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TECHNICAL NOTE

MRL-TN-442

AN INVESTIGATION OF THE RELIABILITY AND SENSITIVITY
OF A POLARIZING VISIBILITY METER

R.P. Rubinfeld and S.E. Jenkins

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16. ABSTRACT (if this is security classified, the announcement of this report will be similarly classified):

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AN INVESTIGATION OF THE RELIABILITY AND SENSITIVITY
OF A POLARIZING VISIBILITY METER

1. INTRODUCTION

There have been several types of visibility meter which have measured how visible an object is by degrading the object by some optical means until it is at threshold visibility.

The degradation can be done by optically blurring the object or, more commonly, by lowering its contrast by adding uniform noise to the field of view (Eastman [1], Blackwell [2]), or by reducing the overall luminance of target and background (Luckiesh-Moss [3]).

The determination of when the object is at threshold is necessarily subjective in such visibility meters, and there may be more than one 'threshold' that can be described. The normal threshold is the detection threshold where the observer's response is that he can no longer detect the object against its background, there is the recognition threshold at which a complex object may no longer be recognised as a particular class of object, e.g. vehicles, buildings, faces, and there is the identification threshold at which the details of the complex object may be below threshold and the object cannot be identified within a class e.g. tank or jeep, male or female face.

There is no sharp cut-off between these three types of threshold and it is the difficulty of maintaining the same threshold criterion through many replications and over periods of days that makes any visibility meter difficult to use. Certainly it would not be possible to claim much precision for absolute measures of visibility found for a particular object at a particular time. At best, only a rank ordering of the visibility of various objects could be expected to give any precision.

It was found in these trials of a polarizing visibility meter that ranking the visibility of simple objects is reliable, whereas measuring the difference in visibility between two nearly equally visible objects is unreliable. The absolute visibility measurements of an object from one day to the next and from one observer to the next vary considerably, but between replications for one observer at one time they are repeatable. It was also found that the form of the object has a large effect on its visibility, but the quantifying of this form variable is at present too difficult.

The visibility meter to be described [4] is one which degrades the visibility of the object by lowering its contrast. The decrease in contrast is achieved by lowering the luminance of the scene and adding a veiling luminance so that the overall luminance level is constant, thus keeping the eye in a constant adaptation state.

The purpose of this investigation was to assess the visibility meter and to use various targets to obtain a measure of its reliability and sensitivity, in particular its usefulness for assessing the visibility of camouflage nets and the pattern of camouflaged vehicles and uniforms.

1.1 *The Polarizing Visibility Meter (PVM)*

A schematic diagram of the PVM is shown in Fig. 1. The light from the object is divided by the 50% beam splitter and travels along the two arms of the PVM. The lens L is a 10-dioptre lens which focuses the scene at the pupil of the eye giving a Maxwellian view, i.e. 'scrambling' the scene. P_1 and P_2 are pieces of polaroid with the polarizing axes at right angles to each other. The two beams, the scene and the scrambled scene, are then combined at the second 50% beam splitter, and viewed by the observer through another piece of a linear-polarized polaroid, which acts as an analyser. Thus when the analyser is aligned with P_2 , only the scene is viewed; when it is aligned with P_1 only a veiling luminance (the scrambled scene) is viewed. Any other rotation will give a mix of these while keeping the luminance level approximately constant. The field view of the PVM is 6.7° .

As the analyser is rotated the target is reduced in contrast until it falls below detection threshold, and with further rotation it reappears. This happens twice for every full rotation of the analyser. A highly visible object will stay visible for a larger angle of rotation than a less visible object. This is illustrated in Fig. 2 which defines the angles measured during the experiments. From this figure it can be seen that all the positions A, B, C and D may be determined by going from 'seeing' to 'not-seeing' or from 'not-seeing' to 'seeing'. Both methods give equivalent results and are valid methods of determining the target's visibility. However, as described later, it was found that going from 'not-seeing' to 'seeing' caused problems for the observers and increased the variability of the measurements. Fig. 3 shows a photograph of the PVM without its top cover.

1.2 *Experimental Method*

The experimental arrangement is shown in Fig. 4. A slide of the object and background was placed in a holder approximately 150 mm from the PVM and illuminated by a lamp behind a diffusing screen. The lens produced a converging beam which just filled the slide.

The PVM was used by rotating the analyser in one direction (say clockwise) and noting the angular position at which the target appeared and disappeared.

The region of visibility, defined as the average of the two θ values, was calculated as that between $2\theta_1 = 360^\circ - A + D$ and $2\theta_2 = B - C$.

It was found that going from 'seeing' to 'not-seeing', the target threshold was easier to specify and more repeatable than going from 'not-seeing' to 'seeing'. This is almost certainly due to the inability of the eye to accommodate for the correct plane when the object is not visible; the object then has to be markedly above threshold before the eye can accommodate properly. This problem was overcome simply by always going from 'seeing' to 'not-seeing' for the determination of positions A, B, C and D. In all, seven complete rotations were made for each target, giving 14 values of θ .

The simple targets used were gratings of various contrasts and spatial frequencies, discs of various contrasts on plain background, 12-pointed stars and tank silhouettes of various contrasts on plain backgrounds. These simple targets were photographed on Pan X film, with 2.25 inch slide format. The contrast was measured on a microdensitometer.

The complex targets viewed were: a tank on grass and bush, a landrover in bush with three camouflage nets, a colour print of a landrover with and without a camouflage net.

The grating targets had spatial frequencies of 1.65 cycles per degree (cpd), 2.4 cpd, 4.5 cpd, 4.96 cpd and 7.4 cpd, with contrasts ranging from approximately 0.8 to 0.04, where grating contrast is conventionally defined as

$$(L_{\max} - L_{\min}) / (L_{\max} + L_{\min})$$

The discs subtended 50' at the observer's eye and had contrasts ranging from approximately 1.0 to 0.09, where disc contrast is defined as

$$(L_B - L_A) / L_B$$

where L_A is the luminance of the disc and L_B the luminance of the background.

The stars and tanks on plain backgrounds had contrasts similar to the discs and had areas equal to the discs.

1.3 Theory

We can assume that for these suprathreshold targets the level of illuminance is not important and we may define contrast in terms of the transmittances of the object and background.

First consider the disc targets; let T_B be the transmittance of the plain background and T_d be the transmittance of the disc object. Then the contrast is

$$C_d = (T_B - T_d) / T_B$$

and hence

$$T_d = T_B (1 - C_d)$$

If the disc occupies a fraction f of the total area, then the transmittance through the slide is

$$(1-f)T_B + fT_d = (1-fC_d)T_B$$

Let the slide be illuminated by an effective illuminance I ; then the luminance of the background is IT_B and of the disc is $IT_B(1-C_d)$ as viewed with no veiling luminance, i.e. with $\theta = 0^\circ$. Consider the analyser rotated by θ° , then let the veiling luminance be L_v , the image luminance L_i and the total luminance at the observer's eye be L_e . Then

$$L_e = L_v \sin^2\theta + L_i \cos^2\theta$$

where θ is the angle between the axes of polarization of the image polarizer and the analyser. Now,

$$L_v = IT_B (1-fC_d);$$

hence the luminance of the disc through the rotated analyser is

$$\begin{aligned} L_d &= IT_B (1-fC_d) \sin^2\theta + IT_B (1-C_d) \cos^2\theta \\ &= IT_B (1-fC_d \sin^2\theta - C_d \cos^2\theta) \end{aligned}$$

and the luminance of the background through the rotated analyser is

$$\begin{aligned} L_B &= IT_B (1-fC_d) \sin^2\theta + IT_B \cos^2\theta \\ &= IT_B (1-fC_d \sin^2\theta) \end{aligned}$$

At the detection threshold, $\theta = \theta_T$ and

$$(L_B - L_d)/L_B = C_T,$$

i.e. $L_d/L_B = 1-C_T$ where C_T is the contrast threshold and is approximately 0.016 for this disc size as determined by Beurle, Daniels and Hills [5].

Thus, substituting for L_B , L_d and rearranging

$$1/C_d = \cos^2\theta_T (1/C_T - f) + f \quad (1)$$

or

$$\cos^2\theta_T = (1/C_d) (1/C_T - f)^{-1} - f (1/C_T - f)^{-1}$$

hence a graph of $\cos^2\theta_T$ against $1/C_d$ should give a slope of $(1/C_T - f)^{-1}$. The value of $1/C_d$ cannot be less than 1 when dealing with targets darker than the background, as in this experiment, consequently the intercept at $1/C_d = 1$ should equal $(1 - f) (1/C_T - f)^{-1}$.

Consider the case for the grating targets. The contrast, C_g , of the grating with no veiling luminance, i.e. $\theta = 0^\circ$ is given by

$$(L_{\max} - L_{\min}) / (L_{\max} + L_{\min})$$

where L_{\max} and L_{\min} are the luminances of the bright and dark bars respectively as seen at the eye position. If the analyser is now rotated through 90° so that only the veiling luminance is viewed, then the luminance of the uniform field of view at the eye position is given by the average luminance of the grating target, i.e. the veiling luminance is $\frac{1}{2}(L_{\max} + L_{\min})$.

At any intermediate position of the analyser the veiling luminance is

$$\frac{1}{2}(L_{\max} + L_{\min}) \sin^2\theta$$

and in the image path the luminances of the bright and dark bars will be

$$L_{\max} \cos^2\theta$$

and

$$L_{\min} \cos^2\theta$$

These two contributions from image path and veiling-luminance path respectively simply add together at the eye so that the total luminance at the eye for the bright bars is

$$L_{\max} \cos^2\theta + \frac{1}{2}(L_{\max} + L_{\min}) \sin^2\theta = \frac{1}{2}(L_{\max} + L_{\min}) + \frac{1}{2}(L_{\max} - L_{\min}) \cos^2\theta$$

and for the dark bars is

$$L_{\min} \cos^2\theta + \frac{1}{2}(L_{\max} + L_{\min}) \sin^2\theta = \frac{1}{2}(L_{\max} + L_{\min}) - \frac{1}{2}(L_{\max} - L_{\min}) \cos^2\theta$$

The contrast of the grating when the analyser is rotated becomes

$$C_g(\theta) = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}} \cos^2\theta = C_g \cos^2\theta$$

At threshold $\theta = \theta_T$ and the threshold contrast $C_T (= C_g(\theta_T))$ is given by

$$C_T = C_g \cos^2\theta_T$$

or

$$\cos^2\theta_T = C_T/C_g$$

A graph of $\cos^2\theta$ against $1/C_g$ should give a straight line of slope C_T . (Note that this expression is similar to equation (1) with $f = 0$).

2. RESULTS

2.1 Gratings and Simple Targets

The results for the small targets on plain backgrounds, i.e. the discs, stars and tanks are given in Table 2 and plotted in Fig. 5. The data points are well fitted by the three regression lines which are given in Table 2 together with the calculated values of their threshold contrast. The value for the disc threshold contrast is in reasonable agreement with the 0.016 found by Beurle *et al.* [5] under ideal observing conditions. The lines for the discs are much steeper than for any other target reflecting their greater threshold contrast, i.e. for a given contrast, discs are less visible than tanks or stars. The regression lines for the gratings 4.96 and 7.4 cpd are taken from Fig. 6(1) and superimposed on this graph as dashed lines and can be seen to approximately span the results for the small targets.

The fourteen values of θ_T for each target were averaged and the values of $\cos^2\theta_T$ are listed in Table 1. These are graphed in Fig. 6 for observers RPR and SEJ. In general the low-spatial-frequency gratings are more visible: gratings 3 and 4 are not well separated, but they are close in spatial frequency also (4.5 cpd and 4.96 cpd). All the functions of $1/C_g$ vs $\cos^2\theta_T$ are well fitted by straight lines and the regression lines are given in Table 1.

The purpose of the discs and gratings is to calibrate the visibility meter so that any other target can be ascribed 'an equivalent contrast', i.e. can be said to be as visible as a disc or grating of a certain contrast. The steepness of the disc regression line in Fig. 6 is an undesirable attribute in that it will reduce the range of equivalent contrast. Conversely a flat regression line such as the 1.64 cpd grating is also disadvantageous as it cannot cope with a large range of $\cos^2\theta_T$, i.e. the grating is always too visible even at low contrasts. A more appropriate calibration target would have a large range of $\cos^2\theta_T$ as well as a large range of

equivalent contrasts; this suggests the use of a grating with a spatial frequency of 5 or 6 cpd and contrasts of 0.1 to 1.0. Observers also found that it was considerably easier to measure the visibility of gratings than of the disc targets and the criterion for detection was more easily maintained for gratings.

2.2 Complex Targets

(a) Slides of a tank in two types of background, bush and grassland were viewed. The tanks were of different colours with and without pattern painting. The results are given in Table 3 and Fig. 5. It can be seen that the type of background is the dominating influence in determining the visibility of the tank. For tanks in bushland, the pattern-painted tanks were more visible than the unpatterned tanks; this is unexpected, but the difference is small.

(b) Slides of a landrover in the same background but without a net and with three different camouflage nets were viewed. The results are shown in Table 3 and Fig. 5. It is evident that the use of nets makes a marked difference to the visibility of the landrover. However the difference between nets is small and not repeatable.

(c) Colour prints of a landrover with and without a net were viewed by three observers. When any scene is viewed the PVM reduces the luminance level by at least 75% and so the resulting image of the colour prints viewed in reflected light is quite dim; this made the task more difficult than for the slides. The difference between the landrover with and without the net is again quite marked for all observers, but there is no agreement between observers, either in the absolute visibilities or in the ratio of visibilities with and without nets.

3. CONCLUSIONS

- (1) The gratings should be used as the standard reference target due to the ease of setting their detection thresholds.
- (2) All thresholds should be set going from 'seeing' state to the 'not-seeing' state due to problems of accommodation in going from 'not-seeing' to 'seeing'.
- (3) Comparisons between targets and the standard reference target should all be made in the same experimental run.
- (4) The PVM is not very sensitive to small differences in visibility, probably due to the difficulty of the observer in deciding when an object cannot be seen.

(5) The field of view of the PVM is only 6.7° which is just adequate for the purposes of this report. With such a small field of view the observer is always aware of the presence of the target unless there are very large amounts of veiling luminance and this may be the reason why observers have difficulty in deciding when an object cannot be seen. In any field use of this type of instrument it is recommended that the field of view be expanded to at least 25° so that the 'detection' threshold of a target can be measured with increased sensitivity.

4. REFERENCES

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2. Blackwell, H.R. (1959). "Development and Use of a Quantitative Method for Specification of Interior Illumination Levels on the Basis of Performance Data". *Ill. Engg.*, 54, 317-353.
3. Luckiesh, M. and Moss, F.K. (1935). "Visibility - Its Measurement and Significance in Seeing". *J. Franklin Inst.*, 220, 43.
4. Note: The Polarizing Visibility Meter used in these experiments was invented and designed by D.R. Skinner at M.R.L. in June, 1974.
5. Beurle, R.L., Daniels, M.V. and Hills, B.L. (1968). "Visual Pattern Detection". *I.E.E. - N.P.L. Conference on Pattern Recognition*, pp 86-94.

TABLE 1

SUMMARY OF RESULTS : THRESHOLD VALUES OF $\cos^2\theta$

GRATINGS		
<u>Contrast (C_g)</u>	<u>$\cos^2\theta_T$ (mean std. error, n = 14)</u>	
<u>1.65 cpd</u>	<u>RPR</u>	<u>SEJ</u>
.64	.0099 ± .0002	.0108 ± .0002
.43	.0113 ± .0003	.0141 ± .0003
.21	.0222 ± .0040	.0194 ± .0005
.09	.0521 ± .0139	.0313 ± .0014
	$\cos^2\theta_T = 0.0045 (1/C_g) + 0.002$	$\cos^2\theta_T = 0.0021 (1/C_g) + 0.009$
<u>2.4 cpd</u>		
.77	.0107 ± .0003	.0162 ± .0004
.35	.0177 ± .0006	.0115 ± .0001
.16	.0352 ± .0033	.0510 ± .0055
.04	.1150 ± .0490	.1316 ± .0372
	$\cos^2\theta_T = 0.0044 (1/C_g) + 0.006$	$\cos^2\theta_T = 0.0050 (1/C_g) + 0.008$
<u>4.5 cpd</u>		
.84	.0226 ± .0039	.0169 ± .0007
.57	.0293 ± .0058	.0170 ± .0003
.30	.0316 ± .0065	.0301 ± .0009
.13	.0549 ± .0134	.0752 ± .0110
	$\cos^2\theta_T = 0.0047 (1/C_g) + 0.018$	$\cos^2\theta_T = 0.0093 (1/C_g) + 0.002$

TABLE 1

(continued)

GRATINGS		
<u>Contrast (C_g)</u>	<u>cos²θ_T (mean ± std. error, n = 14)</u>	
<u>4.96 cpd</u>	<u>RPR</u>	<u>SEJ</u>
.84	.0167 ± .0004	.0134 ± .0003
.57	.0210 ± .0005	.0213 ± .0009
.42	.0293 ± .0042	.0267 ± .0010
.21	.0410 ± .0063	.0465 ± .0028
.08	.0909 ± .0369	.1266 ± .0362
	$\cos^2\theta_T = 0.0064 (1/C_g) + 0.011$	$\cos^2\theta_T = 0.0099 (1/C_g) + 0.002$
<u>7.4 cpd</u>		
.71	.0346 ± .0036	.0207 ± .0007
.52	.0397 ± .0053	.0316 ± .0026
.32	.0575 ± .0167	.0366 ± .0026
.16	.0885 ± 0.325	.0862 ± .0203
	$\cos^2\theta_T = 0.0112 (1/C_g) + 0.020$	$\cos^2\theta_T = 0.0132 (1/C_g) + 0.002$

Values of correlation coefficient for all best-fit lines are highly significant at the $p < 0.001$ level.

TABLE 2

SUMMARY OF RESULTS : THRESHOLD VALUES OF $\cos^2\theta$
FOR DISC, TANK AND STAR TARGETS

DISCS	Observer RPR
<u>Contrast (C_d)</u>	<u>$\cos^2\theta_T$ (mean \pm se, n = 14)</u>
0.98	0.0102 \pm 0.0002
0.92	0.0149 \pm 0.0003
0.82	0.0206 \pm 0.0009
0.71	0.0243 \pm 0.0009
0.60	0.0295 \pm 0.0015
0.51	0.0397 \pm 0.0032
0.42	0.0410 \pm 0.0037
0.27	0.0800 \pm 0.0211
0.24	0.0990 \pm 0.0273

$\cos^2\theta_T = 0.0262/C_d - 0.0143, r = 0.99.$ Hence $C_T = 0.026$

TANKS

<u>Contrast (C_{TA})</u>	
.75	0.0183 \pm 0.0003
.58	0.0233 \pm 0.0010
.33	0.0380 \pm 0.0019

$\cos^2\theta_T = 0.0115/C_{TA} + 0.0032, r = 0.99.$ Hence $C_T = 0.012$

STARS

<u>Contrast (C_s)</u>	
.74	0.0164 \pm 0.0005
.48	0.0241 \pm 0.0009
.13	0.0645 \pm 0.0098

$\cos^2\theta_T = 0.0074/C_s + 0.0074, r = 0.99.$ Hence $C_T = 0.007$

TABLE 3

SUMMARY OF RESULTS : THRESHOLD VALUES OF $\cos^2\theta$
FOR VARIOUS CAMOUFLAGE TARGETS

TANKS IN BUSH		Observer RPR		
<i>Identification</i>	<i>Description</i>	<i>cos²θ (mean ± std. error n = 14)</i>		
1. 16 Sept 76/2-7/	frog green	0.0123 ± 0.0002		
2. 16 Sept 76/1-9/	yellow-green	0.0113 ± 0.0002		
3. 16 Sept 76/3-2/	green pp*	0.0113 ± 0.0002		
4. 16 Sept 76/4-8	yellow-green pp	0.0103 ± 0.0002		
LANDROVER				
5. 10 May 77/1-1	in the open	0.0135 ± 0.0003		
6. 10 May 77/1-9/	MRL Eucalyptus Mark 1 net	0.0330 ± 0.0014		
7. 10 May 77/1-5/	USA Woodland	0.0275 ± 0.0014		
8. 10 May 77/2-4/	Bridport Gundry Woodland	0.0247 ± 0.0011		
TANK IN OPEN				
9 Sept 76/2-7/	brown	0.0040 ± 0.0002		
9 Sept 76/1-5/	frog green pp	0.0037 ± 0.0001		
9 Sept 76/1-9/	brown pp	0.0037 ± 0.0001		
9 Sept 76/2-4	brown	0.0044 ± 0.0001		
		<u>RPR</u>	<u>SEJ</u>	<u>RB</u>
9. PHOTO: LANDROVER NO NET	0.0262 ± 0.0010	0.0330 ± 0.0011	0.0585 ± 0.0129	
10. " WITH NET	0.0400 ± 0.0015	0.1220 ± 0.0390	0.1639 ± 0.0900	

*pp = pattern painted

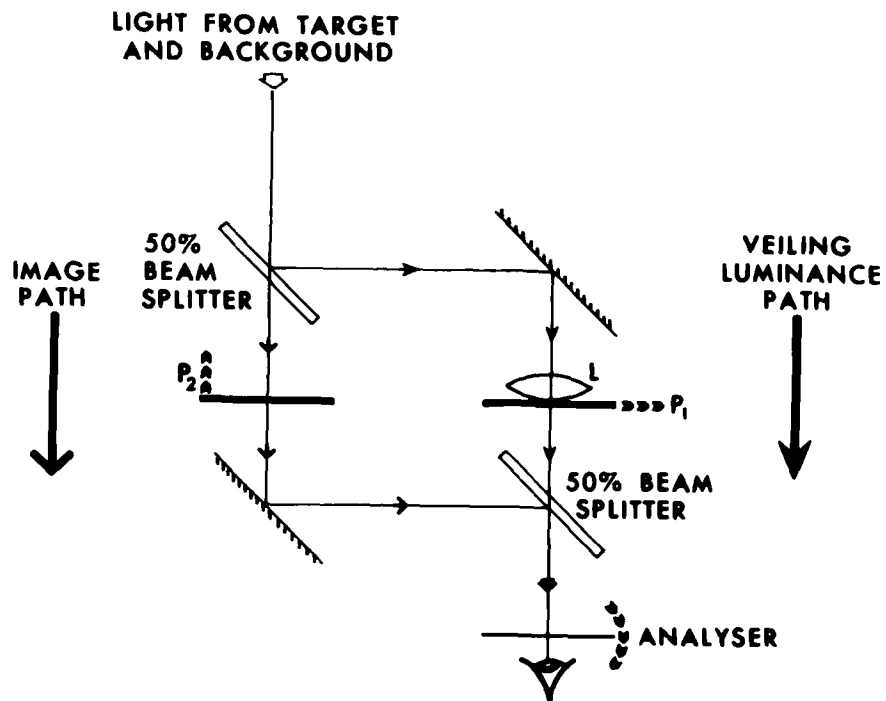


FIG. 1 - Diagram of visibility meter. P_1 and P_2 are polarizers rotated 90° to each other, L is a lens (10D) which brings the scene to a focus at the pupil of the eye (Maxwellian view).

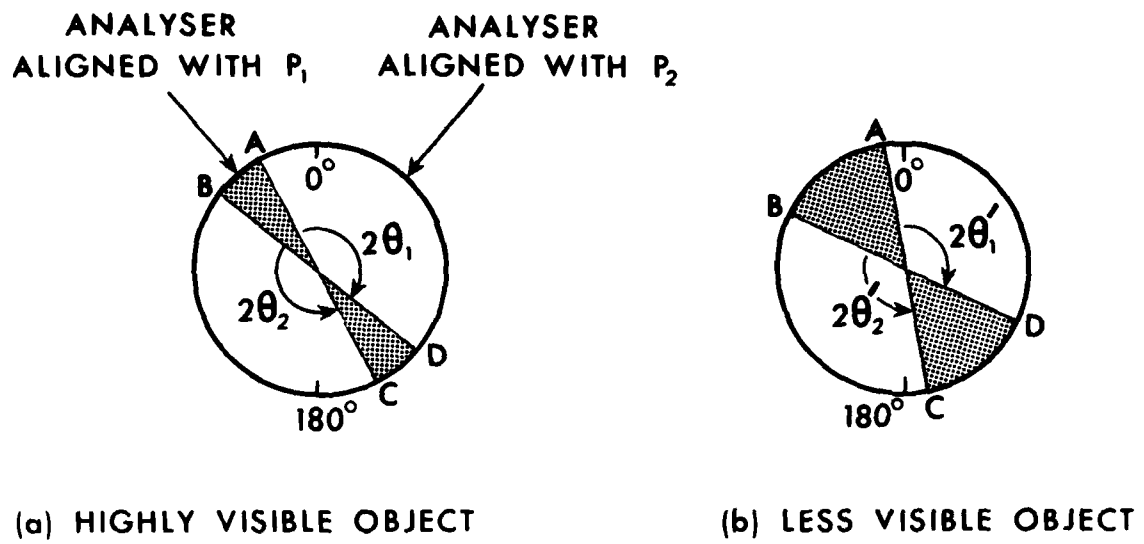


FIG. 2 - A, B, C and D are the angles measured at the detection thresholds. The shaded area is the region for which the target is below threshold.

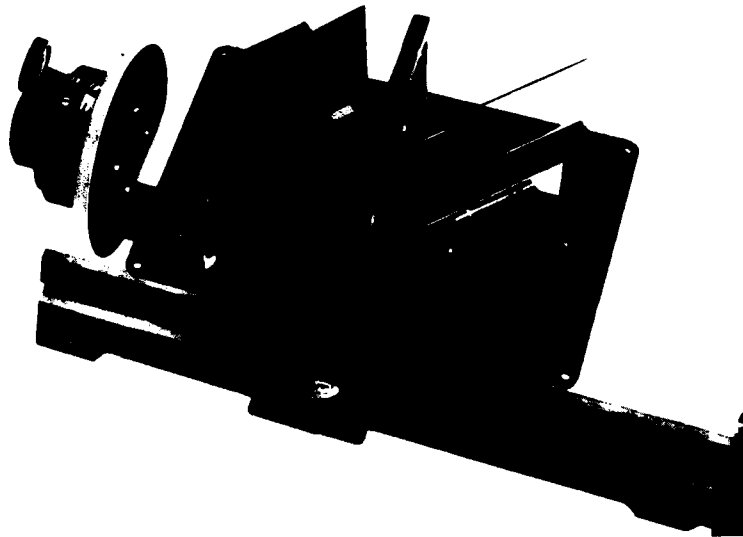


FIG. 3 - This shows the optics inside the polarizing visibility meter.



FIG. 4 - The experimental arrangement.

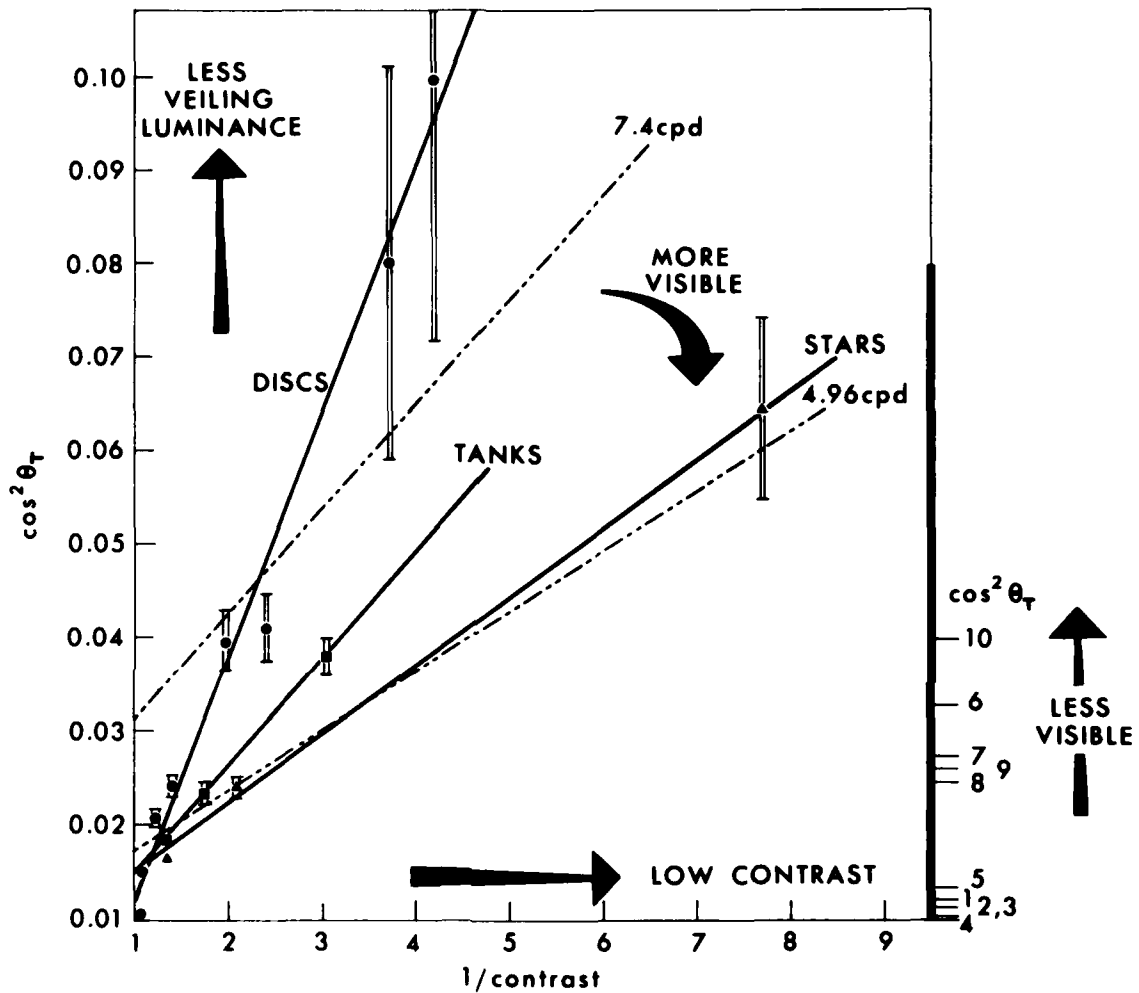


FIG. 5 - Graphs of $1/\text{contrast}$ versus $\cos^2\theta_T$ for discs, tanks and stars. The error bars are for one standard error, $n = 14$. The ordinate scale on the right hand side shows the $\cos^2\theta_T$ values for the numbered complex targets given in Table 3. The dashed lines are the regression lines for the 7.4 cpd and 4.96 cpd grating targets for observer RPR taken from Fig. 6(ii).

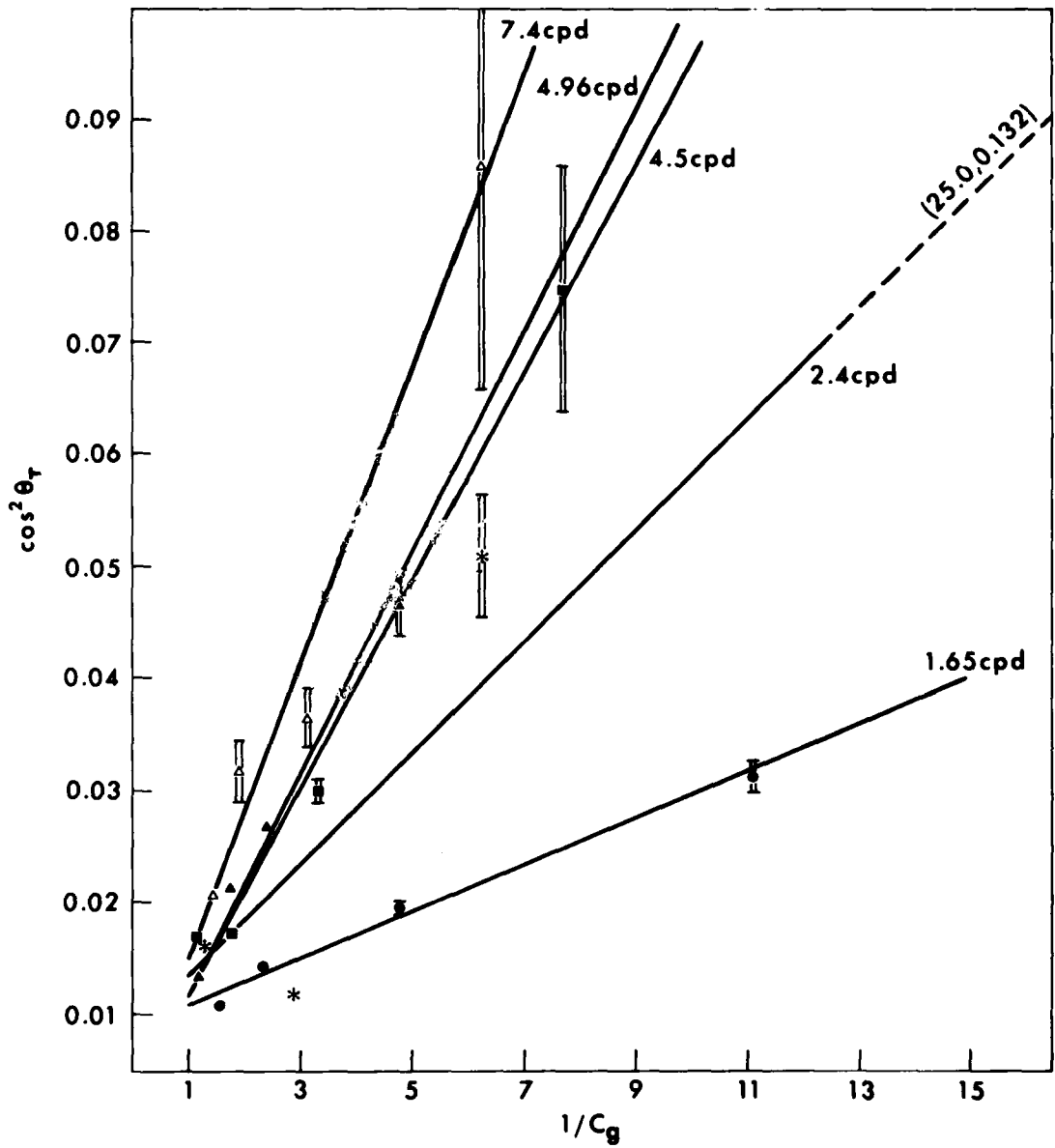


FIG. 6(1) - Graph of $1/C_g$ versus $\cos^2 \theta_T$ for grating targets and for observer SEJ. The parameter is the spatial frequency of the grating. The error bars are for one standard error, $n = 14$.

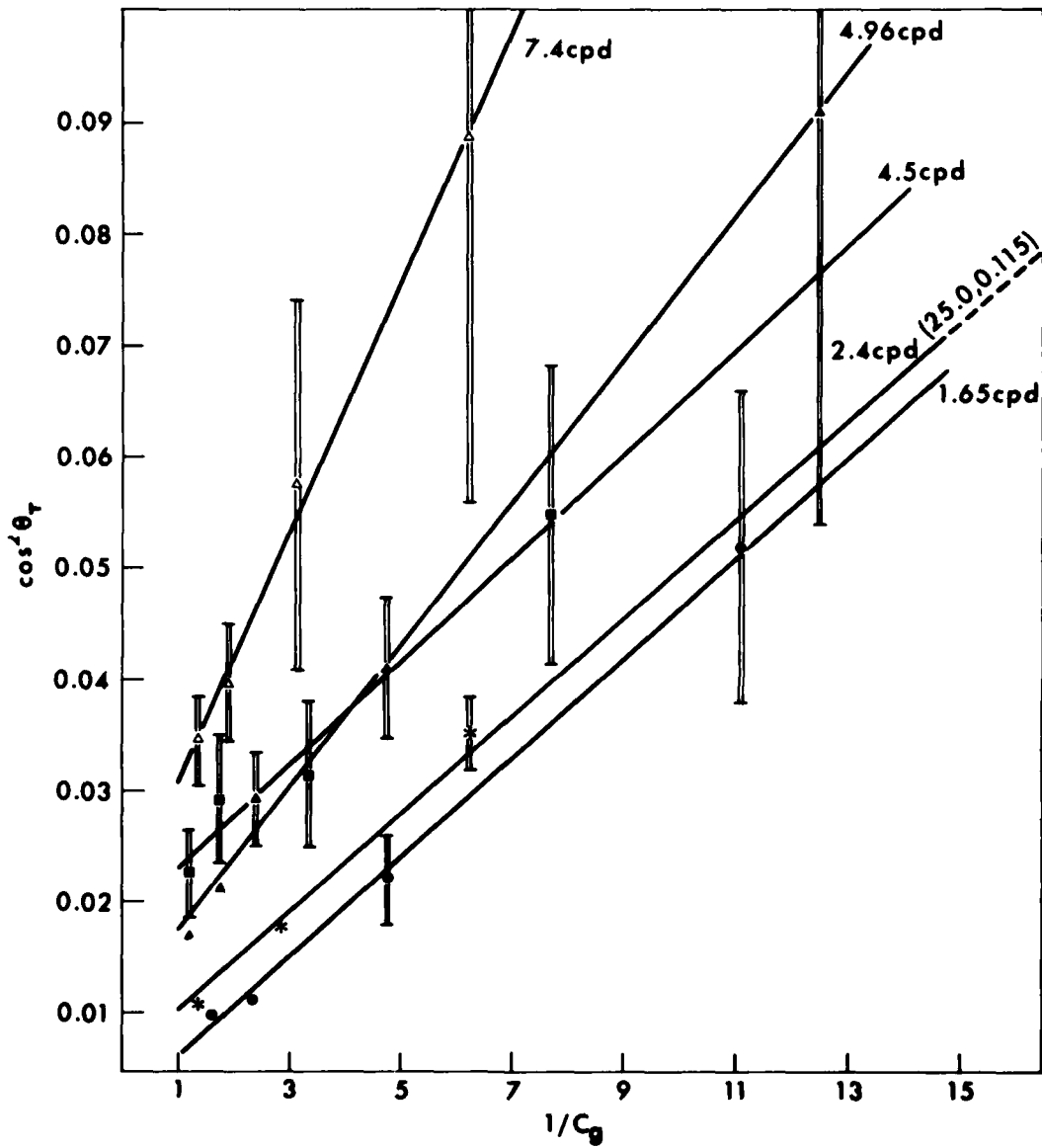


FIG. 6(ii) - Graph of $1/C_g$ versus $\cos^2 \theta_T$ for grating targets and for observer RPR. The parameter is the spatial frequency of the gratings. The error bars are for one standard error, $n = 14$.

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