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PART I

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VISUAL CONTRAST THRESHOLDS FOR LARGE TARGETS

PART I: The case of low adapting luminances

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Introduction

The contrast sensitivity of the human observer has been systematically investigated at a wide range of target sizes and background luminances. Perhaps the most often quoted study is that reported by Blackwell (1) who determined contrast thresholds for circular targets ranging in angular diameter from 0.595 to 360 minutes of arc, and at adapting luminances from 10^{-5} up to 10^{3} foot-lamberts. His observers used binocular vision and fixation was unrestrained; the instruction being to maximize probability of detection by using whatever retinal area seemed most propitious. This choice of method was deliberate, and was intended to yield data which would be suitable for the construction of visibility nomographs for the trained emmetropic observer in situations of practical interest [e.g., (2) and (3)].

The present study was undertaken in an attempt to extend the aforementioned data to the case of targets subtending more than 360 minutes. The need for such extension is apparent in certain contemporary applications such as visibility in dense fogs, in turbid water, and in many cases where low adapting luminances prevail. It is possible, moreover, to foresee the need for data relating to display problems where large areas of low contrast may be encountered.

The limitations of the Blackwell data may most readily be seen from inspection of Figure 1, in which threshold contrast is plotted as a function of angular size of the target at nine values of adapting luminance. Of this family of curves, only those for the three highest values of background luminance (10^3, 10^2 and 10^1 foot-lamberts) appear to have reached asymptotic values of contrast at the largest target sizes studied. As adapting luminance diminishes, the curves fall progressively shorter of reaching an asymptote, and the extrapolation of the data to targets larger than 360 minutes can be done with less and less confidence.

Extension of the data in the direction of larger targets becomes, however, progressively more difficult experimentally, and soon (certainly before the 4th log cycle) meaningless in the context of the original study. Even assuming the experimental attainment of a true <u>Ganzfeld</u>, the presentation of a target whose subtense approaches that of the visual field itself is hardly to be simply considered as an extension of the small-subtense case. In view of these practical and pragmatic difficulties, it was decided to explore the possibility that effective asymptotes for the low-luminance curves might be found by other means.

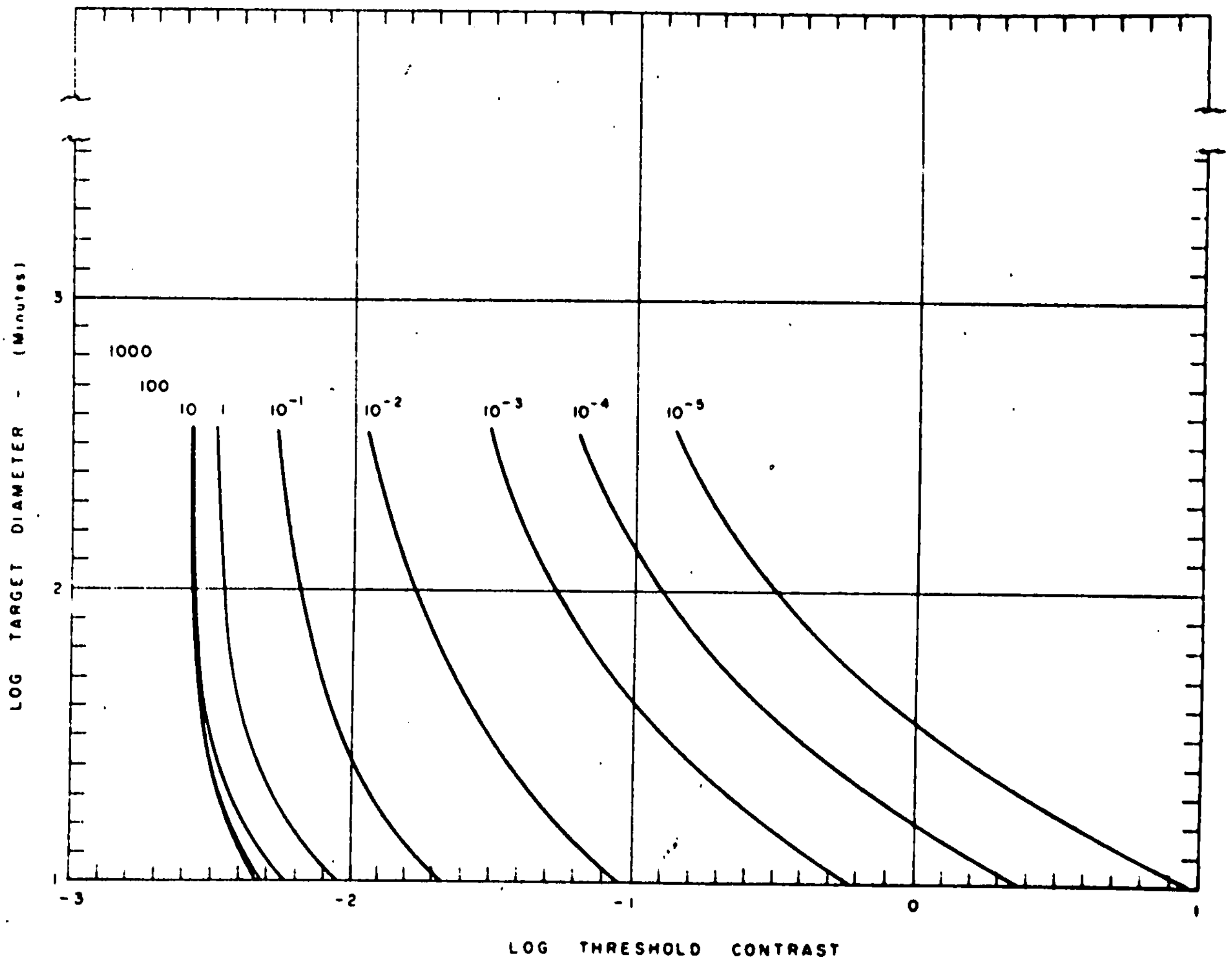

Figure 1

Contrasts thresholds for uniform circular targets as a function of size, for various background luminances (foot-lamberts). Redrawn from Blackwell (1).

As the angular diameter of a circular target increases beyond a few degrees of arc, its detection at contrast values near threshold generally occurs by reason of the observation of some part of its edge rather than of the whole target. Further, in the case of a target of known location, the observer adopts a fixation habit which, in his experience, will bring the brightness gradient upon which he bases his positive response onto that part of his visual field which is most sensitive at a given adapting luminance. At clearly photopic levels the observer is better able to detect the presence of a large target if he can bring the edge gradient into his foveal field than if he fixates the center of the target.* At scotopic luminances he is well advised to adopt a fixation habit which brings the edge to some advantageous peripheral retinal area. In all cases, however, it is probably true that a very large target near threshold is detected on the basis of seeing some part of its edge.

If the foregoing argument be accepted, it suggests that the limiting case of large target detection might be found by determination of the detection threshold for targets of infinite radius of curvature -- that is to say if the target presented experimentally consisted of a luminance difference occupying, say, half of the total visual field, and extending to its limits along some chosen meridian. Avoiding

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* Obviously this situation will be modified in the case of targets whose size is such that central fixation would be advantageous on statistical grounds; i.e., would result in higher probabilities of detection by reason of bringing more of the circumferential gradient onto, perhaps, only slightly less sensitive retinal regions.

the semantic question of what, in such a case constitutes "target" and what "background," we have designated the data from this investigation "split-field" thresholds. Since, in all cases studied, the target consisted of a positive luminance increment of finite duration, it is believed defensible to regard this increment as analogous to conventionally arranged targets. Additional face validity for the procedure would accrue if the threshold values so found actually indicated asymptotes which were reasonable extensions of the existing curves.

Apparatus and Procedure

Three young emmetropic male observers served in the present experiment. All were highly practiced in laboratory observing, and none showed any significant departure from the population mean of thresholds reported by Blackwell. The background was provided by a large, self-luminous integrating box which gave a uniformly bright square field subtending 48.5° both horizontally and vertically at the eye. Circular targets were presented at the center of the screen, and the split-field gradient bisected it vertically. In all cases, the target was a luminance increment. The geometry of the viewing situation is shown in Figure 2.

In an effort to duplicate the conditions and method used by Blackwell, unrestricted binocular vision was used, with the instruction that the observers use whatever viewing technique maximized their

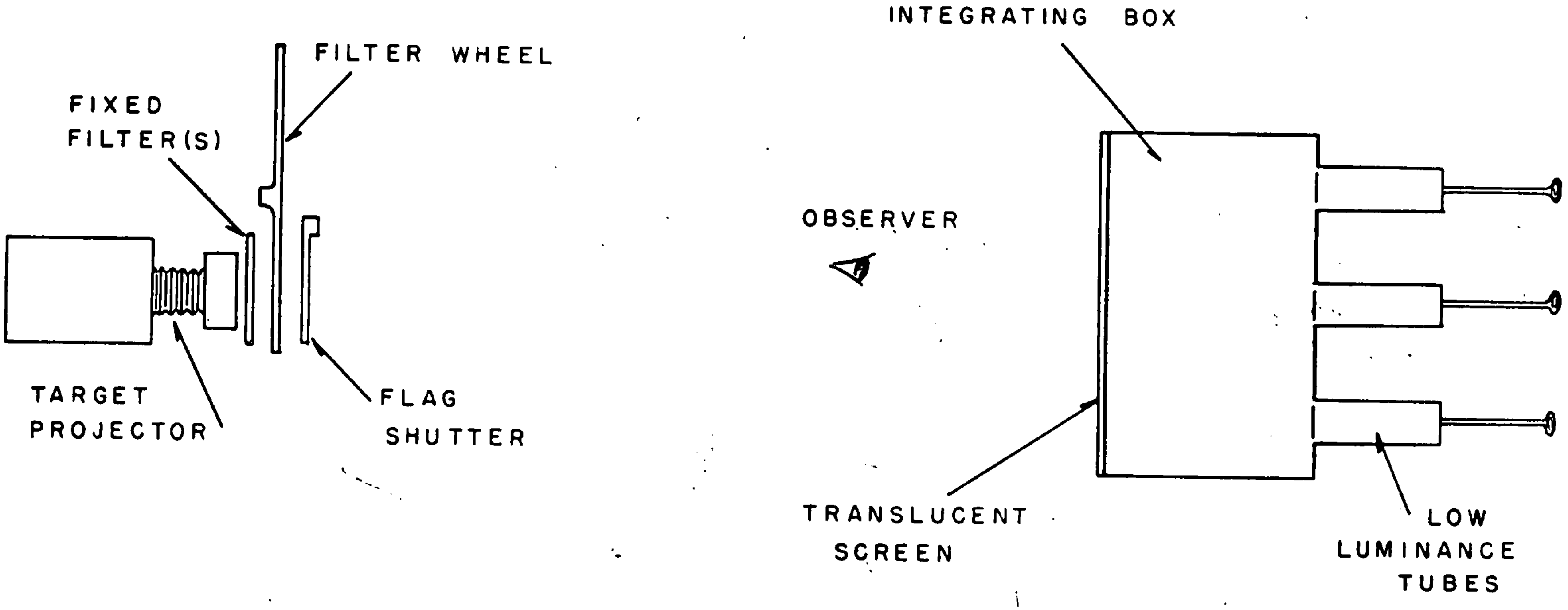

Figure 2. Diagram of the viewing arrangements used, showing integrating box for the production of uniform backgrounds of low luminance.

probabilities of detection. While Blackwell's viewing times were variable, extending to more than 30 seconds in some cases, our targets were restricted to a uniform 6-second duration. The "yes-no" method of constant stimuli was used, with target luminance controlled by interposing neutral filters in the projector beam. Five target luminance levels were used, chosen to yield probabilities of detection from 0 to nearly 1.00. These levels were presented in random order, with Vexierversuche (substituting an opaque plate for a filter) interspersed in order to estimate the probability of false positive responses. In a given experimental session each of the five levels, and the catch trials were presented forty times and the number of positive responses recorded. False positives, when they occurred, were used to correct the proportions of positive responses to real stimuli. The data were fitted by normal Gaussian integrals, using the probit analysis of Finney (4) as adapted by Richardson (5).

All photometry was accomplished by use of a Macbeth illuminometer calibrated against sub-standard lamps from the U. S. Bureau of Standards. The target and background luminances were held in close approximation to color temperature 2360°K. At adaptation luminances too low for precise direct photometry, the integrating box (Figure 2) provides means for relating, by a constant factor, the luminance of the internal variable illuminator tube faces to the resultant luminance of the screen confronting the observers. Thus, the precise direct measurement at high level enables the confident establishment of luminances down to 10^{-5} foot-lambert. At the low levels of adapting luminance (10^{-3}, 10^{-4}, and 10^{-5} ft-L) used, the observers were required to wear red dark-adaptation goggles for 15 to 20 minutes prior to entering the darkroom, followed by 5 to 10 minutes' adaptation to the luminance level of interest.

The photometered, unattenuated target luminance resulting from full projector output was reduced by calibrated 4 x 4" Wratten neutral density filters in the beam. To bring the intensity down to near-threshold value, "fixed" filters (which remained in place throughout a single experiment) were used, while a series of five wheel-mounted "psychometric" filters, together with the opaque plate mentioned above, served to produce the range of target contrasts desired.* Contrast was conventionally defined as the ratio of the luminance increment to the background luminance; $\Delta B/B_0$. Threshold values were taken as those contrasts necessary for a detection probability of 0.50 interpolated on the psychophysical functions obtained from the frequency-of-seeing data. Each point on an individual function was determined on the basis of forty observations, so that the data to be reported represent a total of 7,200 trials, excluding Vexierversuche.

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* Transmission values for the five psychometric filters, chosen to yield detection probabilities from 0 to 1.0, were 1.00 (an open hole), 0.781, 0.512, 0.307, and 0.198.

Results

Data for two scotopic adaptation luminance levels are presented in Table I. In addition to the threshold values, C_T, Table I shows:

σ_T - the standard error of the threshold

b - the slope of the psychophysical function

σ_b - the standard error of the slope

X^2 - the value of Chi-square

$p(X^2)$ - the Chi-square probability for 3 degrees of freedom.

The data of Table I were used to extend the curves relating target size to contrast threshold for adaptation luminances of 10^{-4} and 10^{-5} foot-lamberts. At these scotopic levels our data for the 6° circular target are in very close agreement with the values reported by Blackwell (identical at 10^{-4} and three per cent lower at 10^{-5} ft-L), despite the considerably shorter target durations used.* It was assumed that targets smaller than 6° would yield curves similar in shape to those of Figure 1 and, further, that our data could be considered suitable for extension of the Blackwell curves, provided that the three per cent adjustment were made in the 10^{-5} ft-L data. In constructing the curves the same adjustment was made for the split-field case -- our values being raised to find a new point which could be presumed to be a fair estimate of the hypothetical split-field value

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* At photopic background levels significant differences were found between the six-second data and the longer durations used by Blackwell. These differences are discussed in Part II of the present report.(6)

TABLE 1

Tgt.	Observer	B_o	C_T	σ_T	b	σ_b	X^2	$P(X^2)$
Split Field	R.C.	10^{-5}	.0967	.0268	4.375	.461	9.646	.02-.05
			.0920	.0280	5.628	.849	5.389	.10-.30
			.0932	.0283	5.379	.706	.305	.90
		10^{-4}	.0552	.0272	5.584	.722	2.262	.50-.70
			.0495	.0262	5.442	.682	6.640	.05-.10
			.0575	.0268	4.904	.578	1.050	.70-.90
	J.F.	10^{-5}	.0902	.0216	6.182	.641	.233	.90
			.105	.0258	5.521	.181	.969	.70-.90
			.100	.0198	6.529	.673	3.635	.30-.50
		10^{-4}	.0479	.0261	5.074	.649	6.210	.10-.30
			.0484	.0220	5.885	.635	4.527	.10-.30
			.0490	.0228	5.082	.476	.258	.90
	R.P.	10^{-5}	.0850	.0174	9.039	.914	.495	.90
			.0823	.0199	7.749	.972	.767	.70-.90
			.0890	.0184	8.380	.871	.246	.90
		10^{-4}	.0485	.0195	8.537	1.040	.137	.90
			.0514	.0238	5.551	.648	5.480	.10-.30
			.0500	.0231	4.997	.447	2.766	.30-.50
6°	R.C.	10^{-5}	.123	.0233	4.960	.461	5.050	.10-.30
			.153	.0245	4.547	.423	2.371	.50-.70
			.126	.0242	5.907	.742	1.802	.50-.70
		10^{-4}	.0725	.0258	5.227	.605	7.073	.05-.10
			.0620	.0283	3.752	.391	2.796	.30-.50
			.0675	.0211	5.759	.526	5.155	.10-.30
	J.F.	10^{-5}	.110	.0262	3.866	.375	3.03	.30-.50
			.126	.0249	5.006	.563	.63	.70-.90
			.124	.0290	4.055	.426	11.866	.001-.01
		10^{-4}	.054	.0230	5.510	.567	1.18	.70-.90
			.053	.0246	4.884	.506	.650	.70-.90
			.0501	.0261	5.652	.488	3.746	.10-.30
	R.P.	10^{-5}	.130	.0194	6.777	.679	1.294	.70-.90
			.120	.0199	6.573	.0636	2.166	.50-.70
			.100	.0188	6.787	.680	1.755	.50-.70
		10^{-4}	.057	.0201	5.992	.500	3.084	.30-.50
			.0639	.0175	6.228	.505	4.708	.10-.30
			.0624	.0189	6.592	.573	.455	.90

which might have been obtained by Blackwell's observers.

The extended curves are presented in Figure 3. It will be realized that the curve section interpolated between the real data points for 6° and split-field targets is somewhat arbitrary. A question naturally arises, for example, regarding the point at which the curves should be made to reach the contrast asymptote, and this question was resolved primarily by appeal to the shapes of the curves at higher luminance levels where the asymptote had already been reached in the Blackwell study. Since, however, the latter data do not enable one confidently to establish the relationship between adaptation luminance and the target size at which the contrast asymptote is reached, it is only possible to guess in what manner the points of tangency might be ordered, especially for the two low luminances in question here. Additional guidance was, however, obtained from check data collected with a 9° circular target in the case of the 10^{-5} ft-L level. It was further assumed that the assembly of curves for all adaptation levels studied (including the photopic ones) would form a reasonable family in their upper sections just as they appear to do in Figure 1.

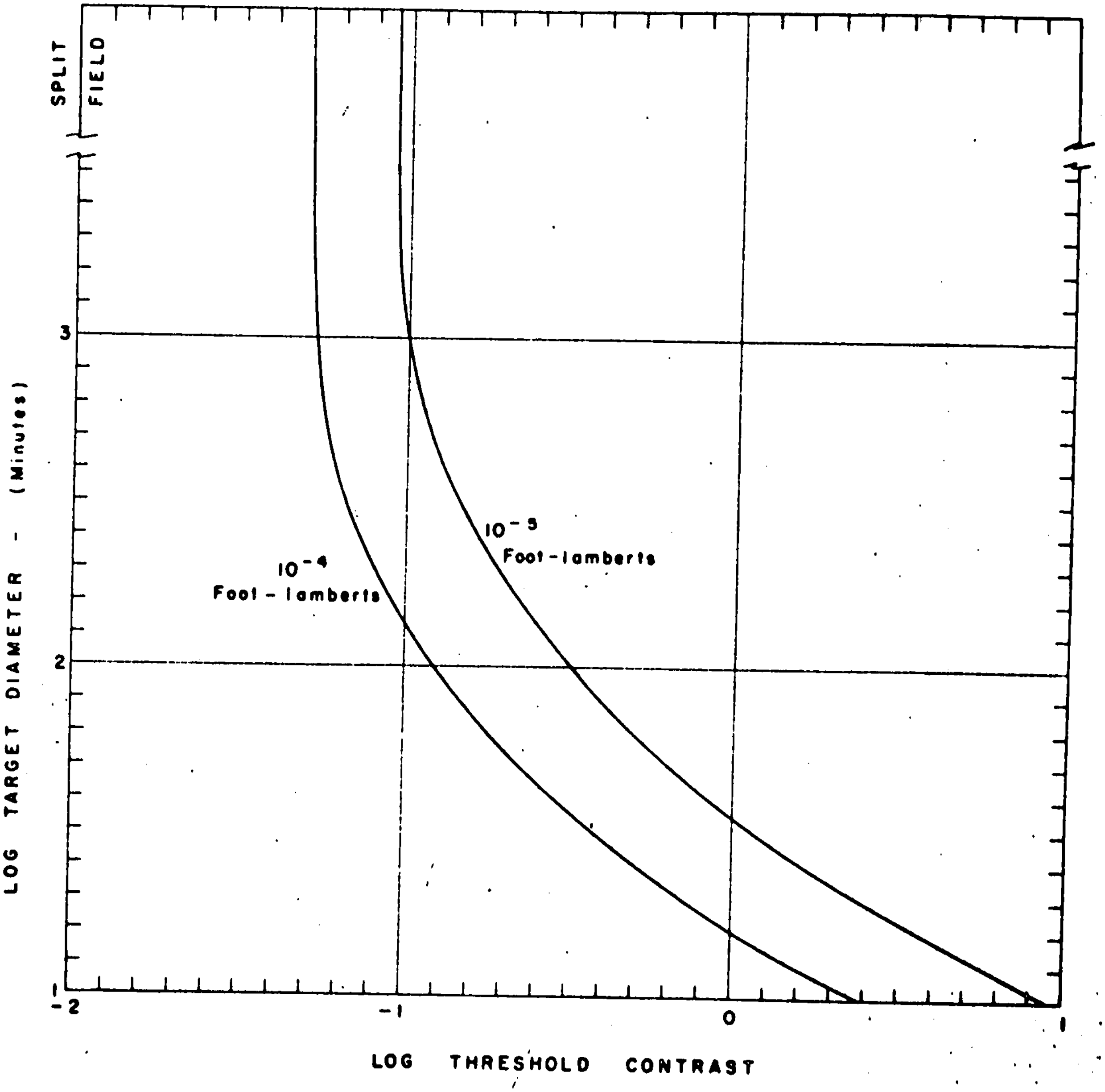

Figure 3

Extended curves relating target diameter to threshold contrast.

Discussion

The human binocular visual field extends both vertically and laterally to about 130°. Far short of this limiting size, however, it is probable that large targets are not detected in the same manner as targets of moderate subtense. In the usual viewing situation involving binocular search, it is more likely that detection occurs when a target edge is brought onto a retinal area of adequate contrast sensitivity. Accordingly, it will be appreciated that the practical use of the upper reaches of the plotted curves of Figure 3 will most generally be limited to target diameters not far above the ones studied by Blackwell. When, however, conditions are such that the observer must use some portion of the edge, rather than the whole target, for detection, it is likely that the split-field data will apply.

The curves of Figure 3 have been used in the preparation of new improved nomographs for the prediction of visibility by swimmers engaged in various underwater tasks of naval interest. A recent report (7) describes the construction and use of these nomographs, and gives examples of problems which have been solved by their use.

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