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A STUDY OF POSSIBLE "PHOTOSENSITIZATION" OF THE HUMAN EYE BY WHITE LIGHT

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"The Effect of Background Luminance
on Brightness Discrimination"

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SUMMARY

The value of the threshold luminance increment has been measured for each of a number of background luminance levels and for a totally dark background. Target and background were white light, of color temperature 2850°K. Targets subtended 1 and 45 minutes of arc, with a 0.01 second exposure duration. It was found that the threshold luminance increment increases smoothly and continuously as background luminance was increased. The threshold was equivalent for a totally dark background and for low levels of background luminance.

These data fail to exhibit any evidence that the human eye can be "photosensitized" with white light. (Photosensitization would occur if the addition of a small amount of light superimposed over a lighted target and its totally dark background made the target more visible.)

The data from the present study suggest that the classical distinction between the "absolute threshold" and the "difference threshold" is not meaningful, since there was no discontinuity in the data obtained with a totally dark background and those obtained with low levels of background luminance.

I. INTRODUCTION

The capability of the human eye for the detection of targets differing from their background in luminance has been frequently studied during more than a century. The usual experiment may be described in the following way. A large area, referred to as the adaptation or background luminance, or simply as the background, is uniformly illuminated to a predetermined level over its entire surface. The luminance of the background may be symbolized by the letter B. An additional quantity of light, ΔB, is added to some portion of the large area for a brief duration. The precise amount of this quantity is varied until a response is evoked from the observer indicating that he has detected a lack of uniformity in the luminance of the background for the brief duration of the increment. The value of ΔB which evokes the signalling response 50% of the time is referred to as the brightness difference threshold, ΔB. The relations between the brightness difference threshold and various aspects of the stimulus situation have been extensively studied.

The level of the luminance of the background is known to have an important effect on the detection capability of the eye. The sensitivity of the eye has usually been described in terms of the value of the contrast, C, which can just be detected where

$$\overset{\circ}{C} = \frac{\Delta^{\circ} B}{B}$$

It is well-known that the threshold value of C decreases steadily and smoothly as B is increased. Experiments involving a finite value of B have been customarily referred to as measurements of the "difference threshold". In the special case where B=0, it is customary to measure sensitivity by the value of $\Delta^{\circ}B$. In these cases, it is customary to refer to the data as measurements of the "absolute threshold".

The usual definitions of the difference and the absolute thresholds make it impossible to compare them. For this reason, one of us (Ref. 1) in 1947 first plotted threshold values of $\Delta^{\circ}B$ for all values of B. Use of this measure of visual detection senstivity makes it possible to compare values of the absolute threshold and values of the difference threshold for low levels of background luminance. Although these comparisons were made in the 1947 study, there were few data available at various low levels of background luminance.

In recent years, there has been considerable interest in the development of theories of visual detection. Quantitative relations between difference and absolute thresholds are of crucial importance to several of these theories. It is imperative that the receptor population be identical for measurements relating these quantities. Most existing data which could be plotted in terms of $\Delta^{\circ}B$ were collected under conditions in which cone photoreceptors were responsible for the threshold for the high values of B whereas rod photo-receptors were responsible at low values of B. Suitable data for theoretical purposes would require that either a pure cone or a pure rod population be utilized. It is, of course, considerably easier to isolate a pure cone than a pure rod population, since cones exist alone in the normal foveal retinae whereas rods do not exist entirely alone at any retinal location.

The present study was undertaken to provide data on the variations in the threshold luminance increment for the foveal retina as a function of a wide range of values of the luminance of the background, including a value of zero. Simple theoretical arguments would lead to the prediction that the threshold value of ΔB would increase steadily and smoothly as B was increased, and that there would not be a discontinuity in the data for $B=0$. From this point of view, the minimum value of $\Delta^{\circ}B$ should occur for $B=0$. Verification or rejection of this theoretical relationship seemed to be a straightforward experimental problem.

The present study was undertaken for an additional reason. Crozier (Ref. 2) has presented data suggesting that $\Delta^{\circ}B$ has a minimum value for $B>0$; this result has been taken to represent "photosensitization" of the eye at low levels of background luminance. There are conceivable mechanisms of the visual detection process which would lead to this result; indeed, some detectors of electromagnetic radiation have this property. It was decided that a concerted effort would be made to verify or reject the possibility of photosensitization of the human eye, by white light.

It should be apparent that photosensitization of the human eye could have important military usefulness in connection with improving the night vision capabilities of night observers. To take military advantage of photosensitization, it would be necessary only to flood the entire retinae of the eyes with a uniform veil of dim light, which would cover the images of targets and their backgrounds existing in real space. The photosensitization mechanism would result in an increase in the visibility of targets under these conditions. Crozier suggested that only one specific value of dim light produced the effect, other values resulting in impaired visibility. Since a particular value presumably had to be used to elicit it, the existence of photosensitization could not be rejected out of hand on the basis that it was not confirmed by ordinary experience in night observing. It was decided to study detection thresholds at a number of values of background luminance in addition to zero to attempt to identify the precise luminance required for the photosensitization process to occur.

II. Apparatus and Procedures

As noted above, the present study is intended to provide evidence on the fundamental nature of the relation between threshold luminance increment, ΔB, and background luminance, B, for the foveal retina. The extent of our knowledge of the functioning of the visual system is sufficiently advanced so that it is possible to specify a number of experimental conditions which must be met if meaningful data are to be obtained. These conditions may be listed briefly as follows:

1. Control of the location of the target on the approximate center of the foveal retina;
2. Control of the pupillary aperture;
3. Control of the refractive state of the eye;
4. Control of the background luminance; and
5. Control of the size, luminance, and duration of the target.

The ways in which these controls were maintained are described in detail in the following sections.

A. OBSERVERS

Four observers were used throughout the experiments so that the results would have reasonable generality. Two of the observers were adult females, one (LP) an emmetrope, and one (HF) with corrected low-order myopia and astigmatism. The other two were adult males, one (OTL) a corrected myope of moderately high-order, the other (AK) with corrected low-order myopia. All observers were thoroughly trained prior to recording the experimental data. Three of the observers were graduate students in experimental psychology, whereas the fourth was a laboratory technician. Motiviation seemed well sustained throughout the long and tedious series of experiments.

Because of individual differences in the sensitivity of the observers, it was necessary at times to collect data on groups of two observers at a time; at other times, because of the nature of the orientation light system used, it was necessary to collect data on observers singly. In general, all observers worked at a given luminance level before they all proceeded to the next luminance level. The possible influence of practice effects due to increases in the observers' familiarity with the conditions and procedures, and their facility in response, was in great part obviated by a protracted period of practice (about two weeks) in the observing situation, and further mitigated by the order of the experimental sessions as described below. Observers were practiced in the situation until their threshold curves showed no further improvement

B. APPARATUS

The apparatus used to produce the background and target luminances is illustrated schematically in Figure 1. The observers viewed the far wall of a large cube, which served as the background luminance, through a large opening in the near wall. The far wall was lighted by a series of incandescent lamps, located on the near wall of the cube around the opening, which were shielded from the observers' eyes. The target appeared from time to time in the center of the far wall, as a luminance increment. The target was produced by a projection system located behind the far wall. The larger portion of the far wall was covered with a translucent plastic screen. The target was produced by transilluminating the screen over a restricted area. The screen was located an average of 10.8 feet from the eyes of the observers.

High background luminances were produced by four arrays of 100-watt lamps, one array on each of the sides of the opening in the near wall. Reduction in the number of these lamps was used to produce luminances in the range from 3 to 100 ft.-L. A level of 1 ft.-L. was produced by three 40-watt incandescent lamps, one at each of the sides and top of the near wall. In each case, direct illumination of the plastic screen by the lamps was prevented by disc deflectors placed on the lamps. For all values below 1 ft.-L., the luminance of the plastic screen was provided by two small integrating light boxes containing 6-volt, 32-candle-power incandescent lamps. Each light-box had an opal glass screen. These screens were not used to illuminate the plastic screen directly, but were used to illuminate the near wall of the cube directly, the plastic screen being illuminated entirely by reflection from the near wall. These two boxes were mounted against the sides of the cube walls at a point which prevented the observers from seeing the opal glass surfaces. The luminance of the plastic screen was adjusted by use of Wratten neutral filters, placed over the opal screens of the light-boxes.

The target projector was based upon a special tungsten ribbon-filament lamp developed by the General Electric Company, the output of which was equivalent to a 1000-watt monoplane projection lamp. The ribbon-filament lamp was operated at 6-volts AC. Two sets of Wratten neutral filters were used to adjust target luminance. "Fixed" filters reduced the target luminance to the threshold range. These filters were fixed during any given experimental session. Additional adjustment of the target luminance was obtained by the "psychophysical" filters. These filters adjusted the target luminance to the values desired within the psychophysical range. Five psychophysical filters were used, mounted on an electrically-driven filter-selector which could position one or another of them in the projection beam. Transmittance values for these filters were: 1.000, 0.752, 0.450, 0.287, and 0.172.

The presentation of the target was controlled by the operation of a flag-type shutter. Whenever a solenoid was activated, the shutter was removed from the projection beam.

The optical system of the projector is shown in Figure 2. The target was presented through the rear of the translucent plastic screen (1). A metal plate with a circular hole was pressed tightly against the rear of the screen, and this aperture defined the size of the target. The projector was used therefore, merely to illuminate the metal plate uniformly. An image of the filament (9) was formed by the condensor lenses (6) in the plane of the shutter wheel (3). The lens (2) imaged the plane of uniform luminance (7) on the metal aperture. The aperture (8) was placed in a lamp house which prevented unfocused light from the lamp from illuminating the screen. The target projector output was reduced by the fixed filters (5) and the psychophysical filters (4). Different focal length lenses (2) were used to illuminate the plates used to produce the two target sizes studied.

The side of the plastic screen facing the observers was covered with an extremely thin layer of white sphere paint, designed to eliminate the specularity of the plastic screen without introducing spectral selectivity. The color temperatures of the target and of the background luminance were set for 2850° K.

The timing of the target presentation was arranged and controlled by a timer comprising two discs mounted on a single shaft, one rotating at seven times the speed of the other, and designed to juxtapose two adjustable slots in the perimeters of the discs and the projection beam. The timer wheels intercepted the projector beam in the plane of a filament image. Variation in the chord length of the slots can be utilized to produce continuous variation in the duration of the pulse of light from about 0.001 to 0.03 second. The time required for the target to come to full luminance was 0.0001 second. (A ribbon-filament was used in order to minimize the onset time.)

In the present experiment, an exposure duration of 0.01 second was used throughout. This duration was selected to be shorter than the critical duration (Ref. 3) at all values of B.

Experiments were conducted with each of two target sizes, representing 1 and 45 minutes of arc. These two sizes represent the extremes of a point source and an extended source which covers nearly the entire rod-free area of the central fovea.

C. EXPERIMENTAL PROCEDURES

1. Psychophysical Method

The temporal forced-choice variant of the method of constant stimuli as described in detail by Blackwell (Ref. 4) was used in this study. Essentially, the temporal forced-choice method presents the observer with four successive, aurally delineated, 2-second time intervals. In one of these only, as determined randomly by the presentation sequence, there appears a target of ramdomly selected luminance. After a cycle of four temporal intervals is completed, the observer is allowed eight seconds to press one of four buttons located on his arm rest indicating in which of the four intervals he believes the stimulus to have appeared. These responses are automatically tallied in a distant room on electrical counters and punched on record cards for permanent reference. Although ten targets of the same luminance succeed each other, each block of ten is randomly arranged with respect to all other blocks of ten in terms of luminance. Five such blocks, ranging in difficulty from a target visible nearly 100% of the time to a value virtually never visible are presented in one experimental session.

After the presentation of fifty targets, observers are permitted a five minute break while the equipment is re-set. A fifteen minute break for refreshment customarily follows the third block of stimuli.

Automatic presentation and recording equipment was used, designed for use with this method and described by Blackwell, Pritchard, and Ohmart (Ref. 5). The amassing of the great amounts of data necessary to this study would have been impossible without this equipment.

The basic experimental data were percentages of correct choice for each of five target luminance increments. Analysis of the data begins by eliminating the effect of chance successes by means of the relation:

$$p' = \frac{p - .25}{.75}$$

where p' = corrected proportion, and

p = raw proportion.

The corrected proportions were analyzed by a variant of the probit analysis developed by Kincaid and Blackwell (Ref. 6), based on the probit method of Finney (Ref. 7). Basically, the probit method fits a theoretical curve to the data to satisfy the maximum likelihood criterion. In this case, the theoretical curve was the normal ogive. Analysis of the data in this manner yields the value of the threshold, the standard error of the threshold, the slope of the ogive, the standard error of the slope, and an estimate of the goodness of fit determined by the Chi-square test.

2. Photometric Procedures

The basis of all photometry was the Macbeth Illuminometer, calibrated against standard lamps and standard reflectance surfaces certified by the Electrical Testing Laboratories, New York. The calibration of the Illuminometer and filters was checked several times during the experiments.

High luminances of the screen were measured directly with the Illuminometer, fitted with a lens which imaged the screen in the photometric cube of the device. Low luminances, produced by the light boxes described above, were photometered indirectly. The ratio between the luminances of the opal screens of these light boxes and the resulting screen luminance was measured at maximum output of the light-boxes. When the output of the light boxes was reduced by filters to produce low luminances of the screen, the luminances of the opal screens of the light boxes were measured and the ratio used to compute the screen luminance. This procedure is entirely adequate since the optics of the light sources were not altered by the use of the filters.

The luminance of the large target was measured directly with the Illuminometer, with all fixed and psychophysical filters removed from the projector. The luminances of the targets actually used in the experiments were computed from the luminance without filters and the transmittances of the filters. The transmittances of the filters were determined by standard photometric procedures, with an optical bench photometer.

The luminance of the small target was more difficult to photometer. The basic measurement involved what may be called a "candle-power box". A closed metal box was made with an opal disc at one end and a small aperture at the other. The aperture was fitted snugly against the screen so that the transilluminated target lay entirely within it. The target thus became a source for illumination of the opal disc at the other end of the box. Baffles were placed within the box to eliminate interreflections. The luminance of the opal disc was measured with the Illuminometer. From the transmittance of the opal disc and the inverse square law, the intensity of the small target could be determined. The luminance of the small target was computed from the measured size of the target.

The measurement with the candlepower box is somewhat tedious. Accordingly, occasional measurements were made in this way and more frequent measurements were made with a photoelectric telephotometer, calibrated in terms of the candlepower box measurements. The telephotometer consisted of a telescope which imaged the small target on the cathode of a 931 photomultiplier tube. The relative luminance of the target was determined by the emf required to compensate the photo-electric current produced by the target.

3. Order of Experiments

All experimental measurements with the 1 minute target were first made and then the measurements were made with the 45 minute target. Studies with the 1 minute target are designated Experiment I; those with the 45 minute target are designated Experiment II.

Experiments were begun for Experiment I with a background luminance of 10 ft.-L. which was then reduced in one log unit steps in successive sessions to a terminal background value of "zero". Keeping all other conditions constant, background luminance was then increased from 3.3 x 10^{-6} ft.-L. in one log unit steps to 33 ft.-L. and finally to 1000 ft.-L. and back to 100 ft.-L. No differential effects of the order of the experimental conditions were observed.

Experiment II began at a background luminance of zero and increased in one log unit steps to 1 x 10^{-4} ft.-L. Experiments were then conducted at 10 ft.-L. and the background luminance was decreased in one log unit steps to 1 x 10^{-3} ft.-L., followed by experiments at 100 ft.-L. and 1000 ft.-L.

4. Other Experimental Procedures

To insure stimulation of the same region of the foveal retina under all conditions, the observers' heads were fixed in position by means of hardened wax dental impressions in which the observers' teeth were clamped during all stimulus presentations. These dental impressions in turn were bolted to supports fastened to the arm rests of the observation chairs.

Constant fixation and accommodation of the eye at the point of eventual appearance of the stimulus was required. Unfortunately, no single method of producing this result could be discovered which would serve satisfactorily throughout the extensive range of background luminance values. Consequently, three different systems were employed which produced equivalent orientation lights. In each case, the system produced four spots of light, each of approximately one minute of arc diameter, surrounding the stimulus spot and equidistant from its edges at a constant distance of eighteen minutes of arc. These four spots were arranged in the form of the terminal points of the arms of a cross, with the point of stimulus appearance located at the intersection of an imaginary line through each of the vertical and horizontal pairs. The orientation spots were maintained at a luminance value approximating ten times the average threshold of the group of observers for the prevailing luminance, a level found in previous studies to be comfortable and effective over long periods.

The system used for producing the orientation lights for background values ranging from 1 ft.-L. to 1 x 10^{-3} ft.-L. consisted of four projectors using the images of the filaments of 6-volt, 32-candlepower tungsten lamps. These projectors were mounted on each of the four sides of the back of the cube and projected the orientation lights directly on the screen.

The system used for background values less than 1 x 10^{-3} ft.-L. involved use of orientation light boxes. A 32 candlepower, 6-volt lamp housed in a light-tight metal case with four small holes provided the orientation spots for Experiment I. Because of the necessarily greater separation of the orientation lights, these were replaced by four 2.2 volt lamps (G.E. No. 222) with small spherical lenses for Experiment II. These light-boxes were mounted at right angles to the observers' line of sight, at an optical distance equal to that of the distance from the observer to the plastic screen. A cover glass mounted at forty-five degrees before the observers' eye reflected the four spots into the observers' eyes so that they appeared to come from the screen. (The values of ΔB and of B were of course corrected for the transmission of the cover glass.) This system eliminated the existence of unintentional illumination of the light cube by the orientation lights. The orientation lights used at higher luminance levels produced an unaccaptable amount of background luminance from reflections within the light cube.

In order to provide sufficient intensity for use at background luminance levels greater than 1 ft.-L., orientation spots were produced by transillumination through the rear of the plastic screen. An orientation light template was made, consisting of four pieces of shimstock with holes made with a number 64 drill, which were fixed to the side of the glass plate bearing the target aperture. A light box containing one 2.2 volt lamp was mounted behind each of these, so that the orientation spots appeared on the face of the screen by transillumination from behind. The luminance of these spots was controlled by means of a variable density 16 mm. photographic film, placed between each light source and the screen. Different positions of the film strip produced different luminances of the individual orientation spots.

Throughout the experiments, monocular vision was employed, using the right eye of each observer. An artificial pupil was used in order to eliminate variations in retinal illumination with changes in the diameter of the natural pupil attendant on luminance changes of the backgrounds, and to make it unnecessary to determine for these experimental conditions the extent of the Stiles-Crawford effect The artificial pupil was fixed 0.2 to 0.3 inches before the eye of each observer, and on line with the optic axis.

Initially a 2 mm. artificial pupil was selected for these experiments, but it was noticed that when viewing an extended surface of uniform luminance through this aperture, the surface appeared to have several distinct areas differing in apparent luminance. The appearance of the field visible through the artificial pupil may be described as follows: There was a fuzzy penumbra region just inside the circular limit of the visible field. There was an annulus of greater apparent luminance and then a central area of lower apparent luminance. The central area of lower apparent luminance was comparatively small with the 2 mm. pupil but was enlarged by use of a 1 mm. artificial pupil. The 1 mm. pupil was selected for use in the experiment, since it was considered expecially undesirable for the boundary between the central dark area and the brighter annulus to fall near the test target. With the 1 mm. pupil, this boundary was separated from the nearest edge of the test target by at least 10 degrees. However, the target definitely fell within the central zone of lower apparent luminance.

This effect of an artificial pupil has apparently never been reported and considerable exploratory experimentation was required to determine the basis for the observed effect. It was found that the effect could be duplicated in an entirely physical way, with an ordinary spherical lens being used in place of the eye. The phenomenon was shown to be absent with an aperture placed at the first principal point of the lens (paralleling the case of the natural pupil of the eye); it was present with the aperture placed about four to six inches before this (paralleling the case with the artificial pupil). Kincaid and Blackwell (Ref. 8) have shown that the effect is apparently due to the presence of spherical aberration in the eye. The annulus of light surrounding the darker inner disc represents an excessive accumulation of light due to the fact that these rays are more nearly in focus than are the rays arriving at other points on the retina.

The refractive condition of the eye of each observer was determined under the conditions of the experiment by a method outlined by Ogle (Ref. 9). An "oculometer" was used to measure dynamic refraction with the stigmatoscopic technique. Measurements were made with this apparatus under conditions identical with those of the experiment proper, with the exceptions that a stigma, or point of light, appeared in the apparent location usually occupied by the target. The stigma was seen by reflection from a half-silvered mirror located in the oculometer. The principal oculometric measurements were made with a 2 mm. artificial pupil to increase the precision of measurement, since the depth of focus of the eye is considerable with a 1 mm. pupil. There is no _a priori_ reason to expect there to be a difference between refractive error with 1 and 2 mm. pupils. Moreover, a crude check was made by obtaining oculometric readings first with the 1 and then with the 2 mm. pupil. No systematic differences were found.

Oculometric readings were taken at each of two background luminances: 10 ft.-L. and zero. There is no _a priori_ reason to expect differences in refractive condition as a function of background luminance, and indeed none were found to exist.

The basic oculometric procedure may be described as follows: the observer fixates the orientation spots situated 10.8 feet from the eye and observes changes in appearance of the bright stigma centered among them. The assembly which houses a tungsten lamp, stigma, and reduction filters in the oculometer is movable along the optic axis parallel to a scale. The distance from the eye to the field lens is made equal to the focal length of the latter, making possible a linear scale calibrated in diopters whose modulus is determined by the dioptric strength of the field lens. (The zero point of the scale corresponds to the point at which the stigma-to-lens distance is equal to the focal length of the field lens and the image is at infinity.) Using the method of limits, the observer adjusts the position of the lamp housing until the stigma appears to have minimum size. A mean of many such settings, translated into diopters by the affixed scale, reveals the refractive state of the eye. Accommodation on the stigma would give a spurious result. This possibility is precluded by causing the lamp to flash intermittently, the "off" period being sustained considerably longer than the "on".

The discrepancy between the mean of these oculometric settings and the theoretical "normal" refractive state of the eye (-0.33 diopters) at this distance represents the refractive "error" of each observer. From refractive errors, it is possible to compute refractive corrections. Oculometric measurements were repeated after corrections were made. This procedure was continued until the refractive state of the eye as measured by this method closely approximated -0.33 diopters.

Results of the oculometric measurements are presented in Table I. We note that one observer obtained negligible refractive errors with corrections. The three observers used the indicated corrections during the experiments.

Although the method described can be used to give a measure of the astigmatic error, it was not considered sufficiently sensitive for specification and correction of the cylindrical error noted in one observer. Accordingly, the method of Tait, using a Stenopaic slit was employed in this instance. This method involves determining the refractive error in each of several meridians by a subjective technique. The observer reports on the least positive correction which gives clear imagery in each meridian and the astigmatic error is computed from the difference between the most different meridians.

III RESULTS

Threshold values resulting from the probit analysis of the experimental proportions are available for each observer for each of the two targets. The data for the 1 minute target are presented in Tables II, III, IV, and V; data for the 45 minute target are presented in Tables VI, VII, VIII, and IX. In each case, the symbols have the following meanings. Values of $\Delta°B$ represent target luminances for which $p' = .50$. Values of $\sigma\Delta°B$ represent the standard errors of the values of $\Delta°B$. Values of σ represent the standard deviations of the normal frequency distributions upon which the ogives were based. Values of σ_σ represent standard errors of the values of σ. Values of χ^2 have the usual statistical meaning, as do values of d.f.. Values of $P(\chi^2)$ represent the probabilities that values of χ^2 as large as those obtained, or larger, could have occurred by chance. Values of VR, the "variability ratios", are obtained by dividing σ by $\Delta°B$. Values of σ_{VR} represent standard errors of these quotients. The data represent in all more than 38,000 observations.

The threshold values are presented in Figure 3 - 10 as functions of log background luminance. There is a separate graph for each observer's data obtained with each target size. An horizontal line has been used in each figure to fit the experimental data for the smallest values of background luminance and for zero. Fit of the data to these lines represents the fact that Δ B is equivalent for zero and for various small values of background luminance. Such a relation means that there is no photosensitization by white light. It is apparent that the eight sets of data fit the horizontal lines adequately over a considerable range of values of background luminance. Hence, there is considerable evidence against the postulation of a photosensitization effect.

Values of $\sigma/\Delta°B$ or VR are presented in Figures 11 and 12, as a function of log background luminance. A separate graph is presented for each target size, representing the averages of the data from the four observers. An horizontal line has been drawn in on Figures 11 and 12 to facilitate evaluation of the extent to which $\sigma/\Delta°B$ has the same value at all values of background luminance. The data points are quite scattered and it is difficult to detect a trend with respect to background luminance. There is a suspicion that the value of $\sigma/\Delta°B$ decreases at the highest background luminance levels.

The hypothesis that $\sigma/\Delta°B$ does not depend upon the background luminance was subjected to statistical test by means of a χ^2 test based on measures weighted for reliability. The results of this test are presented in Table X. The probability of χ^2 values in the table represent the expectation that a value of χ^2 this large or larger will occur by chance alone. It may be seen that, with two or possibly three exceptions, the data may not be represented as arising from a single universe. On a purely statistical basis, then, we must reject the hypothesis that $\sigma/\Delta°B$ is constant.

It must be added that the test applied in this case is not entirely fair to the hypothesis; it represents an extremely conservative estimate of the probability, since the deviations of $\sigma/\Delta B$ from their central value may presumably vary due to day-to-day variability of threshold data.

The fact remains that values of $\sigma/\Delta B$ are remarkably constant as background luminance varies over a considerable range. Values of the ratio also appear to be equivalent for the two target sizes. This fact confirms the result reported elsewhere (Ref. 10) by one of us. The apparent constancy of VR is of considerable practical and theoretical significance.

We may inquire to what extent the probit analysis was justified by the goodness of fit of the data. Data for each observer were tested for the goodness of fit of each set of data to its normal ogive, using the χ^2 test of conformity. These values of χ^2 appear summed at the bottom of the individual data tables. The probabilities of values of χ^2 this large or larger for each of the eight sets of data are as follows: .19, .59, .47, .023, .075, .19, .87, .074. Considering the severity of this test, we may consider the agreement of experimental data to theoretical ogives to be excellent and the probit analysis to be entirely justified.

IV. DISCUSSION

The main experimental data of the present study have revealed that the threshold luminance increment is equivalent for total darkness and for a variety of low background luminance levels. Thus, there is no evidence that the human fovea can be photosensitized by small amounts of white light. There is no conceivable basis for expecting to improve foveal vision on dark nights by the addition of a small amount of veiling white light covering the entire retinae.

These results also suggest that there is absolutely no basis for the usual assumption that the "absolute threshold" differs qualitatively from the "difference threshold". The eye operates as a detector in the same manner when the background is totally dark as when it has a very low luminance. Furthermore, the threshold luminance difference increases as background luminance is increased in a smooth and continuous manner. This result will prove useful in the development of a general theory of visual detection.

REFERENCES

1 Blackwell, H. R., The inter-relations of contrast, area, and adaptation brightness in human binocular vision, Ph.D. dissertation, University of Michigan, 1947.

2 Crozier, W. J., Respired oxygen and visual photosensitization, Minutes and Proceedings of the Armed Forces - NRC Vision Committee, 27th Meeting, 10-11 November 1950.

3 Graham, C. H. and Kemp, E. H., Brightness discrimination as a function of the duration of the increment in intensity, J. Gen. Physiol., 21, 635-650 (1938).

4 Blackwell, H. R., Psychophysical thresholds: Experimental studies of methods of measurement, University of Michigan, Engng. Res. Bull. No. 36, p. 227 (1953).

5 Blackwell, H. R., Pritchard, B. S., and Ohmart, J. G., Automatic apparatus for stimulus presentation and recording in visual threshold experiments, J. Opt. Soc. Amer., 44, 322-326 (1954).

6 Kincaid, W. M. and Blackwell, H. R., Application of probit analysis to psychophysical data I. Techniques for desk computation, University of Michigan, Engineering Research Inst. Report 2144-283-T (in press).

7 Finney, D. J., Probit Analysis, Cambridge: Cambridge University Press, 1947, p. 256.

8 Kincaid, W. M. and Blackwell, H. R., Irregularities of retinal illumination resulting from an artificial pupil, (Abstract), J. Opt. Soc. Amer., 42, 872 (1952).

9 Ogle, K. N., Private communication

10 Blackwell, H. R., Brightness discrimination data for the specification of quantity of illumination, Illum. Eng. N.Y., 47, 602-609 (1952)

TABLE I

Refractive Data from the Oculometer
(Diopters)

Observer	Uncorrected Error	Corrected Error	Strength of Ophthalmic Lens
AK	-0.66	-0.33	-0.375
OTL	-4.46	-0.37	-4.00
HF	-0.76	-0.31	-0.375; -0.75 at 165°
LP	-0.34	---	

TABLE II

Threshold Data for Observer OTL; α = 1 minute

Order	B (ft.-L.)	Δ°B	$\sigma\Delta$°B	σ	σ_σ	χ^2	d.f.	P(χ^2)	VR	σVR
1	10.5	406.	22.1	125.	36.2	1.09	3	.78	.307	.0839
2	.908	182.	11.3	85.5	14.4	2.78	3	.42	.469	.0906
3	.0972	171.	11.3	79.3	12.6	4.45	3	.22	.464	.0892
4	1.12×10^{-2}	122.	7.27	53.9	9.24	2.99	3	.39	.440	.0855
5	1.27×10^{-3}	136.	8.34	56.7	9.06	4.70	3	.20	.418	.0811
6	$.921 \times 10^{-5}$	131.	8.19	54.9	8.70	6.35	3	.094	.420	.0800
7	$.977 \times 10^{-6}$	125.	7.99	52.3	8.31	2.67	3	.46	.418	.0800
8	0.0	141.	9.33	73.1	15.4	.865	3	.83	.520	.111
9	2.62×10^{-6}	130.	5.92	38.0	6.77	7.89	3	.050	.291	.0588
10	2.86×10^{-5}	113.	7.13	53.6	8.84	2.53	3	.49	.475	.0911
11	3.00×10^{-4}	115.	18.7	62.5	9.60	2.41	3	.49	.543	.106
12	2.57×10^{-3}	152.	10.2	77.0	13.1	1.75	3	.64	.508	.101
13	1.65×10^{-2}	153.	8.93	68.4	11.5	5.36	3	.14	.446	.0835
14	.295	132.	9.26	64.1	14.0	5.15	3	.16	.487	.0941
15	3.17	236.	12.4	84.9	14.7	1.79	3	.61	.359	.0701
16	30.2	556.	27.2	183.	33.3	6.28	3	.10	.330	.0659
17	301.	2320.	516.	1270.	2040.	5.06	3	.17	.549	.108
18	1210.	5400.	3730.	2510.	390.	6.07	3	.11	.465	.0893
19	101.	847.	62.2	403.	63.1	10.4	3	.019	.476	.0940
					Total	80.4	57			

P(χ^2) = .023

TABLE III

Threshold Data for Observer AK; $\alpha = 1$ minute

Order	B (ft.-L.)	ΔB	$\sigma\Delta'B$	σ	σ_σ	χ^2	d.f.	$P(\chi^2)$	VR	σVR
1	10.5	292.	10.8	57.0	11.1	2.30	3	.51	.511	.0409
2	1.67	159.	12.1	68.9	10.9	1.35	3	.73	.432	.0818
3	.0932	91.4	6.06	41.7	6.53	3.31	3	.35	.459	.0871
4	1.07×10^{-2}	73.5	5.21	32.3	5.20	.318	3	.96	.440	.0875
5	1.37×10^{-3}	87.4	6.42	47.2	9.79	6.33	3	.097	.540	.103
6	1.20×10^{-4}	97.7	6.35	47.5	7.76	2.36	3	.49	.486	.0933
7	$.915 \times 10^{-5}$	98.3	4.97	30.1	5.19	4.88	3	.19	.307	.0603
8	$.814 \times 10^{-6}$	90.2	5.38	39.0	6.46	4.23	3	.24	.433	.0827
9	0.0	102.	6.23	45.6	9.09	.583	3	.90	.448	.0992
10	3.61×10^{-6}	84.4	5.45	38.3	6.05	1.91	3	.59	.454	.0863
11	3.09×10^{-5}	95.5	5.36	36.6	6.05	5.31	3	.16	.383	.0731
12	3.00×10^{-4}	84.2	5.80	42.8	6.74	4.66	3	.20	.508	.0972
13	2.58×10^{-3}	104.	4.39	26.5	4.98	1.66	3	.64	.255	.0522
14	1.65×10^{-2}	87.9	7.20	48.4	9.33	9.26	3	.027	.550	.127
15	.295	90.2	5.10	29.5	5.12	1.55	3	.68	.327	.0663
16	3.17	160.	7.62	57.5	12.0	2.80	3	.42	.361	.0706
17	30.2	432.	16.8	97.3	20.8	4.55	3	.20	.225	.0505
18	301.	2050.	77.3	434.	84.5	2.60	3	.46	.212	.0442
19	1210.	4660.	259.	1800.	304.	4.89	3	.19	.387	.0744
20	101.	801.	46.8	338.	57.3	5.16	3	.16	.423	.0817
					Total	70.0	60			

$P(\chi^2) = .19$

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TABLE IV

Threshold Data for Observer HF; $\alpha = 1$ minute

Order	B (ft.-L.)	Δ B	$\sigma\Delta$ B	σ	σ_σ	χ^2	d.f.	P(χ^2)	VR	σVR
1	10.8	393.	20.0	137.	16.3	4.19	3	.24	.349	.0695
2	.908	143.	9.71	66.7	10.3	3.63	3	.31	.468	.0892
3	.0972	119.	7.08	46.7	7.53	1.64	3	.66	.393	.0748
4	.0112	127.	9.20	46.7	14.5	1.99	3	.59	.367	.101
5	.00127	137.	5.89	33.6	7.11	2.24	3	.51	.246	.0546
6	1.44×10^{-4}	114.	6.41	45.9	7.90	.511	3	.91	.401	.0780
7	$.921 \times 10^{-5}$	115.	5.72	38.2	6.86	1.55	3	.68	.332	.0660
8	$.977 \times 10^{-6}$	140.	9.70	60.6	9.69	1.27	3	.73	.434	.0858
9	0.0	99.6	5.18	32.0	5.50	3.50	3	.33	.321	.0632
10	2.63×10^{-6}	138.	10.3	65.3	10.4	19.0	3	.0003	.474	.0950
11	3.09×10^{-5}	119.	6.80	47.3	7.82	.271	3	.960	.399	.0762
12	3.00×10^{-4}	105.	5.74	41.2	7.30	1.51	3	.68	.391	.0791
13	2.82×10^{-3}	116.	5.99	41.0	7.30	.627	3	.90	.352	.0697
14	1.65×10^{-2}	99.6	7.38	46.8	7.41	.831	3	.85	.470	.0935
15	.295	96.5	7.07	40.3	68.9	5.13	3	.17	.418	.0874
16	3.17	205.	13.8	106.	17.5	2.87	3	.42	.519	.100
17	30.2	503.	26.0	190.	30.1	1.02	3	.80	.345	.0674
18	301.	2000.	106.	4780.	96.9	.0622	3	.99	.239	.0563
19	1210.	5890.	323.	1930.	332.	5.09	3	.17	.327	.0655
20	101.	803.	36.1	171.	33.1	.711	3	.87	.213	.0455
					Total	57.6	60			

P(χ^2) = .59

TABLE V

Threshold Data for Observer LP; $\alpha \approx 1$ minute

Order	B (ft.-L.)	Δ°B	$\sigma\Delta$°B	σ	σ_σ	χ^2	d.f.	$P(\chi^2)$	VR	σVR
1	10.5	222.	10.9	75.6	15.2	3.61	3	.31	.340	.0725
2	1.67	115.	9.70	42.3	7.14	8.67	3	.03	.367	.0706
3	.0932	54.4	4.31	31.6	4.90	1.27	3	.73	.582	.115
4	1.12×10^{-2}	62.2	.456	28.7	4.48	6.08	3	.11	.462	.0875
5	1.37×10^{-3}	75.8	4.11	29.2	5.15	3.89	3	.26	.386	.0759
6	1.20×10^{-4}	73.2	4.49	34.9	6.37	2.80	3	.42	.476	.0954
7	$.921 \times 10^{-5}$	59.6	5.14	32.8	5.23	1.61	3	.66	.925	.115
8	$.969 \times 10^{-6}$	71.6	4.13	27.6	4.50	2.21	3	.53	.386	.0738
9	0.0	73.6	4.47	32.2	5.24	.804	3	.85	.437	.0833
10	3.61×10^{-6}	60.2	4.48	30.6	4.87	1.31	3	.71	.508	.104
11	3.09×10^{-5}	75.4	3.93	24.5	4.19	1.43	3	.71	.324	.0636
12	3.07×10^{-4}	75.1	4.13	25.6	4.30	1.92	3	.59	.341	.0668
13	2.82×10^{-3}	59.9	4.45	31.3	4.79	.709	3	.87	.523	.101
14	1.65×10^{-2}	49.0	4.84	27.8	5.55	8.69	3	.04	.567	.148
15	.295	60.5	5.29	32.5	5.33	1.02	3	.80	.538	.115
16	3.17	111.	6.30	33.9	6.08	3.18	3	.36	.304	.0634
17	30.2	340.	18.5	131.	23.0	1.30	3	.73	.386	.0754
18	301.	1470.	214.	380.	65.7	6.40	3	.11	.259	.0506
19	1200.	3990.	217.	1310.	223.	3.46	3	.33	.328	.0652
20	101.	622.	31.6	150.	30.0	1.52	3	.68	.241	.0548
					Total	61.9	60			

$P(\chi^2) \approx .47$

TABLE VI

Threshold Data for Observer OTL; α = 45 minutes

Order	B (ft.-L.)	$\Delta'B$	$\sigma\Delta'B$	σ	σ_σ	χ^2	d.f.	$P(\chi^2)$	VR	σVR
1	0.0	.588	.055	.418	.0683	1.02	3	.80	.491	.0911
2	1.11×10^{-6}	.632	.0509	.313	.0550	1.87	3	.59	.302	.0599
3	1.21×10^{-5}	.682	.0522	.376	.0652	6.04	3	.11	.380	.0731
4	1.13×10^{-4}	.646	.0642	.488	.0845	9.57	3	.022	.464	.0907
5	2.32×10^{-4}	.532	.0579	.413	.0644	5.65	3	.13	.481	.0931
6	10.1	.933	.232	1.35	.380	.135	3	.99	.505	.122
7	.961	.851	.0734	.484	.133	8.60	3	.035	.390	.102
8	$.985 \times 10^{-1}$	.821	.0573	.403	.0919	4.45	3	.22	.391	.0881
9	$.942 \times 10^{-2}$	.933	.0486	.349	.0687	1.45	3	.68	.375	.0780
10	$.981 \times 10^{-3}$	.903	.0473	.341	.0677	5.54	3	.13	.377	.0791
11	104.	10.7	.543	3.61	.621	3.44	3	.33	.377	.0659
12	1210.	83.4	4.79	33.7	5.59	1.60	3	.66	.405	.0773
					Total	49.4	36			

$P(\chi^2) = .074$

TABLE VII

Threshold Data for Observer AK; $\alpha = 45$ minutes

Order	B (ft.-L.)	Δ°B	$\sigma\Delta$°B	σ	σ_σ	χ^2	d.f.	P(χ^2)	VR	σVR
1	0.0	.737	.0511	.322	.0513	1.31	3	.73	.437	.0858
2	1.22×10^{-6}	.814	.0387	.256	.0466	4.20	3	.24	.315	.0630
3	1.14×10^{-5}	.675	.0465	.263	.0432	14.9	3	.0018	.390	.0772
4	1.11×10^{-4}	.669	.0513	.419	.0719	7.79	3	.050	.626	.128
5	2.32×10^{-4}	.682	.0342	.241	.0440	3.15	3	.36	.353	.0700
6	10.0	2.66	.151	1.03	.170	3.50	3	.33	.389	.0743
7	.961	.886	.0583	.451	.0757	.463	3	.92	.509	.0992
8	$.985 \times 10^{-1}$	.789	.0398	.250	.0432	1.27	3	.73	.317	.0626
9	$.942 \times 10^{-2}$	.528	.0291	.184	.0307	5.51	3	.14	.349	.0677
10	$.981 \times 10^{-3}$	.524	.0452	.323	.0496	1.92	3	.59	.616	.126
11	104.	12.4	.456	2.53	.487	1.06	3	.78	.204	.00420
12	1210.	120.	5.72	35.0	9.09	4.17	3	.24	.283	.0739
					Total	49.2	36			

P(χ^2) = .075

TABLE VIII

Threshold Data for Observer HF; $\alpha = 45$ minutes

Order	B (ft.-L.)	Δ'B	$\sigma\Delta$'B	σ	σ_σ	χ^2	d.f.	P(χ^2)	VR	σVR
1	0.0	.551	.0349	.228	.0354	5.21	3	.16	.396	.0773
2	1.22×10^{-6}	.564	.0394	.280	.0433	.495	3	.92	.497	.0950
3	1.11×10^{-5}	.490	.0279	.195	.0323	3.77	3	.28	.398	.0762
4	1.35×10^{-4}	.464	.0340	.275	.0472	5.24	3	.16	.593	.120
5	2.78×10^{-4}	.570	.0328	.247	.0143	.822	3	.85	.434	.0866
6	10.0	2.64	.138	.860	.147	1.42	3	.71	.326	.0638
7	.961	.842	.0587	.456	.0750	.999	3	.80	.541	.106
8	$.985 \times 10^{-1}$	.956	.0541	.392	.0796	8.15	3	.042	.410	.0864
9	$.942 \times 10^{-2}$	.696	.0455	.330	.0521	2.66	3	.46	.437	.0899
10	1.04×10^{-3}	.696	.0439	.304	.0481	3.17	3	.36	.437	.103
11	104.	10.2	.597	4.34	.729	9.27	3	.027	.428	.0822
12	1210.	82.8	5.47	42.7	7.23	2.55	3	.46	.516	.101
					Total	43.7	36			

$P(\chi^2) = .19$

TABLE IX

Threshold Data for Observer LP; α = 45 minutes

Order	B (ft.-L.)	$\Delta'B$	$\sigma\Delta'B$	σ	σ_σ	χ^2	d.f.	$P(\chi^2)$	VR	σVR
1	0.0	.369	.0275	.186	.0294	.397	3	.94	.494	.100
2	1.02×10^{-6}	.405	.0325	.240	.0370	14.6	3	.0030	.593	.118
3	$.95 \times 10^{-5}$	.506	.0304	.217	.0353	1.80	3	.61	.428	.0814
4	1.12×10^{-4}	.451	.0303	.221	.0348	1.47	3	.68	.491	.0934
5	2.78×10^{-4}	.424	.0330	.252	.0397	1.19	3	.75	.594	.118
6	10.1	1.91	.103	.719	.126	3.00	3	.39	.376	.0736
7	.961	.520	.0430	.259	.0429	.676	3	.87	.498	.106
8	$.985 \times 10^{-1}$	.406	.0281	.130	.0299	.327	3	.96	.320	.0421
9	$.942 \times 10^{-2}$	.331	.0331	.220	.0347	3.18	3	.36	.665	.148
10	$.981 \times 10^{-3}$	.443	.0356	.214	.0353	1.23	3	.75	.483	.101
11	104.	9.09	.427	2.16	.437	3.37	3	.33	.238	.0195
12	1210.	84.8	4.90	34.5	5.94	6.25	3	.10	.407	.0804
13	1.36×10^{-5}	.525	.0303	.226	.0394	2.66	3	.46	.430	.0835
					Total	27.0	39			

$P(\chi^2) = .87$

TABLE X

Differences in σ_{VR}

Observer	Experiment	χ^2	d.f.	$P(\chi^2)$
AK	I	52.4	19	.000131
AK	II	65.2	11	.000002
HF	I	27.6	19	.0834
HF	II	7.30	11	.799
LP	I	50.2	19	.000131
LP	II	50.9	12	.000001
OTL	I	48.6	18	.000075
OTL	II	6.64	11	.799

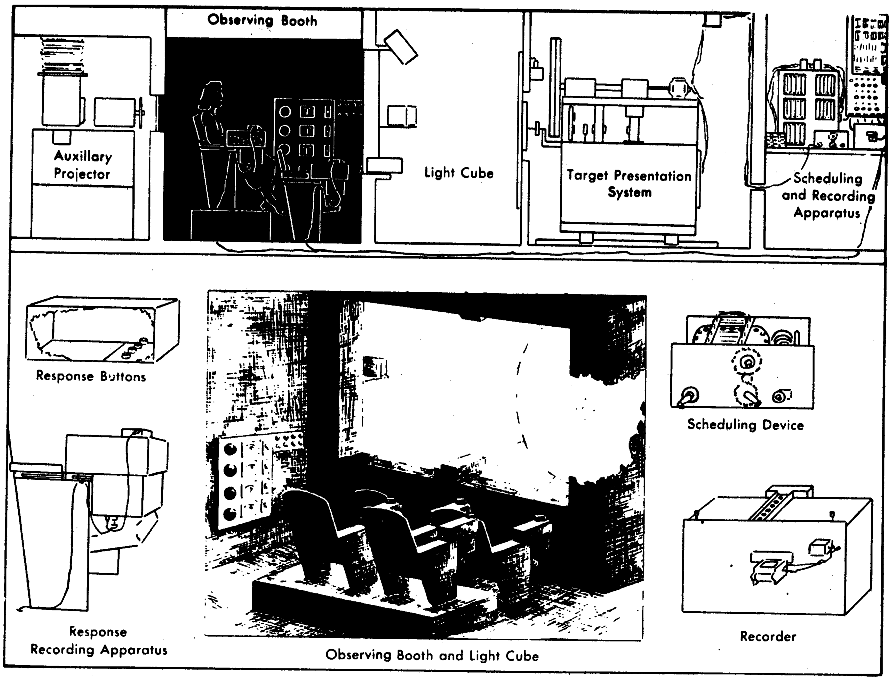

Fig. 1. Artist's conception of the basic psychophysics test facility.

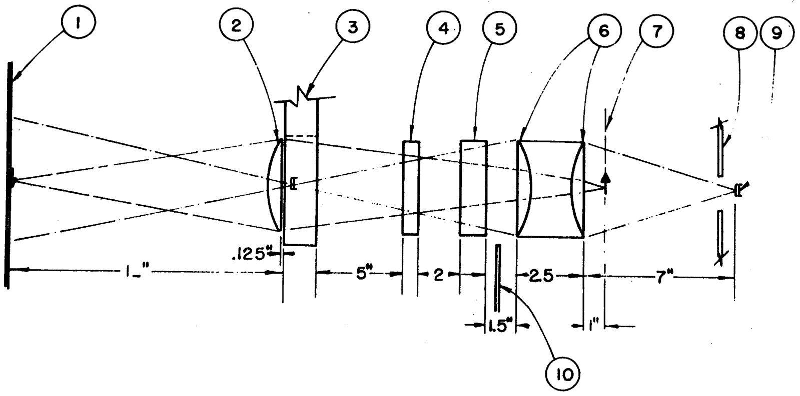

Fig. 2. Optical schematic drawing of the target projector.

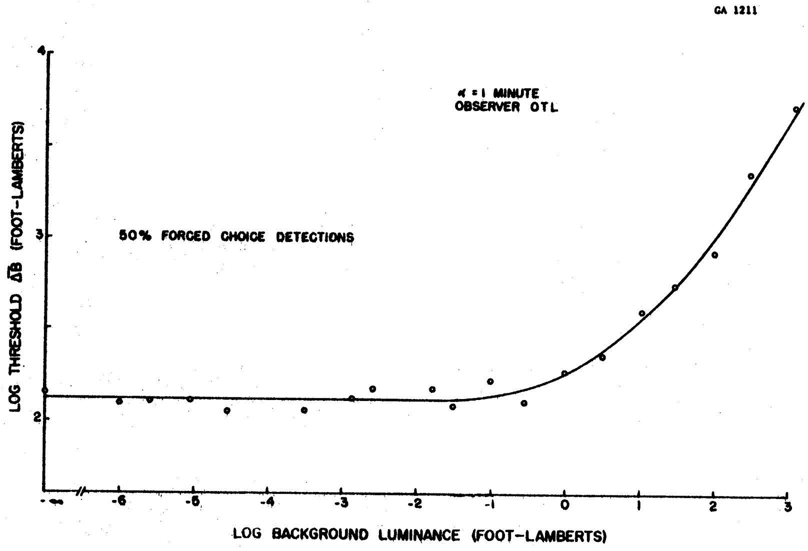

Fig. 3. Threshold data from Experiment I.

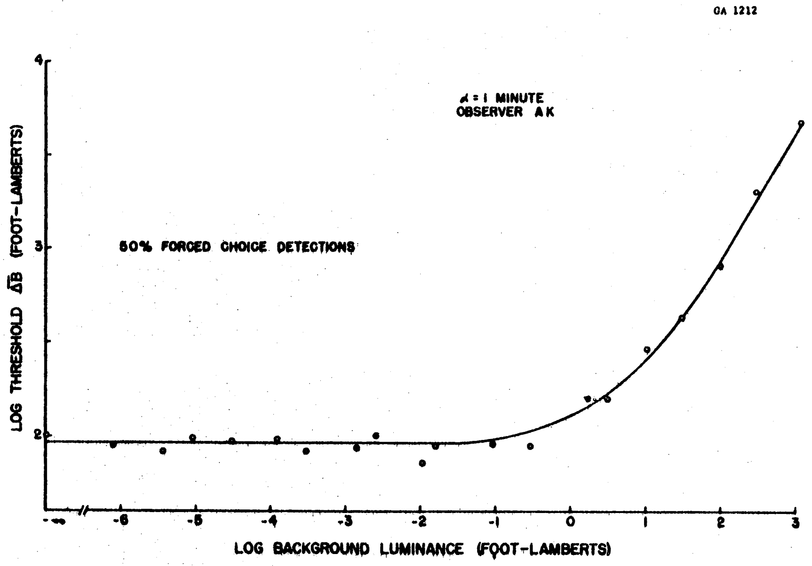

Fig. 4. Threshold data from Experiment I.

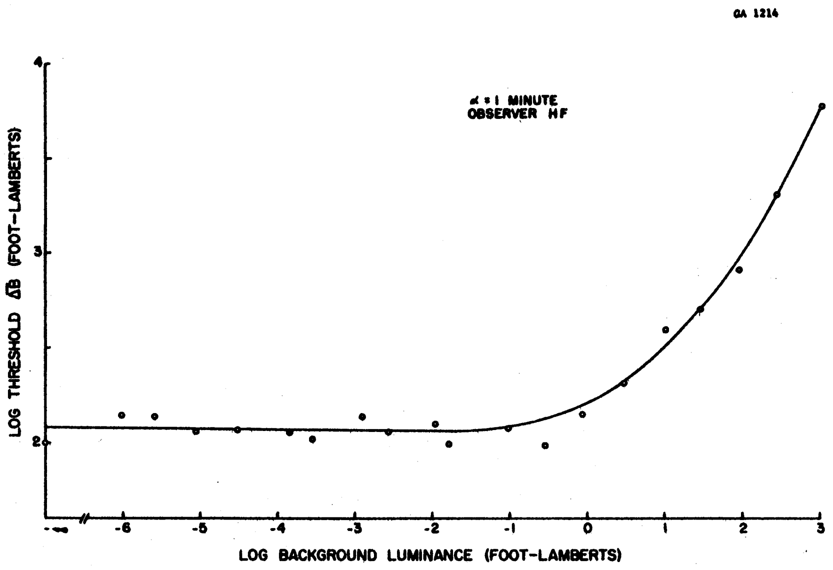

Fig. 5. Threshold data from Experiment I.

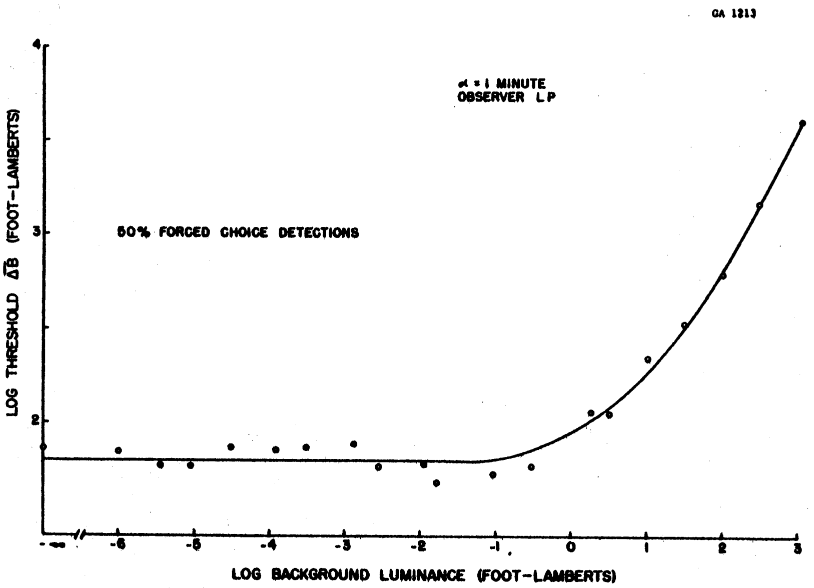

Fig. 6. Threshold data from Experiment I.

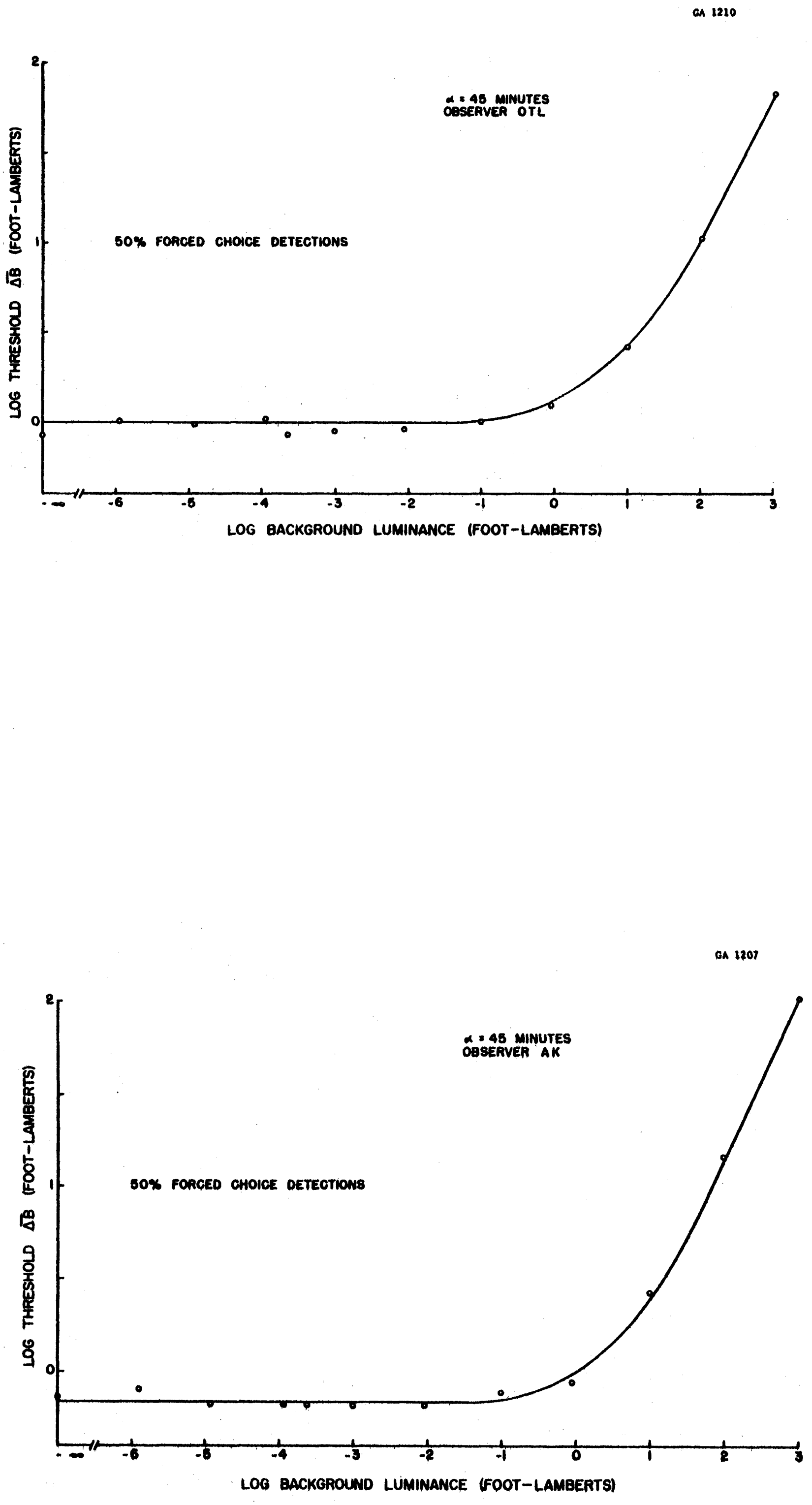

Fig. 8. Threshold data from Experiment II.

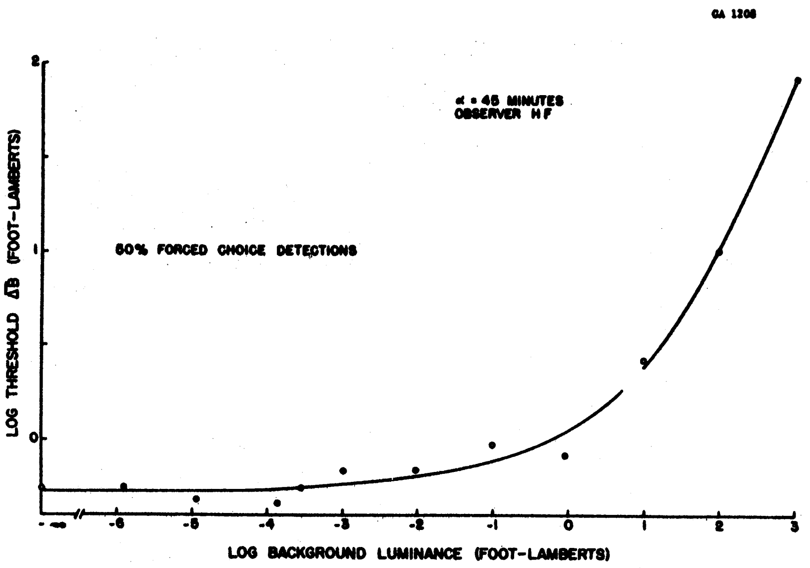

Fig. 9. Threshold data from Experiment II.

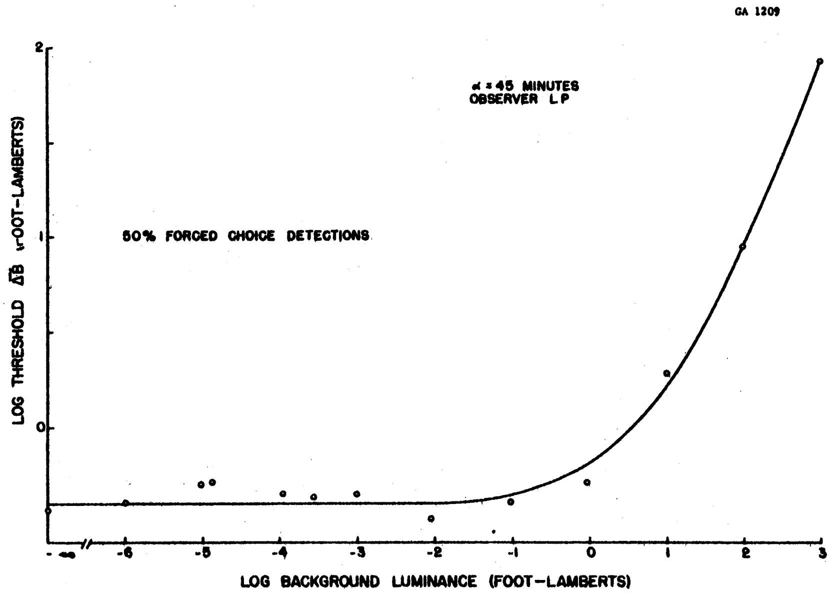

Fig. 10. Threshold data from Experiment II.

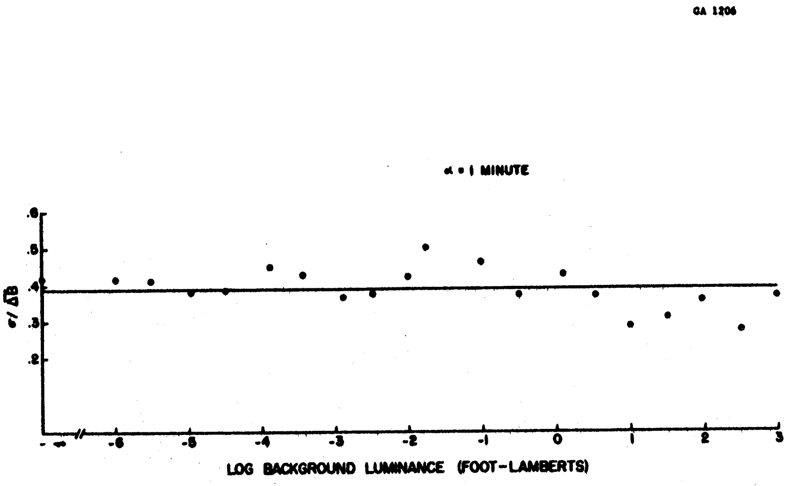

Fig. 11. Psychophysical parameters from Experiment I.

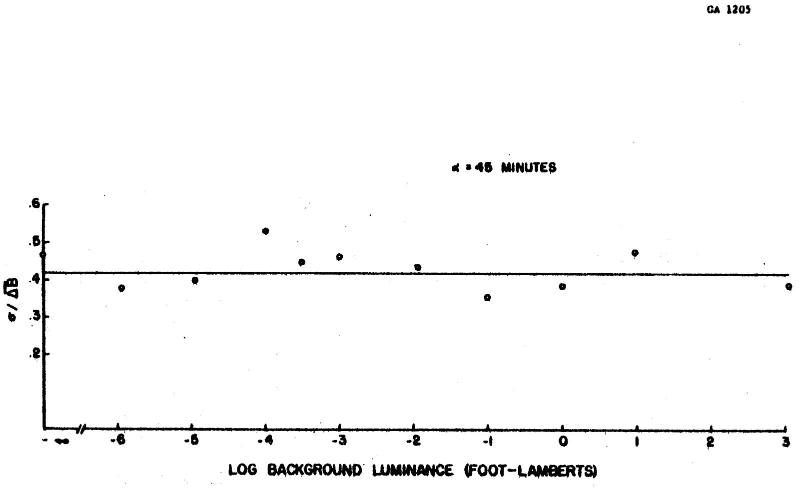

Fig. 12. Psychophysical parameters from Experiment II.