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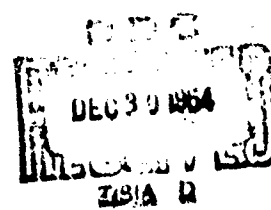
Technical Report 206-28

HUMAN FACTORS RESEARCH, INCORPORATED
SANTA BARBARA • LOS ANGELES • SAN DIEGO

SIX YEARS OF RESEARCH ON HUMAN FACTOR

PROBLEMS IN ASW: A SUMMARY (U)

Technical Report 206-28

Robert R. Mackie

Prepared for

by

Human Factors Research, Incorporated
Santa Barbara * Los Angeles * San Diego

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11

iii

"It is essential that the sonar designer be in-
formed as to the characteristics of observers
as well as to the characteristics of the trans-
mitting medium. Sonar, then, is bounded on one
side by oceanography and on the other by psycho-
physiology . . . .

"The primary purpose of every indicator or re-
corder used in sonar is, in some way or other,
to make the signal perceptible to the observer
. . . the quantitative evaluation of the per-
formance of the instrument involves defining the
limiting conditions under which the effect to be
produced is adequately perceptible. This implies
that the operation of any instrument is a joint
enterprise in which the instrument is one partner
and the observer the other. In stating the per-
formance of the instrument quantitatively, there-
fore, certain physiological and psychological
characteristics of human beings are quite as
relevant as the nature and behavior of acoustic
waves in the sea, or as the properties of the
system by which these waves are caused to
influence the instrument."

> From: The Fundamentals of Sonar,
>   by Dr. J. W. Horton

iv

FOREWORD

In 1958 a contract was established between ONR and HFR for the broad purpose of determining, in objective quantitative terms, the capabilities and limitations of Navy personnel in relation to the performance of various ASW systems. Target classification was the most pressing problem at the time, and much of the early work was concentrated in that area. More recent work has been directed toward measurement of the human role in target detection and equipment calibration and maintenance.

For the most part, the investigations have been experimental rather than analytical in nature. The scene of the experiments has varied with the problem: the laboratory, the ASW Schools, aboard ships and aircraft underway. Attention has been focused on the routine performance problems faced by operating and training personnel in attempting to maximize the performance of systems to which the Navy is fully committed. Little emphasis has been placed on future systems although much of value has been learned that should be applied to future systems.

The emphasis on existing systems has resulted in a far different orientation and a more basic appreciation of the Navy's operating problems than otherwise would have been the case. Project personnel have operated some equipment, calibrated sonar equipment, repaired sonar equipment, designed data collection exercises, directed exercises from CIC, studied the ASW problem through the eyes of seamen, petty officers, and captains, ridden destroyers, submarines, airplanes, and helicopters, and have heard all of the standard rationales for why things don't work better.

v

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The results of this work have been, in some cases, obvious and concrete; in others they have been subtle, constituting more of an influence than an objective achievement. Twenty-seven technical reports have been issued, films, slides, magnetic tapes and technical manuals have been prepared and distributed, the staff has served in working groups concerned with the analysis of ASW systems, the design of sonar trainers, and the conduct of evaluational tests.

This summary report has been prepared as a means of reminding those who design, purchase, or use ASW equipment that the Navy has supported a good deal of research that logically should influence decisions concerned with the "joint enterprise in which the instrument is one partner and the observer the other." In addition, it hopefully will be a more convenient reference than the 27 technical reports, some classified, some not, that by now may be scattered in diverse files, drawers, and libraries.

With apologies, we must confess that the results of psychological experiments are not always reported in a form that immediately suggests the way to apply them in the practical environment. Of course, this is true of nearly all "basic" research. However, many of the findings summarized here _have_ been applied and many others could be with very minor efforts at translation.

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ACKNOWLEDGEMENTS

vii

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Table of Contents

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SIX YEARS OF RESEARCH ON HUMAN FACTOR
PROBLEMS IN ASW: A SUMMARY

INTRODUCTION

The investigations conducted under this contract can be grouped
into nine basic areas. Few studies belong exclusively to a single
area, and it will be seen that findings from a single study are
sometimes appropriately classified under more than one of the fol-
lowing headings:

  I.   Development of fundamental concepts of target
         classification

  II.   Analyses of clues displayed by operational
         equipment

  III.   Determination of operator capabilities in
         target classification

  IV.   Research on experimental display techniques

  V.   Determination of the operator's role in
         target detection

  VI.   Studies of operator vigilance

  VII.   Recording of target data at sea

  VIII. Determination of calibration and maintenance
         skills of sonar technicians

  IX.   Analyses of ASW systems in operation

In the sections that follow, the specific findings in each of
the above areas are concisely summarized. The technical report from
which each finding or conclusion was taken is indicated at the end
of each statement by the number in parentheses. The full title of
each referenced report is listed at the end of this summary.

I. DEVELOPMENT OF FUNDAMENTAL CONCEPTS
OF TARGET CLASSIFICATION

In December 1958, HFR conducted a workshop in target classifi-
cation at the U.S. Navy Tactical ASW School, Norfolk, Virginia.
Discussions centered around fleet experience in relation to the
findings of several years of previous research on target classifi-
cation that had been conducted by NEL and HFR. It became evident
during the workshop, which was attended by representatives of almost
every ASW operational and training command, that there were many
diverse opinions concerning the value and role in target classifi-
cation of various displays and the clues they presumably provided.
Consequently, HFR assumed the oblication of developing a logical
framework for target classification that would encompass all dis-
plays, clues, and procedures known to be of value in classifying
with active, scanning sonars.

Specific Results

1. The logical basis for target classification with
    scanning sonars was established. It was shown how
    classification depends on determining the target's
    motion, size, reflective structure, aspect, and
    depth. The role of each display in contributing
    partial, complementary information about one or
    more of these target attributes was described (0).*

2. It was shown why target classification should be
    based on a test of the "submarine hypothesis" and
    why previous emphasis on identifying various classes
    of nonsubmarine targets was neither necessary nor
    desirable (0).

3. The value of using displayed target aspect (orien-
    tation in the sound beam) as the basis for corre-
    lating and evaluating all other displayed clues was
    established (0).

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*This first report issued under Contract Nonr 2649(00) did not
bear a series number as did subsequent ones. For convenience it
is referred to here a., report No. 0.

2

4. It was shown how each clue and various combinations of clues relate to estimations of the major characteristics of the target (motion, size, reflective structure, aspect depth) and how these characteristics, in turn, are combined to establish the probable nature of the target (0).

5. It was shown how classification is made more or less difficult depending on the target's speed, depth, range from the A/S vessel, apparent aspect, aspect changes, and geographic location (11).

6. It was shown that evaluation of classification evidence is hindered, in part, by the fact that U. S. systems provide no direct information about target depth (10).

Importance to the Navy

The first technical report issued under this contract, Target Classification Using Active Scanning Sonars, has been adopted, unchanged, as an official NAVPERS publication on the subject of classification. It serves as the standard text for target classification training courses in the ASW Schools and has directly influenced the design considerations of engineers concerned with the construction of specialized equipment for target classification. This publication is also serving as a model for a similar one being developed for the British Navy by personnel attached to H.M.S. VERNON.

3

II. ANALYSES OF CLUES DISPLAYED
BY OPERATIONAL EQUIPMENT

The precise character and significance of target clues in dis-
played sonar echoes cannot be determined in advance of actual trials
at sea with targets that are representative of the classification
problem. HFR has collected and analyzed thousands of feet of motion
picture records and tape recordings of displayed signals from a
wide variety of sonar contacts.

Specific Results

7. Detailed descriptions of usable clues from the
audio, PPI, and graphic recorder displays of the
SQS-4 and SQS-29 were developed. The probability
of occurrence and perceptibility of each clue by
operators and the manner in which clues vary or
change as a result of equipment control settings,
sonar conditions and target maneuvers was de-
scribed (0).

8. The number, description, and usefulness (validity)
for classification of target pip shapes displayed
by the SQS-23 PPI was determined. It was shown
that the pip shape categories developed for earlier
scanning sonars were not adequate for the SQS-23
(22).

9. It was shown that pip shapes are not highly related
to target nature in a direct sense, but, in the case
of submarine targets, often provide evidence of
target orientation that is highly useful for evalu-
ating the total clue pattern (22).

10. It was shown that the usefulness for classification
of SQS-23 pip shapes was heavily dependent upon the
range scale in use, that meaningful shapes occur
very infrequently when using the 5000-yard (or greater)
range scale. The relationship between the type of
pip shape obtainable from a submarine target and the
PPI centering mode in use (SCD or TCD) was determined
(22).

11. The extreme difficulty of analyzing the motion of

4

either slow-moving or non-moving targets with
present displays and plotting equipment was
reported, and the superior capability of some
European sonar systems in this respect was
described (23, 27).

Importance to the Navy

Continuing analyses of clue patterns are essential to progress
in target classification since any change in either the transmission,
reception, or processing features of a sonar is likely to introduce
corresponding (and unknown) changes in the meaningfulness of the
clue patterns. Significant details and relationships are not
effectively determined from regular fleet operations or ASW exer-
cises. Furthermore, even the advent of successful automatic classi-
fication systems will not eliminate the need for periodic basic
analyses to determine the meaningful information parameters

The results of these analyses to date have indicated three
important needs for improved display design:

> (1) There continues to be an urgent need for a
> simple, reliable electronic aid to doppler
> discrimination.

> (2) The display of target axis information at
> ranges considerably greater than those
> obtainable with present PPIs is essential.

> (3) Improved means for establishing target
> motion and target track by the sonar team
> is urgently required.

The lack of suitable displays for assessing the motion of slow-
moving (or non-moving) targets in the shortest possible time is
seriously hampering classification. The discrimination of doppler
by operators is unreliable; the DRT plots and the computed fire-
control solution are both too slow and too inaccurate for classi-
fication purposes. (It must be remembered that a fast, or even

5

moderately fast-moving submarine is not a classification problem, although it may well be a tracking and a fire-control problem.)

A sensitive semi-automatic target plot fed by data generated by equipments already in typical shipboard sonar systems would be a major step toward improving classification.

6

III. DETERMINATION OF OPERATOR CAPABILITIES
IN TARGET CLASSIFICATION

It is extremely difficult to make fair, objective assessments of the more subtle capabilities of sonar personnel on the basis of their performance in the actual operating environment. Unlike radar operations which routinely provide the opportunity for radarmen to practice and develop operating techniques, sonar operations simply do not regularly enable sonarmen to exercise and reinforce the complex skills involved in detecting, classifying, and tracking underwater targets. The result is that specific performance deficiencies often go undetected for months, if not years. Furthermore, ASW exercises do not readily permit the diagnosis of the strengths and weaknesses of individual team members, since they are primarily designed and evaluated on the basis of the tactical and weapons-delivery phases of the problem.

The measurement of specific operator capabilities and weaknesses serves at least three very important needs: (1) it enables intelligent training emphasis to be placed on those aspects of the job that are most difficult; (2) it enables meaningful performance standards to be established for evaluating new displays requiring human monitors; and (3) it provides criteria for assessing the capabilities of machines that are proposed as substitutes for functions traditionally performed by men.

Specific Results

12. Both practical and written tests of target classification skills and knowledge have been constructed. "Trained" sonar operators have been found typically to score between 50% and 70% correct on practical tests comprised of fairly difficult classification problems. They score somewhat higher on written tests (10).*

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*Chance performance on a balanced test permitting only two con-

7

13. Marked individual differences have been found among sonarmen in ability to assimilate target classification training (10).

14. Target classification training has been shown to be more effective among operators who have had sea experience than among trainees just out of basic training (10).

15. Sonar trainees make frequent perceptual errors in clue recognition even at the completion of training. Performance is somewhat better on clues displayed by the graphic recorder than on the audio or PPI-- presumably because of the "memory" characteristic of that display (10).

16. Present sonar displays are not well suited to accurate clue recognition. Thirty (or more) successive echoes are frequently required for correct classification concepts to form. A major source of errors results from inability to form correct conclusions about the target's aspect and movement (10).

17. The average sonar operator requires about 22 cps of doppler for accurate doppler recognition using SQS-4 and SQS-29 series sonars. Depending on the model, reliable discrimination thus requires a submarine speed component of from 2.2 to 3.9 knots in the direction of the sound beam (12).

18. The average sonar operator can reliably discriminate about 12 cps of doppler with SQS-23 sonars. This is equivalent to about 3.5 knots of target speed in the direction of the sound beam (23).

19. Operators experience difficulty in recognizing "no" doppler as well as small amounts of "up" and "down" doppler. However, a judgment bias noted with older sonars toward reporting "up" doppler when no doppler was present was found to be less prounounced with RDT-modified sonars (12, 23).

20. There are large individual differences among sonar operators in doppler recognition ability. Task assignments within the team snould reflect these differences (23).

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clusions (i.e., "submarine" and "nonsubmarine") is 50%. Thus the performance level reflected by these figures is 0% to 20% above what would result from sheer guesswork.

8

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21. Only marginal improvement in doppler recognition
(2 to 3 cps) occurs with training once the concept
has been initially grasped. However, experienced
operators may occasionally recognize secondary
cues in the echo that aid in arriving at a correct
judgment (23).

22. A moderate correlation typically is found between
Sonar Pitch Memory Test scores and performance
on tests of doppler discrimination. Higher cut-
off scores on this test or use of an actual doppler
discrimination test would result in improved
selection of operators for this task. Improved
selection is a surer road to improved performance
than is increased training (12).

Importance to the Navy

Improvement in target classification performance can be expected,
provided that: (1) fundamental improvements in the display of cer-
tain clues are achieved; (2) training in classification techniques
is concentrated on those who are highly screened from an aptitude
and motivational point of view. Display improvements are essential;
capitalization on individual differences in aptitude and interest
is only sensible.

Before investing in expensive new displays or automatic process-
ing devices that are proposed as replacements for functions tradi-
tionally performed by men, the performance of such devices should
be compared with that of properly trained operators using appro-
priate problem material. In spite of their limitations, men have
actually performed much better on some tasks involved in classi-
fication than have some fairly expensive electronic substitutes.

9

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IV. RESEARCH ON EXPERIMENTAL DISPLAY TECHNIQUES

Thorough consideration of the man-machine interface is essential to the proper design of any complex system. In sonar, more effort seems to have been spent trying to design the man out of the system than in optimally designing it for his use.

It seems unlikely that signal analysis and interpretation will become fully automatic in the foreseeable future. In the meantime, there appear to be many opportunities to design displays that take better advantage of the unique capabilities of men.

Specific Results

23. The optimal audio frequency for doppler recognition is about 500 cps in contrast to the 800 or 1000 cps typically used in sonar systems (23).

24. A proposed technique for speed-translating sonar signals to enhance doppler effects was shown to produce no systematic improvement in doppler discrimination (12).

25. An experimental device designed to display doppler visually was found to be less effective than aural discrimination by the average sonar operator (12).

26. There is a critical need for achieving an interpretive match between the meaning of a classification display to the tactical officer and the discriminating capabilities of the sensing and data-processing equipment. There is a lack of understanding among many ASW decision-makers of the probabilistic nature of sonar target classification that naturally results from imperfect sensors and information displays (21).

27. Use of the traditional 3-way classification scheme ("probable submarine," "possible submarine," "nonsubmarine") results in serious losses of information for the tactical decision-maker. Displays of the type used with MITEC are much better but require training in interpretation (21).

28. The output of target classification aids or com-
     puters should be directly related to likelihood
     ratio (probability that the target is a submarine
     divided by the probability that it is not) if the
     number of correct tactical decisions is to be
     maximized (21).

Importance to the Navy

The perceptions, judgments, and decisions of humans will con-
tinue to be critically important in any existing or probable future
sonar system. The nature of the demands may change, or they may be
imposed at a different point in the processing and evaluating
sequence, but they will remain critically important to successful
functioning of the overall system. Not only will it continue to be
necessary to deal with human decision functions, but it will remain
desirable to capitalize on the flexibility that only man can bring
to the problem.

Research thus far suggests that far greater skill is necessary
in coupling machine and man functions in sonar systems than has
been demonstrated in the past. Output displays generally need to
be made more meaningful; training in interpretation must be made
more uniform and sophisticated.

11

V. DETERMINATION OF THE OPERATOR'S ROLE
IN TARGET DETECTION

No other requirement has so dominated sonar equipment design requirements over the past 20 years than that of extending the target detection range. The resulting increase in equipment complexity and predictable accompanying maintenance problems have created serious doubt that the detection performance of the newer systems is, in fact, uniformly better than that of older, simpler ones.

A great deal of improvement in sonar detection could be forthcoming, however, through increasing attention to the complementary capabilities of man and machine. Human operators are exceptionally adept at the detection of complex aural and visual signals in heavy background noise. However, they are often very poor at sustaining attention for such signals over prolonged periods of time, especially if the signals occur very infrequently. Machines can be built that are perfectly attentive and have infallible memories but to date their pattern recognition performance has not matched the flexible and adaptive capabilities of man for recognizing a variety of signal types in backgrounds of non-random noise.

There is little doubt that improvement in target detection performance is achievable. There is also little doubt that it will require more effective man-machine coupling than has been typical of past systems. Several HFR studies have been directed toward these problems.

Specific Results

29. There are large individual differences among operators in detecting targets on PPI displays. Performance on watch is moderately predictable from short samples of performance during "alerted" conditions (16).

12

30. The requirement to _search_ the entire PPI scope results in about 13% fewer detections on the average than when the operator is "alerted" to the target's probable bearing. (A performance loss of 3.5 db with respect to a reference signal that is just barely detectable.) (16)

31. Operators more quickly detect targets at mid-range on the PPI scope than at close or far range. The explanation may lie in the visual search patterns adopted by operators (20).

32. There are large, stable individual differences among operators in ability to detect weak infrequent signals (2).

33. Repeated presentations of a target signal (up to 5 echoes) are often necessary to elicit valid detection reports (5).

34. Operators have different personal criteria of what constitutes a sonar target signal. The relative leniency or stringency of each operator's criterion substantially affects the likelihood of a detection being reported and the false alarm rate (5).

35. Faint echo detection is a function of training and experience in addition to basic operator sensitivity (5).

36. Target detection performance is unrelated to traditional achievement scores in sonar operator courses or to scores on presently used aptitude tests (16).

37. In accord with observations by Horton (_Fundamentals of Sonar_), the range between 10% and 90% probability of detection on a PPI scope is only about 4.5 db; the range between "almost never" and "almost always" detecting a target is about 10 db. Thus display design features (or operating procedures) that improve systems performance as little as 1 db are well worth the trouble (16).

38. Setting the PPI scope brightness at "visual reference intensity," as often recommended in technical manuals, adversely affects target detection. The optimum brightness is well above this setting (17).

13

39. Sonar operators typically do not adjust CRT bias and gain optimally for detection performance. Targets producing low intensity signals can be detected with much greater frequency using experimentally determined optimum settings than when using settings "preferred" by operators (20).

40. A 3-db gain in detection performance of an operating SQS-23 was obtained when ship's operators used experimentally determined optimum bias and gain settings in contrast to their normally preferred settings (26).

41. Search radars in patrol aircraft (P2Vs and P5Ms) are also likely to be operated at non-optimum brightness levels; ambient illumination in the P5M aircraft is sufficiently variable to introduce serious losses in detection probability.

    There are also adverse effects on target detection of the relatively high compartment illumination in the HSS-2 and of the consequent requirement that a viewing hood be used (17, 18).

Importance to the Navy

The use of cathode ray tubes as detection displays requires continuing research into the questions of optimal design and operator procedures. It is clear that the actual detection capability of a complex sensor system may be far different from its theoretical capability, as a result either of inappropriate control settings or non-optimum visual search procedures, or both.

Target detection performance also can be improved by proper selection of personnel and more comprehensive training. Selection should be directed toward obtaining personnel who are highly vigilant for the type of displays used for sonar (see Topic VI). Training should be directed toward procedures for calibrating the displays properly, optimum visual search patterns, and echo recognition. Existing training equipment is not properly designed for training these activities, although some films and tapes of sonar echoes are appropriate for training in echo recognition.

14

VI. STUDIES OF OPERATOR VIGILANCE

HFR studies in vigilance have been conducted at a very funda-
mental level. Vigilance is defined as the ability to sustain
attention over prolonged periods of time for an event (signal) that
has a relatively low probability of occurrence. An additional
characteristic of most situations requiring vigilance is that it
is critically important that the signal be detected at the earliest
possible moment. Furthermore, failure to detect a signal can be
disastrous.

The sonar watchstander is confronted with a vigilance task that
is unique in many respects. He may spend hundreds of hours on watch
without experiencing a target signal. He monitors both aural and
visual displays that present unique, partially redundant information.
The search task is demanding, yet boring, and the opportunities for
a sense of contribution and reward are few. Sonar operators can
expect to be virtually ignored for long periods of time by the per-
sonnel of other ship's activities, by the watch officers, and even
by the command.

Specific Results

42.   A vigilance decrement (loss) occurs in the first
few minutes of a sonar watch. On the average
about 20% fewer detections are made of signals
that are of such intensity as to be readily
detectable when the operator is fully alerted (16).

43.   There are large, stable individual differences
among operators in ability to sustain vigilance
for the types of aural and visual stimuli associ-
ated with sonar signals (2).

44.   Individuals who are vigilant for visually dis-
played signals are not necessarily vigilant for
auditory signals and vice versa (2).

15

45. The more difficult it is to recognize the signals on the display, as defined by percentage of detections under alerted conditions. the greater the performance decrement as time on watch progresses (8).

46. The frequency of "non-observing" responses (looking away from a visual detection display) increases with time on watch and is positively related to the number of signals missed (14).

47. Signals can be missed when even the eyes are fixated on the detection display (14).

48. If probability of signal occurrence on a visual and an auditory display is equal, and both displays are being monitored by the same operator, more signals will be detected on the auditory display (8).

49. Operators monitoring more than one display are inclined to attend selectively to the display having the more easily recognizable signals. If the displays are not redundant, this can adversely affect detection probability (8).

50. Detection performance on redundant auditory and visual displays is superior to that on either display used alone (8).

51. Under routine watchstanding conditions there appears to be less performance decrement with auditory than with visual displays (2).

52. The probability of signal detection is (within limits) positively related to the rate of signal occurrence. The less frequently signals appear, the more severe will be the loss in detections due to the vigilance decrement during the watch (1).

53. Signal detection performance is related to "expectancy" on the part of the operator. If the operator has been conditioned to expect signals at very irregular intervals, the probability of signal detection decreases as a function of the amount of time elapsed since the last detection. In contrast, if he is conditioned to expect signals regularly, the probability of detection increases as a function of time since the last detection. Operators expecting long intervals between signals are particularly prone to missing signals that occur soon after one that has been detected (9).

16

54. Immediate knowledge of how well he is doing (performance feedback) reduces the operator's vigilance decrement (1).

55. The introduction of artificial signals increases the probability of detecting infrequent real signals (1).

56. The level of vigilance maintained by the operator is also a function of environmental stimulation from sources other than the detection displays. If the extra stimulation is not actually distracting, the added "arousal" it provides serves to facilitate vigilance (6).

57. Vigilance decrements are less severe in complex monitoring situations than in simple ones although the absolute level of performance may be lower for the complex display (1).

58. When the signal rates on a visual display are low, a variety of auditory stimuli reduces the vigilance decrement (7).

59. Environmental noise reduces vigilance performance on complex vigilance tasks (1).

60. Short, frequent rest periods are better for sustaining vigilance than long, less-frequent ones (1).

61. Performance on vigilance tasks is not reliably predicted from scores on conventional psychological tests of aptitude, temperament or motivation. Traditional sensory threshold measures are only slightly predictive of vigilance performance (4).

62. Detection performance during a short test of vigilance is predictive of vigilance during prolonged watchstanding. Men most sensitive to the discriminations required by the operational display show the least decrement in performance (2).

Importance to the Navy

There is little doubt that sonar target detections are made less frequently and with greater delay as a result of losses in vigilance on the part of operators. The often reported differences

in detection ranges between routine and "alerted" search during
actual sonar operations is an additional objective reminder of this
fact. More serious, however, is the unknown number of detectable
targets that go completely unnoticed.

Failure to detect detectable targets is also, of course, the
result of factors other than vigilance loss, such as equipment cali-
bration, operating technique, and visual search pattern. What to
do about some of the non-vigilance problems has been discussed else-
where in this summary. Concrete steps can also be taken to help
minimize the vigilance decrement:

a) The differences among operators in suscepti-
bility to vigilance loss while monitoring sonar
displays can be measured and used in qualifying
them for various watchstanding tasks.

b) Injection of synthetic signals is a feasible
means of increasing signal rate and consequently
combating the effects of the vigilance decrement.
Minor modifications to presently existing ship-
board equipment (signal injectors) would be quite
adequate for this purpose. However, successful
implementation would require the involvement and
understanding of all watch officers. Signals
should be programmed and performance monitored
by officers on watch, not by other members of
the sonar team.

c) Synthetic signals can also be used to provide
much needed recognition and performance feedback
to operators. It would be possible to extend
the technique to include shipboard training in
search techniques, making proper bias and gain
settings, calibration of displays, etc.

VII.   RECORDING OF TARGET DATA AT SEA

The recording and analysis of representative submarine and non-submarine contacts made while using operational equipment at sea is a fundamental requirement for determining the classification capability of an ASW system. Such data are needed to determine the quantity and quality of clues producible by the equipment. Furthermore, the recordings also can be prepared in test form for measuring the abilities of ASW personnel in clue recognition and actual classification.

The first systematic collection of target data specifically directed at the classification problem was made by NEL, with HFR assistance, using SQS-10/11 equipment.* Since that time, HFR periodically has made additional collections as the fleet received new equipments or important modifications to older equipments. In each case, analyses have been performed to redetermine the adequacy of the displayed information for classification.

Specific Results

63.   Representative samples of submarine and nonsubmarine contacts as displayed by the SQS-29 series sonars (including VDS) were recorded and analyzed (22).

64.   Representative samples of submarine and nonsubmarine contacts as displayed by the SQS-23 sonar were recorded and analyzed (22).

65.   The first system for recording target data from the displays of an airborne (helicopter) sonar system was designed and developed. Successful recordings of contacts as displayed by the AQS-10 sonar were made (15).

66.   The first sound motion pictures for training and testing recognition of faint target signals presented by scanning sonars was developed (5).

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*Under an earlier contract.

67.   The only effective doppler performance tests for
      SQS-4, SQS-29, and SQS-23 sonars were constructed.
      These tests were comprised entirely of actual
      target recordings with doppler values determined
      under carefully controlled conditions (12).

68.   Seven motion picture tests of SQS-23 contact data
      were developed for use in measuring the classifi-
      cation skills of ASW personnel and testing the
      utility of special classification aid such as
      HHIP and MITEC.*

Importance to the Navy

   The motion picture tests have been reproduced and distributed
by the Bureau of Personnel to all ASW training facilities. They
constitute the only existing effective aids to SQS-23 target classi-
fication training.

   Target recordings have also been distributed to industry on a
limited basis when requested by the Navy. These have had an impor-
tant influence on design concepts for specialized classification
equipment now in various stages of development.

   Doppler tests, slides of graphic recorder traces, and films
designed to train faint echo detection have also been made available
on an informal basis to the ASW Schools.

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*No report describing these films was issued under this contract.
A full analysis and an instructor's guide was published under a
separate contract with the Bureau of Personnel.

VIII.   DETERMINATION OF CALIBRATION AND MAINTENANCE SKILLS OF SONAR TECHNICIANS

It has been evident for some time that the complexity of sonar equipments has been increasing at a faster rate than have the abilities of sonar technicians to cope with the calibration and maintenance requirements that are the inevitable result of such complexity.

Until recently little attention has been focused on the capabilities and limitations of sonar technicians in the area of maintenance. There are several reasons for this, and they are largely unique to sonar operations: (1) no easy means exists for checking the actual operating status of the sonar; (2) it is difficult to separate the effects of sonar (water) "conditions" from equipment conditions in evaluating sonar equipment performance; (3) except during ASW exercises, little attention is paid to sonar equipment performance since no means exists for encountering contacts on any but a chance basis; (4) the ASW officer generally is not sufficiently trained to challenge statements of the technicians about the status of the equipment.

Work by HFR in this area has been directed toward the objective determination of the status of equipment, on the one hand, and the corresponding skills and knowledge of sonar technicians, on the other.

Specific Results

69.   A test of calibration proficiency for the SQS-23 was developed which showed that the average rated technician lacks the knowledge necessary to understand the effects of various calibrations (24).

70. The "cookbook" calibration procedures outlined in the technical manuals were found not to produce a fundamental understanding of the effects of various adjustments on the status of the equipment (24).

71. Substantial errors of calibration were found to be the rule rather than the exception in a sample of SQS-23 destroyers. For example, the average error in range calibration was well beyond officially stated tolerance levels (24).

72. An improved procedure for bearing alignment with the SQS-23 was developed (24).

73. An analysis was performed to determine how various calibration errors are specifically related to performance deficiencies in detection, target classification, tracking, and fire control (24).

74. An analysis was performed showing that the training given to U.S. Navy sonar technicians is far less extensive than that given to European technicians with similar maintenance responsibilities (27).

Importance to the Navy

A multitude of interrelated technical and administrative problems have limited progress in developing maintainable sonar systems in the U.S. Navy. Substantial improvement can be predicted, if: (1) the effort to assess technicians' capabilities by objective testing procedures is continued; (2) training programs are extended or modified in accordance with the findings of such assessments; (3) equipment designers are compelled to employ techniques and components that reflect the current state of the art in designing for maintainability.

IX.   ANALYSES OF ASW SYSTEMS IN OPERATION

Although the majority of the investigations conducted by HFR under contract Nonr 2649(00) have been experimental in form and directed toward very specific questions, a few have consisted of broad systems analyses encompassing all phases of operation of a complex ASW system. To date these have been concentrated on airborne systems, usually at the request of an operating command.

Specific Results

75.   Object evidence concerning the actual capabilities of MAD. JULIE, and Sonobuoy systems in the hands of typical operators is extremely limited (18).

76.   Training exercises typically do not provide opportunities for false positives, that is, the possibility of reporting contacts when, in fact, no submarine is present. Exercises should be designed so that "expectancy" is not a contributing factor in measuring operator detection capability (18).

77.   There is much room for improved operating procedures in the use of the weapons system trainer for ASW patrol aircrews. A similar conclusion holds for needed improvement in team communication procedures in the aircraft itself (18).

78.   Better use can be made of ASCAC in evaluating the mission performance of ASW aircraft teams (18).

79.   The trainer developed for AQS-10 sonar operations is useful for routine procedures training only. It is totally inadequate to meet the needs for team training or training in target detection or classification (17).

Importance to the Navy

ASW systems continue to grow in complexity. While some functions will be almost completely automated in systems now under development, humans will continue to play key roles, at some stage

or another, in the processing of data and the making of decisions.
Many past dissatisfactions with human performance in ASW stem from
the limited capabilities of the system's sensors, from poor displays,
and from the limited opportunities the personnel have to practice
basic acquired skills in the operating environment.

The substitution of automatic data processors for human ones
will not solve the fundamental problems of limited sensors, less-
than-optimum displays or insufficient ASW experience. Rather, the
likely result is a substantial increase in calibration and mainte-
nance problems that are just as difficult to cope with, or more so,
than the operational problems the automatic processor was designed
to eliminate.

Side-by-side comparisons of the performance capabilities of new
complex systems with older, simpler systems, under representative
operating conditions, appear to be somewhat unpopular, if their
number is any criterion. There is a growing suspicion, however,
that many of the newer systems have not only failed to achieve their
theoretical performance level in the hands of the fleet, but actually
do not perform as well, from an overall systems point of view, as
some of their grandparents.

There must be a more adequate solution to the Navy's operating
problems than the simple substitution of next year's model for last
year's, at several times the cost. It would seem that the point has
been reached where more improvement might result from concentration
on the human problems rather than on the electronic problems.

24

PROJECT PERSONNEL

The following personnel have made substantial contributions to
the success of the research summarized in this report. The number
of persons does not reflect the level of effort since only a few of
them have been regularly assigned to the project. The average
level of effort has been approximately 4.5 man-years.

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REPORTS ISSUED UNDER CONTRACT NONR 2649(00)

Number	Title	Authors
0	Target Classification Using Active Scanning Sonars (U) (1959) CONF.	Mackie, Gavin and Parker
1	Review and Critique of the Literature on Vigilance Performance (1959)	M:Grath, Harabedian and Buckner
1S*	A Bibliography of Research on Human Vigilance (1961)	McGrath
2	A Study of Individual Differences in Vigilance Performance (1960)	Buckner, Harabedian and McGrath
2S	Subjective Reactions of Vigilance Performers (1960)	McGrath
3	The Probability of Signal Detection in a Vigilance Task as a Function of Intersignal Interval (1960)	Harabedian, McGrath and Buckner
4	An Exploratory Study of the Correlates of Vigilance Performance (1960)	McGrath, Harabedian and Buckner
4S	Cross-validation of Some Correlates of Vigilance Performance (1961)	McGrath
5	The Development of an Experimental Motion Picture Sonar Target Recognition Test (U) (1960) CONF.	McGrath, High and Mackie
6	The Effect of Irrelevant Environmental Stimulation on Vigilance Performance (1960)	McGrath
7	Irrelevant Stimulation and Vigilance Under Fast and Slow Stimulus Rates (1961)	McGrath and Hatcher
8	A Comparison of Performances on Single and Dual Sensory Mode Vigilance Tasks (1961)	Buckner and McGrath
9	Signal Detection as a Function of Intersignal Interval Duration (1962)	McGrath and Harabedian

*S = Supplement to principal report.

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10	Further Experimentation in Training Target Classification Principles Applicable to Active Scanning Sonars (U) (1961) CONF.	Gavin, Mackie and Harris
11	The Production of Target Classification Information by Submarines (U) (1960) CONF.	Mackie
12	Three Studies of Sonar Doppler Discrimination: RDT Versus Omnidirectional Transmission; Effects of Speed Translation; Use of the NRL Doppler Discriminator (U) (1961) CONF.	Harabedian and Parker
206-13	The Accuracy of Judgments of Eye Fixations: A Methodological Note on Vigilance (1961)	McGrath and Hatcher
206-14	Human Performance During Five Days Confinement (1962)	McGrath, Maag, Hatcher and Breyer
206-15	Feasibility Study and Suggested Program for Collecting Recorded AQS-10 Detection and Classification Materials (U) (1962) CONF.	Gavin
206-16	A Study of Target Detection by Trained Sonar Operators (1962)	Baker and Harabedian
206-17	Notes on the Problem of Training Operators for the AQS-10 Sonar (U) (1962) CONF.	Baker
206-18	Notes on Some Human Factors Problems in Fixed Wing ASW (U) (1962) CONF.	Baker
206-19	Unpublished	
206-20	Improvement in Sonar Operator Detection Performance Consequent to the Use of Optimum Bias and Gain (1963)	Baker

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206-23	Studies of Doppler Recognition Using SQS-23 Sonar (U) (1963) CONF.	Narabedian and Mackie
206-24	The Effect of Calibration Accuracy on Basic Sonar Operations (U) (1964) CONF.	Parker
206-25	The Relationships Between Echo Envelope Characteristics and the Judgment of Echo Quality	Dossett, Gavin and Seltzer
206-26	Sonar Operator Detection Performance at Sea (1964)	Baker, Parker and Rittger
206-27	Sonar Operation, Maintenance and Research: Some Contrasts Between the U.S. and Western European Navies (U) (1964) CONF.	Mackie

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The results and implications of six years of investigation into
the problems associated with the operation and maintenance of
ASW systems are described under nine topical headings:

1. Development of Fundamental Concepts of Target Classification
2. Analyses of Clues Displayed by Operational Equipment
3. Determination of Operator Capabilities in Target Classification
4. Research on Experimental Display Techniques
5. Determination of the Operator's Role in Target Detection
6. Studies of Operator Vigilance
7. Recording of Target Data at Sea
8. Determination of Calibration and Maintenance Skills of Sonar
      Technicians
9. Analyses of ASW Systems in Operation

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