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Office of Scientific Research and Development  
**NATIONAL DEFENSE RESEARCH COMMITTEE**  
Section 16.1 — Optical Instruments

Dartmouth College  
Final Report  
on  
The Effects of Binocular Magnification  
on the  
Visibility of Targets at Low Levels of Illumination  
Contract OEMsr-1058  
November 30, 1944

Dr. S. Howard Bartley  
Assistant Professor  
Research in Physiological Optics  
Miss Eloise Chute  
Research Associate  
in Visual Science

Section 16.1 Report No. 62  
Copy No. 72  
OSRD Report No. 4433

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of Report on**

**"EFFECT OF BINOCULAR MAGNIFICATION  
ON VISIBILITY OF TARGETS AT LOW LEVELS  
OF ILLUMINATION"**

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**DARTMOUTH REPORT**

**Foreword**

Project NO-210 was assigned to Section 16.1 on January 1, 1944. The request for the project states: "The primary purpose of the project is to determine the optimum relation between magnification, angular field of view, exit pupil, size and weight, and such other factors as may appear. The project is directed primarily at night glasses, though not necessarily so limited."

The present contractors' report is the first of a series on binocular testing, and covers an investigation of the gain in range with increasing magnification, up to 10X, which was carried out at the Dartmouth Eye Institute under Contract OEMsr-1058. Four levels of illumination have been used, covering ranges of sky brightness from that of a very dark night to full moonlight with a high haze. The binoculars used were 6X30, 7X50 (diaphragmed to 7X35), 8X40 and 10X50.

The effect of angular field of view in scanning is being investigated at the Johnson Foundation of the University of Pennsylvania, under Contract OEMsr-1228.

A study of the gain in range with increasing exit pupil has been carried out at Brown University under Contract OEMsr-1229, at 40 mm, 400mm and 4000mm, using 5-power binoculars.

The group at Brown has also undertaken to study the best choice of magnification and exit pupil when the diameter of the objective is specified. An observing

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program is in progress using binoculars of 50mm aperture, as follows:

<u>Magnification</u>	<u>Exit pupil diameter (mm)</u>
5	10.0
6	8.3
7	7.1
10	5.0
14	3.5

A similar study will be made with binoculars of 70mm aperture.

It is hoped that the binocular testing program as a whole will be completed by June 30, 1945.

Dr. Harold F. Weaver, Consultant to Section 16.1, NDRC, made numerous suggestions regarding the planning of the program at Dartmouth and regarding the correction factor to be used in allowing for the effect of incorrect observations. Miss Lillian R. Elvebeck, Technical Aide, Section 16.1, has worked closely with the group at Dartmouth on the discussion data and on the preparation of the text of the report.

Theodore Dunham, Jr.

6-105, Massachusetts Institute of Technology  
Cambridge, Massachusetts  
December 13, 1944

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**EFFECT OF BINOCULAR MAGNIFICATION  
ON VISIBILITY OF TARGETS AT LOW LEVELS  
OF ILLUMINATION**

**PART I: SUMMARY**

The present investigation was carried out with 6X30, 7X50 (diaphragmed to 7X35), 8X40 and 10X50 binoculars, all having a 5mm exit pupil, and optical surfaces coated with fluoride to prevent loss of light by reflection. The levels of screen brightness used, 40m<sup>l</sup>, 400m<sup>l</sup>, 4000m<sup>l</sup>, and 40,000m<sup>l</sup>, cover night sky brightnesses from that of a very dark night to full moonlight with a high haze. Circular targets were used, which appeared as black against the screen, in any of four possible positions. The three observers who stood on a steady platform, holding the binoculars by hand, were asked to name the position of the target after each six-second exposure.

The results agree reasonably well with those which are predicted theoretically by taking into account the brightness level, the binocular transmission, the pupil size and the magnification of the glasses. It is concluded from the results of this study that, when these factors have been taken into account, under conditions in which no haze is present to reduce the contrast of the targets,

1. The gain in range with magnification is linear from 1X to 10X, provided that the exit pupil is held constant.

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**2. None of the following factors:**

- a) difficulties connected with looking through any instrument held in front of the eyes
- b) inaccuracy in centering the exit pupil of the instrument on the pupil of the eye
- c) apparent motion of the target due to unsteadiness of holding at high magnifications

appears to have a first order effect on detection of targets in the range of magnification considered here.

It is recommended that the study be extended to investigate higher magnifications, in order to determine the maximum magnification for which the conclusions drawn here are valid.

It is recommended also that further experiments be made to determine the cause and the significance of the high efficiency values obtained in this study for the "7X35" binocular.

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**PART II: DESCRIPTION OF THE METHOD  
EMPLOYED (Final Procedure\*)**

**Observers**

Three full time observers were used, two of whom had visual acuity of 20-20 or better, without refractive correction. The third, who obtained the highest scores throughout, wore glasses which corrected his vision to 20-20 or better. The procedure during the forty-five minutes allowed for dark adaptation was as follows:

1. Thirty minutes were spent in a dark-walled room which was illuminated at about 1.5 foot candles. Red goggles were worn.
2. A final fifteen-minute period was spent in total darkness.

**Observing Booths**

The observing booths were placed sixty feet from the screen. The observers stood, and held the glasses by hand. In each booth was a chair for use during the frequent rest periods. In front of the observer was a board on which were placed the toggle keys which were used to indicate responses.

**Screen**

The screen was twelve feet square and was uniformly illuminated to the desired level. At the center was a weak

\* For a discussion of the Preliminary Procedures, see Pages i - iii of the Appendix.

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red fixation light. The targets appeared in one of four positions on a circle of radius 8-7/8" about this fixation light. The possible positions were at 12, 3, 6, and 9 o'clock, and are referred to, in that order, as positions 1, 2, 3, and 4.

**Targets**

The targets were circular holes in the screen, and appeared as black against the dimly lit background. Six target sizes were used for each set of screen brightness and magnification conditions.

**Target Presentation**

The glasses were lowered between observations. A shift in the illumination of the screen from a level one-fourth as bright back to the previous observation level was the signal to raise the glasses for the next trial. This fore-period was of four seconds duration. A buzzer signalled to the observer each time a target was exposed. During the sounding of the buzzer (six seconds) the observer searched for the target and indicated its position by use of one of the toggle keys described below.

The fore-period was made no longer than four seconds because of the report of the observers that, at least for higher brightness levels, afterimages disturbed them if they gazed at the screen too long. The six-second exposure period was believed to be long enough to insure detection for conditions above threshold. There is some indication, however, that a longer exposure period would have increased the scores made with the naked eye. It is probable that this would decrease significantly the efficiency values obtained for the binoculars studied. Further experimentation has been planned at Brown University to determine the effect

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of variations in exposure time.

Order of Presentation of the Targets

The six target sizes were each presented in four series of twelve observations. Numbering these target sizes 1 - 6, from smallest to largest, and letting each entry stand for a series of twelve presentations followed by a five minute rest period, the order was:

Morning: 1, 2, 3, 4, 5, 6  
Fifteen minute rest period  
6, 5, 4, 3, 2, 1

Afternoon: 6, 5, 4, 3, 2, 1  
Fifteen minute rest period  
1, 2, 3, 4, 5, 6

Scoring

The observer was asked, after each observation, to indicate the position of the target by throwing one of the four toggle keys arranged on a board before him as the target positions were arranged on the screen. Forced guessing was not employed. The observers were told to respond only if they had some indication of the position of the target.

Scores were computed on a percentage scale for each set of 48 observations of a single target size. The data obtained during a day of observing gave six percentage scores,  $P_u(d)$ , corresponding to the six target sizes. These scores, after correction for guessing, are denoted as  $P_c(d)$ .

The correction, which has been determined separately for each observer, has been considered as a function of the difficulty of detection. It is based at each difficulty level, on the average number of incorrect

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responses which indicate the position directly opposite to the true position of the target. The correction functions for the three observers are discussed in Part II of the Appendix.

PART III: EQUIPMENT\*

A large, high-ceilinged room, 25 feet wide, was made available for the experiments. The windows were sealed so that it could be used as a dark room. Booths for observers were constructed at one end of the room, and a screen and operator's platform at the other. This gave a visual working distance of sixty feet.

Screen

The field of view, against which the targets were displayed, was an area twelve feet square, covering a visual angle more than twice as great as the field of view of any of the binoculars used. The screen was made of heavy wall board, painted matte white, and was uniformly illuminated to the desired level. Black cloth tapered outward from the twelve foot square toward the observers and the side walls of the room, so that the area outside the screen should appear as black.

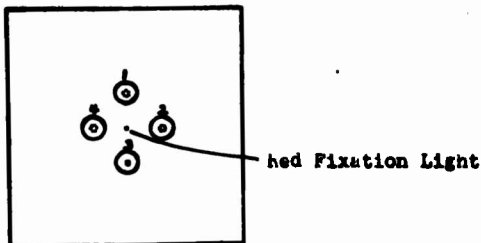
In the center of the screen was a red fixation spot about 1/32" in diameter. A one and one-half volt flashlight lamp working through red cellophane supplied the light. No attempt was made to evaluate the intensity of the light in absolute units; instead the spot was made bright enough so that the observer, in raising his glasses at a natural rate, would see it.

\* See photographs following page 20.

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Targets



In the screen were four large circular holes, greater in diameter than the largest of the targets, and placed on the screen in the positions shown in the diagram above. Into each hole a metal plate could be clipped. There were four plates for each target size, one for each hole. In each was a door, which, when closed, made the plate appear as a uniform piece of the screen. To expose a target, the door of the plate was swung open, displaying a hole of the desired size, which appears as black against the screen. These holes were drilled in the metal plate. For each series of observations the four plates bearing the same size holes were clipped into place, and operated by a man stationed behind the screen.

Binoculars

Preliminary tests were run to determine the best focus setting for each of the observers. This best setting was used throughout the program. Each observer was told how to set the inter-pupillary distance after careful measurements had been made. Every effort was made to maintain the accurate setting through the day's work. The table of Page 9 gives the identification number, the light transmission measurements, the weight, and moment of

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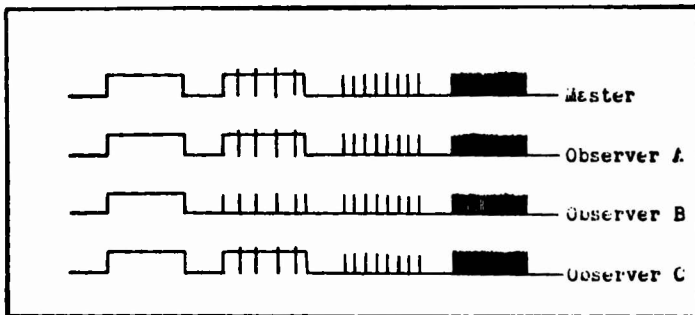
inertia about each of three mutually perpendicular axes through the center of mass, for each of the binoculars used.

Observing Booths and Recording Equipment

The front of each observing booth was closed in except for an aperture approximately eight inches square which was placed according to the height of the observer, and which served to limit his visual field approximately to the screen itself. Each booth contained a chair for use during rest periods.

Each observer was provided with a set of four mercury toggle keys, which corresponded in position to the target positions on the screen.

The recording system consisted of a battery of signal-magnet ink-writers, one for each observer and one giving the master record. The circuits for each included an interrupter system, so that if the observer's switch designated position one, a smooth offset in the line of the paper recording tape was made. For positions 2, 3, and 4 pulsations of different frequencies were introduced into the line. The interrupting system was a group of keys tripped by pawls on a well-machined revolving cylinder. A sample record is shown below:



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BINOCULARS

	Transmission	Weight (GRAMS)	MOMENTS OF INERTIA IN CM CM <sup>2</sup> AXES THROUGH CENTER OF M/SS.		
			Axis A	Axis B	Axis C
6x30	80.8	606	26,100	6,300	15,100
6x30	75.1	630	22,000	6,530	15,400
7x50	77.2	1180	72,700	36,700	44,500
7x50	78.3	1250	78,300	37,500	45,600
8x40	76.7	813	41,900	19,600	24,600
10x50	73.0	1183	72,900	32,300	45,100
10x50	71.3	1257	79,000	38,700	44,600

\* Fixed Focus  
\*\* Wide Field

The moments of inertia of the binoculars have been measured by comparison to a bob of calculable inertia, using a torsion suspension of light bessemer rod. The bob was a length of iron pipe hung on an axis through its center, perpendicular to its axis of figure. Times of oscillation were measured with a stop watch. The binoculars were fastened to the suspension rigidly by attachments of aluminum which added insignificant moment to the assembly. These moments have been computed and subtracted from the totals calculated.

The axes, all taken through the center of gravity of the glass, are:  
A) perpendicular both to the interocular line and the axes of collimation (vertical in viewing the marine horizon); B) perpendicular to the axes of collimation and in their plane; C) parallel to the axes of collimation. The binoculars were measured with an inter-ocular distance of 70 mm. The precision of the moment values is probably not much above 1 per cent.

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**Photometry**

The source of light was a Leitz 250-watt projector. Opsl glass was inserted in the system to bring the intensity of the projected beam within the desired range. The levels of screen brightness desired were first established by trial and error in reaming the diaphragms used on the projector. The screen brightness was measured with the Rochester Sky Photometer. Once the levels had been established they could be produced easily by selecting the proper diaphragm for the projector.

The reading on the voltmeter across the line at the lamp was close to 114 volts. The voltmeter was across the line where the recorder could keep track of any variation in readings. The maximum fluctuation observed was 2.5 volts. Average variations in voltage were so small that it appeared safe to neglect them.

Once a month the lamp output was checked with the Rochester photometer. On the occasion on which the lamp was replaced, the diaphragms were recalibrated.

The Rochester Sky Photometer was checked at the University of Pennsylvania in September, 1944, and found to give results corresponding satisfactorily with those obtained during the course of these observations.

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BRIGHTNESS OF THE NIGHT SKY  
(log millimicrolamberts)

Sky	Brightness: log ml*			
	Mean	Maximum	Minimum	Spread
1. Moonless overcast	1.62	1.80	1.40	0.40
2. Moonless clear	2.08	2.16	2.00	0.16
3. Moonlit (light overcast. 8-day moon near horizon)		2.76	2.32	0.44
4. Moonlit clear (10-day moon near horizon)		3.00	2.48	0.52
5. Moonlit (medium overcast somewhat irregular. Light snow flurries)		3.20	2.68	0.32
6. Moonlit clear (9-10-day moon near meridian)		3.56	2.84	0.72
7. Moonlit (medium overcast. 15-day moon)		4.44	3.40	1.04
8. Moonlit (broken overcast. 16-day moon near meridian)		4.52	3.76	0.76

The readings were taken at an altitude of 45°.

\*This table was taken from "A Series of Measurements of the Brightness of the Night Sky," a report prepared at the University of Rochester under OEMsr-265 of Section C-6 of the NDRC.

SCREEN BRIGHTNESS USED IN DARTMOUTH STUDY

LOG ml

1.6	Very dark, moonless overcast
2.6	Moonlight, some overcast
3.6	Fairly bright moonlight and clear sky
4.6	Full moon and high haze, or 50 minutes after sunset on a clear night

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**PART IV: RESULTS AND CONCLUSIONS**

Theoretically an increase in magnification merely permits a corresponding increase in the distance to which a target may be moved, without altering the display as seen by the observer. Thus a linear increase in range is to be expected with increasing binocular magnification. If the absorption of light by the binoculars is taken into account, the range should increase linearly from 1X to 10X, provided that the pupil size is held constant.

In considering the conclusions drawn below it is important to bear in mind the fact that the present investigation was carried out indoors, and that the factor of atmospheric haze, which reduces the contrast of the target, particularly at long ranges, has not been taken into account. It is also important to note that the observers were standing on a perfectly steady platform, and that they were holding the binoculars by hand.

Actually the gain in range may be less than expected, due to (1) difficulties connected with looking through any instrument held in front of the eyes, (2) inaccuracy in centering the exit pupil of the instrument on the pupil of the eye, and (3) apparent motion of the target due to unsteadiness of holding, particularly at high magnifications.

The conclusions drawn from the results of this investigation are:

1. None of the three factors listed above appears as a first order effect for magnification up to 10X. While

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some contributions from them may be present, it is not possible to assess them from these data, since all of the deviations from expectancy lie within the experimental error. If their effects are to be studied in the present ranges of magnification, special experiments must be designed.

2. When the transmission of the binoculars has been taken into account, the gain in range from 1X to 10X is linear, provided that the pupil size is held constant.

3. A similar investigation should be carried out for magnifications greater than 10X, in order to determine the maximum magnification for which the conclusions drawn here are valid.

4. Further investigation should be made to determine the significance of what appears in this study to be a relative superiority of the 7X50 binoculars.

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The corrected percentage probability of detection scores,  $P_c(d)$ , have been plotted in Figure I, for each observer, against target size on a log  $\theta$  scale, where  $\theta$  is the angle in mils subtended at the observer's eye by the target. The illumination level, in each case, is indicated in terms of log B, where B is the brightness of the screen in millimicrolamberts. Figure I provides a method of comparing, at each illumination level, the performance of the various binoculars and of the naked eye with natural pupil. It is to be noted that, with but few exceptions, the curve which represents the performance of the 7X50 binocular is displaced from its expected position toward the left to a position which represents smaller targets and therefore greater range. The displacement can be evaluated quantitatively from the tables which follow.

Absolute Range

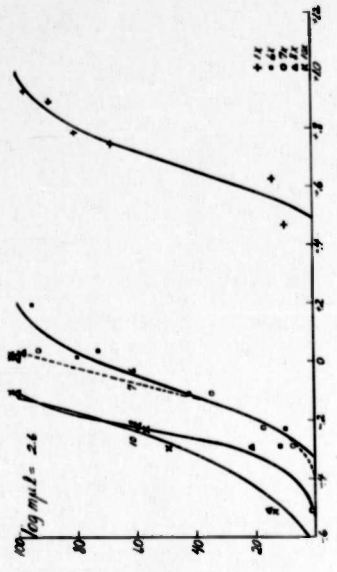
At 50% and at 90% probability of detection, range values on an absolute scale have been obtained. This measure is referred to as "Absolute Range," and is equal to  $1000/\theta$ , or to the ratio of the viewing distance to the diameter of the target.

Of the three observers, only two made observations without the use of binoculars. These naked eye observations were made with the natural pupil. Since it was not possible to obtain pupil measurements for these observers in the time at our disposal, the following table of average values has been used:<sup>+</sup>

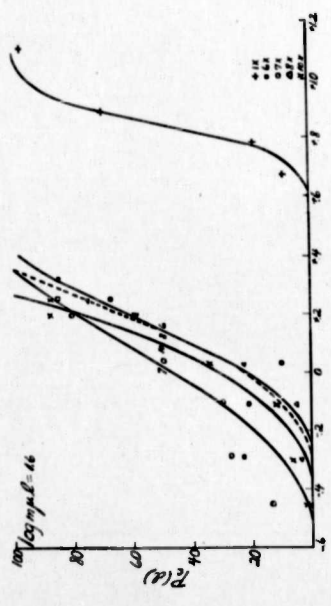
Brightness level (m $\mu$ l)	Pupil diameter (mm)
40	7.30
400	7.12
4000	6.86
40000	6.50

<sup>+</sup> British Report A.R.L./N.2/O.502

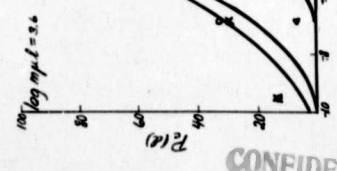
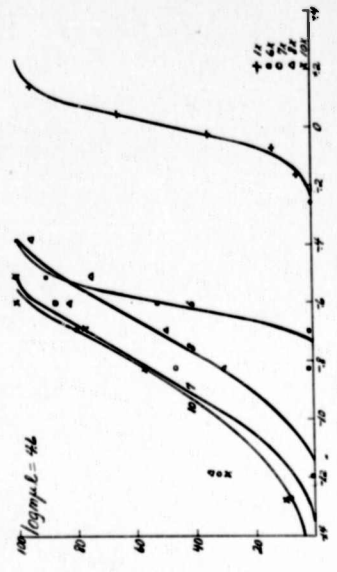
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LOG e



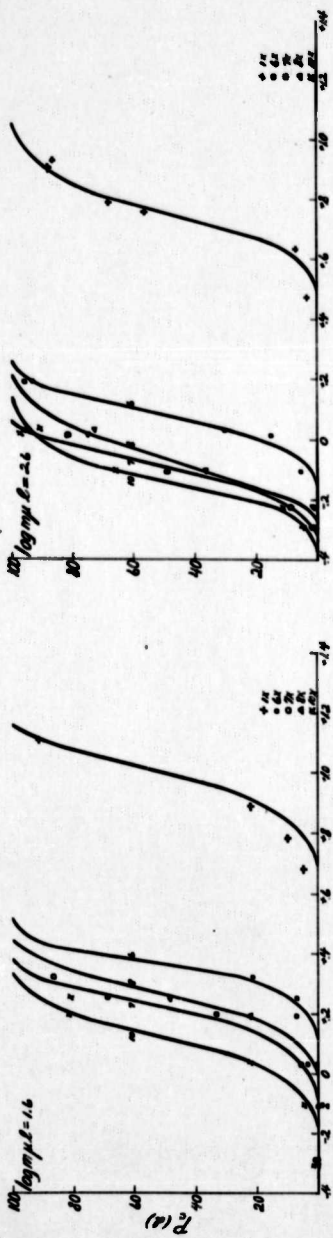
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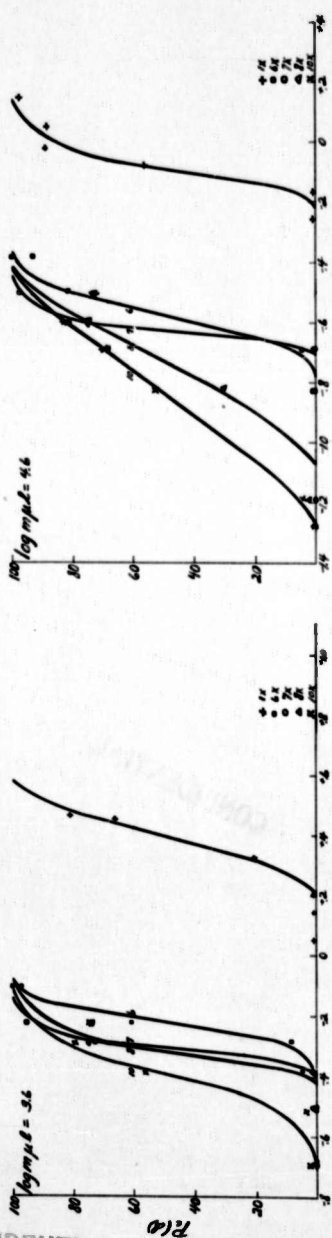
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FIGURE I. - OBSERVER A  
 PERCENTAGE PROBABILITY OF DETECTION AS A FUNCTION OF THE TARGET SIZE (θ IN MILES)



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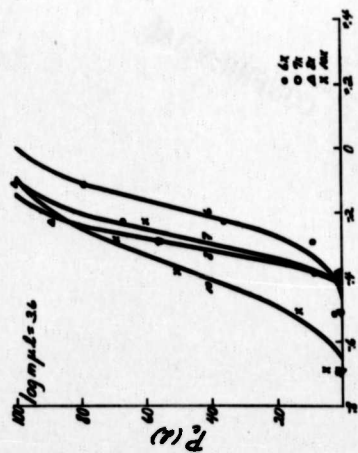
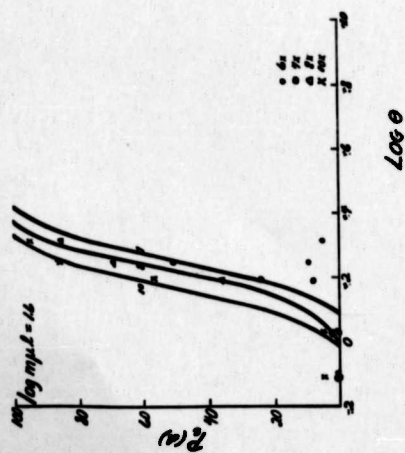
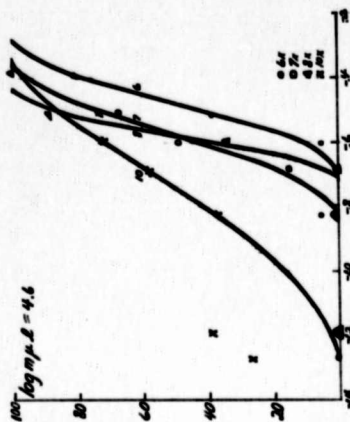
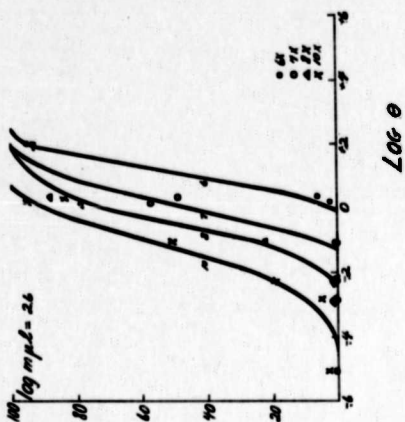


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OBSERVER B

FIGURE I

PERCENTAGE PROBABILITY OF DETECTION AS A FUNCTION OF THE TARGET SIZE (IN MILS)



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OBSERVER C

FIGURE I

PERCENTAGE PROBABILITY OF DETECTION AS A FUNCTION OF THE TARGET SIZE (0 IN MILS)

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The range values obtained by observers A and B with the naked eye and natural pupil, have been averaged, and the mean value at each level listed in the first column of the table below. From these the LX values have been predicted, supposing the observers to be using unit power binoculars with 5mm exit pupil, and transmission equivalent to the average of those of the binoculars used in the other parts of the experiment. The remaining columns of the table give the average of the range values obtained by the three observers. (For range values for individual observers see Table II.)

ABSOLUTE RANGE CORRESPONDING TO  $P_c(d) = 50\%$

log B	N.E.	LX	6X	7X	8X	10X
1.6	120	87	580	705	625	750
2.6	190	160	935	1150	1340	1540
3.6	390	294	1710	2420	2160	2880
4.6	1100	759	3580	5110	4770	6660

ABSOLUTE RANGE CORRESPONDING TO  $P_c(d) = 90\%$

1.6	95	74	410	480	460	565
2.6	130	120	705	895	1010	1130
3.6	300	220	1360	1730	1660	1860
4.6	850	590	2720	3440	3020	3570

The discussion and graph which follow will give some idea of the agreement of these values with those obtained in previous studies.

- M = magnification
- r = target diameter
- d = viewing distance
- R = absolute range =  $d/r$  (as defined above)
- A = pupil area in  $\text{mm}^2$  (see page 14)
- B = screen brightness in  $\text{m}\mu\text{l}$
- T = binocular transmission
- $I_R$  = retinal illumination =  $B \cdot T \cdot A$
- $I_R = \Delta I_R$ , since the targets are black
- $\Omega = \text{solid visual angle of target} = M^2 \frac{\pi(r)^2}{4d^2} = M^2 \frac{\pi}{4 \cdot R^2}$

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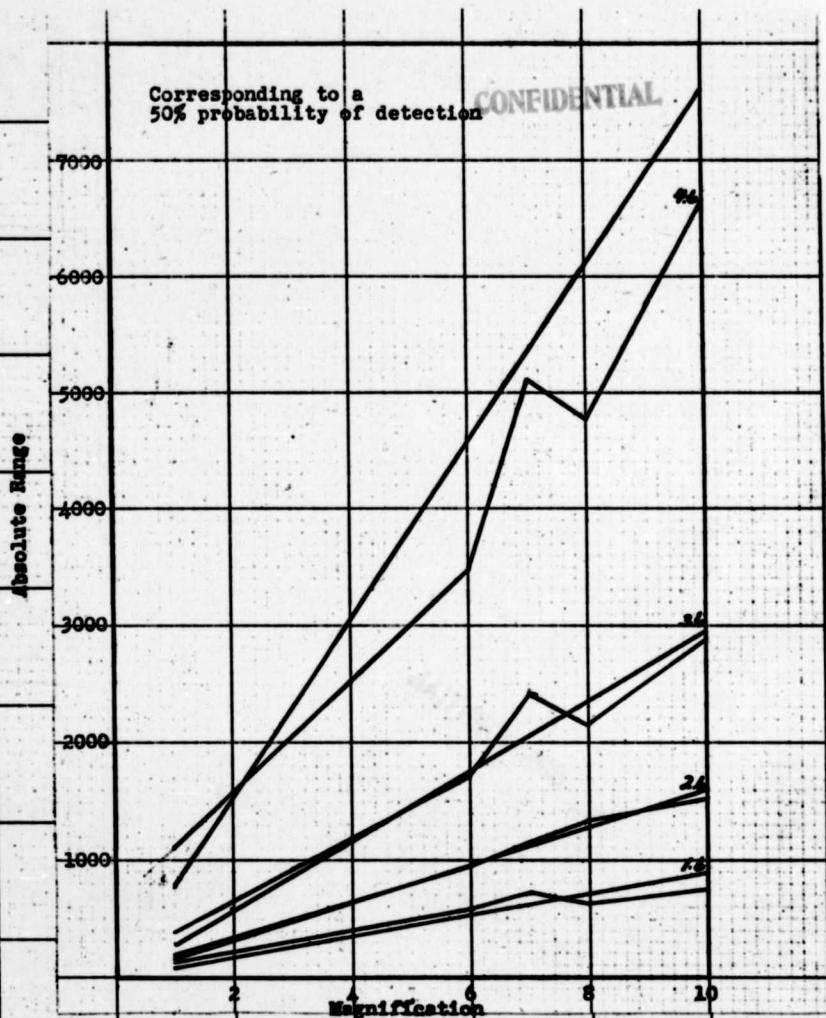


FIGURE II

**Absolute Range as a Function of Magnification**

Absolute range is defined here as the ratio of the viewing distance to the diameter of the target. The values shown correspond to mean range values for the three observers. The straight lines represent the predicted ranges, based on the IX values of the table on page 15.

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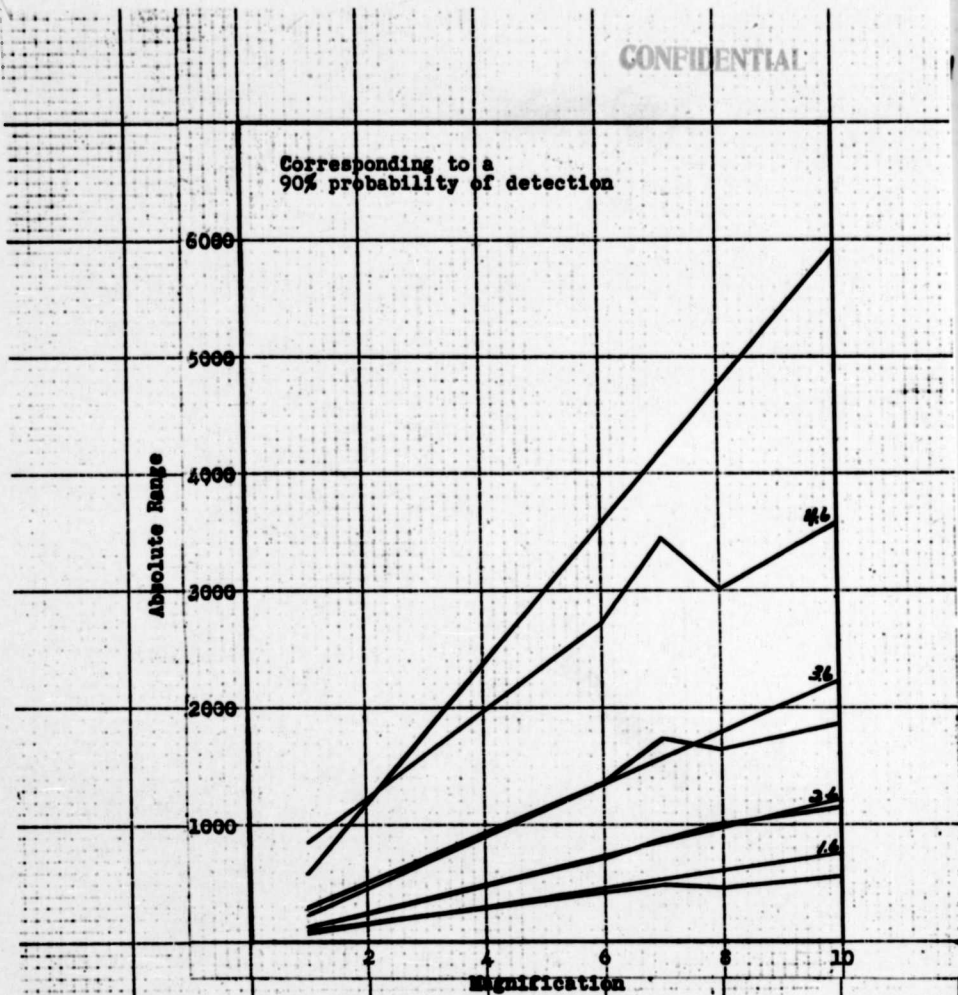


FIGURE III

Absolute Range as a Function of Magnification

Absolute range is defined here as the ratio of the viewing distance to the diameter of the target. The values shown correspond to mean range values for the three observers. The straight lines represent the predicted ranges, based on the IX values of the table on page 15.

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In Figure IV,  $\log \Delta I_R \cdot \Omega$  has been plotted against  $\log I_R$ . The values derived from the naked eye ranges were first plotted. The curve which has been drawn through them is suggested by Hecht's treatment of brightness discrimination.\* The values corresponding to the binocular performance have been plotted also, and are seen to cluster closely about the theoretical curve.

It will be noted that the agreement of the binocular ranges with expectancy is very good indeed. The predicted range value for any set of conditions can be found most simply from the table of page 15 by multiplying the proper IX value by the magnification concerned. The agreement can also be seen from Figures II and III. The differences which do exist can be evaluated by considering the following table, based on the 50% range values, which are the most reliable. Again it is to be noted that the data used here involve naked eye range values for two observers, A and B, and the mean binocular range values for all three observers.

DIFFERENCES OF MEAN RANGE FROM PREDICTED VALUES

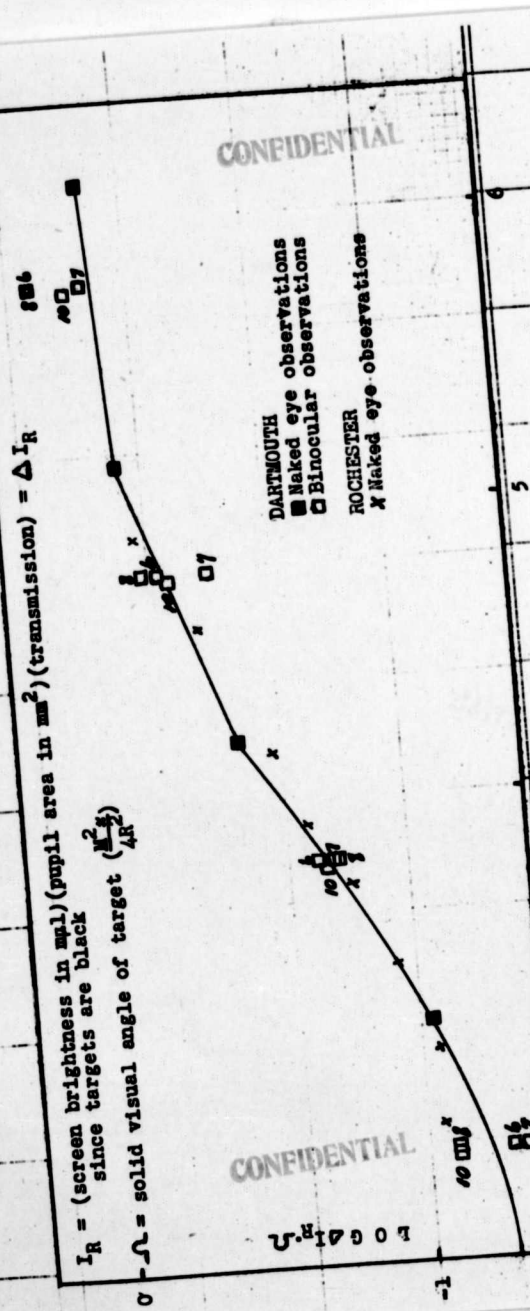
Log mean range - Log predicted range				
<u>log B</u>	<u>6X</u>	<u>7X</u>	<u>8X</u>	<u>10X</u>
1.6	.045	.065	-.045	-.065
2.6	-.010	.010	.020	-.015
3.6	-.015	.070	-.035	-.010
4.6	-.105	-.015	-.105	-.055
Mean	<u>-.021</u>	<u>+.033</u>	<u>-.041</u>	<u>-.036</u>

Where S.E. Log R = .022

\* Hecht, S., Proc. Nat'l. Acad. Sci., 20, 644-655, 1934

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$I_R = (\text{screen brightness in mpl.}) (\text{pupil area in mm}^2) (\text{transmission}) = \Delta I_R$

$\alpha - \alpha = \text{solid visual angle of target } \left( \frac{M^2}{AR^2} \right)$

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LOG I\_R

Figure IV shows total signal plotted against retinal brightness. The curve has been fitted to the points determined by the naked-eye data. The points determined by the Rochester naked eye data is excellent. The agreement with the Hecht's paper, Proc. Nat'l. Acad. Sci., 20, 1934, is excellent. This means of presenting the data is suggested by Hecht's paper, Proc. Nat'l. Acad. Sci., 20, 1934. The results of the present study agree very well with the theory presented in this paper up to about 3.5 mpl and show the usual break in the transition region between rod and cone vision.

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On the basis of these figures it would be difficult to make out a convincing argument to the effect that the "7X35" binocular is significantly better than the others tested. The figures do, however, suggest that further study be made of the standard 7X50 binocular in comparison with higher power instruments. An experiment designed specifically to determine whether or not the difference between the mean value for the "7X35" in the table above, and those for the other binoculars is real, could be carried out in a relatively short time.

Individual Differences

Table II of the Appendix gives the absolute range values for the individual observers. On the whole, the best of the observers, A, obtained range values approximately 20% greater than the mean for the three observers, based on  $P_c(d) = 50\%$ , and 12% greater than the mean values based on  $P_c(d) = 90\%$ . It should be noted that the naked eye range values show much greater agreement than do the binocular range values.

It is to be noted that the highest efficiency values are obtained at brightness levels of  $\log \mu_{pl} = 2.6$  and  $\log \mu_{pl} = 3.6$ , that is for brightnesses ranging from that of a moonless starlit night to full moonlight.

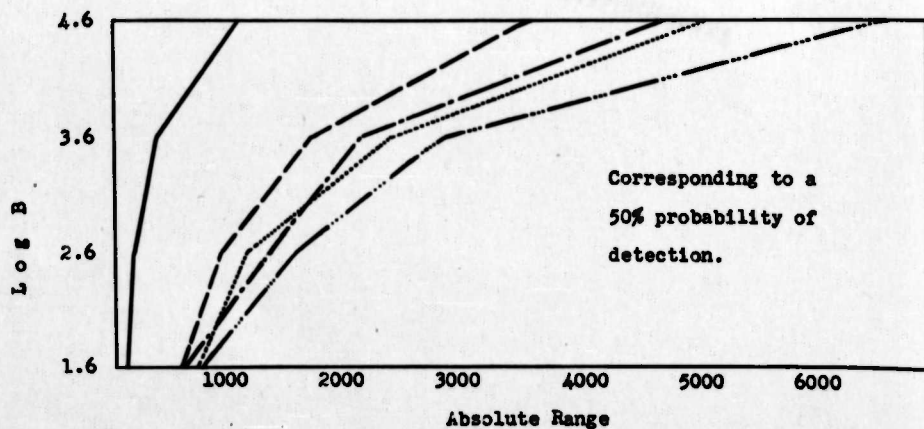
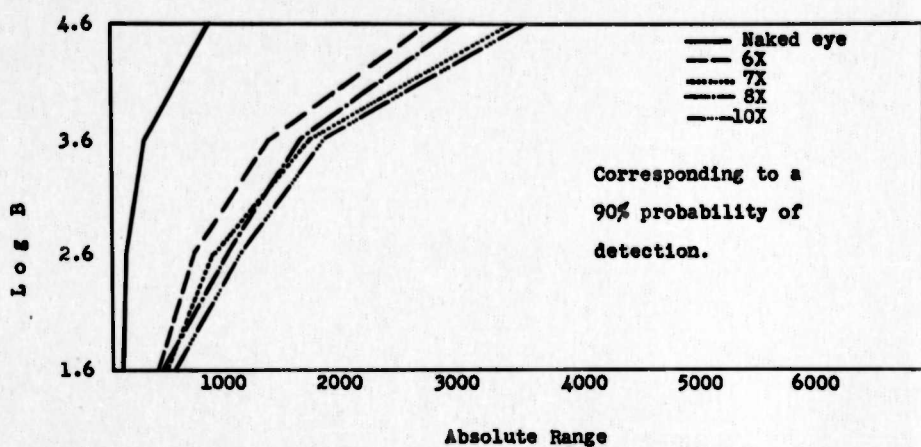
At the lowest illumination level,  $\log \mu_{pl} = 1.6$ , corresponding to the brightness of a very dark night sky, the 6X and 7X glasses give range values which are greater than those which would be predicted from the corresponding naked eye range values, while the 8X and 10X glasses give values which are smaller.

The highest level,  $\log \mu_{pl} = 4.6$ , corresponding to the brightness of the night sky with a full moon and

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**Absolute Range x Log Screen Brightness  
Mean Range Values for Three Observers**



**FIGURE V**

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high haze, or to the sky brightness on a clear night about 50 minutes after sunset, lies in the transmission range in which both rod and cone vision are functioning. Here the range values obtained are all smaller than those predicted from the naked eye performance.

Detection Factors

The detection factor of a binocular has been defined as the ratio of the range obtained with the binocular to the range obtained with the naked eye. The table of page 19 gives the detection factors which are based on the naked eye range values as well as those based on the computed LX values.

Efficiencies

The efficiency of a binocular has been defined as the ratio of the detection factor to the magnification. The table on page 20 gives efficiency value corresponding to the detection factors given on page 19. The values computed for the individual observers will be found in the Appendix.

The efficiency values of page 20 give, in different form, the results shown in Figure IV. In connection with this table it is interesting to note that the average efficiency (N.E.) values for the binoculars concerned are, except in the case of the "7X35," slightly less than the average transmission values. If, however, the efficiencies are computed on the basis of the LX ranges, that is, if the transmission of the binocular and the size of the pupil are both taken into account, the efficiency of the "7X35" binocular is greater than 100% at 40, 400 and 4000 m $\mu$ l screen brightness. As stated on page 17, this suggests that further investigation should be made of the possible superiority of the standard 7X50 binocular.

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**EFFICIENCIES**

BASED ON MEAN ABSOLUTE RANGE VALUES FOR P(d) = 50%  
(Three Observers)

LOG B	6X		7X		8X		10X	
	N.E.	LX	N.E.	LX	N.E.	LX	N.E.	LX
1.6	80	112	84	116	65	90	62	86
2.6	82	97	88	103	88	105	81	96
3.6	73	97	88	117	69	92	74	98
4.6	55	78	66	96	54	79	61	88
Mean	72	96	81	108	69	92	70	90

BASED ON MEAN ABSOLUTE RANGE VALUES FOR P(d) = 90%

1.6	72	92	73	93	61	78	60	76
2.6	90	98	99	106	98	105	87	94
3.6	75	103	83	113	69	94	62	85
4.6	53	77	57	83	45	64	42	61
Mean	72	92	78	99	68	85	63	79

The efficiency is defined as the ratio of the detection factor to the magnification. The values given here correspond to those on page 19.

AVERAGE TRANSMISSION VALUES FOR THE BINOCULARS USED (See table of page 9)

6X	77%	8X	77%	10X	73%
78%					

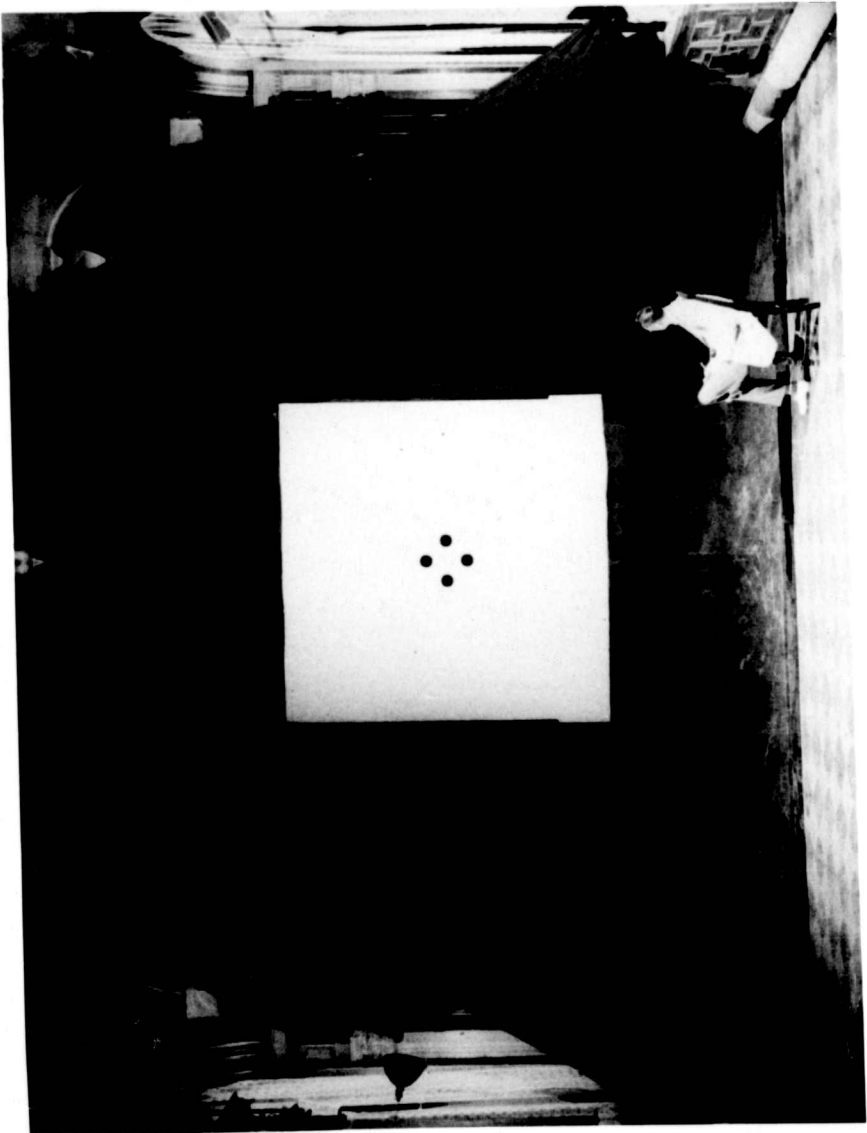
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THE RECORDING BOOTH  
Professor Bartley and Miss Chute  
Operating the Recording Equipment

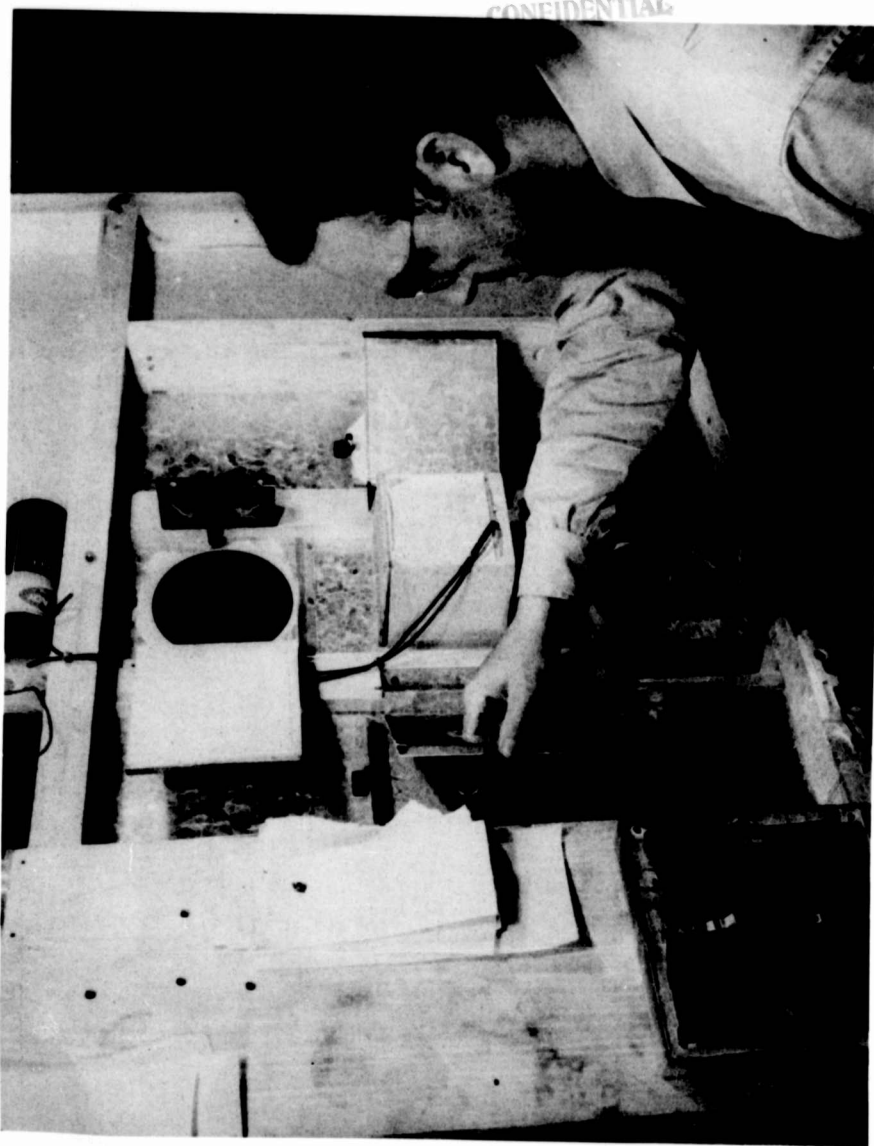
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THE SCREEN  
Showing Four Large Targets in Position

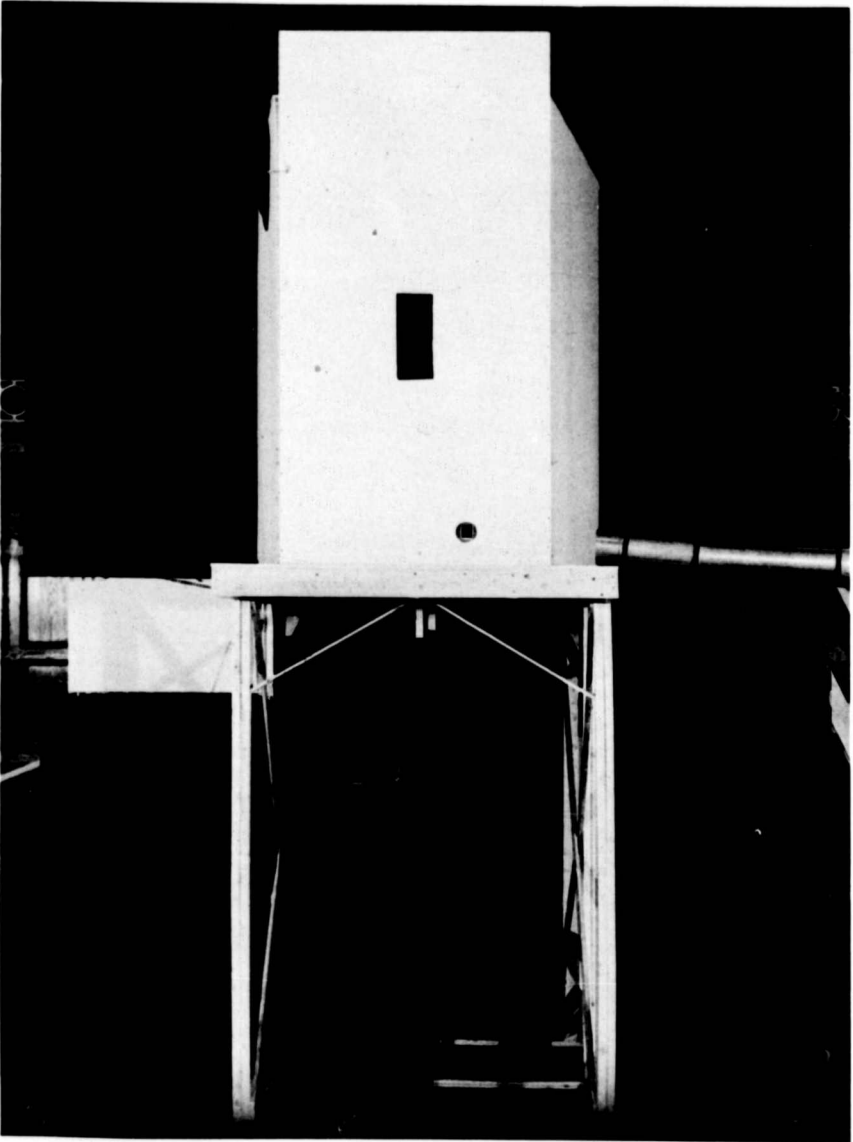
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THE TARGET EXPOSURE SETUP BEHIND THE SCREEN

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OBSERVING BOOTHS

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APPENDIX

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PART I. PRELIMINARY PROCEDURE

The method and schedule described in Part II were decided on after it became clear that the original procedure would not yield adequate results in the time allotted for the study.

From February 10, 1944 to April 24, 1944, observations were made under the Preliminary Procedure. No orderly plan of presentation of target sizes was used. Changes were often made in screen brightness and in binoculars during the day. The basic series was one of twenty observations on each target size. The final percentage score for a given target was the mean value of scores obtained on several different days sometimes as much as a month apart.

The schedule for March 14, 1944 is a typical one:

Log B	Target size	Observer A	Observer B	Observer C
1.6	.375	6X	7X	10X
	.428	6X	7X	10X
	.500	6X	7X	10X
2.6	.428	6X	7X	8X
	.188	6X	7X	8X
	.237	6X	7X	8X

The accumulation of scores for a target of .237" diameter at 2.6 log m $\mu$ l with a 10X glass is typical. The uncorrected percentages and the corresponding dates are given.

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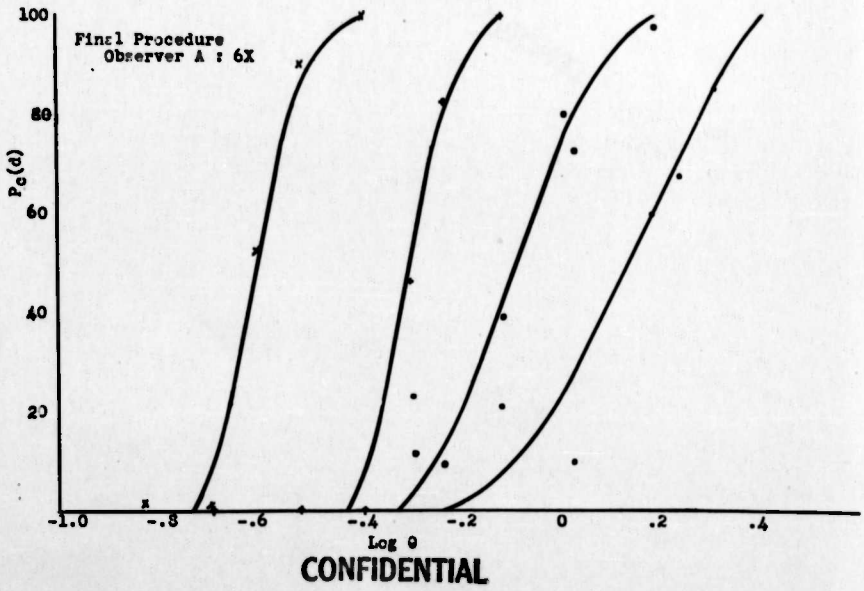
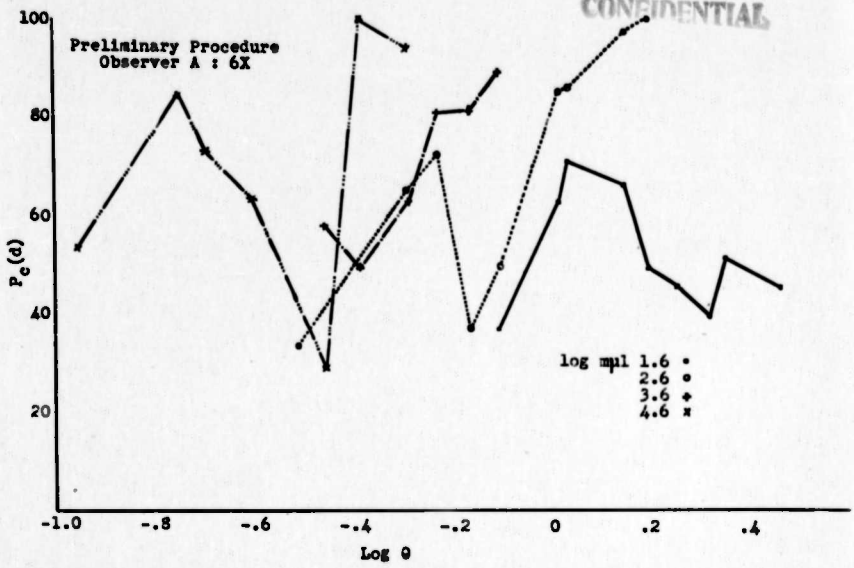
Observer A	Observer B	Observer C
<u>%</u> <u>Date</u>	<u>%</u> <u>Date</u>	<u>%</u> <u>Date</u>
50    2/2	35    2/2	60    3/2
45    2/2	30    2/2	45    3/2
35    2/2	20    2/2	5    3/2
75    3/6	75    3/2	5    3/7
75    3/6	70    3/2	10    3/18
70    3/7	65    3/2	5    3/18
55    4/18	35    3/8	20    3/18
50    4/18	35    3/22	0    3/22
50    4/18	50    3/22	20    3/22
60    4/18	40    3/22	10    3/22
65    4/18	15    3/22	
	50    4/14	
Mean 57.3	Mean 43.3	Mean 18
S.D. 12.2	S.D. 18.4	S.D. 18.6

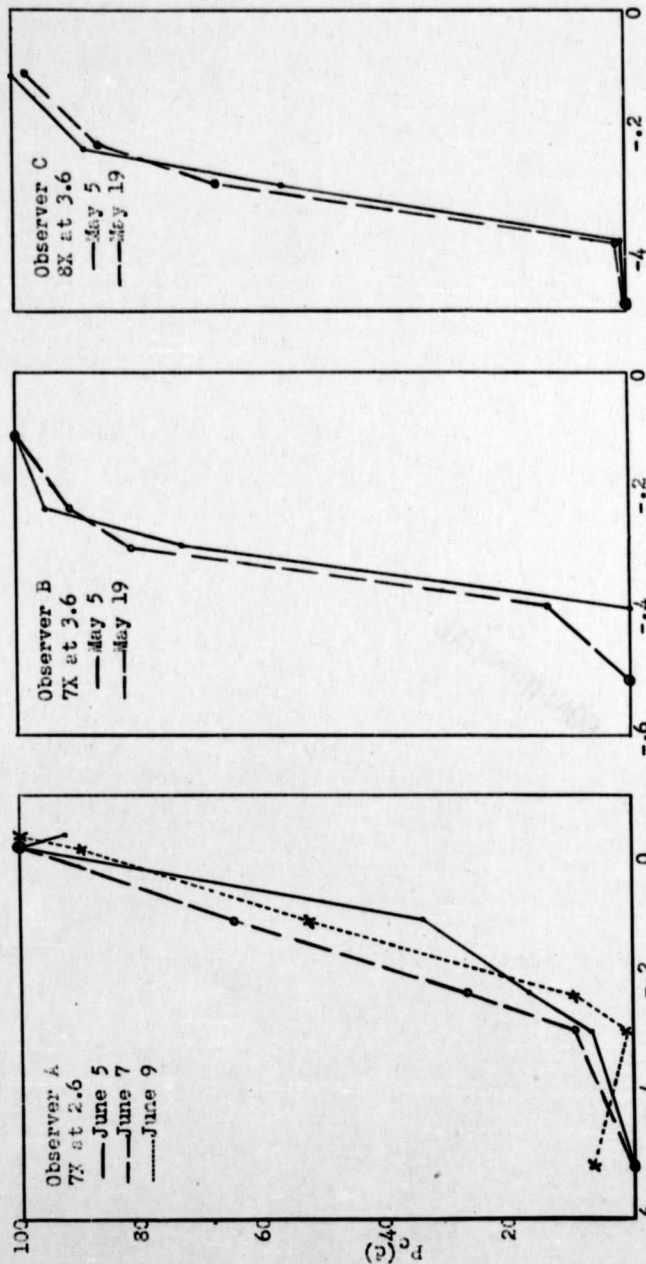
The scatter in the percentages suggests that a tremendous amount of data would be needed if a reliable mean score was to be obtained. It was felt that by reducing the number of observations in an unbroken series from twenty to twelve, and by presenting the targets in orderly sequence, better results could be obtained. The results of the two procedures are compared in the graphs of Figure VI. The reproducibility of the results under the final procedure is illustrated in Figure VII, which shows, for each observer, the agreement of the results obtained by a repetition of a previous day's work with the original data.

It was decided that the data of the preliminary procedure could not be used to advantage in conjunction with the data of the final procedure. The time involved pursuing the original plan must be regarded as expended in exploratory studies, which cleared the way for the plan of the final procedure.

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FIGURE VI





LOG theta

FIGURE VII

Showing the Agreement Between Two Trials on the Same Set of Conditions under the Final Procedure

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PART II. CORRECTION FUNCTION

Two methods have been considered for correcting the apparent percentage probability of detection values which were computed directly from the number of correct observations made in each series of 48. The second method was used.

I. The first correction is defined algebraically in terms of the correct responses (R), the incorrect responses (W), the failures to respond (N), and the number of target positions, n, in this case, 4. It is based on the assumption that, in each series of 48 responses, the incorrect responses are distributed randomly among the three positions where the target does not appear. For convenience these positions are referred to as:

- +2, the position directly opposite the true target position,
- +1, the adjacent position, clockwise from the true target position,
- 1, the adjacent position, counter-clockwise from the true target position.

Then  $W/3$  should represent the number of incorrect responses occurring in each of the three positions +2, +1, and -1. This would also represent the number of correct responses due to chance, and should be subtracted from R before the percentage score is computed. The formula for the corrected percentage score becomes:

$$P'_c(d) = \frac{R - W/3}{R + W + N}.$$

The score on each series of 48 observations is computed by use of this formula, employing the W, R and N values for

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that particular series.

II. The second is the method which has been used in treating the data in this report. It differs from that described above in two ways:

- a) The correction is considered to be a function of the level of difficulty, and standardized at each level, so that, for a given observer, all series giving the same  $P_u(d)$  values would be corrected to give the same  $P_c(d)$  values.
- b) The assumption is not made that the incorrect responses are distributed equally in the three positions +2, +1 and -1. It was found, by tabulating the three types of errors separately, that this assumption is not justified.

The table of page vii shows the distribution of corrections given by the first method, and the standardized value of the second method. (Columns headed  $W/3$  and +2)

The data given here on the distribution of incorrect responses, as a function of the difficulty of detection, demonstrates that the average value of the correction term

$$W/(n-1)$$

overestimates the number of correct responses which are due to chance alone, and that the formula

$$P'_c(d) = \frac{R - W/3}{R + W + N}$$

gives values which are too low by as much as 10% in some cases. The range values based on these percentages are too low by 5%

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in some cases.

The graphs of Figures VIII and IX show that, when the difficulty is great, i.e., when  $P(d) < 30$ , the incorrect responses are equally distributed in the three positions, and approximate the average value of  $W/3$  in each case. When  $P(d)$  is greater than 30, however, this is no longer the case. For  $P(d) > 30$ , the number of responses falling in the position (+2) directly opposite the true target position, (0), is significantly smaller than the number designating either of the two adjacent positions (+1 and -1). This implies that, for  $P(d) > 30$ , the observer is aware of the target in a general way. Although in some cases he cannot localize his response completely, he can say that the target is in a certain semicircle, or quadrant. This implies that the occurrence of responses due to guessing will be reflected more clearly by the number of +2 responses than by the average of this and the larger number in the +1 and -1 positions.

As an example, for Observer A, for a difficulty level corresponding to a  $P_u(d)$  of 65% there were, on the average, 3.7 responses in each 48 in which the observer chose the target position directly opposite the target. In 5.3 cases he chose the +1 position, and in 5.6 cases he chose the -1 position. The contention here is that 3.7 is the best estimate of the number of correct responses which were due to guessing, and that the  $5.3 - 3.7 = 1.6$  and  $5.6 - 3.7 = 1.9$  additional responses in the adjacent positions are due to stimulus which is near threshold, but not great enough to give actual location. Thus if, instead of 3.7, the mean number of incorrect responses,  $W/3 = 5.45$  is used, correct responses due to threshold stimulus will be eliminated.

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ANALYSIS OF ERRORS AND CORRECTION FUNCTION  
BASED ON THE FINAL PROCEDURE

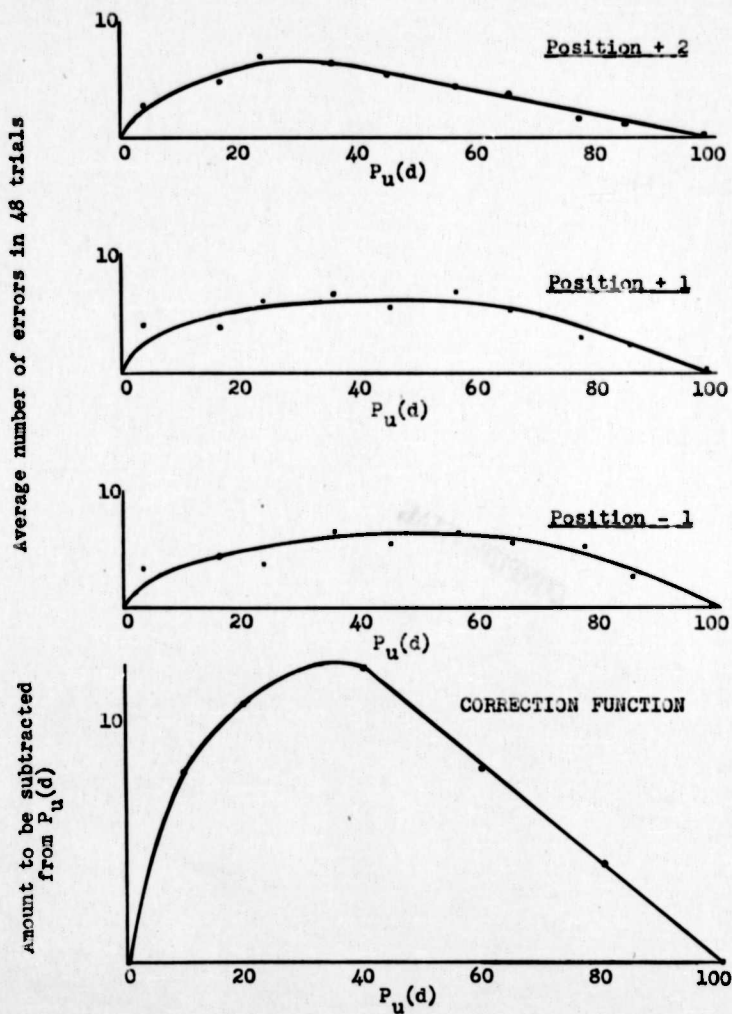


FIGURE VIII OBSERVER A

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 ANALYSIS OF ERRORS AND CORRECTION FUNCTION  
 BASED ON THE FINAL PROCEDURE

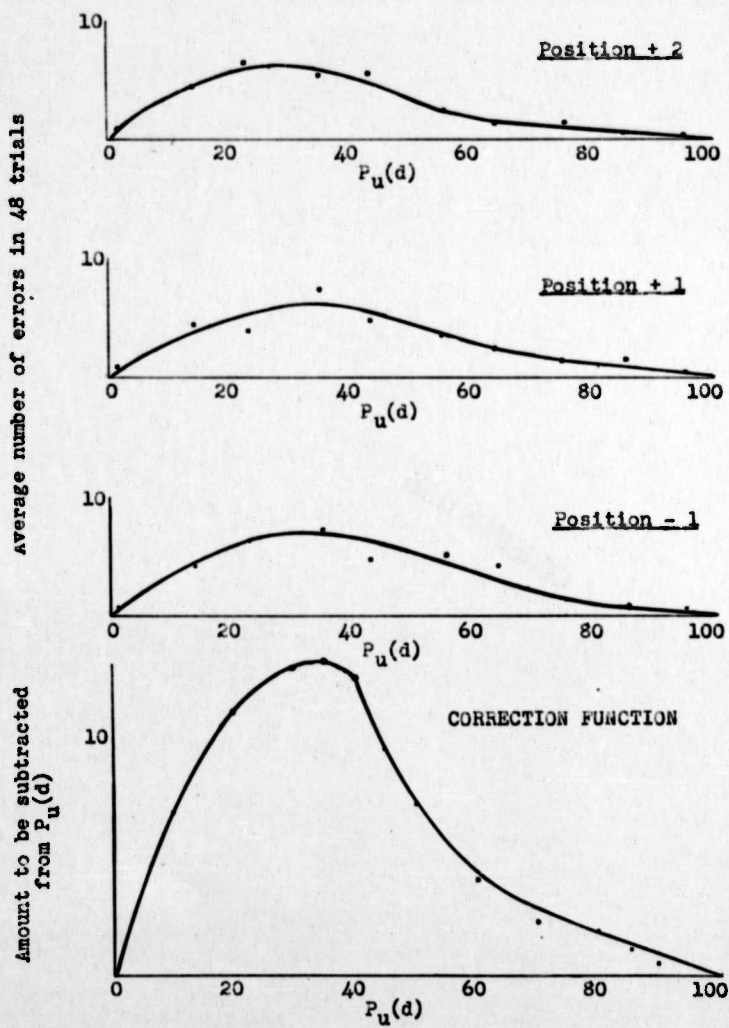


FIGURE VIII OBSERVER B

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ANALYSIS OF ERRORS AND CORRECTION FUNCTION  
BASED ON THE FINAL PROCEDURE

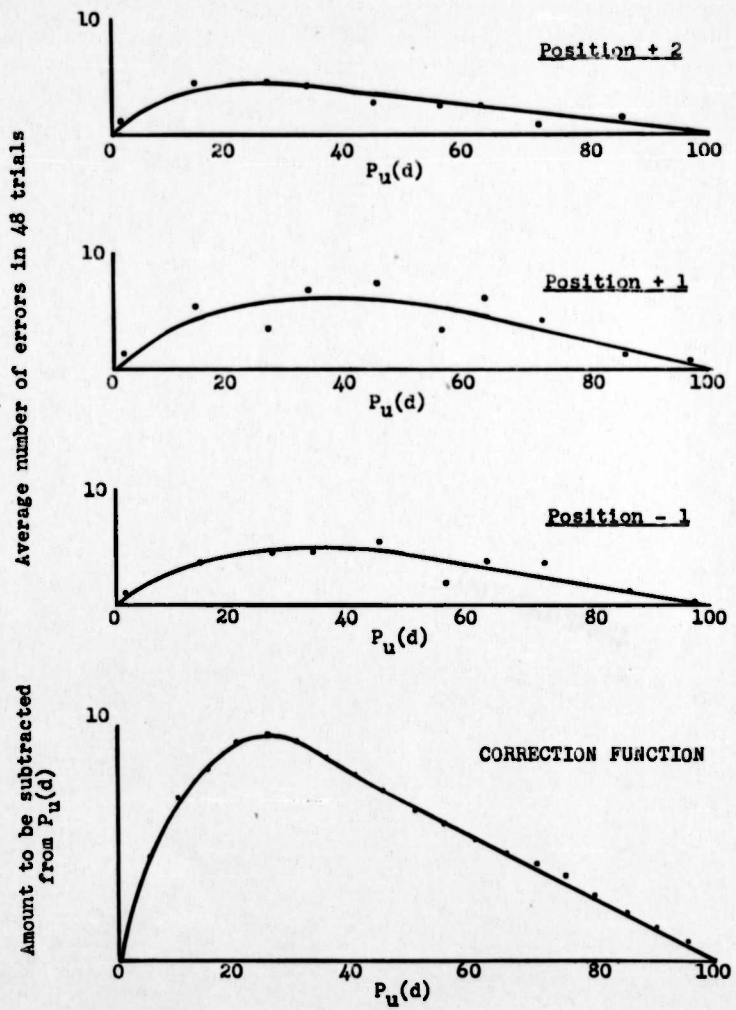
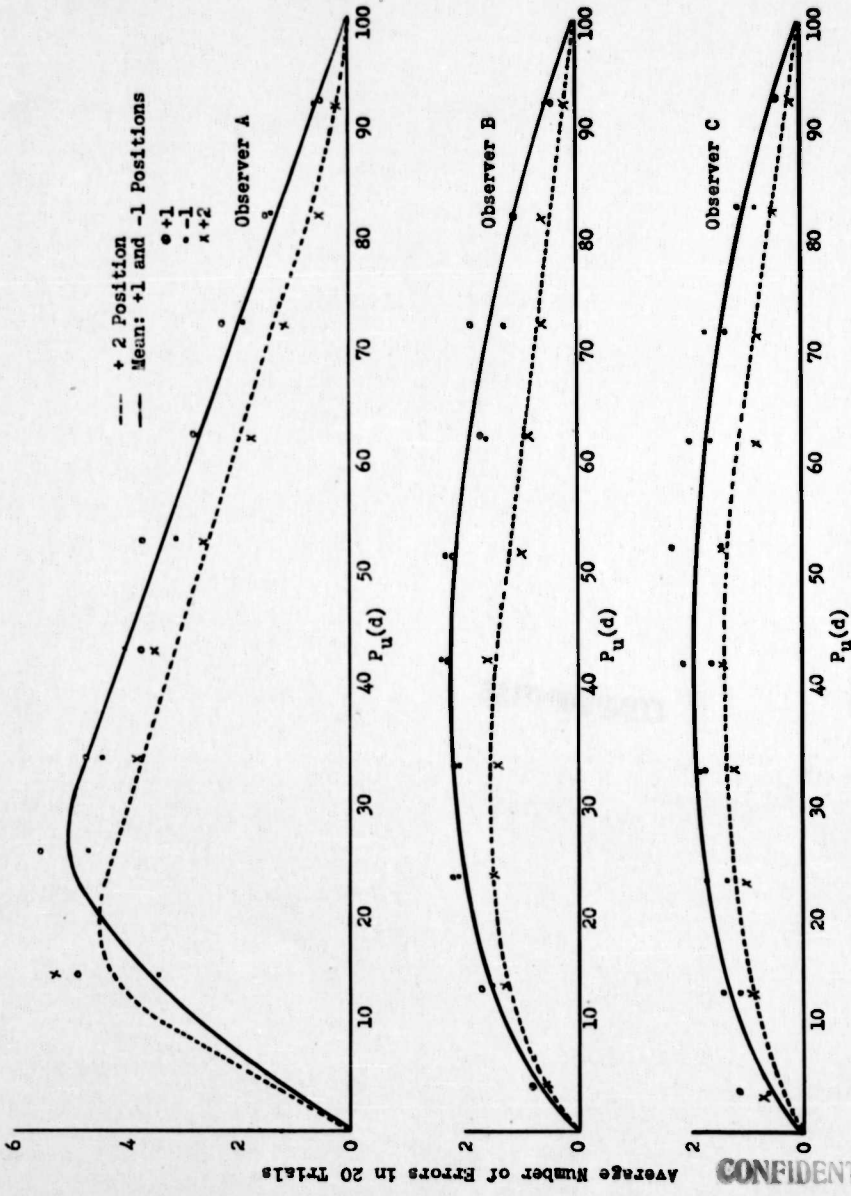


FIGURE VIII OBSERVER C  
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ANALYSIS OF ERRORS - PRELIMINARY PROCEDURE  
 FIGURE IX

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It is reasonable then, to adopt as a correction one which is determined by the +2 graph alone. It must be realized that this is very probably an upper limit to the correction; the true correction may be appreciably less than this, but unfortunately it cannot be more accurately determined.

**THE FINAL ERROR DISTRIBUTION**

For each set of 48 observations,  $P_u(d)$  was calculated. The number of failures to respond was denoted by  $N$ . The incorrect responses were classified and tabulated as +2, +1, and -1, as defined on Page vi. The correct responses are denoted by (0).

The sets were then sorted into ten groups according to  $P_u(d)$ : 0 - 10, 10 - 20, . . . 90 - 100. The number of sets falling into a group is denoted by  $n$ . In each group the average number of failures to respond, +2 responses, +1 responses, 0 responses, and -1 responses was computed. The average value of  $W/3$  for each interval is given for comparison with the +2 value.

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**THE FINAL ERROR DISTRIBUTION**

**Observer A**  
**Final Procedure**

<u>P<sub>u</sub>(d)</u>	<u>n</u>	<u>N</u>	<u>+1</u>	<u>0</u>	<u>-1</u>	<u>+2</u>	<u><math>\frac{1}{3}</math></u>
3.9	9	35.8	4.0	1.8	3.3	2.7	3.3
16.6	6	27.2	4.0	7.7	4.3	4.8	4.4
23.7	12	19.9	6.0	11.4	3.7	6.9	5.5
35.5	5	11.8	6.6	17.1	6.4	6.1	6.4
44.6	10	10.3	5.6	21.4	5.5	5.2	5.4
56.0	7	3.9	6.9	26.8	6.2	4.3	5.8
65.0	7	2.2	5.3	31.2	5.6	3.7	4.9
77.1	5	1.6	3.0	36.6	5.2	1.6	3.3
85.8	12	0.2	2.3	41.3	2.8	1.4	2.2
98.2	23	0.	0.4	47.1	0.3	0.2	0.3

**Preliminary Procedure**

14.0	4	3.8	4.8	2.8	3.4	5.2
25.0	14	0.3	5.5	5.0	4.6	4.2
33.5	26	0.4	4.6	6.7	4.4	3.8
43.0	51	0.3	3.7	8.6	4.0	3.5
53.0	76	0.01	3.7	10.6	3.1	2.6
62.5	104	0.05	2.8	12.5	2.7	1.8
72.5	95	0.1	2.3	14.5	1.9	1.2
82.5	107	0.04	1.5	16.5	1.4	0.6
92.5	117	0.01	0.5	18.5	0.6	0.3

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THE FINAL ERROR DISTRIBUTION

Observer B  
Final Procedure

<u>P<sub>n</sub>(d)</u>	<u>n</u>	<u>N</u>	<u>+1</u>	<u>0</u>	<u>-1</u>	<u>+2</u>	<u><math>\frac{N}{3}</math></u>
1.2	46	45.4	0.6	0.6	0.6	0.9	0.7
14.0	17	28.7	4.2	6.7	4.1	4.2	4.2
22.9	8	20.8	6.1	10.7	3.9	6.4	5.5
35.2	6	11.4	7.2	16.9	7.2	5.2	6.5
43.2	4	12.2	4.8	20.8	4.9	5.3	5.0
55.4	3	10.7	5.0	26.6	3.4	2.4	3.6
63.9	6	9.7	4.2	30.7	2.2	1.3	2.6
75.1	15	8.5	1.2	36.0	1.1	1.1	1.1
85.1	13	3.8	0.9	40.9	1.6	0.7	1.1
95.7	18	0.6	0.4	46.0	0.5	0.4	0.4

Preliminary Procedure

4.0	22	17.1	0.8	0.8	0.8	0.6
13.0	64	12.8	1.7	2.6	1.5	1.3
23.0	84	9.6	2.2	4.6	2.1	1.5
33.0	100	7.7	2.2	6.6	2.1	1.4
42.5	66	5.3	2.3	8.5	2.4	1.6
52.0	60	4.2	2.2	10.4	2.3	1.0
62.5	70	3.3	1.7	12.5	1.6	0.9
72.5	61	1.7	1.9	14.5	1.3	0.6
82.0	57	0.8	1.1	16.4	1.1	0.6
92.5	62	3.6	0.4	18.5	0.5	0.2

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THE FINAL ERROR DISTRIBUTION

Observer C  
Final Procedure

<u>P<sub>H</sub>(d)</u>	<u>n</u>	<u>N</u>	<u>+1</u>	<u>0</u>	<u>-1</u>	<u>+2</u>	<u><math>\frac{1}{3}</math></u>
1.92	43	42.0	1.3	0.9	1.0	1.1	1.1
14.4	17	26.5	5.2	6.8	3.8	4.6	4.5
26.6	4	22.8	3.5	12.8	4.5	4.5	4.2
33.3	3	16.3	6.7	16.0	4.7	4.3	5.2
44.3	6	11.0	7.3	21.2	5.5	2.8	5.2
55.4	5	13.6	3.2	26.6	2.0	2.6	2.6
62.5	7	3.6	6.0	30.3	3.9	2.4	4.1
72.7	7	4.1	4.1	34.3	3.6	1.0	2.9
86.2	9	2.2	1.4	41.1	1.4	1.4	1.4
97.0	7	0.1	0.7	46.6	0.1	0.4	0.4

Preliminary Procedure

3.5	49	16.9	1.1	0.7	0.6	0.7
12.5	94	14.0	1.4	2.5	1.1	0.9
22.5	87	11.5	1.7	4.5	1.3	1.0
32.5	72	8.8	1.7	6.5	1.8	1.2
42.0	67	6.4	2.1	8.4	1.6	1.4
52.5	45	4.4	2.3	10.5	1.4	1.4
62.0	38	3.4	2.0	12.4	1.6	0.7
72.0	36	1.9	1.3	14.4	1.7	0.7
83.0	41	1.0	1.1	16.6	0.8	0.5
93.0	61	0.5	0.4	18.6	0.4	0.2

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DISTRIBUTION OF ACTUAL RESPONSES FOR EACH TRUE TARGET POSITION

Final Procedure

<u>Target in Position I</u>	<u>Target in Position II</u>	<u>Target in Position III</u>	<u>Target in Position IV</u>
<u>OBSERVER A</u>			
105 <u>786*</u> 111	46 106 <u>829</u> 90	67 130 <u>783</u> 101	<u>709</u> 134 100 80
N = 310	N = 276	N = 369	N = 301

<u>OBSERVER B</u>			
71 <u>722</u> 30	70 91 <u>443</u> 84	69 76 <u>709</u> 39	<u>670</u> 75 83 34
N = 725	N = 859	N = 758	N = 702

<u>OBSERVER C</u>			
123 <u>418</u> 47	61 77 <u>381</u> 73	52 69 <u>430</u> 69	<u>431</u> 75 58 49
N = 656	N = 626	N = 679	N = 646

\* The underlined numbers represent correct responses.

Total Errors - Number of times each position was given as an incorrect response.

	N	1	2	3	4
Observer A	1256	370	292	300	218
Observer B	3044	242	103	244	210
Observer C	2607	221	165	179	236

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DISTRIBUTION OF ACTUAL RESPONSES FOR EACH

TRUE TARGET POSITION

Preliminary Procedure

<u>Target in Position I</u>	<u>Target in Position II</u>	<u>Target in Position III</u>	<u>Target in Position IV</u>
<u>OBSERVER A</u>			
383 <u>2439*</u> 227	163 274 <u>2424</u>	297 272 370	<u>2453</u> 350 148
346	430	<u>2423</u>	400
N = 22	N = 17	N = 21	N = 18

<u>OBSERVER B</u>			
334 <u>2054</u> 150	150 169 <u>1783</u>	257 163 234	<u>1951</u> 260 131
227	436	<u>1948</u>	388
N = 963	N = 1114	N = 844	N = 999

<u>OBSERVER C</u>			
230 <u>1511</u> 132	93 179 <u>1414</u>	165 154 243	<u>1400</u> 220 111
157	211	<u>1206</u>	282
N = 1613	N = 1555	N = 1604	N = 1564

\* The underlined numbers represent correct responses.

Total Errors - Number of times each position was given as an incorrect response.

	N	1	2	3	4
Observer A	78	896	745	1176	843
Observer B	3920	592	515	1051	741
Observer C	6336	553	486	650	488

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SCHEDULE  
and  
TABLES

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SCHEDULE OF EXPERIMENTS

Date	Target Diameter in Mils						Binocular Magnification			Log R
	1	2	3	4	5	6	A	B	C	
April 24	.308	.514	.595	.780	1.04	1.08	8	10	10	2.6
	.349	.514	.780	1.08	1.56	1.76	7	10	10	1.6
	.111	.203	.308	.412	.514	.595	7	10	10	3.6
	.053	.064	.150	.203	.251	.308	7	10	10	4.6
May	.111	.064	.308	.412	.514	.595	10	8	7	4.6
	.111	.203	.308	.412	1.04	1.08	10	8	7	3.6
	.308	.514	.595	.780	1.56	1.76	10	8	7	1.6
	.349	.514	.780	1.08	1.56	.412	6	7	8	4.6
	.064	.150	.203	.251	.308	.412	6	7	8	3.6
	.203	.308	.412	.514	.595	.780	6	7	8	2.6
	.514	.595	.780	1.04	1.08	1.56	6	7	8	1.6
	.514	.780	1.08	1.56	1.76	2.08	6	6	6	4.6
	.064	.150	.203	.251	.308	.412	8	6	6	3.6
	.203	.308	.412	.514	.595	.780	8	6	6	2.6
	.514	.595	.780	1.04	1.08	1.56	8	6	6	1.6
	June	.349	.514	.780	1.08	1.56	1.76	10	10	10
.111		.203	.308	.412	.514	.595	10	10	10	3.6
.111		.064	1.08	1.56	1.76	2.08	10	10	10	4.6
.111		.203	1.08	1.56	1.76	2.08	10	10	10	1.6
.111		.203	1.08	1.56	1.76	2.08	10	10	10	3.6
.111		.203	1.08	1.56	1.76	2.08	10	10	10	4.6
.111		.203	1.08	1.56	1.76	2.08	10	10	10	1.6
.111		.203	1.08	1.56	1.76	2.08	10	10	10	3.6
.111		.203	1.08	1.56	1.76	2.08	10	10	10	4.6
.111		.203	1.08	1.56	1.76	2.08	10	10	10	1.6
.111		.203	1.08	1.56	1.76	2.08	10	10	10	3.6
.111		.203	1.08	1.56	1.76	2.08	10	10	10	4.6

\* B is screen brightness in m.p.l.

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TABLE I

OBSERVER A

1.6 ml					2.6 ml					
Q	N	W	R	P <sub>c</sub> (d)		Q	N	W	R	P <sub>c</sub> (d)
4.80	33	6	9	8.2	1X	2.95	24	14	10	9.6
6.09	14	19	15	18.7		4.30	4	32	12	13.2
7.80	0	12	36	69.8		5.74	1	12	35	67.5
12.67	0	1	47	97.5		6.09	0	8	40	79.5
						7.80*	0	4	43	89.7
						8.36	0	1	47	97.5
-----										
.514†	9	14	13	23.3	6X	.514	20	17	11	11.4
.780	12	20	16	20.7		.595	19	19	10	9.6
1.08	13	25	10	9.6		.780	2	21	25	42.1
1.56	5	11	32	59.8		1.04	0	8	40	79.8
1.76	0	13	35	67.2		1.08	0	11	37	72.3
2.08	0	6	42	85.0		1.56	0	2	46	95.0
-----										
.349	26	10	12	13.2	7X	.308	37	9	2	0
.514	18	11	19	27.1		.514	24	16	8	6.4
.780	7	21	20	29.6		.595	13	21	14	16.9
1.08	0	20	28	49.6		.780	6	20	22	34.5
1.56	0	8	40	79.8		1.04	0	0	48	100
1.76	0	6	42	85.0		1.08	0	3	45	92.5
-----										
.349	44	3	1	0	8X	.308	18	17	13	15.1
.514	32	10	6	3.5		.514	12	20	16	20.9
.780	24	17	7	4.8		.595	0	16	32	59.9
1.08	5	26	17	22.8		.780	0	0	48	100
1.56	0	16	32	59.8		1.04	0	0	48	100
1.76	0	10	38	74.9		1.08	0	1	47	97.5
-----										
.349	34	10	4	1.1	10X	.308	28	8	12	13.2
.514	27	13	8	6.4		.514	7	13	28	49.6
.780	6	31	11	11.4		.595	0	17	31	57.4
1.08	0	26	22	34.5		.780	0	0	48	100
1.56	0	5	43	87.5		1.04	0	0	48	100
1.76	0	5	43	87.5		1.08	0	0	48	100

\* Some responses not included because of difficulty in reading records.

† Total number of trials = 36.

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TABLE I

OBSERVER A

3.6 mil					4.6 mil				
0	M	W	R	P <sub>c</sub> (d)	0	M	W	R	P <sub>c</sub> (d)
1.12	42	3	3	0.5	1X .553	45	2	1	0
1.40	38	7	3	0.5	.686	31	10	7	5.2
1.62	37	10	1	0	.841	29	7	12	13.2
2.12*	22	13	12	13.2	.951	13	13	22	34.8
2.84	6	7	35	67.5	1.12	4	10	34	65.0
2.96	8	8	32	59.4	1.40	0	2	46	94.5
-----									
.203+	26	10	0	0	6X .064	48	0	0	0
.308+	30	5	1	0	.150	31	13	4	1.1
.412**	26	8	1	0	.203	20	25	3	0.5
.514+	1	15	20	46.3	.251	4	15	29	52.2
.595	0	7	41	82.3	.308	0	4	44	90.0
.780	0	0	48	100	.412	0	0	48	100
-----									
.111*	23	12	11	12.3	7X .053	29	10	9	8.0
.203*	17	9	21	33.2	.064	17	10	21	32.1
.308	9	14	25	42.1	.150	4	17	27	47.2
.412	1	12	35	67.4	.203	0	8	40	79.8
.514	0	3	45	92.5	.251	1	4	43	87.6
.595	1	0	47	97.5	.308	0	0	48	100
-----									
.203	27	13	8	6.4	8X .064*	11	10	18	35.1
.308	15	23	10	9.6	.150*	10	16	19	30.2
.412	5	18	25	42.1	.203	1	19	28	49.6
.514	0	4	44	90.0	.251	1	6	41	82.2
.595	0	2	46	95.0	.308	7	3	38	74.8
.780	0	0	48	100	.412*	0	2	45	94.7
-----									
.111	34	2	12	13.2	10X .053*	23	14	10	10.0
.203	17	11	20	29.5	.064	12	16	20	29.5
.308	6	11	31	57.4	.150	0	17	31	57.4
.412	0	6	42	85.0	.203	0	9	39	77.3
.514	0	0	48	100	.251	0	0	48	100
.595*	0	0	47	100	.308	0	0	48	100

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TABLE I

OBSERVER B

1.6 mm					2.6 mm					
<u>Q</u>	<u>N</u>	<u>W</u>	<u>R</u>	<u>P<sub>c</sub>(d)</u>		<u>Q</u>	<u>N</u>	<u>W</u>	<u>R</u>	<u>P<sub>c</sub>(d)</u>
4.80	37	5	6	4.5	1X	2.95	28	15	5	3.4
6.09	11	27	10	9.6		4.30	18	22	8	6.8
7.80	0	31	17	22.2		5.74	5	14	29	56.2
12.67	0	4	44	91.1		6.09	3	11	34	68.2
						7.80*	1	4	42	88.4
						8.36	1	5	42	86.6
-----										
.514	48	0	0	0	6X	.514	48	0	0	0
.780	43	5	0	0		.595	39	8	1	0.5
1.08	36	7	5	3.4		.780*	26	14	6	4.7
1.56	19	21	8	6.9		1.04+	11	15	10	15.2
1.76	8	32	8	6.9		1.08+	2	19	15	30.1
2.08	4	27	17	22.1		1.56	0	3	45	93.4
-----										
.514+	34	1	1	0.7	7X	.514	45	2	1	0.5
.780	45	3	0	0		.595	24	15	9	8.2
1.08	30	11	7	5.6		.780	6	16	26	48.1
1.56	9	18	21	33.7		1.04	4	4	40	81.9
1.76	6	8	34	68.2		1.08*	1	1	45	95.5
2.08	3	3	42	86.6		1.56	0	2	46	95.6
-----										
.349	48	0	0	0	8X	.308	48	0	0	0
.514	48	0	0	0		.514	48	0	0	0
.780	48	0	0	0		.595	44	2	2	1.0
1.08	39	8	1	0.5		.780	15	11	22	36.7
1.56	17	14	17	22.2		1.04	9	2	37	75.1
1.76	10	12	26	48.1		1.08	9	3	36	72.8
-----										
.349	47	1	0	0	10X	.308	46	0	2	1.0
.514	44	4	0	0		.514	42	0	6	4.5
.780	39	3	6	4.5		.595	32	5	11	11.2
1.08	17	14	17	22.4		.780	10	5	33	66.0
1.56	3	5	40	81.9		1.04	1	0	47	97.7
1.76	6	2	40	81.9		1.08	4	0	44	91.1

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TABLE I

OBSERVER B

3.6 mil					4.6 mil					
θ	N	W	R	P <sub>c</sub> (d)		θ	N	W	R	P <sub>c</sub> (d)
1.12	47	1	0	0	1X	.553	48	0	0	0
1.40	43	4	1	0.5		.686	45	2	1	0.5
1.62	34	13	1	0.5		.841	13	6	29	56.2
2.12*	21	10	16	20.9		.951	1	4	43	88.9
2.84	13	2	33	66.0		1.12	5	0	43	88.9
2.95	2	2	44	91.1		1.40	1	0	47	97.8
-----										
.203	48	0	0	0	6X	.064*	37	0	1	0.6
.308	48	0	0	0		.150*	45	0	0	0
.412	26	16	6	4.5		.203	37	5	6	4.5
.514	9	30	9	8.2		.251	4	7	37	75.1
.595	3	14	31	61.2		.308	1	7	40	81.9
.780	1	0	47	97.8		.412*	1	2	44	93.3
-----										
.203+	36	0	0	0	7X	.064	48	0	0	0
.308+	36	0	0	0		.150	48	0	0	0
.412+	36	0	0	0		.203	48	0	0	0
.514+	5	4	27	72.8		.251	6	2	40	81.9
.595	0	2	46	95.6		.308	0	1	47	97.8
.780	0	0	48	100		.412	0	0	48	100
-----										
.111	48	0	0	0	8X	.053*	47	0	0	0
.203	48	0	0	0		.064	44	1	3	1.6
.308	48	0	0	0		.150	22	6	20	30.1
.412	41	5	2	1.0		.203	13	1	34	68.2
.514	9	2	37	75.1		.251	11	0	37	75.1
.595*	10	1	35	74.0		.308	12	0	36	72.8
-----										
.111*	45	1	0	0	10X	.053*	44	0	0	0
.203*	45	1	1	0.5		.064*	34	3	5	4.2
.308	41	2	5	3.4		.150*	15	4	26	52.8
.412	14	5	29	56.2		.203*	11	2	34	69.8
.514	9	0	39	79.6		.251*	7	0	38	83.1
.595	11	0	37	75.1		.308	11	1	36	72.8

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TABLE I

OBSERVER G

θ	1.6 mil					2.6 mil				
	N	W	R	P <sub>c</sub> (d)		θ	N	W	R	P <sub>c</sub> (d)
.514	48	0	0	0	6X	.514	48	0	0	0
.780	48	0	0	0		.595	48	0	0	0
1.08	37	10	1	0.2		.780*	31	13	2	0.6
1.56	20	20	8	8.1		1.04+	28	5	3	2.3
1.76	10	29	9	9.8		1.08+	20	11	5	6.0
2.08	16	26	6	5.0		1.56	0	2	46	95.2
-----										
.349	48	0	0	0	7X	.308	48	0	0	0
.514	48	0	0	0		.514	46	2	0	0
.780	48	0	0	0		.595	48	0	0	0
1.08	48	0	0	0		.780	41	5	2	0.6
1.56	26	6	16	24.4		1.04	7	11	30	57.7
1.76	13	8	27	50.5		1.08	16	6	26	48.3
-----										
.514+	36	0	0	0	8X	.514	48	0	0	0
.780	45	3	0	0		.595	42	5	1	0.2
1.08	28	16	4	2.3		.780	11	22	15	22.0
1.56	13	14	21	36.4		1.04*	3	6	38	78.4
1.76*	4	8	33	69.8		1.08*	3	2	42	88.0
2.08	3	3	42	85.9		1.56	0	3	45	93.0
-----										
.514	38	7	3	1.2	10X	.308	37	6	5	3.4
.780	32	10	6	5.0		.514	41	1	6	5.0
1.08	33	9	6	5.0		.595	26	8	14	19.9
1.56*	4	14	29	56.8		.780	12	9	27	50.5
1.76	2	4	42	85.9		1.04	0	2	46	95.2
2.08	1	1	46	95.2		1.08	1	6	41	84.0

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TABLE I

OBSERVER C

3.6 mil					4.6 mil					
<u>Ø</u>	<u>N</u>	<u>W</u>	<u>R</u>	<u>P<sub>c</sub>(d)</u>		<u>Ø</u>	<u>N</u>	<u>W</u>	<u>R</u>	<u>P<sub>c</sub>(d)</u>
.203	33	13	2	0.6	6X	.064*	38	0	0	0
.308	24	20	4	2.3		.150*	39	0	6	5.6
.412	19	21	8	8.2		.203	42	5	1	0.2
.514	12	27	9	9.8		.251	34	8	6	5.0
.595	10	17	21	36.4		.308	16	10	22	38.7
.780	2	7	39	78.7		.412*	2	6	39	80.8
-----										
.111	43	3	2	0.6	7X	.053*	46	0	1	0.2
.203	42	5	1	0.2		.064	45	2	1	0.2
.308	48	0	0	0		.150	43	3	2	0.6
.412	45	1	2	0.6		.203	31	5	12	15.5
.514	3	16	29	55.3		.251	18	4	26	48.3
.595*	4	10	33	66.4		.308	9	5	34	67.0
-----										
.203+	36	0	0	0	8X	.064	48	0	0	0
.308+	36	0	0	0		.150	48	0	0	0
.412+	35	0	1	0.3		.203	48	0	0	0
.514+	6	8	22	56.1		.251	13	15	20	34.0
.595	3	2	43	88.2		.308	0	5	43	88.2
.780	0	0	48	100		.412	0	0	48	100
-----										
.111*	30	7	9	10.5	10X	.053	12	19	17	26.8
.203*	29	12	6	5.1		.064	7	19	22	38.7
.308	25	12	11	13.5		.150*	7	19	21	37.4
.412	9	12	27	50.5		.203	2	16	30	57.7
.514	3	10	35	69.4		.251	0	12	36	71.7
.595	2	15	31	60.0		.308*	2	9	36	73.6

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TABLE II  
ABSOLUTE RANGE VS. MAGNIFICATION\*  
Observers A, B, and C

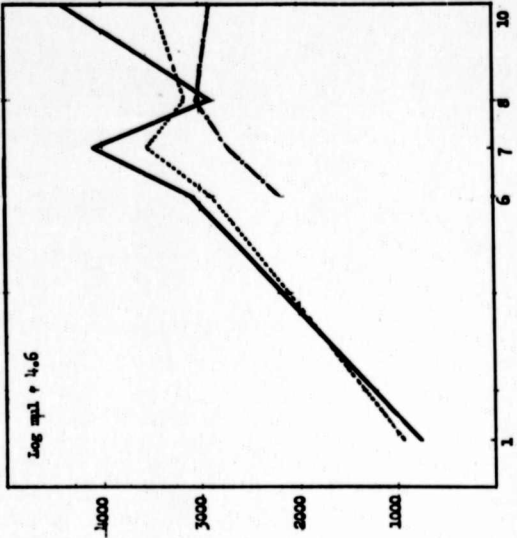
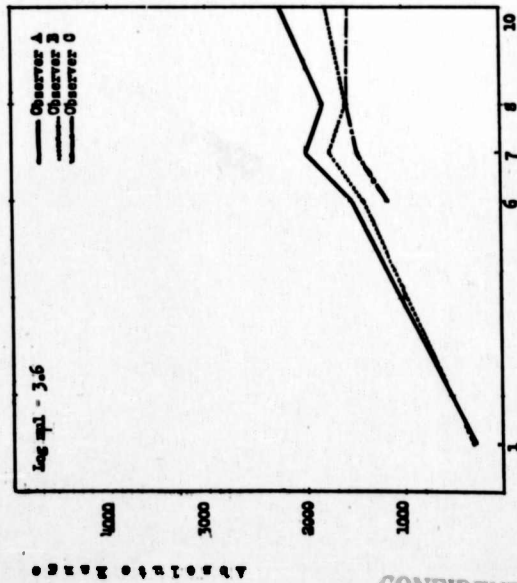
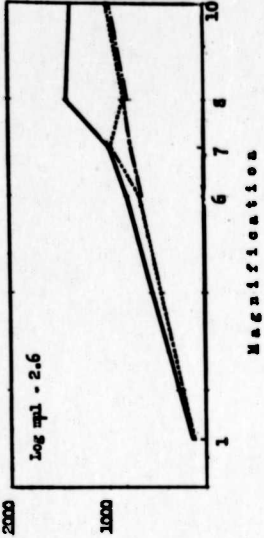
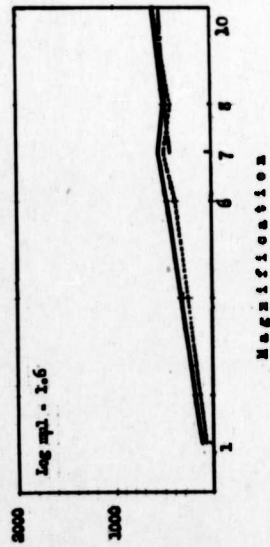
Log R		M.E.	90% Detection			
			6X	7X	8X	10X
1.6	A	110	455	525	490	590
	B	78	370	490	415	575
	C			425	480	525
	Mean	95	410	480	460	565
2.6	A	135	795	975	1410	1380
	B	125	660	975	815	1000
	C		660	740	815	1000
	Mean	130	705	895	1010	1130
3.6	A	295	1510	2000	1820	2240
	B	300	1410	1740	1580	1780
	C		1150	1450	1580	1550
	Mean	300	1360	1730	1660	1860
4.6	A	760	3090	4070	2880	4370
	B	935	2880	3550	3160	3470
	C		2190	2690	3020	2880
	Mean	850	2720	3440	3020	3570

Log R		M.E.	50% Detection			
			6X	7X	8X	10X
1.6	A	140	725	955	725	815
	B	100	435	605	550	760
	C			560	605	675
	Mean	120	580	705	625	750
2.6	A	205	1200	1260	1740	1910
	B	180	830	1230	1150	1380
	C		775	955	1120	1320
	Mean	190	935	1150	1340	1540
3.6	A	380	1950	3310	2400	3800
	B	400	1660	2040	2090	2450
	C		1510	1910	2000	2400
	Mean	390	1710	2420	2160	2880
4.6	A	975	3980	7250	5130	7410
	B	1230	3800	4270	5370	7080
	C		2950	3800	3800	5500
	Mean	1100	3580	5110	4770	6660

\* See Figure X on following pages.

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FIGURE I  
Corresponding to a 90% Probability of Detection

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TABLE III

DETECTION FACTOR VS. MAGNIFICATION  
Observers A, B, and C\*

LOG B	50% Detection					
	6X	7X	8X	9X	10X	11X
	M.E.	L.E.	LX	M.E.	LX	L.E.
1.6 A	5.2	6.8	11.0	5.2	8.3	5.8
B	4.4	6.0	7.0	5.5	6.3	7.6
C		4.7	6.4	5.0	7.0	5.6
2.6 A	5.9	6.1	7.9	8.5	10.9	9.3
B	4.6	6.8	7.7	6.4	7.2	7.7
C	4.1	5.0	6.0	5.9	7.0	8.2
3.6 A	5.1	8.7	11.2	6.3	8.2	10.0
B	4.2	5.1	6.9	5.2	7.1	8.3
C	3.9	4.9	6.5	5.1	6.8	6.2
4.6 A	4.1	7.4	9.5	5.3	6.8	7.6
B	3.1	3.5	5.6	4.4	7.1	5.8
C	2.7	3.5	5.0	3.5	5.0	5.0

The detection factor is defined as the ratio of the range obtained with the binocular to the range obtained with the naked eye (N.E.). The LX values are based on the range values computed, supposing the observer to be using a unit power binocular of 5 ma. exit pupil and transmission equivalent to that of the average of those of the binoculars used in the other parts of the observing.

\* Since no naked eye observations were made by Observer C, the values given here have been computed by use of the mean of the naked eye range values obtained by the two other observers.

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TABLE III  
DETECTION FACTOR VS. MAGNIFICATION  
 Observers A, B, and C\*

LOG B	6X			7X			8X			10X		
	M.E.	LX	M.E.	LX	M.E.	LX	M.E.	LX	M.E.	LX	M.E.	LX
1.6 A	4.1	6.2	4.8	7.1	4.5	6.6	5.4	8.0	7.4	5.6	7.4	7.8
B	4.7	5.0	6.3	6.6	5.3	5.6	7.4	7.1	5.5	6.5	5.5	7.1
C			4.5	5.7	5.1	6.5						
2.6 A	5.9	6.6	7.2	8.1	10.4	11.7	10.2	11.5	8.0	8.0	10.2	11.5
B	5.3	5.5	7.8	8.1	6.5	6.8	8.0	8.3	6.8	7.7	8.0	8.3
C	5.1	5.5	5.7	6.2	6.3	6.8	7.7	8.3	6.8	7.7	8.0	8.3
3.6 A	5.1	6.9	6.8	9.1	6.2	8.3	7.6	10.2	7.6	7.6	10.2	11.5
B	4.7	6.4	5.8	7.9	5.3	7.2	5.9	8.1	5.9	5.9	8.1	8.1
C	3.8	5.2	4.8	6.6	5.3	7.2	5.2	7.0	5.2	5.2	7.0	7.0
4.6 A	4.1	5.2	5.4	6.9	3.8	4.9	5.7	7.4	5.7	5.7	7.4	7.4
B	3.1	4.9	3.8	6.0	3.4	5.4	3.7	5.9	3.7	3.7	5.9	5.9
C	2.6	3.7	3.2	4.6	3.6	5.1	3.4	4.9	3.4	3.4	4.9	4.9

The detection factor is defined as the ratio of the range obtained with the binocular to the range obtained with the naked eye (M.E.). The LX values are based on the range values computed, supposing the observer to be using a unit power binocular of 5 mm. exit pupil and transmission equivalent to that of the average of those of the binoculars used in the other parts of the observing.

\* Since no naked eye observations were made by Observer C, the values given here have been computed by use of the mean of the naked eye range values obtained by the two other observers.

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TABLE IV

EFFICIENCY VS. MAGNIFICATION

Observers A, B, and C\*

50% Detection

MAGNIFICATION	OBSERVER	6X		7X		8X		10X	
		L.E. %	LX %	L.E. %	LX %	L.E. %	LX %	L.E. %	LX %
1.6	A	87	138	97	157	65	104	58	94
	B	73	83	86	100	69	79	76	87
	C			67	91	62	88	56	78
2.6	A	98	125	87	113	106	136	93	119
	B	77	87	97	110	80	90	77	86
	C	68	80	71	86	74	88	70	82
3.6	A	85	110	128	160	79	102	100	129
	B	70	93	73	99	65	89	61	83
	C	65	85	70	93	64	85	62	82
4.6	A	68	87	106	136	66	85	76	98
	B	52	83	50	80	55	89	58	93
	C	45	65	50	71	44	62	50	72

The efficiency is defined as the ratio of the detection factor to the magnification. The values given here correspond to those of Table III.

\*Since no naked eye observations were made by Observer C, the values given here have been computed by use of the mean of the naked eye range values obtained by the two other observers.

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TABLE IV  
**EFFICIENCY vs. MAGNIFICATION**  
 Observers A, B, and C\*  
 90% Detection

LOG B %	6X		7X		8X		10X	
	L.E. %	L.E. %	L.E. %	L.E. %	L.E. %	L.E. %	L.E. %	L.E. %
1.6 A	68	103	69	101	56	82	54	80
B	78	83	90	94	66	70	74	78
C	78	83	64	81	64	81	55	71
2.6 A	98	110	103	116	130	146	102	115
B	88	92	111	116	81	85	80	83
C	85	92	81	89	79	85	77	83
3.6 A	85	115	97	130	78	104	76	102
B	78	107	83	113	66	90	59	81
C	63	87	69	94	66	90	52	70
4.6 A	68	87	77	99	48	61	57	74
B	52	82	54	86	42	68	37	59
C	43	62	46	66	45	64	34	49

The efficiency is defined as the ratio of the detection factor to the magnification. The values given here correspond to those of Table III.

\*Since no naked eye observations were made by Observer C, the values given here have been computed by use of the mean of the naked eye range values obtained by the two other observers.

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## ABSTRACT

Investigation was carried out with 6 x 30, 7 x 50 (diaphragmed to 7 x 35), 8 x 40, and 10 x 50 binoculars, all having a 5 mm exit pupil and optical surfaces coated with fluoride to prevent loss of light by reflection. Various levels of screen brightness were used along with circular targets which appeared black against screen in any of four possible positions. Three observers using binoculars named position of target after each six-second exposure. Results agreed reasonably well with those predicted theoretically accounting for brightness level, binocular transmission, pupil size, and glass magnification.

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② p 20/6, p17/5

②③ \* Magnification

\* Binoculars

Illumination

Targeting

**AD-B808 572**

