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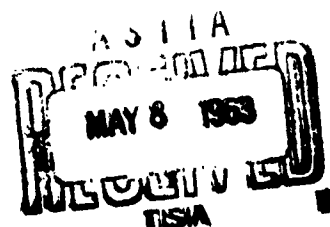
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HUMAN FACTOR PROBLEMS IN ANTI-SUBMARINE WARFARE

Technical Report 206-20

IMPROVEMENT IN SONAR OPERATOR DETECTION PERFORMANCE CONSEQUENT TO THE USE OF OPTIMUM BIAS AND GAIN



HUMAN FACTORS RESEARCH, INCORPORATED
1112 Crenshaw Boulevard • Los Angeles 19, California • WEbster 3-7356

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**IMPROVEMENT IN SONAR OPERATOR DETECTION PERFORMANCE
CONSEQUENT TO THE USE OF OPTIMUM BIAS AND GAIN**

C. H. Baker

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ABSTRACT

Five experiments were undertaken using the visual display of a sonar stack. The first three experiments were psychophysical in nature, undertaken to determine the effects of CRT bias (display brightness) and gain upon operators' target detection performance, at various ranges, with and without reverberations present. Optimum values of bias and gain were determined.

The fourth experiment was undertaken to determine values of CRT bias and gain considered optimum by experienced operators. In comparison with the values determined in the first experiment to be optimum, the average values of the experienced observers represented a performance loss of about 10 decibels.

The fifth experiment compared target detection performance of 26 operators in searching for targets when (1), the display was at experimentally determined optima of bias and gain, with that when (2), the display was at values of bias and gain set by the operators.

When experimentally determined values of bias and gain were employed, there was an improvement in the percentage of targets detected by a factor of 10, and one quarter as many false reports of targets were made.

A brief survey conducted aboard seven ships in port indicated that the findings of the fourth experiment would have been virtually the same had the data been collected at sea.

Consideration is given to several techniques which might be feasible in an operational setting for setting optimum bias and gain.

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IMPROVEMENT IN SONAR OPERATOR DETECTION PERFORMANCE CONSEQUENT TO THE USE OF OPTIMUM BIAS AND GAIN

INTRODUCTION

Readers will be familiar with the fact that operation of any of several controls on a television receiver can result in rather dramatic changes in picture quality. Similarly, operation of controls on radar and sonar indicators can produce qualitative changes in the CRT display. The display can be made to vary in brightness from dark to very bright. Noise can be varied from "virtually absent" to "extremely heavy." In the sonar case the character of displayed noise is dependent, also, upon ambient water conditions which often complicate the perceptual problem by superimposing reverberations upon the random noise pattern.

It has been known for a number of years that the operation of the brightness (CRT bias) and gain controls on a radar indicator can have a marked effect upon the ease with which a radar pip (displayed target) can be visually detected. Representative data with respect to display brightness are shown in Figure 1. These data were obtained by increasing signal voltage (actually by decreasing the attenuation of a signal reference voltage, in decibel units), until the observer reported a just visible pip. The observers knew precisely where to expect the pip to appear. The degree of attenuation in decibels, which rendered the pip just visible, was considered to be a "visibility threshold."

It can be seen that the pip visibility threshold varies as a function of display brightness. At "Visual Reference," the brightness at which the sweep-line was just visible, the threshold was of the order of 29 decibels, i.e., any greater attenuation rendered the pip invisible. With a brighter display, in the region of -17 volts bias, however, the signal voltage could

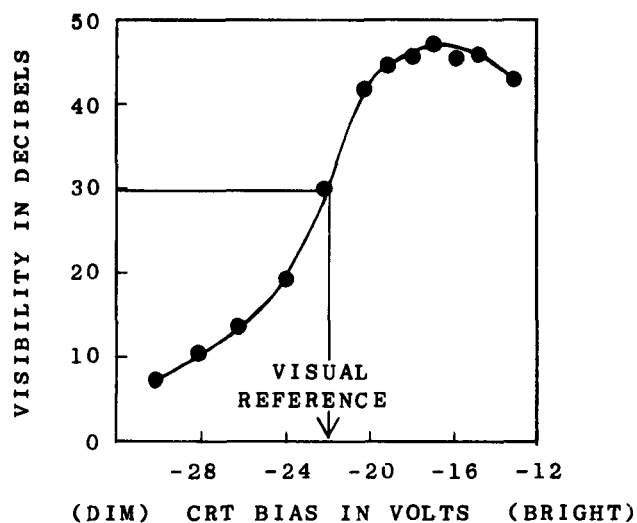


Figure 1. Pip visibility threshold and display brightness (CRT bias) on a PPI. From Williams et al. (1948).

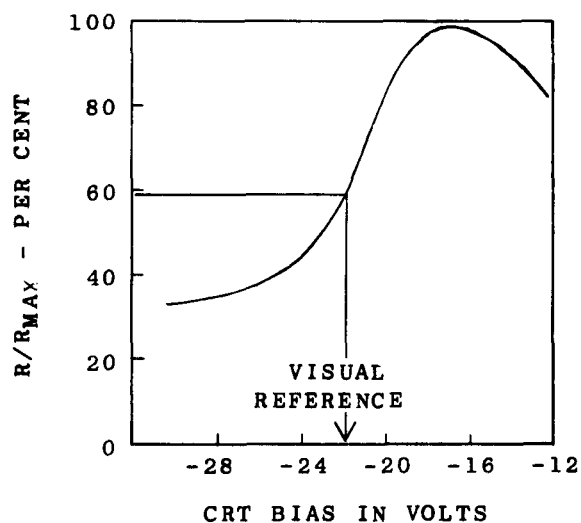


Figure 2. Percentage of maximum range at which a pip is visible as a function of display brightness. (Data translated from Figure 1.) From Thornton (1956).

be attenuated by some 48 decibels before the visibility threshold was reached. In other words, increasing display brightness from that at which the sweep-line was just visible (a common brightness in some operational settings) by some five volts of bias, produced an improvement of about 18 decibels. At still greater brightnesses, performance deteriorated due to phosphor saturation. At -17 volts bias, the display can be said to have been at optimum brightness.

The data of Figure 1 have been translated into terms of percentage of maximum range performance obtained with various display brightnesses, as shown in Figure 2. Here optimum brightness has been credited with maximum range performance, and it can be seen that operation at Visual Reference involves a loss of some 40 per cent in range, or about 65 per cent in radar coverage.

The above data were collected in a noise-free situation. The effect of the addition of noise was demonstrated in another experiment, data from which are shown in Figure 3. It can be seen that successive increments of noise progressively reduce the degree of improvement consequent to operating at optimum brightness, though an optimum brightness was found even at the highest noise level employed.

With respect to the variable of gain, Garner (1946) found that, for the radar case, the higher the video gain the greater the ease of pip detection. This finding has been substantiated by Smith and Hunt (1957), working at an operational radar site, who found that, "In general, the higher the gain--and hence the noise level*--the better is target visibility at all CRT biases."

The radar studies referred to above are but a sample of a large number reported. In the sonar case, however, we know of only one pertinent study, by Hamilton (1958). Hamilton simulated

*The apparent incompatibility between this statement and the data in Figure 3 is explained by the manner in which the noise was generated. Williams et al. inserted noise independently of signal voltage. On the other hand, when gain is varied, both noise and signal voltage are affected.

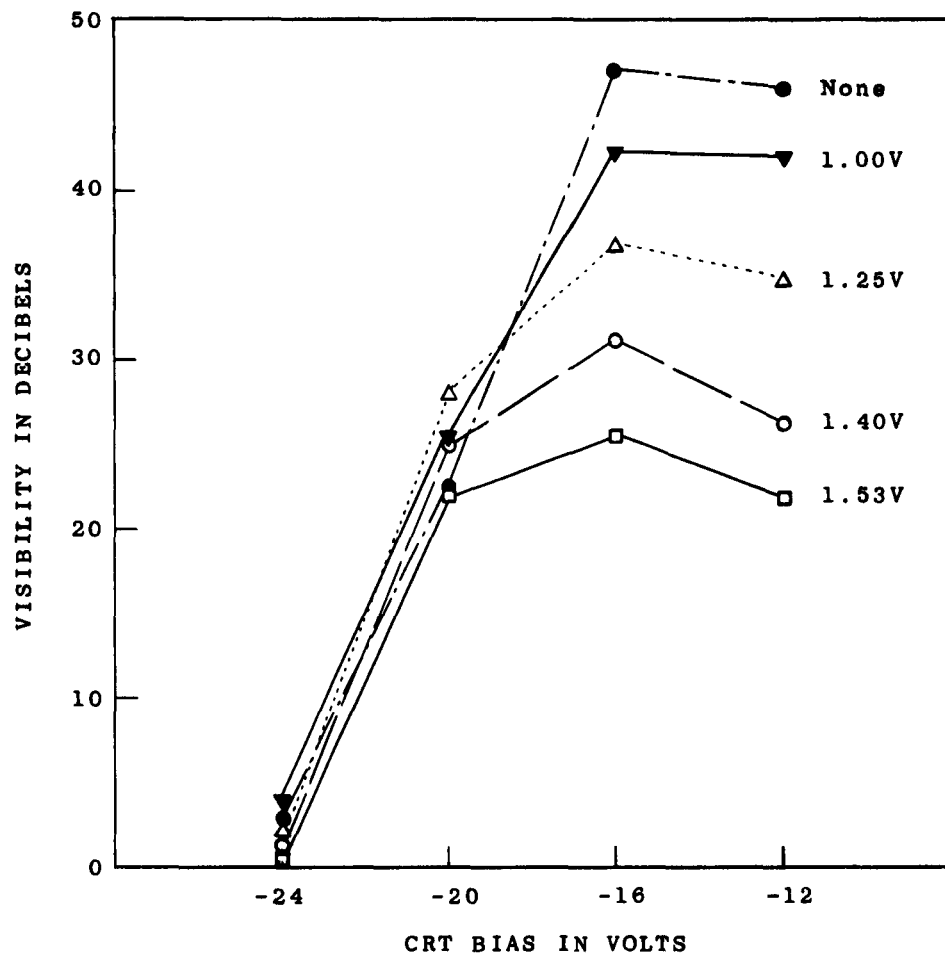


Figure 3. Pip visibility threshold and display brightness for various increments of noise. From Williams et al. (1948).

a sonar display electronically and in general found that, as for the radar case, an optimum brightness exists, and that, in general, increasing gain improves target visibility. Hamilton did not attempt to simulate reverberation.

The study reported here had four aims:

1. To determine, for the sonar case, the effect of display brightness and gain settings on the visibility threshold, in the absence of reverberation.
2. To determine the effect of a fixed amount of reverberation upon the visibility threshold.
3. To determine which settings of brightness and gain are employed by experienced sonar operators.
4. Provided that (3) differed significantly from the optimum values found in (1), the primary aim was to demonstrate the merits of employing the optimum values when searching for sonar targets.

APPARATUS AND METHOD

The experimental work was carried out in a two-room sonar trainer at the Fleet ASW School, San Diego. The observer's room was equipped with a control indicator (stack) for sonar set AN/SQS-10.* Inputs to the indicator were made from the other (experimenter's) room by means of a target simulator SM-28/UQS-T1. Modifications to the circuitry included the attachment of meters and voltage controls to permit control of CRT bias and gain from the experimenter's room. In addition, the circuitry controlling target aspect was disengaged so that a target had the same aspect at every bearing. A reference signal voltage could be attenuated in one-decibel steps by an attenuator mounted on the experimenter's table. For all conditions the range selector switch was maintained at 3,000 yards, the pulse was "medium," and sum brightening was employed.

*Due to training commitments, a trainer for more modern equipment was not available.

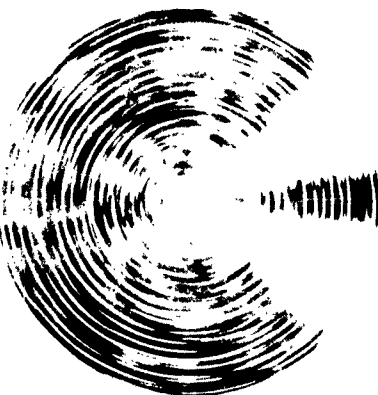
The several aims of this study involved the use of several methods, each of which is described with the pertinent experiment.

Experiment 1

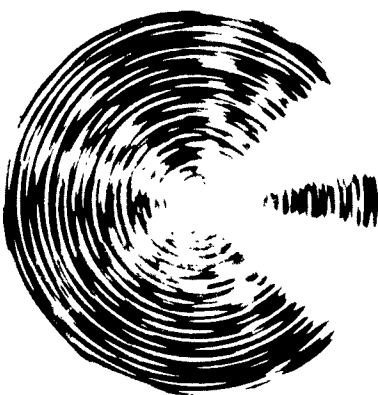
The purpose of Experiment 1 was to determine the effect of display brightness and gain upon the target visibility threshold.* The target appeared within a 3/4-inch circle drawn on the display at 000° and half-range (1500 yards). The experimental technique was to decrease signal voltage attenuation by one decibel on each successive sweep until the operator reported target appearance. For each value of bias and gain, eight such reports were made by each observer. The threshold was computed to be the mean of the eight values between the last decibel value at which target appearance was not reported, and the (next highest) value at which it was. All communication between the two rooms was by intercom headsets. The audio display was not employed. Ambient illumination at the display was 0.1 foot-candle. Subjects were four trained observers.

Target visibility thresholds were determined for eight bias voltages at each of six gain voltages. The bias voltages were: 56 volts (very dark display, sweep-line just below visual threshold), 55 volts (sweep-line just visible), 54, 53, 52, 51, 50, and 49 volts (very bright). The six gain voltages were 22 volts (very infrequent noise spots), 20, 18, 16, 14, and 12 volts (dense noise). Representative displays are shown in Figure 4. At a CRT bias of 53 volts and a gain of 18 volts, the linear dimensions of the target at half-range were 7/16 inch in cross-range and 3/32 inch in

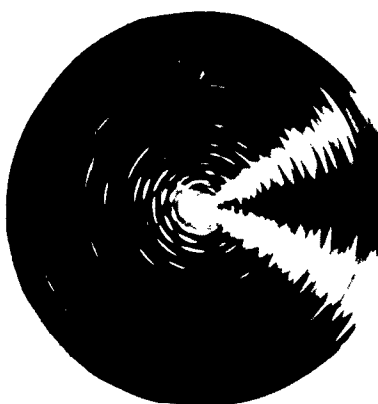
*A distinction is conventionally made between visibility thresholds and detectability thresholds (which were determined later). A visibility threshold refers to the intensity of a target which can just be seen when the observer knows precisely at which part of the display to expect its appearance. No visual search is involved. A detectability threshold, on the other hand, involves the factor of visual search: the observer is informed that the target will appear anywhere on the display, and must search for it. As would be expected, visibility thresholds are lower (superior to) detectability thresholds.



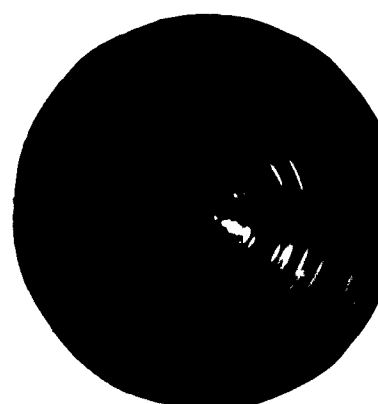
53 Volts Bias
14 Volts Gain
No reverberations
(Optimum setting in
Experiment 5)



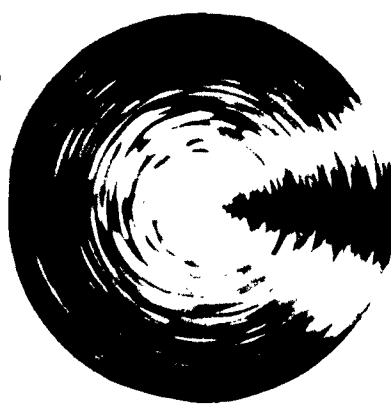
55 Volts Bias
14 Volts Gain
No reverberations



53 Volts Bias
18 Volts Gain
No reverberations



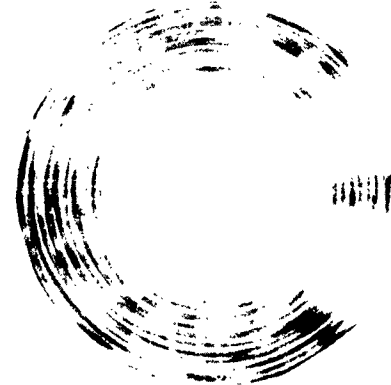
55 Volts Bias
18 Volts Gain
No reverberations



53 Volts Bias
16 Volts Gain
WITH REVERBERATIONS
(Optimum setting in
Experiment 5)



54.5 Volts Bias
19.8 Volts Gain
WITH REVERBERATIONS
(Average setting in
Experiment 4)



49 Volts Bias
14 Volts Gain
No reverberations

Figure 4. The appearance of the display at several settings of bias and gain. Dimmer displays could not be photographed. To obtain these photographs, several exposure value settings were employed and consequently the photos are not truly representative with respect to each other. A Polaroid Land camera was used, with Polascope film Type 410.

range.

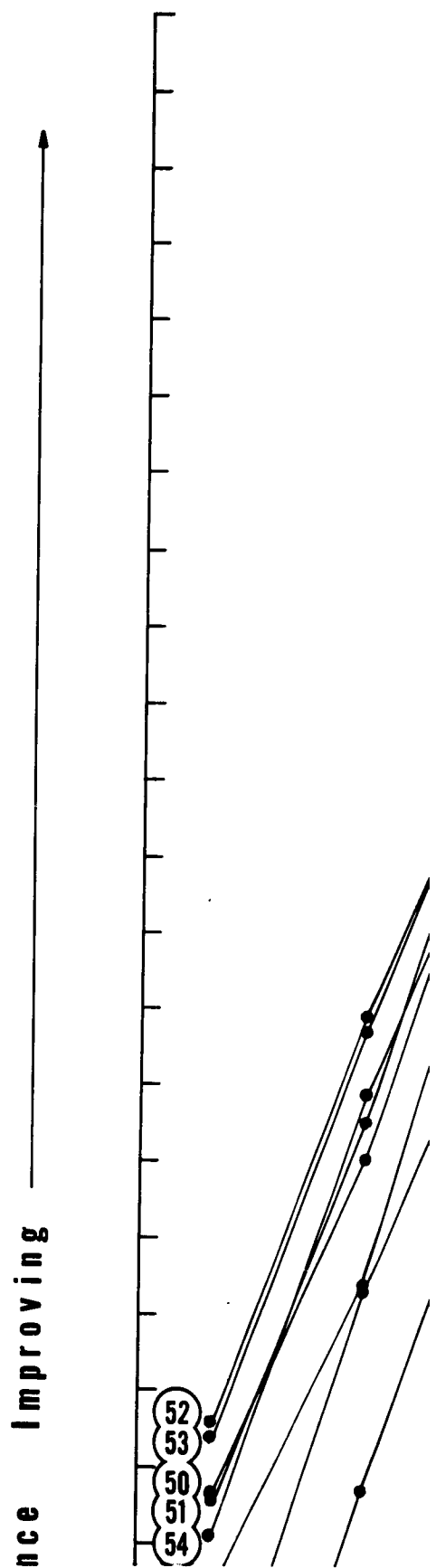
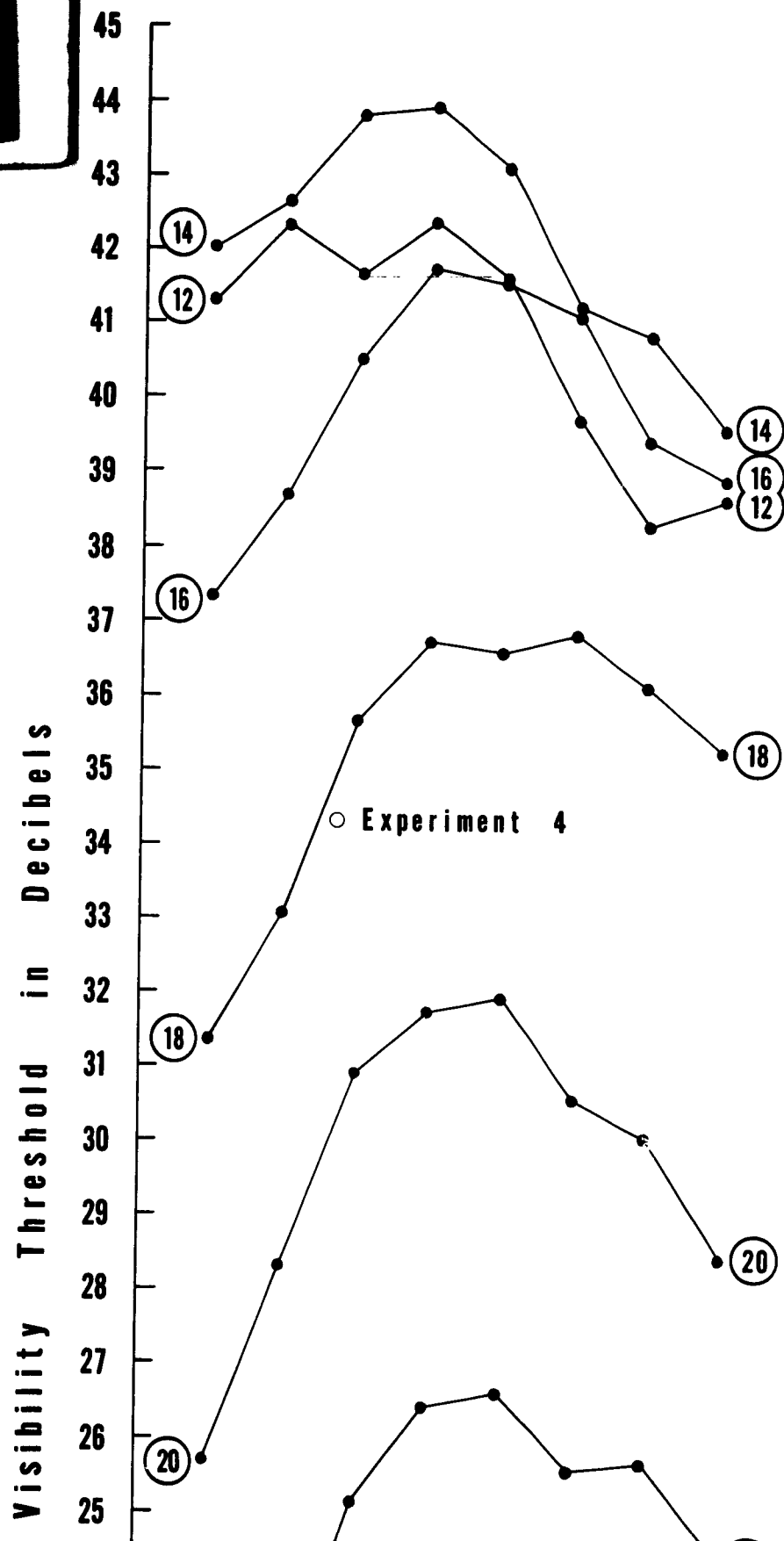
It was found that, as for an earlier study using a different trainer (Baker and Harabedian, 1962), input signal voltages fluctuated with time. This was apparent from an oscilloscope used to monitor signal voltage and also from the fact that thresholds taken an hour or so apart, using the same bias and gain values, and observer, varied by as much as 2 1/2 decibels. For this reason one combination of bias and gain was arbitrarily chosen as a "standard" and each observer's visibility threshold for the "standard" condition was determined immediately prior to the 64 reports of target appearance (eight reports for each of eight bias voltages) made for each value of gain. The deviation of each "standard" threshold from the first one determined was then considered as a correction factor, and this correction factor was applied to each of the eight thresholds determined for each value of gain. The "standard" condition was one in which successive observer responses were extremely stable, 55 volts bias (sweep-line just visible) and 22 volts gain (virtually no noise): in such a situation the target, when it appears, is easily perceptible in an otherwise dark field--observers seldom varied more than one decibel in series of successive responses. Such correction factors were determined in each experiment and have been applied to all the data reported.*

Results (Experiment 1)

Results from Experiment 1 are given in Figure 5. The left

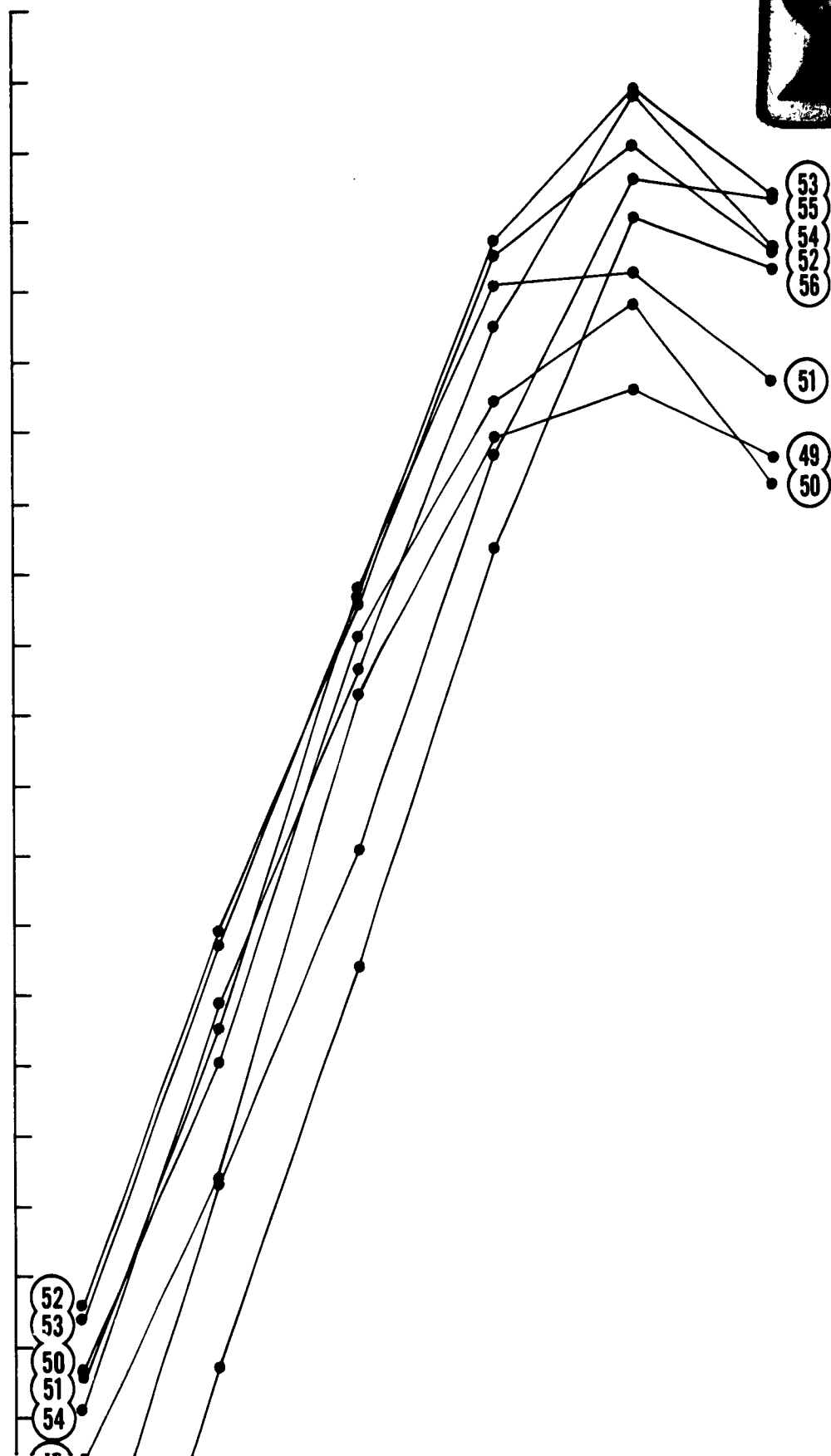
*With respect to the lack of stability of the type of equipment employed here, it must be pointed out that psychophysical research characterized by the precision typically obtained in a vision laboratory is probably impossible with such equipment. Precision signal generators and highly stable circuitry are mandatory for such research. At the same time, precise psychophysical research was not the main aim of the present study. The psychophysical data generated, Figures 5, 6, 7, and 8, although relatively gross in nature, were sufficiently precise to permit accomplishment of the primary aim which was, "to demonstrate the merits of employing the optimum values when searching for sonar targets" (page 3).

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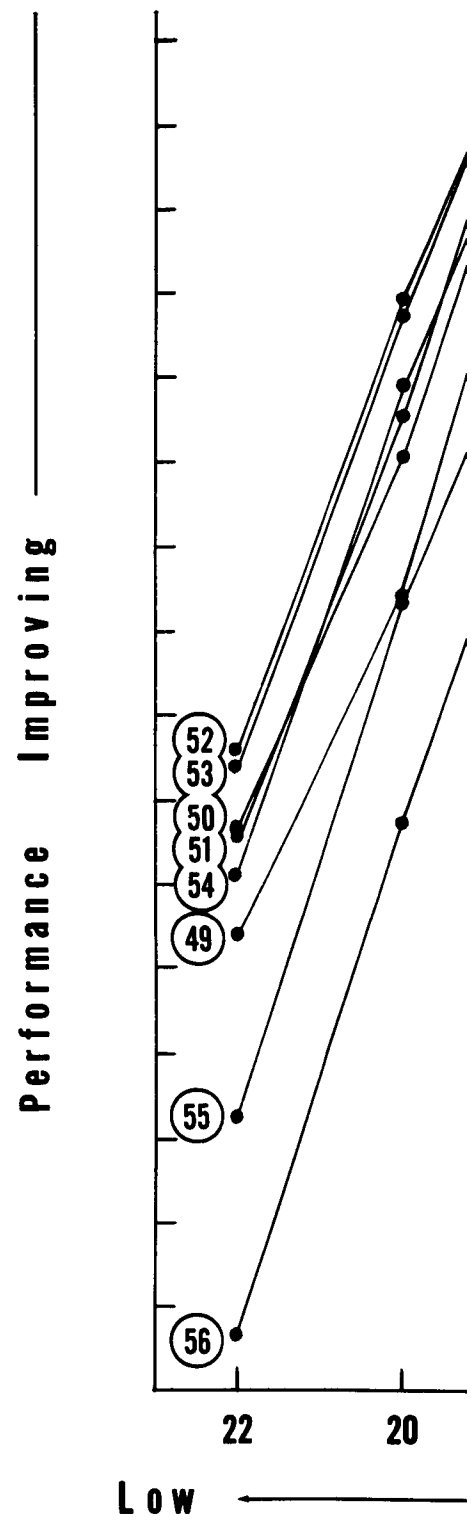
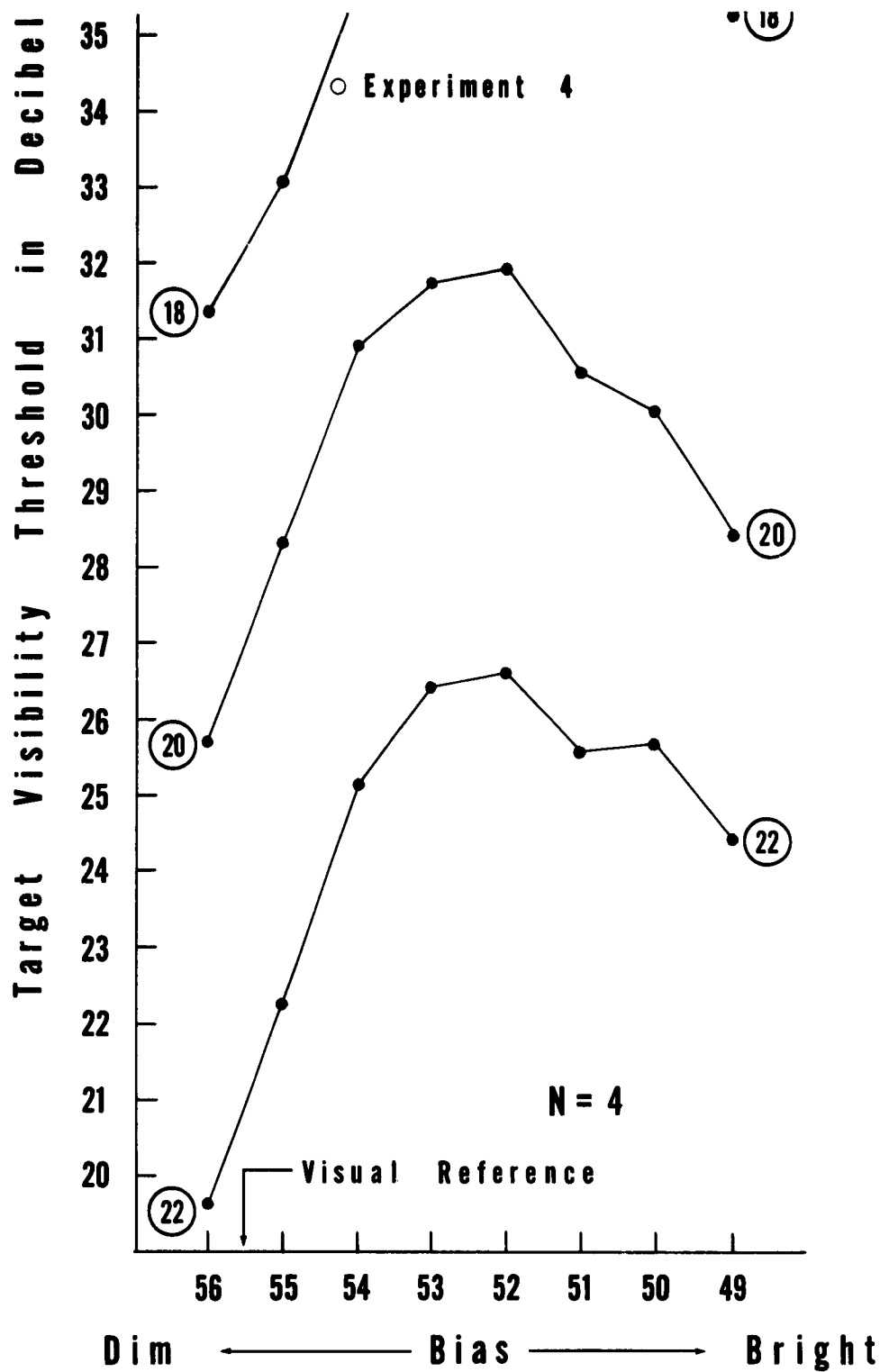
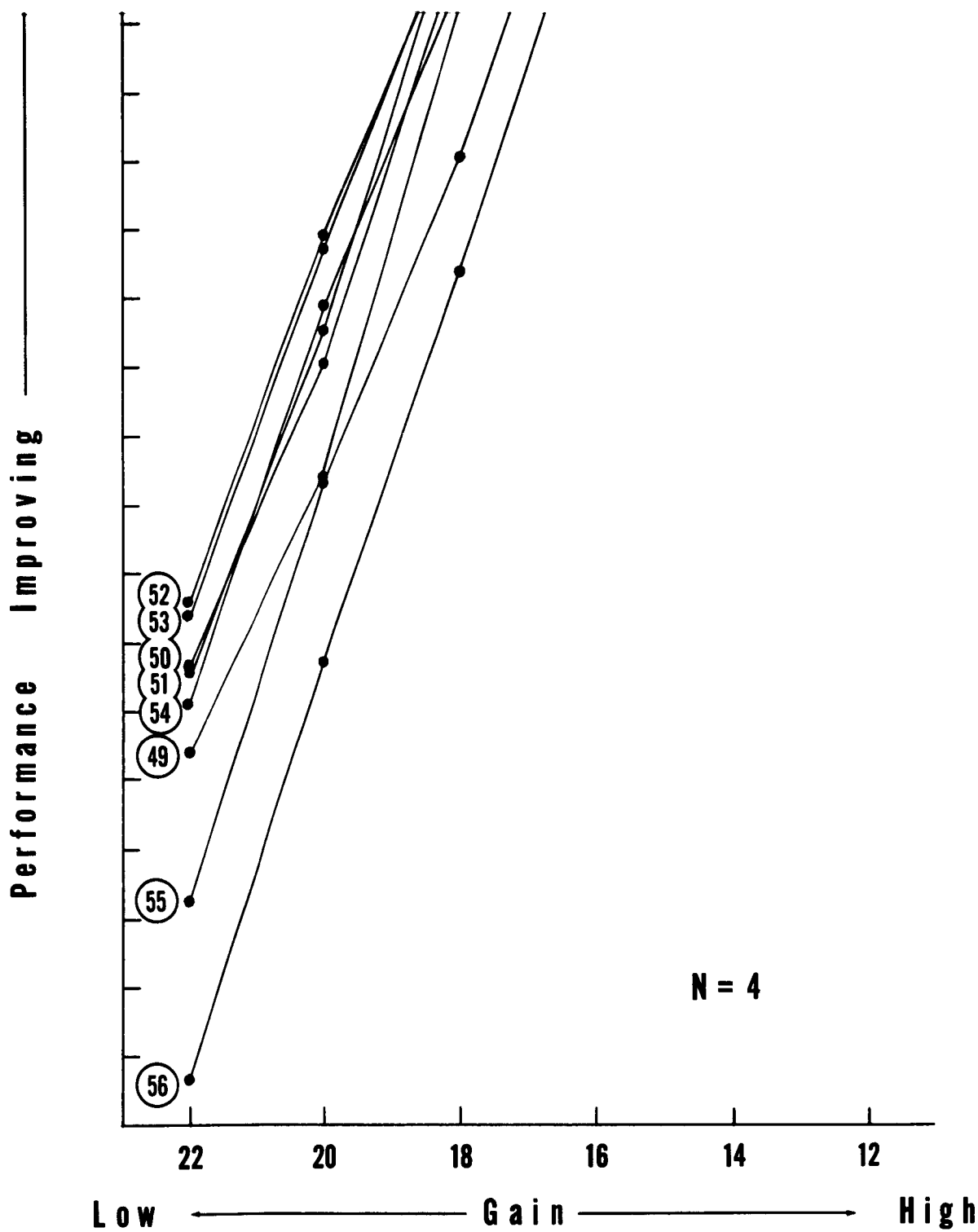
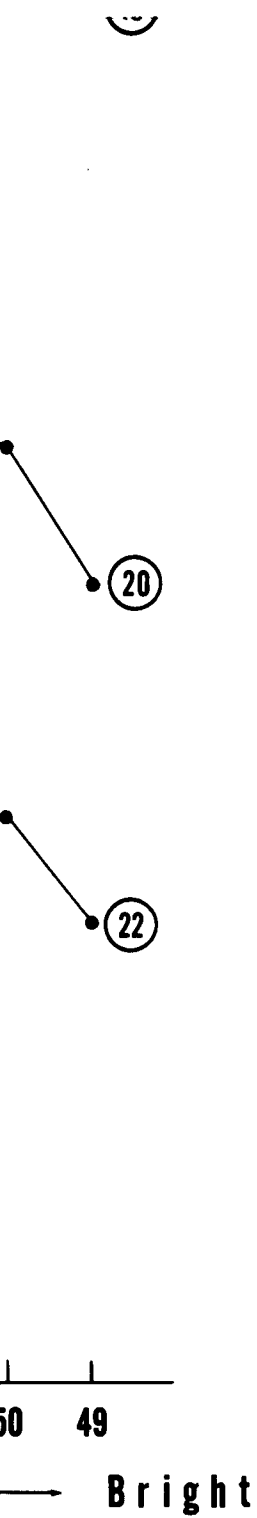


FIGURE 5.

Target visibility threshold
and CRT bias for six levels of
gain.



Targ
for eigl



threshold
x levels of

Target visibility threshold and gain
for eight levels of CRT bias.

half of Figure 5 shows target visibility thresholds as a function of display brightness (bias on the cathode of the CRT), with gain as a parameter.

Several points must be noted. First, each curve has an optimum value in the general region of 53 volts bias (which generates a display brightness which can be described as "moderate"). Second, this optimum value is somewhat removed (by about 2 1/2 volts bias) from that which generates a sweep-line at visual threshold (55.5 volts bias). Third, at gain values of from 22 to 16 volts the advantage of the optimum brightness over that prevailing with a sweep-line at visual threshold is of the order of three to four decibels. Fourth, relatively enormous improvements in performance, some 17 decibels, result from increasing the gain from 22 to 14 volts: at a still greater gain, 12 volts, performance deteriorated, presumably due to phosphor saturation.

These same data have been replotted in the right half of Figure 5, which shows target visibility thresholds as a function of gain, for eight values of CRT brightness. It is clearly apparent that performance is linearly related to gain, up to a gain of 16 volts, and is optimum at 14 volts.

The general conclusion from Experiment 1 was that for the conditions employed, optimum brightness and gain are achieved with a cathode bias of about 53 volts and a gain voltage of 14.

Experiment 2

Experiment 1 was undertaken with a target at half-range, and in the absence of reverberations. Because of the manner in which reverberations decrease with range it was anticipated that the target visibility thresholds determined in Experiment 1 would be differentially affected by various ranges when reverberations were present.

Experiment 2 was a study of target visibility thresholds at

three ranges, 1000, 1500, and 2300 yards, with reverberations present. The reverberations were generated by an AN/UQS T1 Sonar Training Set, with reverberation duration set at a value of 10, and volume set at a value of 1.* Thresholds were determined at three bias values, 55, 53, and 49 volts, and at five values of gain, 22, 18, 16, 14, and 12 volts. Other conditions were as for Experiment 1. The same four experienced operators were employed.

Results (Experiment 2)

The results are given in Figures 6 and 7. Figure 6 shows target visibility thresholds as a function of range and bias, reverberations present, having gain as a parameter. From Figure 6 it is apparent that, first, with the lowest gain employed, 22 volts (when neither reverberations nor noise spots were visually apparent), there is no effect of range upon the visibility thresholds. Second, it is apparent that in general the bias value of 53 volts was again optimum, though not so pronounced as in Experiment 1. Third, as reverberations decrease with range, target visibility thresholds improve: excluding the data for a gain of 22 volts, performance at 2300 yards was about 10 decibels superior to that at 1000 yards. Finally with respect to Figure 6, it should be noted that, again excluding the data for a gain of 22 volts, there is an almost complete reversal in the order of superiority of gain values at 1500 yards when compared with those at 2300 yards: at 1500 yards the highest gain, 12 volts, resulted in the poorest performance, while at 2300 yards it resulted in the best performance. It is presumed that at 2300 yards this high gain value added needed brightness to the display, which was, of course, much brighter at closer ranges. Figure 7 is a summary figure showing some of the same data as Figure 6; those for a bias of 55 volts (dim display). In addition, threshold data have been plotted for a gain value of 22 volts with no reverberation present; these data are virtually identical to those for the same gain condition with reverberations

*Electrical values are given in Appendix I.

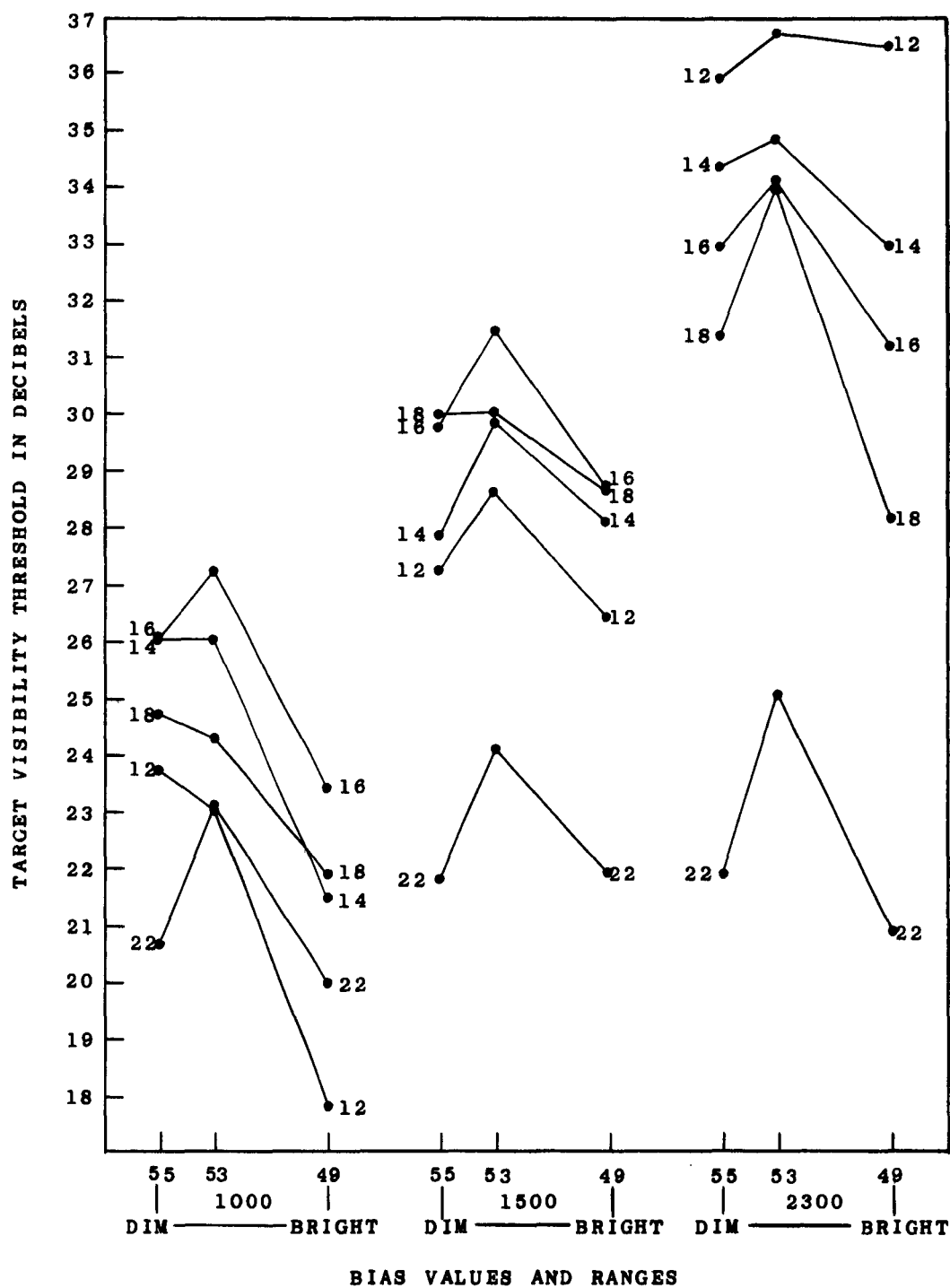


Figure 6. Target visibility threshold for three values of CRT bias, three ranges, and five values of gain. Reverberations present.

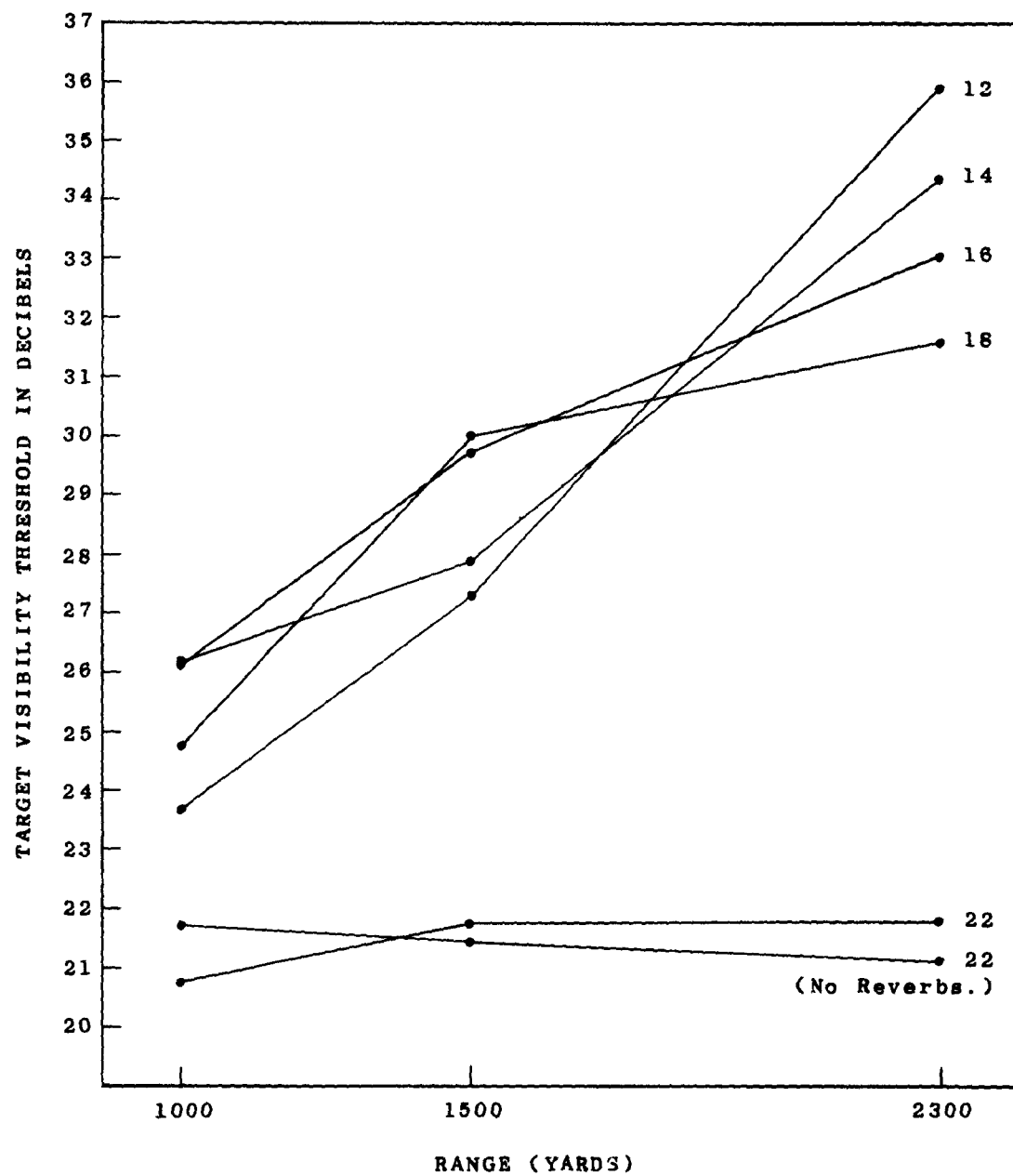


Figure 7. Target visibility threshold and range for five values of gain. Reverberations present.

being generated, and demonstrate that even though reverberation pulses are electronically initiated they do not affect the visibility threshold unless they are visually present. Finally, the reversal in the order of superiority of gain values referred to above (Figure 6) is quite apparent in Figure 7.

The general conclusion from Experiment 2 was that, with the reverberations employed, visibility thresholds are superior out to half-range when bias is about 53 volts, and when gain is 16 volts. At greater range, 2300 yards, more gain is an advantage: the best performance was achieved with a gain of 12 volts, the highest value employed.

Experiment 3

Experiments 1 and 2 were concerned with visibility thresholds, whereas the experimental determination of detectability thresholds in which the factor of visual search is introduced, is much more like the standard operational situation. In Experiment 3, detectability thresholds were determined without and with the reverberations present. Targets were introduced at 12 different locations (3 ranges: 1000, 1500, and 2300 yards; 4 bearings: 275, 325, 45, and 90 degrees*) and detectability thresholds were determined for each of the four observers at each location. When reverberations were added, only eight locations were employed: those four at 1000 yards were excluded. A single condition of bias was employed, 55 volts, with gain values of 22, 18, 16, and 14 volts.

Results (Experiment 3)

The results of Experiment 3 are shown in Figure 8 which shows target detectability thresholds at three different ranges for four values of gain and a single value of bias, 55 volts. From Figure 8

*Owing to inherent equipment instability and small though deliberate variations in the control settings by the experimenter, these locations varied slightly from operator to operator and from trial to trial.

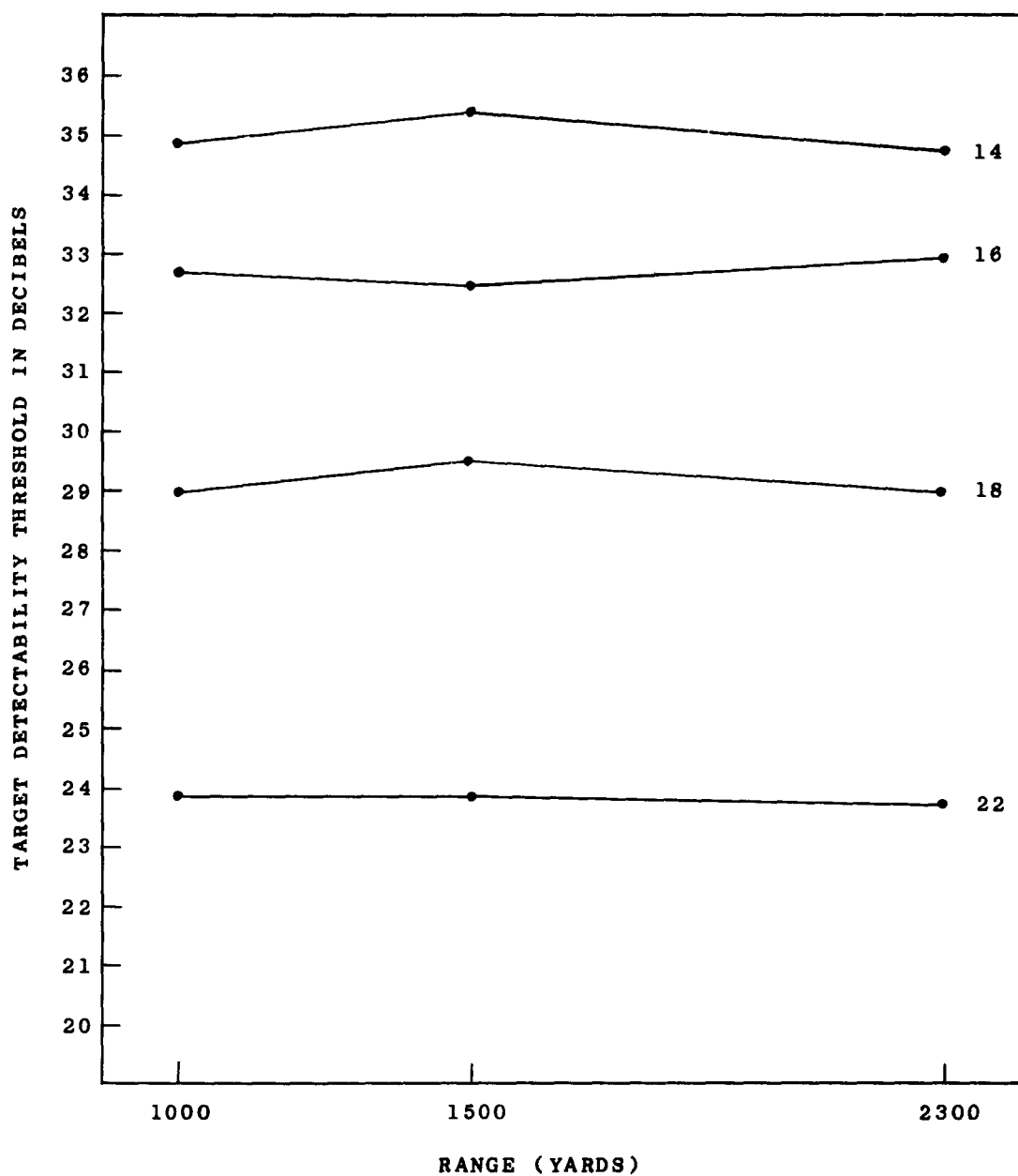


Figure 8. Target detectability threshold and range for four values of gain. No reverberations present.

it can be seen, once again, that gain has a marked effect upon thresholds, that of 14 volts being superior to all others employed. It can be seen that, second, target range has, under the conditions employed, no effect on target detectability thresholds. By comparison of Figure 8 with Figure 5 for the appropriate condition (bias of 55 volts), it is possible to determine the penalty paid as a consequence of visually searching for target (detectability thresholds), compared with the situation where the target location is known (visibility thresholds). For a gain of 22 volts, it is about two decibels, while for gains of 18, 16, and 14 volts the penalties are, respectively, about four, five, and seven decibels. The progressively decreasing advantage with increasing gain is as anticipated: the more gain, the more noise spots to be examined as possible targets, and rejected, while the signal voltage is being increased one decibel after each two pings.

When reverberations were added, detectability thresholds were about three decibels poorer with a gain of 22 volts, at both ranges, while they were as much as 11 decibels poorer at 1500 yards, with the highest gain employed, 14 volts.

The conclusion from Experiment 3 was that target detectability thresholds were not affected by range, and that within the values of gain investigated, the greater the gain, the superior the target detection performance. In addition, reverberations degrade detection performance, the amount of degradation decreasing with increasing range.

The general conclusion, from Experiments 1, 2, and 3, was that sufficient data had been acquired to permit fairly accurate predictions of target detection performance, at various values of bias and gain, in the presence and absence of rather heavy reverberations.

Experiment 4

Experiment 4 was undertaken to determine the bias and gain

settings made by experienced sonar operators when rather heavy reverberations are and are not present. Seven experienced operators were employed. Each operator sat at the stack and over the communication system gave instructions to the experimenter for setting both bias and gain. The display to begin with was dark; a bias of 56 volts and a gain of 22 volts. Instructions by the operators were generally as follows. "Move the intensity up . . . a bit more . . . a bit more . . . move it back a little . . . it's about right just there."

Each setting of bias and gain was made twice for each of the conditions of reverberation and no-reverberation.

Results (Experiment 4)

The results, in voltage settings, are shown in Table I, for each operator designated by rank.

Table I
Bias and Gain Settings of Seven Experienced Operators

Operator by Rank	No Reverberations				Reverberations			
	Bias		Gain		Bias		Gain	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
SO1	54.1	54.1	17.5	17.9	54.0	54.2	20.0	20.0
SOG2	53.0	53.5	18.0	18.0	53.8	53.6	20.0	20.0
SO1	54.2	54.0	17.5	18.0	55.0	54.2	20.0	20.0
SO1	54.2	54.6	18.0	18.2	55.0	55.0	20.1	21.0
SOG3	54.5	54.5	17.9	18.5	54.6	54.7	20.1	20.0
SOG SN	54.0	54.0	18.2	19.6	54.5	54.1	20.5	21.9
SO1	55.0	54.5	19.0	19.2	55.0	55.2	18.0	18.2
Mean	54.14	54.17	18.01	18.48	54.55	54.42	19.81	19.81

From Table I several things are apparent. First, there was considerable agreement among operators, and each operator was

quite consistent from his first to his second setting. Next to be noted is that the average bias settings were virtually the same for the two conditions of reverberations and no-reverberations, but that with the exception of the seventh operator, less gain voltage was employed when reverberations were present.

Of greatest import, however, is that these settings of bias and gain are such that, when considered in conjunction with Figure 5 (see plotted point in Figure 5), a loss would be expected of the order of 10 decibels if these values were employed in determining visibility thresholds.*

It was concluded from Experiment 4 that the bias and gain settings made by experienced operators deviated from optimum settings to a degree which would seriously degrade detection performance.

Experiment 5

Experiment 5 was undertaken to determine the difference in visual target detection performance when using a display having bias and gain set by sonar operators, versus a display operated at optimum settings of bias and gain.

Each operator sat at the stack and, as in Experiment 4, instructed the experimenter concerning the settings of bias and

*Presumably these settings reflect the doctrine laid down in the technical manuals. For the AN/SQS-29 series, the operators' instructions for setting bias are: "turn the master gain control to zero and adjust the intensity control until the circular sweep is just below the threshold visibility." For gain, the instructions are: "Set master gain control to the point where water noise causes faint and random brightening at the outer edge of the cathode-ray tube display" (para. 3-2).

For the AN/SQS-4 series, the operator is informed (page 4-4) that "optimum use of the visual indicator requires that the cathode-ray tube basic intensity be adjusted to the level of illumination of the sonar control room," while the instructions for making the adjustment (page 4-5) are identical with those for the AN/SQS-29 series. Concerning gain, "Set master gain control to the point where water noise causes faint and random brightening of the cathode-ray tube" (page 4-6).

gain at which he wished to operate. The actual instructions received over the operators' headphones were as follows:

The scope is now dark. I want you to set it to the proper intensity and gain, as you would aboard ship, for detecting targets. I have the intensity and gain controls in here so you'll have to tell me how you want me to move them. First you'll want to set intensity . . . now the gain. (Both voltages were recorded.)

Now I want you to go ahead and search for targets for several minutes. If you see one, just call out 'Target,' and then give me the bearing and range. Do not turn up your audio.* There may be very few targets, or none at all, but keep your eyes open. Start now.

The first target was brought from below the known detectability threshold, in one-decibel steps every second ping, until the operator reported its appearance. This single report was a gross indication of the operator's detectability threshold. Depending on the difference between this gross threshold and the known decibel value at which, under optimum conditions, it was expected that a target would be rather easily detectable, the signal strength represented by the threshold was attenuated, generally by from two to three decibels.

Using this attenuated signal, a target was generated at each of the 12 locations employed in Experiment 3. Each target was left on for six pings, removed if not detected and generated at another of the 12 locations, in random order. If the target was detected, the ping number at detection was recorded, as were reports of false targets.

*The decision to not use the audio display was made solely in the interest of intelligibility of verbal communication. There is no reason to believe that the use of the audio display would have generated different results as the gain circuits of the visual and audio display operate quite independently (though the gain employed on the visual display imposes an upper limit to that of the audio display). In addition, owing to the signal processing circuitry, the video signal strength is six db greater than that of the audio display when in the sum brightening mode.

When 12 targets had been generated, new instructions were given, as follows.

We're now going to experiment with a different intensity and gain. The scope will be much brighter than you are used to. This time you may see more targets. When you see one just call out 'Target,' and give bearing and range.

Bias and gain were set to optimum values: bias was set at 53 volts, gain at 14 volts. Signal strength remained unchanged.

When this phase was completed, new instructions followed.

We're now going to add reverberations. The scope is dark again. This time I want you to again give me instructions for setting up the scope as you would at sea. The reverbs are pretty heavy. First, set intensity . . . now gain. Now go ahead and search.

For the reverberation condition only six target locations were employed, three at a range of approximately 1500 yards, and three at approximately 2300 yards. With respect to Figure 6, it will be recalled that optimum gains at these two ranges differed, being 16 volts at a range of 1500 yards and 12 volts at 2300 yards. Rather than "loading the dice" in favor of the optimum values by using these different optima for targets at these two ranges, a value of 16 volts was used for both. The first target was, again, a gross indication of the operators' detectability threshold, an attenuated value of their threshold being employed during the remainder of the search.

Instructions for this final condition were as follows.

Now we're going to experiment again with a much brighter scope. Go ahead and search.

Again, signal strength remained unchanged.

The operators in Experiment 5 were 17 trainees in the 5th of an eight-week course in sonar operation, and nine experienced

instructors, including four CPO's, making a total of 26. None of the seven operators in Experiment 4 was employed.

Results (Experiment 5)

The main results of Experiment 5 are given in Table II, which shows the percentages of targets detected when operators set bias and gain, and when optimum settings were employed.

Table II
Percentage of Targets Detected When Using
Bias and Gain Set by Operators, and
When Operated at Optimum Settings

	No Reverberations			Reverberations		
	Instructors	Students	All	Instructors	Students	All
Operator Settings	12.9	6.8	8.9	1.8	9.8	7.0
Optimum Settings	87.9	95.1	92.6	57.4	72.5	67.3

The point of overriding importance, with respect to Table II, is that when optimum settings of bias and gain were employed, there was an improvement in the percentage of targets detected by a factor of approximately 10. There were no significant differences between instructors and students.

In Table III are shown the average number of false reports of targets when using operator settings of bias and gain, and when using optimum settings.

The point of importance with respect to Table III is that when optimum settings of bias and gain were employed, there was an improvement (decrease) in the average number of false targets reported, by a factor of approximately four. There were no significant differences between instructors and students. While it may appear that fewer false reports were made when reverberations were

Table III
Average Number of False Reports of Targets
When Using Operator Settings of Bias and Gain, and
When Using Optimum Settings

	No Reverberations			Reverberations		
	Instructors	Students	All	Instructors	Students	All
Operator Settings	5.5	4.3	4.7	1.7	2.1	2.1
Optimum Settings	0.5	0.6	0.6	0.6	0.9	0.8

present, it will be recalled that targets were generated at only six locations, i.e., the "reverberation" trials lasted about half as long as those without reverberations.

In Table IV are shown the average voltages of bias and gain employed when the operators made the settings.

Table IV
Average Voltage Settings of Bias and Gain
Employed by the Operators

	No Reverberations			Reverberations		
	Instructors	Students	All	Instructors	Students	All
Average Bias Voltage Setting	54.4	52.7	52.9	53.4	52.4	52.7
Average Gain Voltage Setting	18.13	18.97	18.68	18.32	19.39	19.02

*Significantly different at the 0.05 level of confidence.

The data of Table IV, when compared with those of Table I, indicate that the average gain settings employed by the two groups of operators (Experiment 4 and Experiment 5) were virtually the same, but that the 26 operators represented in Table IV employed

average bias voltages which were very close to the optimum, while those represented in Table I employed a darker display. It is further apparent that the brighter display represented by the value of 52.9 in Table IV is predominantly due to the students, the instructors employing a significantly greater (dimmer) value, 54.4, which was virtually the same as that in Table I. With reverberation present, the instructors still employed a significantly dimmer display, in terms of bias voltage. At the same time, for both conditions, instructors used significantly more gain in the statistical sense.

A final analysis of the data was undertaken to determine the effect of target range on detection. The data analyzed were those obtained with optimum display values prevailing and no reverberations present, these data being the most numerous. The analysis was with respect to the ping number at which each detection was made, i.e., the data varied from values of 1 to 6. For instances when targets were not detected, a value of 7 was assumed. The average ping number at detection was computed to be, for ranges 1000, 1500, and 2300 yards, 4.07, 3.35, and 3.53 pings, respectively. In other words, targets were detected, on the average, more quickly (in fewer pings) when at 1500 yards than when at closer or greater ranges. Analysis of variance showed these three average values to be significantly different at the 0.001 level of confidence. A t test showed that the greatest difference, that between 1000 yards (4.07) and 1500 yards (3.35), was significant at the 0.05 level of confidence, while that between 1500 yards and 2300 yards was not. There were no significant differences between the percentages of targets detected at each range.

DISCUSSION

These experiments have demonstrated that (1) there are settings of bias and gain which can be considered optimum when visually searching for sonar targets; (2) the optimum values of bias and gain differ substantially from those considered appropriate by

experienced sonar operators, and (3) when employing the experimentally determined values of bias and gain, rather dramatic improvements can be obtained both in target detection performance and in the frequency with which false targets are reported.

A few points warrant amplification. It is apparent that whereas the trained operators in Experiment 4 made bias settings which resulted in a display slightly dimmer than optimum, those in Experiment 5 did not. In general, the bias settings were virtually at the optimum value. Why this occurred, being as it is contrary to the general doctrine (page 18), we don't know. We suspect, however, that "word got out" to the effect that "these fellows like a bright scope," or that "they let you see more targets when you make the scope bright." In either event, the significant results consequent to the use of optimum values, Experiment 5, were predominantly due to differences in gain. Had more conventional values of bias been employed, the difference in performance between the two experimental conditions would presumably have been even greater.

Another point of interest is that the operators in Experiment 5 were quite unused to working with a display as bright (consequent to both bias and gain settings) as that when optimum values are employed. On several occasions there were exclamations when the optimum settings were first made, such as "that's too bright," "pretty hard on the eyes," and even "it's lit up like a Christmas tree." Presumably performance would be even more superior, when optimum values are employed, after operators have had considerably more experience with such displays.*

In this general connection, it should be noted that complaints such as "hard on the eyes" can be relieved by introducing more

*The writer has experienced a situation in which observers were more or less forced to adopt the use of unusually bright (i.e., optimum) radar displays. In time they completely accepted the new values and seldom failed to inform the uninitiated that they were operating "too damned dim."

ambient illumination (0.1 foot-candle was maintained throughout the experiments reported here). There are additional advantages to increased ambient illumination, of course, and, happily, greater illumination, while impairing detection performance on dim displays, is tolerable on bright displays. The general rule is, the brighter the display, the greater the amount of tolerable illumination. While precise studies have not been undertaken in the setting of these experiments, our opinion is that at optimum display values, ambient illumination of 0.5 foot-candle would be tolerable.

With respect to false targets, many fewer were reported when the display was operated at optimum values. While it is tempting to consider the possibility that through fortuitous circumstance, noise and reverberation spots are shaped much less like targets when optimum values are employed, we suggest a more prosaic and less heartening explanation. We propose that under optimum display conditions the targets were so "loud and clear" that the perceptual judgment between what did and did not constitute a target was based upon a relatively simple brightness discrimination.

The finding that targets in Experiment 5 were detected sooner when at half-range than when at lesser range, and (though not significantly so) when at greater range, confirms earlier work with radar (Baker, 1962), and with sonar (Baker and Harabedian, 1962). Explanation of the phenomenon is offered in these references. However, we are at a loss to explain why no such result was found in Experiment 3 (Figure 8). We suggest, tentatively, that the pattern of visual search employed by the four sophisticated trained observers (HFR personnel) may differ from that conventionally employed by radar and sonar operators.

Current Operational Practice

The data in this report were obtained in an experimental setting ashore. The question can be raised as to whether or not the findings reported here are indicative of operational practice

at sea. In other words, are settings of bias and gain aboard ship similar to those found in this study?

To answer this question, 12 operating personnel were interviewed in visits to seven USN ships in port. The ships were equipped with SQS-23 or SQS-23A sonar. The personnel interviewed ranged in rating from SOC to SO3. While it was not possible, in port, to have these personnel set the gain on their sonar indicators, it was possible to have them set what they considered to be optimum display brightness. Data with respect to gain were obtained by the admittedly gross procedure of showing them the various photos given in Figure 4.

Three questions were asked each of the 12 sonar personnel. They were as follows:

1. I want you to pretend that we're now at sea and that you are going to set the sonar so as to search for targets. You can't set the gain, but you can show me where you'd set the intensity. (The bias of each setting was then measured.)
2. Look at these pictures (these being the first five photos of Figure 4, arranged on a neutral grey background without any explanatory labels). They show very light reverberations, or it may look as if there are none at all. Which of these is closest to the gain setting you would use?
3. On these other two pictures (the sixth and seventh photos of Figure 4) reverberations are pretty heavy. Which one is closest to the setting you would use?

With respect to bias values set by the 12 personnel, voltage ranged from 24.0 to 35.5 with the meter in the circuit. In all cases, the setting was at or just slightly above visual threshold. Upon questioning, it was confirmed that in all 12 cases the aim had been to set brightness at threshold.

Concerning gain, without reverberations, the first photo (55 volts bias, 18 volts gain) was chosen four times, and the second photo (53 volts bias, 18 volts gain) was chosen eight times.

With reverberations, the sixth photo (54.5 volts bias, 19.8 volts gain) was chosen 10 times, while the seventh (optimum) photo was chosen twice.

The results of this brief survey are interpreted to indicate that current operating practice at sea is virtually the same as that demonstrated by the operators studied ashore.

CONCLUSION

The general conclusion from these experiments is that sonar operators do not operate their displays at optimum values of bias and gain. Operation at optimum values of bias and gain should result in substantial improvements in detection performance.

IMPLICATIONS FOR FURTHER RESEARCH

This study raises the whole question of a practical method of setting optimum bias and gain in an operational setting. At least four methods appear to warrant consideration.

One method would involve the use of voltmeters to set optimum values. Presumably such a technique would entail different correction factors to be applied as a CRT ages.

Another method would involve the use of the test signal equipment which is an integral part of some operating sonar systems. Brief determinations of target thresholds just prior to a sonar watch appear to be quite feasible.

A third method is one which has been proven successful in the radar case (Bessey and Machen, 1957; Machen, 1956; Smith, 1956; Smith and Boyes, 1957; for a summary of these studies see Baker, 1962). Briefly, the method involves making a visual threshold determination of CRT brightness, through a dense optical filter placed over the CRT. When the filter is removed, optimum brightness prevails. Whether or not reverberations could be handled by this procedure is not known.

The fourth method would involve the development of a hemispheric light integrator (photoelectric photometer), similar to an automobile headlamp reflector, which could be placed over the CRT. All lights would be reflected to the focal point, with a meter indication on top. Bias and gain could be turned up to values known to be optimum.

Prior to the consideration of any or all of these proposed methods it would be necessary to confirm the findings of the present study at sea, using operational equipment, and subsequent research aimed at finding a practical setting method would, of course, depend upon the availability of such equipment in a laboratory setting.

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APPENDIX I

Electrical Measurements

Bias Voltage

Bias voltage was registered and set at the experimenter's desk on a Triplet voltmeter with a one-megohm input impedance at 50VDC. The bias voltage, measured at the cathode of the CRT, was positive with respect to ground. More precise measures with a vacuum tube voltmeter were made, with and without the experimenter's meter in the circuit. These values are tabled immediately below.

<u>Bias Voltage on Experimenter's Meter</u>	<u>Voltage Measured by Vacuum Tube Meter, Experimenter's Meter in Circuit</u>	<u>Voltage Measured by Vacuum Tube Meter, Experimenter's Meter Out of Circuit</u>
56	53.00	56.0
55	52.10	55.5
54	50.50	54.0
53	49.75	53.0
52	49.25	52.0
51	48.50	51.0
50	47.50	49.5
49	47.00	49.0

Gain Voltage

Gain voltage was registered and set at the experimenter's desk on a (different) Triplet D.C. voltmeter, model 327-PL, which was connected to the center tap of the master gain control on the stack. All measurements were with respect to ground. More precise measurements with a vacuum tube voltmeter were made, with and without the experimenter's meter in the circuit. These values are tabled immediately below.

<u>Gain Voltage on Experimenter's Meter</u>	<u>Voltage Measured by Vacuum Tube Meter, Experimenter's Meter in Circuit</u>	<u>Voltage Measured by Vacuum Tube Meter, Experimenter's Meter Out of Circuit</u>
22	21.5	22.20
20	19.5	20.00
18	17.7	18.10
16	15.8	16.10
14	13.8	14.10
12	11.5	11.75

Signal Voltage

The average signal voltage, set by the control for target sound level, was measured at the input to the decibel attenuator to be 0.15 ± 0.01 volt.

Reverberation Voltage

Reverberation voltage was measured at the receiver output by an oscilloscope. The average value was determined for each tenth of the range of 3,000 yards. The values are tabled immediately below.

Range: 300 . 600 . 900 . 1200 . 1500 . 1800 . 2100 . 2400 . 2700 . 3000
(yards)

Voltage: 150 . 125 . 100 . 75 . 50 . 40 . 30 . 20 . 20 . 20