 39 | -04 | 06 | 02 | 12 | 08 | 18 | 43 |
| 18. -5dB | 33 | -05 | 06 | 06 | 15 | 11 | 15 | 39 |
| 19. 0dB | 36 | 00 | 04 | 06 | 15 | 11 | 17 | 41 |
| 20. +5dB | 41 | 02 | 00 | 00 | 09 | 10 | 19 | 43 |
| 21. TOTAL | 38 | -05 | 02 | 04 | 13 | 12 | 18 | 43 |

*Loadings rounded to two places; decimals omitted.

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

Estimated Loadings for Performance Data. Inspection of the communalities ($h^2$) shown in Table 6 for the criterion task conditions (variables 6-21) indicates that roughly twice as much variance is being accounted for in these measures relative to those studied during acquisition. Examination of the nine basic experimental conditions (variables 6-14) shows that only one of the six factors is an especially significant contributor to individual differences in signal identification. That factor is again Auditory Perception (I).

Within each signal duration the loadings on Factor I increase as the background noise increases. The same is generally true within each background noise level where Factor I loadings increase as signal durations grow shorter. In other words, the contribution of Factor I to individual differences in signal identification increases as the criterion task becomes more difficult. This relationship is seen more clearly upon examination of Factor I loadings presented in Table 6 for the pooled criterion conditions (variables 15-20).

The criterion task conditions generally have very small and stable loadings on the remaining five factors. The only other significant loadings occur on the Induction factor (V). These, however, appear to be neither as strong nor as consistent as those associated with Factor I.

Similar analyses were conducted to determine how the various task conditions loaded on the reference factor structure when each signal category was considered separately. Generally, within each signal type (i.e., cargo, lightcraft, warship, and submarine), the 9-second, 6-second, and 3-second conditions showed the same slight increase in loadings on the Auditory Perceptual factor (I) as signal duration decreased. Loadings of the background noise conditions (i.e., -5dB, 0dB, and +5dB) on Factor I did not, however, behave similarly across signal categories. As shown in Figure 5, the loadings increased for the cargo and lightcraft signals and decreased for the warship and submarine signals. The identification accuracy for each of these signals is shown in Figure 2.

Examination of the loadings for the duration and background noise conditions on the Induction factor (V) also revealed apparent differences among signal types. In this case, however, different trends for the cargo and lightcraft versus the warship and submarine signals were not as readily discernable. Each signal appeared to have a slightly different pattern of loadings as duration decreased or background noise increased. Considered signal by signal, none of the criterion conditions loaded significantly on any of the remaining factors.

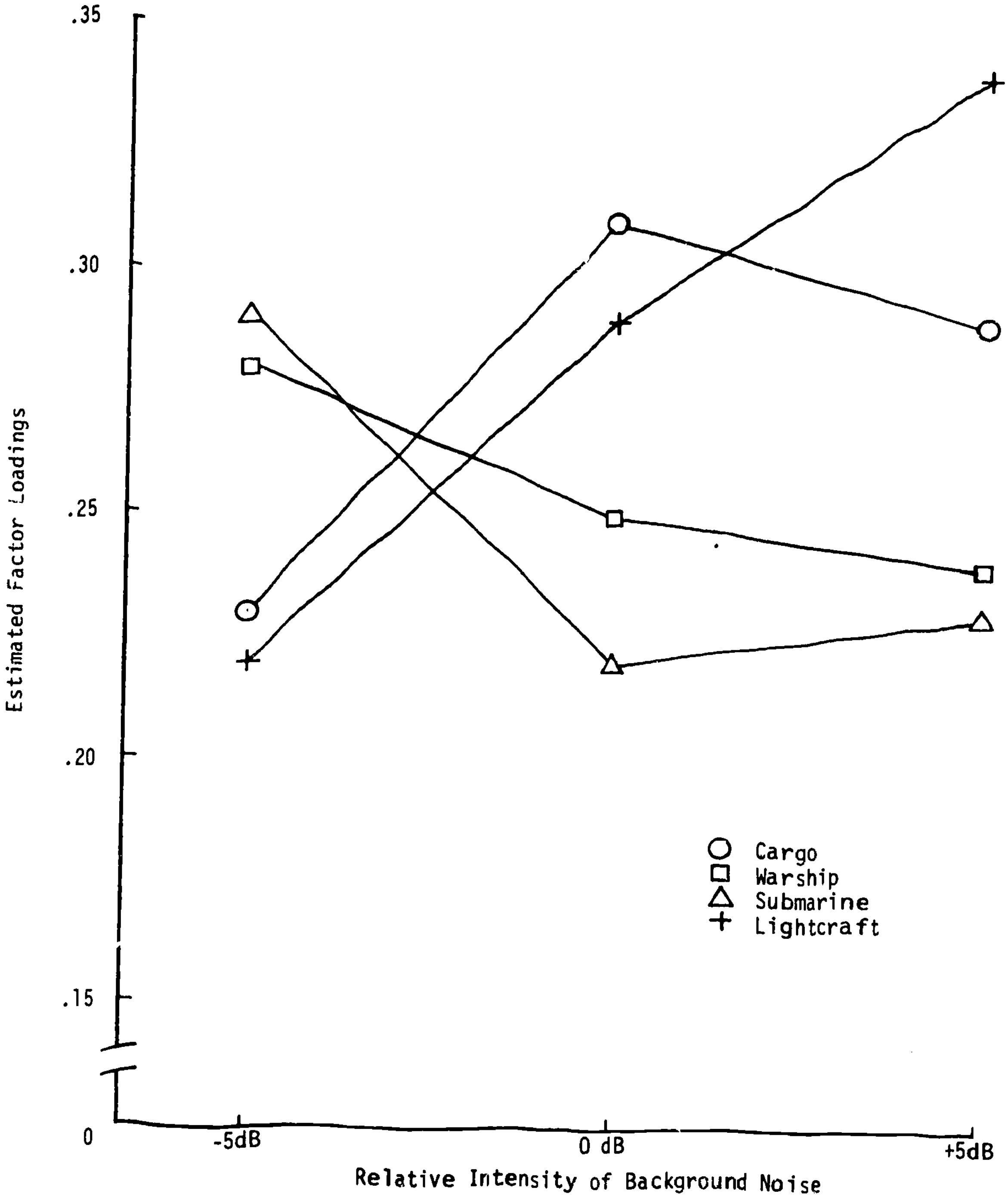


Figure 5. Estimated loadings of the four signal categories on the Auditory Perceptual factor (I) as a function of background noise level.

Estimated Loadings for Easy and Difficult Signals. Given the possibility that important patterns of loadings were being masked when all signal categories were combined (Table 6), two new sets of scores were created for each individual. These simply represented performance under every task condition, on the easier (e.g., cargo + lightcraft) and on the more difficult signals (e.g., submarine + warship). Using these two measures, the loadings of the three duration and three noise conditions were estimated for the Auditory Perceptual (I) and Induction (V) factors. Loadings on both factors have been plotted in Figure 6 for the duration variable and Figure 7 for the noise variable. In both cases a loading equal to or greater than .174 is significant ($p < .05$).

The loadings shown in Figure 6 for the different conditions of signal duration on the Auditory Perceptual factor (I) behave similarly for both easy and difficult signals. While loadings associated with the easy signals are somewhat higher, the loadings for both easy and difficult signals show a slight increase as signal duration decreases. This trend parallels that presented in Table 6 for the overall analysis. Referring to Figure 6 again, however, the loadings on Factor V differ as a function of easy or difficult signals. Loadings increase on easy signals and decrease on difficult signals as signal duration grows shorter. The decrease in loadings for difficult signals between nine and three seconds is significant ($p < .01$) as is the difference between easy and hard signals at three seconds ($p < .025$).

As may be seen in Figure 7, it is the Auditory Perceptual factor (I) which shows different trends for difficult and easy signals as background noise increases. The loadings on Factor I increase for easy signals and decrease for difficult signals. The increase in loadings from -5dB to +5dB for the easy signals is significant ($p < .05$). The loadings for the difficult and easy signals on the Induction factor (V) parallel each other and together mirror the decrease in loadings seen in the overall analysis (Table 6) for increasing background noise.

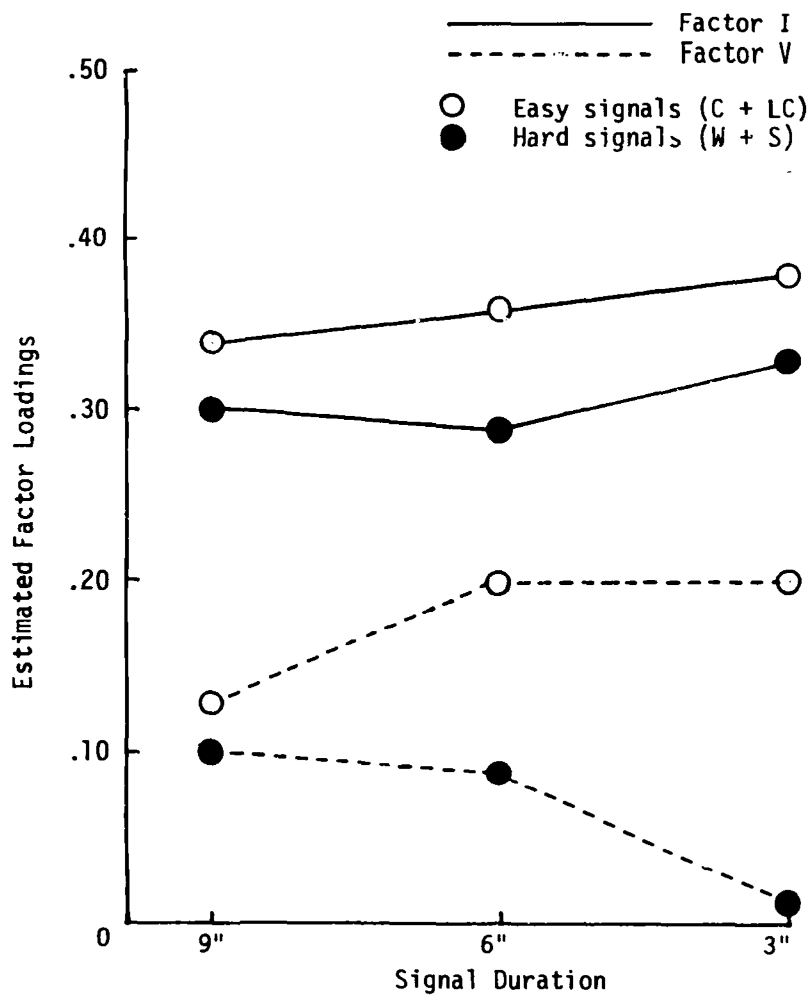


Figure 6. Estimated factor loadings of easy and hard signals on the Auditory Perceptual (I) and Induction (V) factors as a function of signal duration.

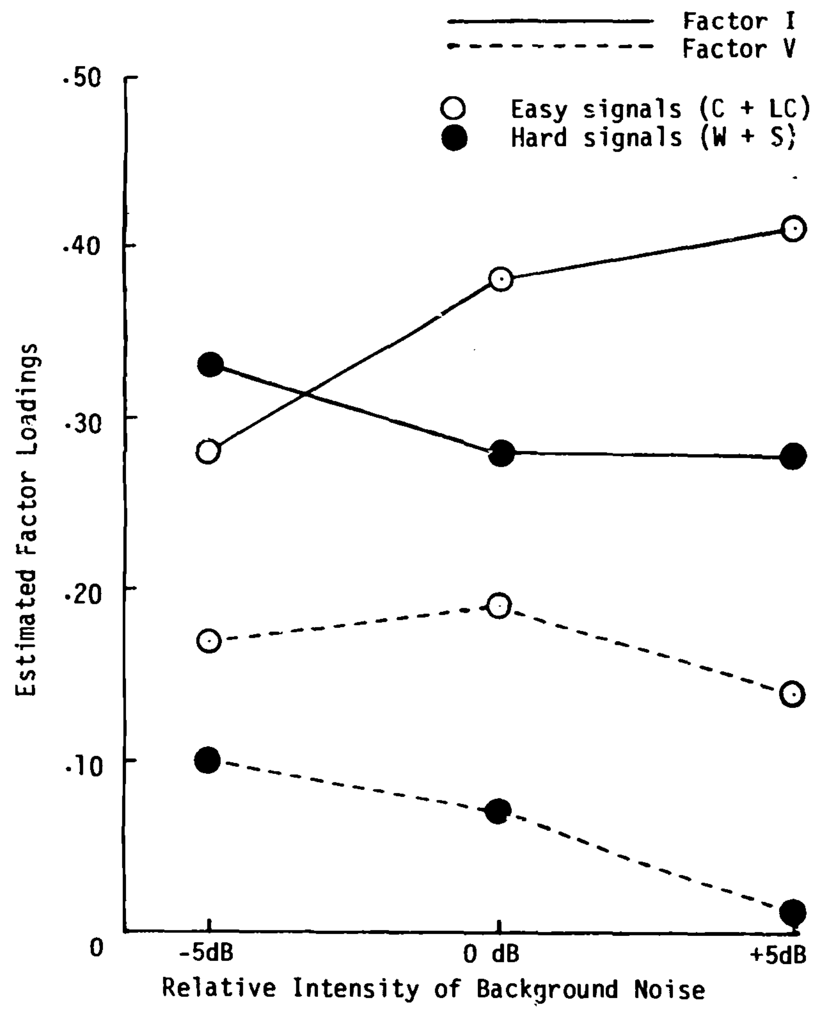


Figure 7. Estimated factor loadings of easy and hard signals on the Auditory Perceptual (I) and Induction (V) factors as a function of background noise.

## DISCUSSION AND CONCLUSIONS

The present research was undertaken to explore the effect which variations in the characteristics of a criterion task may have on the pattern(s) of abilities which account for individual differences in performance under the various task conditions. While few experimental and correlational studies of this type have been conducted, the data which they have provided (and can potentially supply) are of great value. Given such data it may be possible to generate a set of principles matching the features of a job to those capabilities and capacities which a successful job incumbent should possess. In other words, such principles would provide a basis for translating information about the specific nature of the job or task to be performed into statements about the capabilities which operators should possess in order to perform effectively.

The specific task chosen in order to address these issues involved identification of a set of auditory signals. Variations in the characteristics of this task were introduced by systematically manipulating signal duration and signal-to-noise ratio. Choice of this kind of task provided an opportunity to extend the general findings of previous studies which had not dealt with the auditory perceptual area. At the same time, the specific form of the task which was used permitted collection of data of possible relevance to the task of passive sonar operation. With these considerations in mind there are several aspects of the study which are of either general or more specific interest.

With respect to the general methodological issues addressed by the study, the crux of the results lies in the estimated loadings of the different criterion task conditions on the reference factor structure. Generally speaking, changes in these loadings occur as a function of the signal duration and signal-to-noise ratio manipulations. As either of these task characteristics is varied so as to increase task difficulty, the loadings on some but not all of the reference factors change accordingly.

The nature of the change in factor loadings which arises as task characteristics are varied differs from that found in previous studies. The difference lies in a systematic change in the magnitude of the loadings of a set of abilities as opposed to a change in the pattern of abilities involved under different task conditions. For example, in the earlier studies both Fleishman (1956) and Zimmerman (1954) found that: (1) several abilities were involved in criterion task performance; and (2) they were differentially involved, specific abilities increasing or decreasing in importance as a function of level of task difficulty. In the present study, however, in spite of the fact that a rational analysis of the criterion task suggested six abilities which should relate to individual differences in performance, the results indicate that performance is primarily a function of the Auditory Perceptual ability. Under certain conditions there is some evidence to suggest that an Induction ability may also be involved. In contrast to the earlier studies, there is no strong evidence to suggest that these or any of the other abilities studied are differentially recruited as a function of task difficulty.

Although the reference battery was quite comprehensive, it is possible that some relevant abilities, which might have differentially increased or decreased in importance as difficulty varied, were not represented in the reference battery used. One can also argue that differential involvement of abilities in task performance is not a necessary outcome of certain kinds of task variations. As long as the same basic task is being performed, the same pattern of abilities can be relevant. Variations in the conditions under which that task is performed, therefore, while contributing to task difficulty, may affect only the degree to which the relevant pattern is involved and not the pattern itself.

The relevant question now is whether one can identify differences in the kinds of task characteristics which were manipulated in this and the earlier studies to vary task difficulty. The display rotations and sequences of maneuvers used by Fleishman and Zimmerman, respectively, seem to differ in at least one important respect from the signal duration and background noise conditions used in the present research. Variations in the kinds of variables which they employed may have changed task difficulty by introducing subtle "intrinsic" variations in the task itself. Were this the case, one might anticipate changes in the pattern of abilities related to different versions of the task. Variations in the kinds of variables used in the current study, however, affected task difficulty by changing the "extrinsic" conditions under which the task was performed, but not the basic task itself. In this case, where there is no change in the nature of the task, the importance of a fixed set of abilities would be expected to wax or wane as difficulty increased or decreased. Specifically, one might anticipate an inverted U-shaped distribution of loadings as the conditions of performance progressed from very easy to very difficult. Under the simplest conditions, all subjects might perform relatively well, despite different levels of ability. Under the most difficult conditions, performance would be generally poor, no matter how much ability a given subject possessed. Between these extremes the advantage would be with those subjects possessing the greatest amount of the relevant abilities.

For instance, in the present study, it would appear that the four signal categories, although not intended to represent a task parameter, actually behaved as extrinsic variables serving to increase or decrease the difficulty of the basic task. The ancillary analyses which examined loadings of the duration and noise variables on the ability factor structure for each signal category (Figure 5) and for easy and difficult signals (Figures 6 and 7) support this view.

Generally these results, coupled with those from the earlier studies, are encouraging with respect to being able to specify the pattern(s) of abilities related to changes in a particular task setting. They indicate that more precise description is required of variations in the basic task which the operator must perform. Equally important, there must be an indication of the range of conditions extrinsic to the task itself under which the operator may have to perform. Principles relating features of the task to be performed to the abilities required must, therefore, be based on variables which reflect the range of difficulty in the conditions of performance as well as the degrees of complexity which the task itself may assume. The results of this study show how this can be done and extend the ability-task characteristics paradigm to auditory perceptual tasks. Other studies in this program are investigating the linkages between abilities and changes in task characteristics relevant to other classes of human task performance.

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