MEDICAL RESEARCH LABORATORY

U. S. Naval Submarine Base
New London

Volume 9 1950 pp. 128-149

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PERISCOPE ACUITY AT NIGHT

Central and Paracentral Acuity as a Function of Contrast and Adaptation.

by
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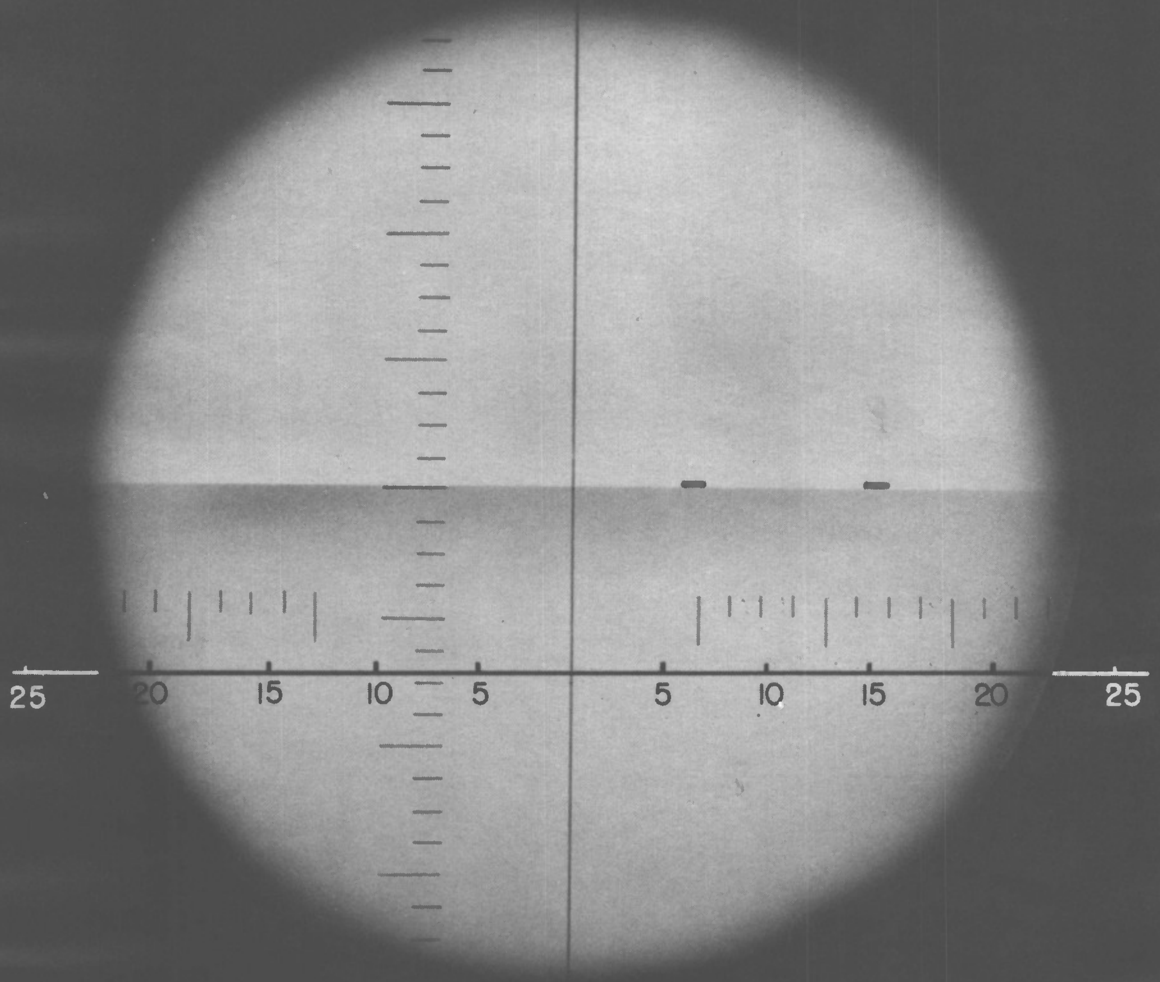
Medical Research Laboratory Report No. 157

BuMed Project NM 003 041.39.01

APPROVED: T.L. Willmon, Captain, MC, USN; OinC 28 Nov 1950



If this drawing is held 6 inches from the eye it illustrates the actual angular and size relationships dealt with in this study. A visual angle scale has been laid over a periscope field. The location of a visual angle on the horizontal periscope scales does not change from low to high power. A target at 6° visual angle would be at 4° relative bearing on low power and 1° relative bearing on high power. Throughout this study target position has been designated in visual angles. The results show discrimination is best at 6° visual angle, and good from 6° to 15° visual angle, over a wide range of contrasts at low brightnesses.

PERISCOPE ACUITY AT NIGHT

I. Central and Paracentral Acuity as a Function of Contrast and Adaptation

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Reference may be made to this report as follows: H.G. Sperling, D. Farnsworth, Periscope acuity at night. I. Central and paracentral acuity as a function of contrast and adaptation, MRL No. 157, Vol. 9, pp. 128-149, 1950.

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OPERATIONAL APPLICATIONS

1. The results of this experiment indicate that there are low contrast targets at twilight or night brightness which are detectable in the periscope with 6° off-center vision which are not detectable centrally. It is also shown that exposure to common types of visual indicators, dials, radar and Christmas Tree, just prior to periscope observation will prevent or decrease the chances of detecting targets under the above conditions.

2. In consequence of these findings it is suggested (a) that periscope operators practice the use of off-center vision at low sky brightnesses and (b) avoid observation of compartment instruments immediately previous to observation.

3. To determine the best application of these findings to submarine operation it will be necessary to make field trials to determine the effect of operating conditions and for the development of devices to promote controlled off-center fixation in the periscope.

ABSTRACT

Discrimination of a target approximating the visual subtense of a ship at 5,000 yards on low power was measured with the right eye at nine retinal positions, from central fixation to 15° off central vision. Target to background contrast was varied to sample a range of visibility conditions at sea. It was found that for all target contrasts at light levels at or below twilight (.27 millilamberts) off-center acuity was greater than central acuity. Acuity at 6° from central fixation was found best but little decline was discovered out to 15°.

The subsequent effect upon discrimination of the targets of viewing three common visual indicators was measured. After viewing the S.S. radar P.P.I. a long recovery time was required to detect targets illuminated even as high as full moonlight. The "Christmas Tree" and red illuminated dials produced smaller but appreciable decrement.

These laboratory tests indicate that viewing radar indicator lights and dials at normal operating brightness is detrimental to periscope vision at night.

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INTRODUCTION

This paper presents an investigation of the capacity of the eye for discriminating a small target from its background under low levels of illumination at various positions from the point of central vision. The project was undertaken to find an answer to the practical questions of whether it is necessary to darkadapt or partially darkadapt the submarine periscope operator in order to preserve maximum vision at night through the periscope.

It is well known that the rods, located in the periphery of the retina, are many times more light sensitive than the cones, located in the rod free area of the center of the retina. It is for this reason that off-center vision is used by "night lookouts". The sensitivity of the rods increases with time in the dark and is reduced by exposure to light, especially of short wavelengths.

While it is known that the ability to detect dim light increases towards the periphery of the eye, it is also true that the ability to discriminate detail decreases towards the periphery. It was therefore necessary to determine whether the ability to discriminate targets at low light levels from their backgrounds was sufficiently better in the periphery of vision than in the center of vision to justify dark adaptation.

The problem was complicated by the fact that fog and mist at sea reduce target-background contrast by varying amounts. Thus, it was necessary to measure target discrimination at various places from the central to peripheral field, at varying light levels and over a range of target-background contrasts.

The results showed that peripheral vision was considerably better than central vision for the target size and shape used and that it remained better over a wide range of contrasts. The next step was to consider dark adaptation. This was taken as far as to examine the time necessary to recover to maximum discrimination after viewing each of the three most important visual indicator devices; radar, dials and hull opening indicator panel ''Christmas Tree''.

This experiment was performed under ideal conditions in the Laboratory, using persons highly trained in this type of observation. This paper indicates the capacities and limitations of the eye for a periscope-type task. In order fully to apply these results to submarine operations further studies should be made under field conditions.

PERISCOPE ACUITY AT NIGHT

Central and Paracentral Acuity as a Function of Target Contrast and Adaptation

PROBLEM

Among the changes in design recommended for submarines has been the consolidation of the facilities for communication, information and attack in a single compartment to be called the Attack Center. Essentially, this will be a combination of the features of the present conning tower and control room.

Such an arrangement has presented the problem of what restrictions must be placed upon the periscope operator's vision in the compartment in order to preserve his adaptation for maximum vision through the periscope at night. Since the periscope operator must have the widest possible knowledge of conditions within the submarine and of the target, it is desirable that he be free where possible to consult visual indicators at the time of search. It is the purpose of this study to determine if adaptation to normal light levels in the most important visual indicators will impair subsequent vision through the periscope.

The problem may be divided into two phases. First, following optimum adaptation, the limits of visibility through the periscope for a range of probable target brightnesses and contrasts at various peripheral angles must be determined. Then it must be determined how previous adaptation to standard visual indicators affects these values.

The particular combination of conditions present in this problem prevented it from being answered from existing data. Following from the well established fact that parafoveal rod vision is many times more sensitive at night than central vision, it was necessary to specify the retinal position of stimulation. It was also desirable that the data be gathered for a target approximating the shape and area of a ship on the horizon at attack range. Since perfectly clear visibility conditions at sea are, by far, the exception, it appeared highly desirable to specify conditions of lowered target-background contrast in keeping with the lowered effective contrast of targets at sea under varying atmospheric conditions. While there is data available for acuity at different retinal positions under dim illumination (Mandelbaum and Rowland, 1) it was gathered from a gap-acuity target of high contrast and while extensive results on the visibility of low contrasts are available (Blackwell, 2) no control of position of retinal stimulation was made. Therefore, an experiment was planned to abstract what were believed to be the essential variables in periscope viewing and to subject these to laboratory study.

PHASE 1

To determine the useful visual field of the periscope operator under various conditions of moderately low brightness.

APPARATUS:

a. Target: The target size and shape were chosen to approximate the shape and visual subtense of a medium size freighter at 5000 yards range under low-power magnification of the periscope. The targets were rectangular and subtended 1.0° x .33° of visual angle at 10 feet.

Five gray targets were used which were graded in reflectance from 2 percent to 69 percent and yielded a series of contrasts to a 76% reflectance white of approximately 10%, 25%, 40%, 70% and 97%*. The contrasts employed were chosen to sample a wide range of visual contrasts since atmospheric conditions at sea are subject to extreme variation.

Atmospheric conditions affect visibility by reducing the apparent contrast of objects. Duntley[3] has expressed this variable in terms of "meterological range". The "meterological range" is the distance at which the apparent contrast of an object C_R is reduced to 2 percent of its inherent contrast C_o. For any fixed viewing distance R, meterological range V is expressed according to the following relationship:

$$C_R = \frac{B_o}{B_R} \cdot C_o \cdot e^{\frac{-3.912\bar{R}}{V}}$$

B_o and B_R are the inherent and apparent brightness of the background, which are equal for a target against the sky and thus drop from the equation. R equals R, the distance of view, for horizontal viewing. Thus the formula becomes:

$$\frac{C_R}{C_o} = e^{\frac{-3.912R}{V}}$$

where the e is the base of the natural logarithm. If we assume the reflectance of the target to be 25%, a close approximation to the reflectance of naval vessels, C_o becomes .75. Then if we use our intended 5,000 yards as the range (R), the meterological ranges (V) corresponding to our five targets are 10%: 9,696 yds., 25%: 17,738 yds., 40%: 31,085 yds., 70%: 282,048 yds. 97% which was used to obtain data on very **high contrasts** for comparison, yields an infinite meterological range. These relationships are illustrated in Figure 1.

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*Target-background contrast was calculated by the formula used by Blackwell[2] and Duntley[3] where $\frac{B_o - B_1}{B_o}$ x 100) is expressed as percent contrast. B_o is the brightness of the background and B_1 is the brightness of the target.

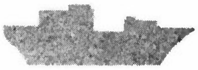
	Percent Contrast	Meterological Range for 25% reflectance Target at 5,000 yds.
	97	∞
	70	282, 047 yds.
	40	31, 085 yds.
	25	17, 788 yds.
	10	9, 696 yds.

Figure 1

Within the limits of reproduction this figure shows the contrasts of the targets used in this study. It is presented to enable the reader to visualize the appearance of ships at sea at equivalent contrasts. In the last column are shown the "meterological range" conditions under which a 25% reflectance ship at 5,000 yards will appear to have these contrasts.

b. Illumination: The target background was illuminated evenly out to 15° on either side of the target. In the periphery beyond that, there was grading off of brightness to approximately 2% dimmer at 90°. Thirteen brightness steps were provided ranging from the region of overcast starlight to that of twilight (Cols. 1 and 2, Table I).

The illumination was provided by an ellipsoidal projectow which was set to illuminate the target background to 1.0 millilambert brightness. Lower light levels were achieved by placing neutral density filters in front of the projector lens. These filters were calibrated for visible transmission using a special densitometer which employed the Photovolt 512 photocell, filtered to match the spectral sensitivity of scotopic vision.

c. Fixation and Target Display: The first fixation point was a radium phosphor assembly of .55 millilamberts brightness which subtended .1° of visual angle. It could be placed at 1° intervals from the target so that the target fell at retinal positions from 1° to 15° along the horizontal meridian in the nasal field of the right eye.

The target was mounted on a pivoted arm and could be presented in four positions - vertical, horizontal, tilted 45° right and 45° left.

A second fixation point was used for 0° (foveal) fixation. It consisted of a regulated low brightness lamp located in the hollow arm upon which the target was mounted. It shone through a small hole in the rectangular target to provide central fixation.

d. Observer's Station and Communications: The observer's station was provided with a head and chin rest which fixed the observer's eye just 10 ft. from the target center. A leaf shutter was located in front of the observer and prevented his seeing the target between trials. A small hole in the shutter permitted a view of the fixation point between exposures. The closed shutter reflected light of the same brightness as the target background and provided continuous adaptation to the same light level.

A three-way telephone system permitted the experimenter to designate target positions for each trial and record responses in a separate room while the assistant experimenter received target designations, gave ready signals to the observer and set target positions. The observer was provided with a microphone to give responses.

PROCEDURE:

Acuity was measured at nine positions from 0 to 15 degrees in the nasal field of the right eye for each of the five contrast targets. A selection of light levels was employed for each target so that the acuity range was explored from close to 0% to close to 100% correct responses.

The instructions to the observer were as follows:

"You are going to be shown the target which you see before you under various dim illuminations and at different distances from fixation. Your task is to judge the position of the rectangle while looking directly at the fixation point.

1. You will adapt in complete darkness for five minutes (or 10 minutes for light levels lower than .006 Ml).

2. Then the projector will be turned on at which time you will put the occluder over your left eye.

3. Adjust the chin and head rest so that you are looking directly at the small fixation light through the hole in the shutter.

4. The first group of observations will be practice.

5. When A says 'ready', fixate the light and when it is clearly seen respond 'ready'.

6. During the 3 second exposure maintain constant fixation on the fixation light. It is very important that you do not look away from it.

7. While fixating, determine whether you can perceive the position of the target.

8. As soon as the shutter is closed respond 'no', if you were unable to determine the target position or name the target position if you were. Say 'up' for the vertical, 'right' where the top of the target was tilted 45° right, 'left' where the top was tilted 45° left and 'cross' for the horizontal.

9. Do not guess. If you are not reasonably sure of the position of the target, say 'no'.

10. There will be 24 judgments in each group. You will be given a ten minute rest period after the first five groups.

11. If at any time during a series of observations the field becomes clouded, report this immediately to the E."

One session was run per day and consisted of nine groups each employing a different retinal location at a single light level, for one of the 5 targets.

A complete set of data was collected from one observer. A second observer was used at selected light levels to supplement the first Observer's data.

RESULTS:

The basic values presented are percent correct responses of the 24 trials under each condition. These values are shown in Table I, for the inspection of the reader. Figure 2 shows 50% threshold brightness* as a function of retinal position from 0 to 15 degrees of visual angle. Five curves are shown, one for each contrast target. Figure 3 shows threshold brightness as a function of percent contrast of the target. Each curve represents a different retinal area.

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*That brightness at which the target position can be seen correctly on 50% of trials.

TABLE 1

Percent Correct Responses at all Target Positions, Target Contrasts and Background Brightnesses

Target Background Contrast % Contrast	Background Brightness B_o Millilamberts	Fixation - Degree from central Obs. 1 0°	1°	2°	4°	6°	8°	10°	12°	15°
97%	.000048	-	-	0.00	4.16	25.00	12.50	16.67	-	12.50
	.000064	0.00	0.00	0.00	25.00	37.50	16.67	20.84	20.84	16.67
	.00013	0.00	0.00	12.50	91.67	75.00	95.84	75.00	-	58.34
	.00046	0.00	0.00	83.34	100.00	100.00	100.00	100.00	95.84	62.50
	.0018	91.67	100.00	-	-	-	-	-	-	100.00
	.0066	100.00	100.00	100.00	100.00	-	-	-	-	-
70%	.00013	-	-	0.00	0.00	33.34	29.17	33.34	33.34	25.00
	.00046	-	0.00	16.67	83.34	95.84	75.00	95.84	75.00	66.67
	.0018	12.50	33.34	62.50	100.00	100.00	100.00	100.00	100.00	95.84
	.0066	100.00	100.00	-	-	100.00	-	-	-	100.00
40%	.00013	-	0.00	0.00	8.33	8.33	8.33	12.50	0.00	4.16
	.00046	0.00	0.00	20.84	33.34	37.50	20.89	33.34	37.50	12.50
	.0018	0.00	4.16	62.50	87.51	91.67	79.17	87.51	83.34	83.34
	.0030	16.67	20.84	79.17	95.84	100.00	95.84	100.00	100.00	66.67
	.0066	100.00	-	100.00	-	-	100.00	-	-	95.84
25%	.00046	-	-	8.34	-	-	-	-	-	-
	.00088	-	-	12.50	29.17	25.00	20.84	12.50	16.67	8.33
	.0018	-	0.00	12.50	29.17	50.00	37.50	25.00	12.50	8.33
	.0030	-	0.00	8.33	87.51	87.51	79.17	58.34	58.34	29.17
	.0066	41.67	100.00	100.00	-	-	100.00	95.84	87.51	62.51
10%	.0066	0.00	0.00	8.33	16.67	25.00	0.00	-	-	-
	.011	0.00	37.50	75.00	100.00	50.00	29.17	12.50	12.50	8.33
	.019	0.00	79.17	95.84	100.00	66.67	41.67	20.84	16.67	4.16
	.039	100.00	100.00	100.00	95.84	87.50	83.34	50.00	25.00	0.00
	.074	100.00	100.00	100.00	100.00	100.00	100.00	91.67	70.84	54.17
		Obs. 2								
25%	.00088	-	-	-	0.00	4.16	4.16	12.50	16.67	8.33
	.0018	-	-	0.00	33.34	33.34	50.00	45.84	33.34	50.00
	.0030	-	0.00	29.17	58.34	58.34	58.34	58.34	75.00	70.84
	.0066	12.50	58.34	100.00	-	-	100.00	87.51	95.84	100.00
	.011	100.00	-	-	-	-	-	100.00	-	100:00
10%	.0030	-	-	4.16	12.50	33.34	29.17	16.67	20.83	16.67
	.0066	0.00	20.83	25.00	58.33	62.50	58.33	37.50	45.83	41.67
	.011	-	66.67	95.84	100.00	100.00	91.67	91.67	100.00	75.00
	.019	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

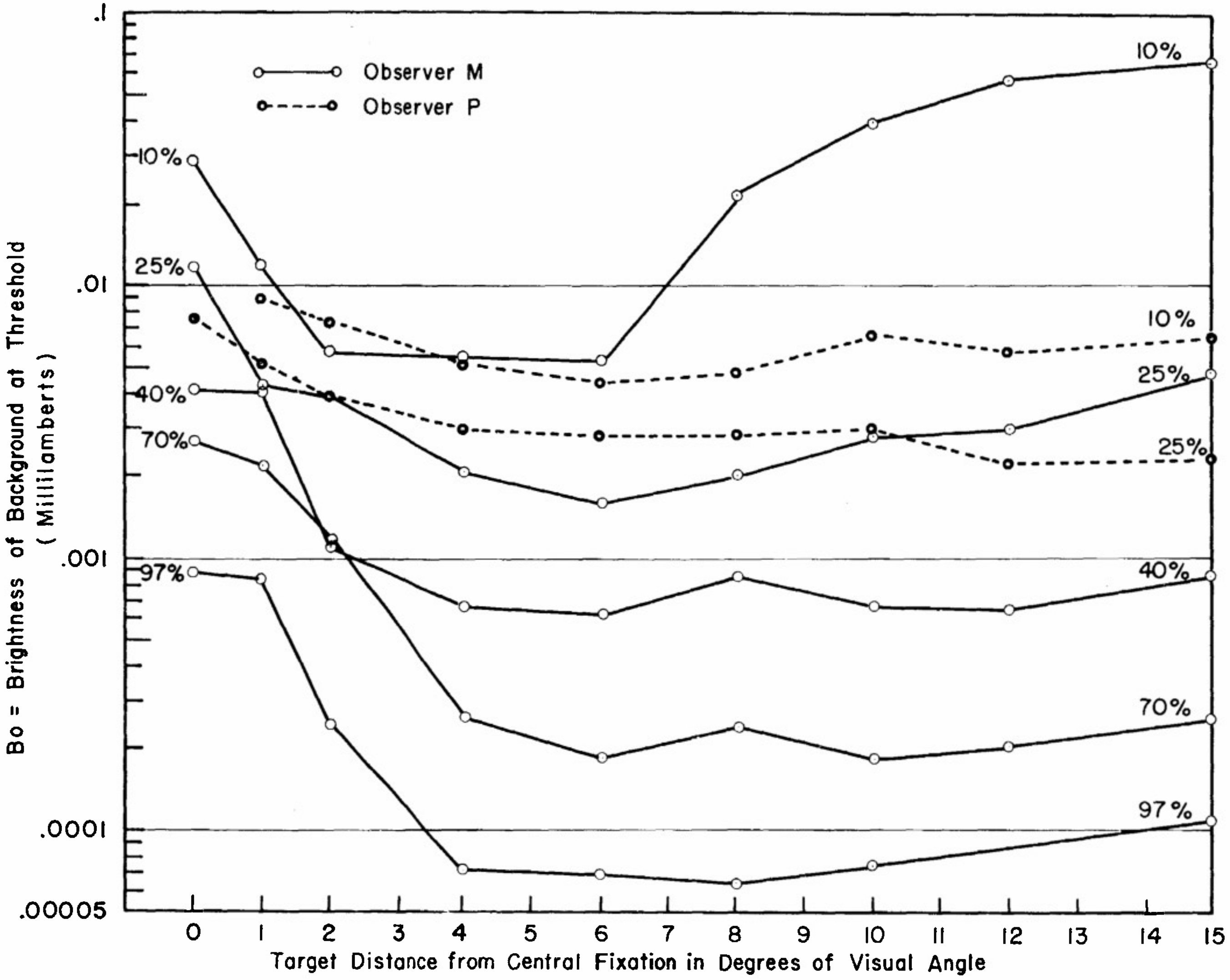

Figure 2

Threshold brightness as a function of Target distance from central fixation for 5 targets from 10% to 97% contrast.

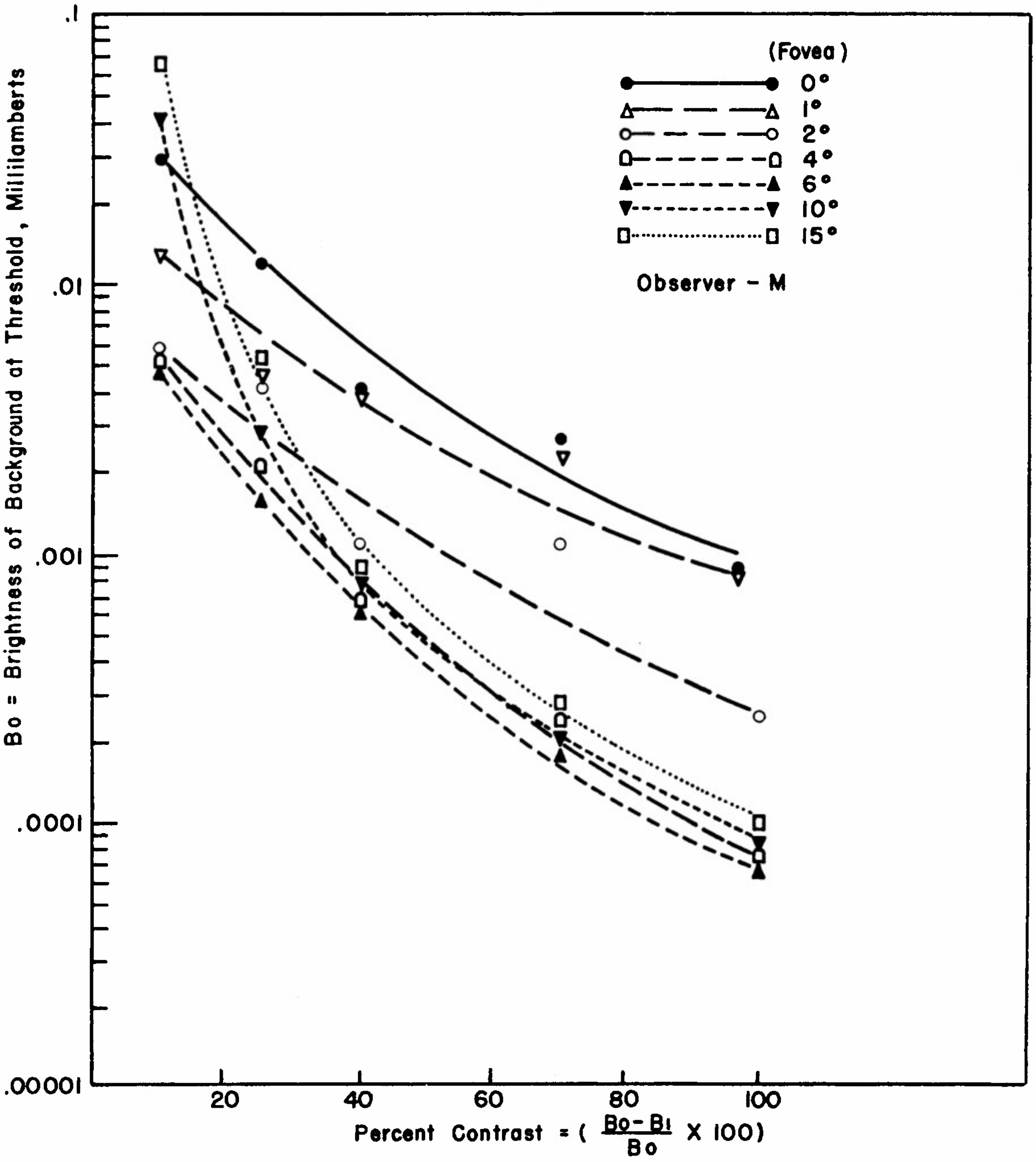

Figure 3

Threshold brightness as a function of target contrast for 8 retinal positions from central to 15^{o} peripheral vision.

In Figure 2 it may be seen that the general shape of the threshold brightness curve, as the target is moved from central vision to 15° peripheral vision, is similar for all contrasts. Foveal vision (0°) is relatively low; peak discrimination occurs at 6° and there is little decline in discrimination out to 15° except for the lowest (10%) contrast target, which for observer M shows peak discrimination from 2° to 6° and falls off rapidly past 6°.

Figure 3 is more useful for describing the quantitative relationships present in the data. This graph has been simplified for inspection by selecting representative contrast levels and drawing visually fitted smooth curves through the plotted points. It is seen that the brightness threshold is lowered, thus discrimination is increased, in a regular fashion with increased target contrast. This holds true for all retinal positions although the shape of the function differs with retinal position.

We may compare central with peripheral discrimination on this graph. In central vision at 0°, the brightness threshold decreases from .03 millilamberts (full moonlight*) to .0009 millilamberts (quarter moonlight) with increased contrast from 10% to 97%. In 6° peripheral vision the brightness thresholds drop from .006 millilamberts (about half moonlight) to .00007 millilamberts (starlight) with increased contrast from 10% to 97%.

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*To aid the reader in visualizing the light levels described in millilamberts, indications are added - full moonlight, quarter moonlight, starlight, etc.,- which are sky brightnesses which approximate the actual light levels. Under some conditions, especially direct moonlight, considerable variation from these values is frequently encountered.

Thus it may be seen that central vision requires from 5 to 15 times more brightness than 6° vision. Also of note in Figure 3, is the fact that the 10° and 15° vision, and we assume vision further in the periphery, show comparably high values of the brightness threshold with 6° at high contrasts but a rapid loss of discrimination for low contrasts (10% and 25% contrast).

PHASE 2

Having established the discrimination threshold values for varying conditions relevant to periscope operation, we now ask what the effect of adaptation to the brightness of standard visual indicators will be upon those values. Three types of indicators were selected - the radar P.P.I., the Hull Opening Indicator Panel (Christmas Tree) and standard red illuminated dials. As well as being important to submarine operation individually, these three instruments represent the three main types of indicators used on submarines. An additional reason for choosing these instruments was that they sample the extremes of brightness and of color encountered in submarine indicators. Each of the three was fixated individually, burned at prescribed brightness and the time necessary to return to the previously determined acuity levels was measured.

APPARATUS:

The three types of visual indicators are described together with their color, brightness and the viewing conditions as follows:

Radar Scope: The S.S. type radar employs incandescent lamps to illuminate the relative and true bearing scales. The lamps may be varied in brightness. The face of the instrument consists of an orange filter which serves to block short wavelength radiation. Its spectral transmission is shown in Figure 4.

The brightness at the scope face was set at 1.0 foot-lambert, which is 1 log unit above recommended brightness for optimum pip-background contrast. The brighter setting was selected so as to be certainly above the brightness region where acuity rapidly declines. Since the bearing scales, which must be read, are etched in small characters on metal and are of low

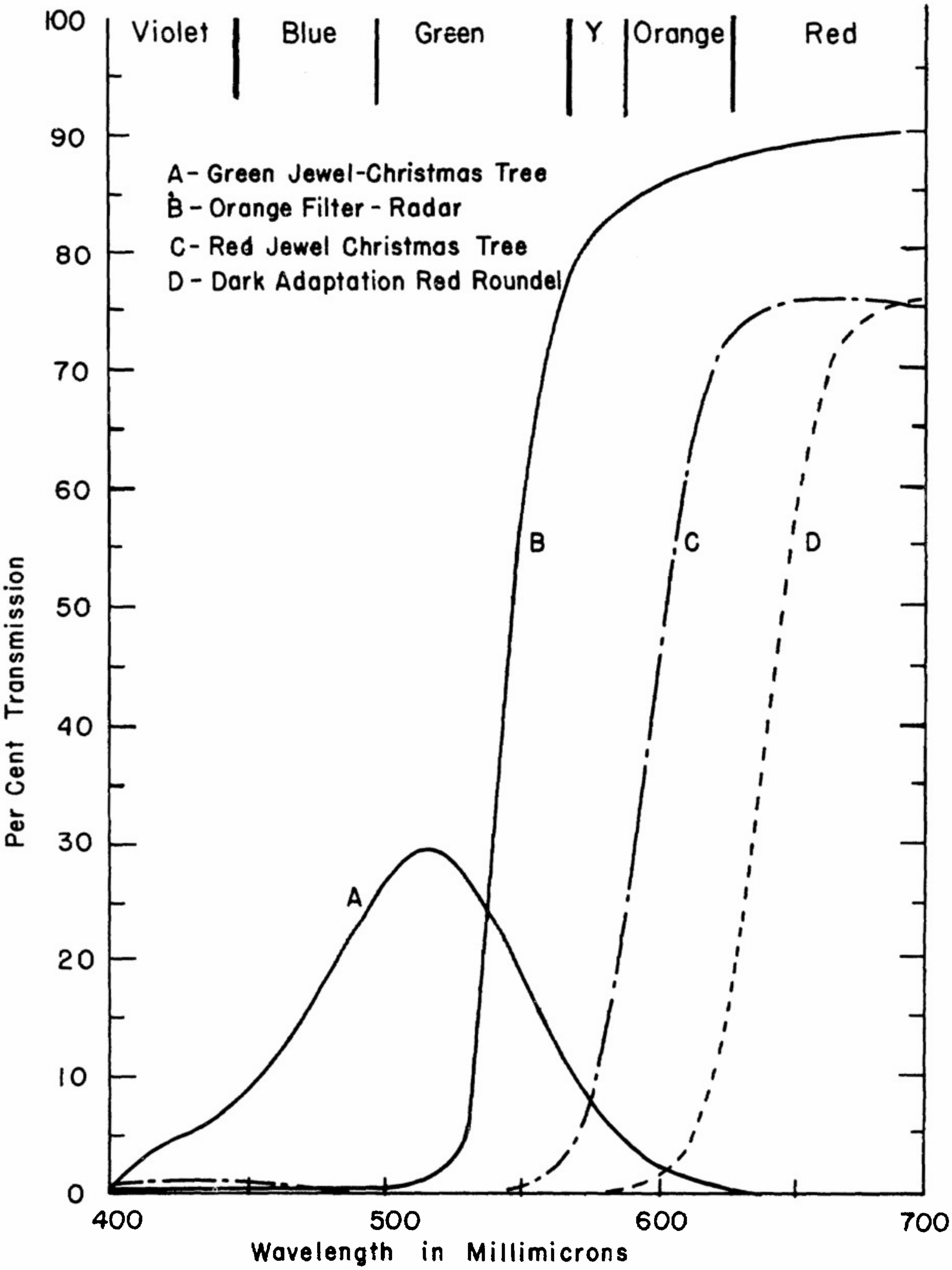

Figure 4

Spectrophotometric transmission curves showing the color distribution of the signalling devices used to study adaptation effects upon periscope vision.

contrast, it may be expected that radar operators would set the scope-face brightness for visibility of the bearing scales rather than for optimum pip-background contrast.

The scope face was fixated at between 10 and 28 inches, varying in order to include those parts of the retina where acuity measurements were to be made. Fixation was maintained on a simulated target at 0° relative bearing, one-fourth the distance from scope center to periphery. The fixation was of 5 minutes duration in order to certainly reach terminal light adaptation.

Hull Opening Indicator Panel (Christmas Tree):

The Christmas Tree is of vital importance to the safety of the submarine. It indicates the - open or closed condition - of every vent and port of the submarine by red or green lights. While the diving officer and his enlisted assistants are those directly concerned with controlling the diving operation, the periscope officer undoubtedly will observe this indicator routinely if it and the periscope become located in the same compartment.

In testing the effect of adaptation to the "Christmas Tree" upon vision through the periscope, it was first necessary to determine the brightness at which to burn the instrument. No brightness had been recommended in the past. This was done by simulating actual lighting conditions and requiring five experienced "Chiefs of the Boat" to set the Christmas Tree to the brightness they would use in actual operation. The results show a narrow range of brightnesses. The highest value of this range was chosen as the adapting brightness, in order to include the brightest settings likely to be made in practice. The value was 1.8 footlamberts, measured at the surface of a representative jewel.

The Christmas tree was viewed for five minutes at 28 inches with the instruction to, "start at the upper lefthand corner and continue to scan the board up and down each column of jewels". This assured coverage of the retinal area to be studied and would be expected to average the effects of red and green lights at any point on the retina.

Red Illuminated Dials:

The most frequent type of visual indicator aboard the submarine is the dial. Dials are either illuminated by the general compartment illumination or by internal bulbs or both. In either case, .1 footlamberts of dark adaptation red is the recommended brightness for night operations. This level has been specified by the Medical Research Laboratory.

Three representative dials were mounted horizontally adjacent and illuminated to .1 footlambert at their face. A 60 watt incandescent bulb was filtered by a standard dark adaptation red roundel to provide this illumination. The roundel was checked with Navy test goggles and found to have negligible transmission below 592 mμ. The typical spectral transmission curve for the roundel is shown in Figure 4.

Either the center of the center or right hand dial, depending upon the retinal area to be covered, was fixated at 28 inches for 5 minutes.

PROCEDURE:

The same procedure was followed as described for Phase 1 to measure acuity at the nine retinal locations. Following each such measurement, there was a 5 minute rest period, then the observer fixated one of the three visual indicators at the prescribed distance for 5 minutes. At the end of 4 minutes, the Observer and Assistant Experimenter were alerted with "4 minutes", then, "45 seconds", "30 seconds", "15", "10", "5-

4-3-2-1", "switch". At the word "switch", the indicator was turned off, the projector beam was turned on the acuity target, Observer returned to the previously set chin and head positions, fixated the fixation point and the shutter was opened for the first exposure. The time elapse from the word "switch" to Observer's first judgment was sufficiently small so that the first trial averaged no longer than the other trials.

The session was continued until the same number of correct responses in a block of 24 trials was obtained as had been found after optimum dark adaptation. Where this would have required longer than 400 seconds the session was terminated after that interval. The affect of adaptation to the visual indicators was taken as the time necessary to reach the previously determined discrimination level.

One target was used, the 25% contrast target, which was chosen as representative of a commonly encountered contrast at sea.

RESULTS:

The data are tabulated separately for the three indicators in Tables II, III and IV. They report percent correct responses of 24 judgments after optimum dark adaptation, percent correct response of 24 judgments after adaptation to the indicator and the time in seconds before that number of correct responses was achieved.

The following facts result:

(1) It was found that the time necessary to recover from adaptation to all three indicators increased as the brightness of the target was decreased.

(2) The radar P.P.I. showed the greatest effect. Measurably long adaptation times were required after looking at the radar when the target was as bright as .006 millilamberts (about

TABLE II

5 Minutes Radar Adaptation at 1 fL

Target: 25% Contrast Observer: M.

Brightness	Degrees from Central	% Correct of 24 Judgments after dark adaptation	% Correct of 24 Judgments after adapt. to Radar	Time to Criterion in seconds
.002 Ml	1°	16%	8%	400"
(quarter moon)	6°	42%	54%	40"
	15°	25%	21%	240"
.003 Ml	6°	75%	58%	260"
(quarter moon)	10°	63%	58%	340"
	15°	21%	32%	40"
.006 Ml	1°	83%	88%	50"
(half moon)	6°	100%	96%	40"
	15°	75%	75%	140"
.011 Ml	1°	100%	100%	0"
(very dark day)	6°	100%	100%	0"
	15°	88%	83%	0"

TABLE III

5 Minutes "Christmas Tree" Adaptation at 1.8 fL
on Jewel Surface Target: 25% Contrast
Observer: M.

Brightness	Degrees from Central	% Correct of 24 Judgments after dark adaptation	% Correct of 24 Judgments after adapt. Xmas Tree	Time to Criterion in seconds
.002 Ml	1°	21%	< 5%	> 400"
(quarter moon)	6°	71%	63%	340"
	15°	58%	63%	160"
.003 Ml	1°	8%	17%	260"
(quarter moon)	6°	71%	67%	260"
	15°	42%	38%	20"
.006 Ml	1°	100%	96%	0"
(half moon)	6°	100%	100%	0"
	15°	67%	67%	0"

TABLE IV

5 Minute Dial Adaptation at .1 fL of Red Light

Target: 25% Contrast Observer: M.

Brightness	Degrees from Central	% Contrast of 24 Judgments after dark adaptation	% Contrast of 24 Judgments after adapt. to dials	Time to Criterion in seconds
.002 Ml	1°	-	-	-
(quarter moon)	6°	54%	46%	245''
	15°	29%	33%	185''
.003 Ml	1°	13%	-	>400''
(quarter moon)	6°	79%	75%	30''
	15°	38%	38%	40''
.006 Ml	1°	100%	80%	0''
(half moon)	6°	100%	100%	0''
	15°	67%	67%	0''

half moon). At the next brighter target illumination of .011 millilamberts no adaptation time was necessary to give the same acuity measure as after optimum dark adaptation. (See Table II).

(3) The Hull Opening Indicator Panel or "Christmas Tree" showed less effect than the radar. When the target was at .002 millilamberts (about quarter moon brightness) in excess of $2\frac{1}{2}$ minutes was required to reach optimum acuity after fixating the "Christmas Tree" (Table III). At .006 millilamberts target brightness (half moonlight) there was no measurable adaptation time required to reach optimum acuity after fixating that indicator.

(4) Approximately the same results were obtained for the bank of red illuminated dials as for the "Christmas Tree". There was no measurable adaptation time necessary following fixation when the target was illuminated to .006 millilamberts or brighter (half moon or brighter). 30 seconds or more were required to reach optimum acuity after the same fixation when the target was illuminated to .003 millilamberts (quarter moon) or darker.

INTERPRETATION AND CONCLUSIONS

Phase 1 of this work has shown that off-center visual discrimination is better than central discrimination for a comprehensive range of the target-background contrast conditions that are likely to be met at sea. Further, it has been shown that paracentral discrimination does not decline appreciably at least as far as 15° in the periphery, except for very low contrasts. It therefore appears likely that off-center vision at night will benefit periscope operation both for detection and gross recognition.

Since it appears that the paracentral, rod regions, of the eye may be useful in periscope observation and since rod vision at low brightnesses requires dark adaptation, it is necessary to examine limiting adaptation conditions for the periscope operator. This data was gathered in Phase 2.

It may be concluded from those observations that paracentral acuity will be impaired by inspection of the radar P.P.I. if the target illumination is at about .006 millilamberts (half moon) background brightness with target-background contrast of 25% or lower. No appreciable effect was obtained for brighter illumination levels.

Inspection of the Hull Opening Indicator and of red illuminated dials was found to have a slightly smaller effect upon paracentral acuity than the radar scope. Adaptation to these indicators had no effect upon acuity when the target was illuminated as if by half moonlight (.006 ml) or brighter. There was a measurable impairment of acuity at approximate quarter moon illumination and lower (.003 ml).

In view of the above findings it appears reasonable to conclude that any prolonged fixation of the radar P.P.I. hull opening indicator panel and dials should be avoided just prior to and during periscope search at late twilight and night. Also, it may be concluded that if the instruments have been under inspection prior to periscope observation full acuity cannot be expected to be regained for from 1 to 5 or more minutes.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Forrest L. Dimmick and the General Vision Facility for the use of their laboratory facilities and apparatus in this experiment. With only minor changes, the apparatus was used as described by Morris and Dimmick[4].

The authors are especially grateful to Miss Ailene Morris for the many hours that she spent as primary observer. They are also grateful to Miss Helen Paulson who acted as assistant experimenter and to Mr. Ivan Partridge who was the second observer and aided in the computations.

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