SUMMARY PAGE

PROBLEM: To predict which men will ultimately make the best operators of visual sonar displays in order to provide for most effective manpower allocation.

FINDINGS: This report presents the test results from a battery of visual, perceptual and cognitive measures on 100 experienced sonar technicians. Large individual differences are found.

APPLICATION: Upon completion of the evaluation against the on-board performance of the sonar technicians, the results will be used to predict success as visual sonar technicians.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Naval Medical Research and Development Command Research Work Unit M0100.PN.001-1002 -- "Visual Requirements for operators of visual sonar displays". The manuscript was submitted for review on 18 April 1979, approved for publication on 31 May 1979, and was accepted for publication in Perceptual and Motor Skills where it appeared in volume 50, pp 59-69, 1980. It has been designated as NavSubMedRschLab Report No. 892.

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FACTOR ANALYSIS OF PERCEPTUAL AND COGNITIVE ABILITIES TESTED BY DIFFERENT METHODS[1]

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Summary.—A battery of visual, perceptual, and cognitive tests, believed to be important for operation of visual sonar displays, was administered to 100 sonar technicians. The measures varied from standard paper-and-pencil tests to computer-administered perceptual tasks. The results of 33 different measures on these men were compiled and subjected to a factor analysis. The factors extracted represent cohesive and reasonable groups which cut, to some extent, across testing techniques. However, all of the paper-and-pencil, perceptual-cognitive tests had high loadings on the same common factor, a result with general implications for occupational testing.

A major goal of aptitude testing is the ability to predict which individuals will succeed in a specific occupation. Such information is important for vocational counseling, selection, training, and effective manpower allocation. This type of testing has been widely used in the past and has been particularly successful in government and military settings (Anastasi, 1976; Bemis, 1968; Freeman, 1962; Super, 1962). This study stems from research designed to determine the particular skills and abilities required to become an effective operator of visual sonar displays. These displays are becoming increasingly common; they are very complex and demanding, and require exceptional abilities.

Standard procedures have evolved over the years to address such a question. These are summarized by Anastasi (1976, p. 436) to include (a) job analysis, (b) assembly of trial battery of tests to measure the traits identified in the job analysis, (c) validation against an independent criterion of job success and choice of tests for final battery; and (d) choosing a strategy for personnel decisions based upon the test results. These procedures are being utilized in our work and this paper describes the selection and administration of tests to a group of 100 experienced sonar technicians. The results of validation will be presented in a later report.

METHOD

Test Battery

The test battery was selected on the basis of a questionnaire completed by 17 sonar technicians who identified the traits and abilities which they consider to be fundamental for a successful sonar operator. The literature on occupa-

[1]From Naval Medical Research & Development Command, Navy Department, Research Work Unit M0100-Pn.001-1002. The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Navy Department or the Naval Service at large. Request reprints from Dr. J. A. S. Kinney, Director Vision Department, Naval Submarine Medical Research Lab, Naval Submarine Base, New London, Groton, CT 06340.

tional testing was then surveyed to identify tests which were reported to measure these traits and abilities. In addition, visual tests, which varied from simple measures of ability to assessments of more complex perceptual skills, were selected. The measures included visual screening tests, routine optometric practices, paper-and-pencil tests, and visual displays generated on CRTs.

Tests of Basic Vision

Acuity.—A rapid measure of both monocular and binocular acuity at both near (13 in.) and far (simulated 26 ft.) viewing distances was made using the Ortho-Rater, an instrument used for mass screening.

Phoria.—Measures of vertical and horizontal phoria, both at near and far viewing distances, are included in the Ortho-Rater.

Depth perception.—The ability to perceive three dimensions, based upon binocular disparity alone, is also tested in the Ortho-Rater.

Accommodation.—The ability to focus at close distances was tested with the Prentiss Ruler.

Refraction.—Standard manifest refractions were performed using a Bausch & Lomb Phoropter and an American Optical Co. Projecto-Chart.

Tests of Perceptual and Cognitive Factors

Extensive research on ability and aptitude has evolved the concept of many independent factors. Although the number and degree of independence is a matter of debate, most test batteries employ this concept and agree on many of the underlying factors to be included. Five common factors were included because all sonar technicians agreed that they were important; all are paper-and-pencil tests.

Speed of closure.—The ability to unify an apparently disparate perceptual field into a single percept was measured by the Gestalt Completion Test of Educational Testing Service (French, Ekstrom, & Price, 1963).

Flexibility of closure.—The ability to identify one or more configurations in spite of perceptual distractions was measured by ETS' Hidden Pattern Test.

Spatial orientation.—The ability to perceive spatial patterns or to maintain orientation with respect to objects in space was measured by ETS' Cube Comparison Test.

Perceptual speed.—Speed in finding figures and making visual comparisons and classifications, or quick and accurate grasping of visual details, similarities and differences, was measured by Thurstone and Jeffrey's (1956) Identical Pictures Test.

Induction.—This covers such conceptual abilities as finding general concepts or forming and trying out hypotheses. The test was Figure Classification by ETS.

Perceptual Tests on Visual Displays

Two tests, designed on the basis of current theories of visual perception, were presented on cathode ray tubes. They had obvious face validity for the men, since they were similar in over-all appearance and operation to the visual sonar displays.

Texture discrimination.—Rectangular patterns of random dots subtending $6° \times 8°$ visual angle were computer generated. The distribution of dots in one quadrant of the array was different than that in the other three. Each array was exposed for 1.5 sec. The subject's task was to decide which quadrant was different in 100 different arrays.

The various textures were generated by manipulating the probability that adjacent dots in the matrix would be illuminated or not. Previous work with these textures (Santoro & Fender, 1976) had identified percepts of granularity (varying from fine to coarse) and of directionality (horizontal, vertical or diagonal). On the basis of this work, specific textures were selected to be discriminated. These varied from easy to difficult depending upon whether the discrimination was between textures that differed in granularity or directionality. For example, discrimination between two fine-grained patterns that differ only in directionality is much more difficult than discrimination between a fine-grained and a clumpy pattern.

Contrast sensitivity.—The determination of contrast sensitivity for different spatial frequencies is now widely used to assess visual ability (Campbell & Robson, 1968). Numerous experiments in the past 10 years have led many investigators to hypothesize that the human visual system performs Fourier analyses on incoming stimuli and that these data are the basis for perception of form and pattern (Graham & Nachmias, 1971; Sullivan, Georgeson, & Oatley, 1972; Thomas, 1970).

Five spatial frequencies (.2, .5, 2, 5, and 10 cpd) were each presented at four contrasts, chosen to range from very easy to very difficult. The average luminance was 4.5 cd/m^2, and the display subtended about $10.5 \times 13.5°$ at the observing distance of 114 cm. The order of presentations was randomized and the same for all men.

Non-perceptual Measures

Excellence in operating a visual sonar system presumably requires many traits that are unrelated to vision or to perception, such as general intelligence, experience, good motivation, and a positive attitude. A number of indices were included to assess these components.

General Classification Test and Arithmetic Test.—These standardized measures of verbal and arithmetical aptitudes are qualification measures for acceptance into the sonar program. The scores were obtained from the personnel records of the sonar technicians.

Age and experience.—The age, rating, and years of submarine service were recorded.

Attitude.—One personality characteristic, out of the dozens possible, was chosen for investigation. This was Internal-External Control (Rotter, 1966), the extent to which a person either feels in control of the things which happen to him or feels that events are beyond his control. It was chosen because it has been shown to be related to job performance in the Navy (Broedling, 1974).

Procedure

The men were briefed on the reasons for the research, given identification numbers and a list of the tests in the order they were to be given. To assess reliability, the Gestalt Completion Test, the Cube Comparison Test, and the Hidden Patterns Test have two sections which can be scored separately. The Texture Discrimination and the Contrast Sensitivity tests were each given twice, once during the first hour of testing and once during the second. Total testing time was about two hours for 100 sonar technicians who served as subjects. Only men from submarines that have the newest visual displays were used. Since optimum vision was desired, glasses were worn if the men normally wore them.

RESULTS

Individual Tests

Tables 1 to 4 provide the means and standard deviations for the 100 men for each of the tests in the battery. The non-visual measures are presented in Table 1. The men averaged 25 yr. of age and had more than four years in submarine service; the latter however varied greatly from 1 mo. to 16 yr. The General Classification Test and Arithmetic Test scores were uniformly above the

TABLE 1

NON-PERCEPTUAL MEASURES ON 100 SONAR TECHNICIANS

	M	*SD*
Age (yr.)	24.8	5.2
Submarine Service (mo.)	51.1	51.7
General Classification Test	60.2	6.2
Arithmetic	58.6	6.1
Internal-External measure	8.6	3.7

general average of 50 ± 10 because the GCT/ARI cut-off is set at about the 84th percentile for acceptance into sonar training.[2] Scores on the I-E test can vary from zero (completely internal) to 23 (completely external); the mean of 8.6 is comparable to that reported for civilian groups in the literature (Rotter, 1966) but indicates somewhat more external control than was found in another study of Navy men (Broedling, 1974).

The results of the basic vision tests are shown in Table 2. Corrected acuities are good: 75% of the men have corrected, binocular distance vision of 20/20

[2]The specific criterion has varied over the years but in general is about 1 standard deviation above the mean.

TABLE 2

BASIC TESTS OF VISION*

	M	*SD*
Far acuity	1.04 min. v.a.	.16
Near acuity	1.14 min. v.a.	.09
Vertical phoria—far	.06 ΔD LH	.38
Vertical phoria—near	.12 ΔD LH	.34
Horizontal phoria—far	+.52 ΔD (eso)	2.33
Horizontal phoria—near	−5.26 ΔD (exo)	4.55
Depth perception (correct out of 9)	5.0	2.6
Accommodation	8.2 D	1.8
Refractive error	−.74 D	1.43

*Acuity is the reciprocal of the detail size measured in minutes of visual angle; phorias are measured in prism diopters, and accommodation and refractive error in spherical diopters.

or better, and even more, 95%, have equivalent near acuities because they tend to be myopic; 55% of the men have some degree of myopia, 25% have more than 1 diopter of myopia, and the mean refractive error is —.74 D. These results are comparable to those of 750 submariners tested previously (Kinney, *et al.*, 1974).

The results of the tests of perceptual cognitive factors are summarized in Table 3, which gives the means, standard deviations, average percent correct and reliability estimates for three of the tests. For example, the mean number of correct, out of 20 possible, on the Gestalt Completion Test was 15.6 ± 4.0, representing 78% correct; the correlation between parts 1 and 2 was .74. The

TABLE 3

PERCEPTUAL AND COGNITIVE FACTORS

Test	No. Test Items	Number Correct		Test-retest Reliability	% Correct
		M	*SD*	r_{tt}	
Gestalt Completion	20	15.6	4.0	.74	78.0
Hidden Patterns	400	166.3	34.9	.81	41.6
Cube Comparison	42	19.9	9.6	.64	47.4
Perceptual Speed	140	62.0	18.5	*	44.2
Figure Classification	112	51.9	20.3	*	46.3

*No test-retest data were available for these two measures due to constraints of time.

tests are difficult so as to assure a wide distribution of scores and very few perfect scores, and in general, the scores were less than 50% correct and were normally distributed. The one exception is the Gestalt Completion Test on which eight men had perfect scores.

Data are available for three of the tests from a group of 600 Navy recruits (R. S. Biersner, CDR, MSC, USN, Unpublished data, 1975). The sonar technicians obtained higher scores on the Gestalt Completion Test and on the Hidden Patterns Test than did the recruits, but they performed essentially the same as the recruits on Cube Comparison Test.

Table 4 gives the results of the two remaining tests, texture discrimination and contrast sensitivity. The over-all percent correct on the texture discrimination, 52.1%, can be fractionated into the subcategories of discriminations (a) among patterns differing in only directionality, and (b) among those differing in degree of granularity. The latter proved much easier to discriminate, yielding a mean percent correct of 67.2, while the former, with a mean of 29.6% correct, is barely above the chance level of response, 25% correct. While the over-all test-retest reliability was .67, the correlation between subcategories was only .16, again pointing to a high level of chance functioning for the discriminations of directionality.

TABLE 4
PERCEPTUAL TESTS ON VISUAL DISPLAYS

Tests	*M*	*SD*	r_{tt}
Discrimination of Texture			
Total Percent Correct	52.1	7.09	.67
% Correct in textures of the same granularity	29.6	5.72	
Fine	34.8	11.32	
Medium	26.6	8.93	
Coarse	29.1	10.61	
% Correct in textures of different granularity	67.2	10.38	
Fine vs medium	44.5	15.62	
Coarse vs medium	57.1	13.86	
Fine vs coarse	76.2	11.14	
Contrast Sensitivity			
Contrast thresholds			.74
.2 cpd	.00528	.00147	
.5 cpd	.00395	.00109	
2.0 cpd	.00183	.00057	
5.0 cpd	.00436	.00308	
10.0 cpd	.01956	.01785	
Hits (20 difficult trials)	7.5	4.15	
Fars (20 noise trials)	2.6	2.74	
d'	.93	.59	

The contrast sensitivity test, representing responses to five different spatial frequencies, was constructed so that both contrast thresholds and estimates of over-all sensitivity, d', could be obtained from the same data. The contrast thresholds for each spatial frequency are plotted in Fig. 1. They are typical of those found in the literature for these experimental conditions. Sensitivity is

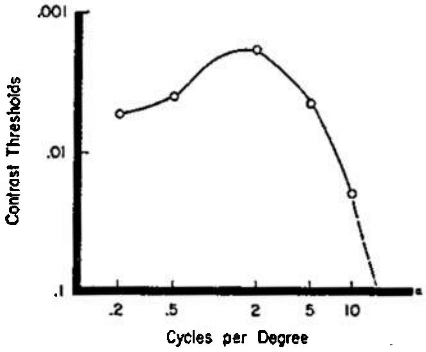

FIG. 1. Mean contrast thresholds for 100 men. Square wave modulation was around an average luminance of 4.5 cd/m².

greatest in the mid-frequency range, at 1 and 2 cpd, and falls off on either side. Extrapolating the high frequency decline to its theoretical limit of 1.0 predicts an acuity threshold near 30 cpd or 1 minute of arc, an entirely reasonable acuity for this light level.

In order to estimate *d′*, the number correct for the most difficult 20 trials (4 trials at each of the 5 spatial frequencies) was employed as the HIT rate and the number of false positives on the 20 no-signal trials as the FAR. The latter distribution, with a mean of 2.6 or 13%, was skewed, with 30% of the men achieving a zero error rate. The average value of *d′* was .93, with a range from zero to 2.25.

Factor Analysis of Data From Test Battery

A factor analysis was performed on the results of the various tests using the principal component procedure (Gorsuch, 1974). This is a standard, computer-executed procedure, employing unity in the diagonals, and yielding a rotated factor matrix with Kaiser's varimax rotation method. All available measures,[3] tabulated in Tables 1 through 4, were included to yield 33 different test scores for each man. The scree test indicated seven non-trivial factors; this number was obtained with the criterion of an eigenvalue or roots >1.5.[4] Table 5 lists all of the measures that attained a factor loading of over .4 on each factor; a descriptive title, the eigenvalue, and the percentage of total eigenvalues are also given for each factor.

The first factor includes contrast thresholds for the high spatial frequencies and distant acuity, both resolution and stereo.[5] Contrast thresholds for low spatial frequencies, however, are unrelated to those at higher frequencies—a fact

[3]Only the six subcategories of texture were entered into the factor analysis, since the various totals of subcategories are obviously redundant assessments of the same data.

[4]Gorsuch (1974) recommends the use of both the Scree and the Roots >1.0 test to determine the number of factors. The lower criterion of Roots >1.0 yields 10 factors. However the additional factors have only one or two measures each, and therefore were not included.

[5]The change in sign is appropriate since the lower the contrast threshold and the higher the acuity measure, the better the vision.

TABLE 5

FACTOR ANALYSIS OF 33 MEASURES ON 100 MEN

Factor No.	Tests with factor loading greater than .4	Factor loading	Descriptive title/Eigenvalue
1	*d'* for contrast sensitivity	−.82	Vision for fine detail 4.92 (15%)
	Contrast threshold for 2 cpd	.52	
	Contrast threshold for 5 cpd	.79	
	Contrast threshold for 10 cpd	.76	
	Far acuity	−.75	
	Near acuity	−.43	
	Depth or stereoacuity	−.53	
2	Figure Classification	.67	Paper-and-pencil tests of perceptual or cognitive abilities 3.12 (9%)
	Hidden Patterns	.64	
	Cube Comparison	.64	
	Perceptual Speed	.58	
	Gestalt Completion	.62	
	GCT	.57	
3	Time in service	.88	Time or age 2.69 (8%)
	Age	.85	
	Accommodation	−.68	
4	FARS	.84	Vision for large objects 2.12 (7%)
	HITS	.73	
	Contrast threshold for .5 cpd	.73	
	Contrast threshold for .2 cpd	.62	
	Contrast threshold for 2 cpd	.63	
5	% Correct on Textures		Discrimination of texture 1.95 (6%)
	within fine patterns	.65	
	between fine and neutral patterns	.52	
	between clumpy and neutral patterns	.78	
	between clumpy and fine patterns	.76	
6	Phoria, vertical near	.81	Vertical eye alignment 1.72 (5%)
	Phoria, vertical far	.80	
7	Phoria, lateral far	.85	Horizontal eye alignment 1.57 (5%)
	Phoria, lateral near	.77	

suggested by many studies (Furchner, Thomas, & Campbell, 1977; Kelly, 1977; Legge, 1978)—and consequently constitute a separate factor (No. 4 in Table 5).

The second factor includes almost all of the paper-and-pencil tests of perceptual or cognitive ability. The one exception was the Arithmetic Reasoning Test which did not load highly on any of the 7 factors; however, its highest loading, 0.31, was on this factor.

The third factor brings together all items related to the age of the men, including time in service and poor accommodation scores.

The fourth factor reflects the ability to see large objects and includes the contrast thresholds for the low spatial frequencies. The threshold for 2 cpd has a high loading on both Factors 1 and 4, indicating that 2 cpd is the dividing line between the two sets of frequencies.

The measures of texture, vertical phoria, and horizontal phoria all yield independent factors. However, two of the texture subcategories, discriminations of direction within medium and coarsely granular patterns, did not have significant loadings on any factor. These were the two most difficult discriminations, with distributions centered on chance levels. In addition to the Arithmetic test and these two textures, two other tests did not have loadings above 0.4 on any factor; most notable was the internal-external test which was unrelated to any of the other measures. The highest loading for spherical correction was on Factor 1, —.38. The latter indicates some relationship between increasing myopia and poor vision for detail. Since the men wore their corrections during testing, it could result from some individuals not having adequate correction.

Discussion

The data base for this investigation of visual-perceptual abilities is extensive and has been obtained by a variety of different testing techniques. The factors extracted, however, represent cohesive and reasonable groupings which cut across testing methods. The interesting exception is the paper-and-pencil tests; all of these, whether tests of intellectual or perceptual ability, fell into the same group. This result is contrary to much data in the literature which suggests that the factors underlying verbal tests of intelligence and spatial or perceptual tests are independent. Cattell (1971), for example, lists spatial ability, speed of closure, and perceptual speed as three primary abilities that have been empirically determined. Anastasi (1976) reports that, of Thurstone's proposed independent factors, verbal comprehension, word fluency, spatial ability and perceptual speed have been frequently corroborated. Guilford (1972) goes even further in believing that each of these is a composite of many underlying factors in the structure of intellect.

The present factor analysis gave no evidence of independent verbal, spatial, or perceptual factors. To determine whether these commonly cited factors were buried in the variance of our extensive data bank, a separate factor analysis was performed on the data from only the eight paper-and-pencil tests. This analysis is presented in Table 6. For these measusre, both the Scree Test and Roots >1.0 yielded three factors. The first factor was a visual or perceptual factor; the Hidden Patterns, Perceptual Speed, and Gestalt Completion Tests sorted into this factor. The second factor was a cognitive or intellectual factor, composed of the General Classification Test, Arithmetic, and Figure Classification tests. Two of the tests, Cube Comparison and Figure Classification, had sizable loadings on both of these factors. The third factor held only one test, the Internal-External test.

The fact that more conventional factors can indeed be extracted when the factor analysis is confined to the paper-and-pencil tests suggests that they share a common variance which is distinct from that measured by the other techniques.

TABLE 6

FACTOR ANALYSIS OF 8 PAPER-AND-PENCIL TESTS WITH 100 MEN

Tests	Factor Loading		
	I	II	III
Hidden Patterns	.75	.08	−.31
Cube Comparison	.46	.53	−.14
Perceptual Speed	.66	.14	−.04
Gestalt Completion	.76	.04	.22
General Classification Test	.25	.59	.33
Arithmetic	−.18	.83	−.08
Internal/External	−.08	−.02	.91
Figure Classification	.41	.56	−.04

Moreover, this factor, which might be called the ability to take paper-and-pencil tests, dominates when data from different measurement techniques are combined. One might expect, for example, that the ability to discriminate texture or to see large, low contrast objects would be related to some of the paper-and-pencil tests of perceptual ability. This was not the case, however, indicating that the method of testing is an important influence.

This finding suggests a promising line of investigation for occupational testing whenever paper-and-pencil tests fail to predict occupational achievement. The idea that the form of the test may be as important as the content of the test will be tested in the next step of this research, the validation against criteria of occupational success.

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common factor, a result with general implications for occupational testing.