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LUMINANCE THRESHOLDS FOR THE RESOLUTION OF
VISUAL DETAIL DURING DARK ADAPTATION

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COLUMBIA UNIVERSITY

JANUARY 1952

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**LUMINANCE THRESHOLDS FOR THE RESOLUTION OF
VISUAL DETAIL DURING DARK ADAPTATION**

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January 1952

**Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio**

FOREWORD

This report was prepared by Columbia University under USAF Contract No. AF 33(038)-22616 covering work on Visual Factors in Cathode Ray Tube Data Presentation. The contract was initiated under a project identified by Research and Development Order No. 694-45, and was administered by the Psychology Branch of the Aero Medical Laboratory, Research Division, Wright Air Development Center, with J. M. Christensen acting as Project Engineer.

ABSTRACT

Luminance thresholds for the visual resolution of various widths of alternating light and dark lines were determined at various times during dark adaptation. The finest gratings, representing high degrees of visual acuity, show only a single cone curve that drops from a high luminance threshold during the first moments of dark adaptation to a final steady level that is reached after about 7 to 10 minutes in the dark. Coarse gratings produce a duplex curve that shows an initial cone portion and a delayed rod portion. Visual acuity is a parameter that sets the position of a given curve on the log threshold axis. The higher the degree of resolution required, the higher the dark adaptation threshold. At a constant grating luminance, visual acuity rises rapidly to a maximum during dark adaptation; the higher the luminance, the earlier and more rapid the rise and the higher the maximum. Visual acuity increases at all dark adaptation times with increase in luminance. Implications of these findings for instrument lighting are discussed.

PUBLICATION REVIEW

Manuscript copy of this report has been reviewed
and found satisfactory for publication.

FOR THE COMMANDING GENERAL:


ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Research Division

INTRODUCTION

This experiment determines the minimum luminance required by a subject to discriminate various grades of visual detail during the process of dark adaptation following stimulation by a preadapting light. Visual detail is provided by acuity gratings displaying different widths of alternating light and dark lines; thus, various grades of detail may be specified in visual acuity units. Visual acuity is defined as the reciprocal of the visual angle in minutes that separates two contours, and so fine lines indicate a high degree of acuity and wide lines, a low degree.

Consider the relevance of the research to a practical problem. A pilot has been subjected to the brightness of the sky for a given period of time. (The sky brightness constitutes a preadapting light for subsequent dark adaptation.) He turns to look at instruments that vary in pattern and that are dimly illuminated by comparison with the sky. How long will it take him (i.e., how long must he dark adapt?) to see the instrument markings? By how much could his wait be shortened if the illumination of the markings were increased? This much can be said: he will see the markings when the sensitivity of his eye increases sufficiently (in the dim cockpit illumination) for previously imperceptible instrument markings to become perceptible; and the time required for him to see is shortened if the brightness of the markings is increased.

Dark adaptation and visual acuity are influenced by a number of variables. Two succeeding subsections consider these variables, and the hypothesis of the experiment is stated in a third.

Dark adaptation. Dark adaptation is defined as the increase in a subject's visual sensitivity that takes place in darkness (or in decreased illumination) following exposure to a preadapting light. The most frequently used measure of sensitivity is the least perceptible luminance that can just be seen, i.e., the threshold luminance. The threshold luminance is high in the first few minutes of dark adaptation, and drops thereafter to a limiting low final value.

The retina possesses two kinds of receptors: (a) the cones which are concerned with color vision and function at high (daylight) illuminations and (b) the rods which are sensitive to low light illuminations and are concerned with colorless vision. Many experiments (Hecht, 1937) show that dark adaptation proceeds in two stages. The first stage is rapid and complete in a few minutes. The second appears after the first and goes on for a half hour or more. The rapid first stage is due to cones while the second is due to the rods. The separation of dark adaptation into two curves is in accord with the well known duplicity theory.

Hecht and Shlaer (1938) have specified a number of important parameters that influence the course of dark adaptation. Luminance of the preadapting light influences the course of dark adaptation by determining the extent of the cone section of the curve; the cone section is extended and

the rod section delayed as luminance of the preadapting light increases (Hecht, Haig and Chase, 1937; Winsor and Clark, 1936). Wald and Clark (1937) have shown that the rate and the initial threshold of adaptation are functions of the duration as well as the luminance of the pre-exposure. Short durations of pre-exposure, particularly at low luminances, result in rapid dark adaptation of the rods. Long pre-exposures result in a slower course of adaptation. Johannsen (1934) has shown similar effects for cone adaptation. See also Mote, Riopelle and Meyer (1950) on the influence of intermittent preadaptation.

The shape of the dark adaptation curve is also influenced by parameters of the threshold light (Hecht, Haig and Chase, 1937). Rods are relatively more sensitive to blue and violet light than the cones due to the shape of the respective luminosity curves (Hecht, 1937). However, the two systems have about the same threshold for red light. Thus, when measurements are made with extreme red light only a cone section appears. With yellow, green and blue lights the rod section appears earlier and earlier in the course of dark adaptation.

The area of the threshold light is also an important determiner of the shape of the dark adaptation curve and its final threshold (Graham, Brown and Mote, 1939). A small centrally fixated area gives the cone curve alone (Hecht, 1937). Centrally fixated large areas show both branches, and large peripheral locations give the rod curve predominantly. The duration of the threshold determining light is another parameter of dark adaptation because the luminance necessary for threshold varies inversely with the duration (Graham and Margaria, 1935).

Experiments on the course of dark adaptation ordinarily use the light threshold of a simple object (e.g., an illuminated circular disc) as an indicator of the course of dark adaptation. Wolf and Zigler (1950) used square areas in some series and the fine lines of a single grating (within each square) in other series. The energy required for the discrimination of fine lines is higher than the energy required for the just perceptible detection of light.

Visual acuity. The characteristic curve of visual acuity as a function of luminance is well known (e.g., Shlaer, 1937). For stimulus areas not wholly restricted to the fovea, visual acuity is low at low luminances and increases as luminance increases along a shallow rising branch. This branch has been identified as due to rod function. As luminance increases, visual acuity increases rapidly from the maximum rod level along another branch that is due to cone function. Maximum acuity is reached at high luminances. Thus, rods provide low acuities at low luminances and cones provide high acuities at medium to high luminances.

The experiment. The visual acuity-luminance function tells us that low luminances provide low degrees of acuity and high luminances, high degrees of acuity. On this basis it would be expected that dark adaptation thresholds would be (a) high when the subject is required to resolve fine

lines and (b) low when he resolves coarse lines. Visual acuity then is a parameter that might be expected to set the position of a dark adaptation curve on the threshold intensity axis. In addition, because of the fact that high degrees of acuity are mediated by cones and low degrees by rods, it would also be expected that fine acuity gratings would show only dark adaptation for the cones while coarse gratings would show dark adaptation for both rods and cones. These expectations are verified by the results of the experiment. The data also provide a useful basis for estimating light requirements for the discrimination of detail following adaptation to high luminances.

In a given group of experimental sessions data are determined for a dark adaptation curve which plots the logarithm of the luminance required for a subject to discriminate the detail of a given acuity grating against time in the dark. In successive groups of sessions, different acuity gratings are used. The different gratings present line thicknesses extending from a low value of acuity to a medium value discriminable only by the cones.

APPARATUS AND PROCEDURE

The apparatus used was the Hecht-Shlaer adaptometer (Hecht and Shlaer, 1938) modified so that acuity gratings could be placed in the field, and with a central fixation object in the form of a cross.

The optical system usually used for preadaptation was not used in this experiment since, as will be seen, both eyes were used alternately during each run. The preadapting light consisted of a 75 watt frosted bulb which had been seasoned for 48 hours and which was operated at 117.5 volts dc. The lamp was housed in a wooden box, the inside of which was painted flat white, and the front of which consisted of an eight inch square of flashed opal glass. The luminance of the surface of the opal glass at this voltage was 1500 millilamberts as measured by a Macbeth illuminometer. A luminance of one millilambert (strictly speaking a unit of luminous emittance) is the luminous intensity per unit area of a perfectly diffusing surface having a luminous emittance of one millilambert, viewed normal to the surface. A head rest was provided inside the dark room. By tilting his chair back, the subject could place his head in the rest, with his eyes at a distance of 24 inches from the opal glass of the preadapting light which was located just above the front part of the adaptometer.

The source of illumination in the adaptometer was a 40 watt frosted bulb operated at 120 volts dc. Light from the bulb passed through an aperture in its containing housing and then through (a) the wedge and balancing wedge, (b) a photographic shutter and (c) appropriate filters in a filter holder. It then encountered a lens at focal distance (12 cm) from the lighted aperture and passed through a circular field stop (4.45 cm diameter) in front of and touching another lens at focal distance (36 cm) from the artificial pupil (3 mm diameter) of the eye piece.

The grating test objects were the ones that Shlaer (1937) used and described. Each one presents a pattern of alternating opaque and transparent lines of equal width. Five gratings, each with a different width

of line, were used. The corresponding visual acuity values are listed in Table 1. It was also considered worthwhile to determine dark adaptation thresholds for the area defined by the field stop that limits the size of the acuity object.

The acuity objects were placed in a special holder directly in front (i.e., "eyeward") of the filter holder. A special arrangement of the holder made it possible to rotate any grating to any one of three positions: 45 degrees clockwise (from vertical), vertical, and 45 degrees counter-clockwise.

The luminance of the source was measured by means of the special split field monocular photometer originally provided with the apparatus (Hecht and Shlaer, 1938). With half the field illuminated by a lamp calibrated with the Macbeth illuminometer at the specific operating current used, and the other half by the source to be measured, a match was obtained by adjusting the wedge, with a filter of density 2.1 in the field. The luminance was thus determined to be 13,900 millilamberts with no filters in the field and the wedge set at a reference scale reading. All the filters used were previously calibrated on the Martens photometer. A previous calibration of the wedge was verified by inserting different filters in the field and matching the calibrated field of the photometer by adjusting the wedge.

The visual angles subtended by the lines of each grating were computed relative to a measured value for a single grating. A scale was placed across the lens nearest the eye and the number of lines per inch was counted for the reference grating. Since the distance to the eye was known, the visual angle per line was easily ascertained. This value agreed with the one determined from the magnification of the optical system (3.16), the optical distance of the test object image (57.2 cm), and the actual width of the grating lines.

The red fixation cross was reflected into the center of the field by a piece of cover glass, 0.007 inch thick, placed at 45 degrees to the line of sight. The cross was cut in a thin piece of brass which was covered with a red filter and placed at approximately the same distance from the subject as the gratings. The distance of the cross was adjusted to eliminate movement parallax with the grating. The length of the arms of the cross subtended a visual angle of 22 min at the eye, the width of the arms, approximately 3 min. A rheostat enabled the subject to control the luminance of the cross.

Chin rests were placed below the single ocular in positions such that, with the chin on the left rest the right eye was in position, and with the chin in the right rest the left eye was in position for viewing the test field.

The test field, limited by the circular field stop behind the lens nearest the eye, subtended a visual angle of 7.3 degrees. Thus with

central fixation, both rods and cones were stimulated.

Two subjects were used, one male and one female. The eyes of both subjects were examined and found to be nearly emmetropic. (For SS, the right eye was found to require a spherical correction of +0.25 diopter and the left a cylindrical correction of +0.50 diopter on an axis of 80 degrees. The eyes of JB each required oblique cylindrical corrections of +0.25 diopter. The acuity of SS was found to be 20-20 by clinical standards while that of JB was 20-15.) Since the eyes of both subjects did not deviate greatly from normal standards, no correcting devices were used in the apparatus.

The present experiment involves much higher threshold luminances than are ordinarily encountered in dark adaptation studies. It would be expected, and it so turns out, that the luminance requirements for the resolution of the finest lines that we used are high, up to about 5 log units higher than the absolute threshold for the 7.3 degree visual field without any lines in it. Lights of such high luminance will certainly provide noticeable light adaptation effects which can seriously disturb the course of dark adaptation. Because of this fact, we tried to minimize the light adapting effect of the threshold light by presenting it infrequently. This objective was accomplished in the following way. In any one session the subject was given only one flash per minute, and since the two eyes alternated in viewing, two minutes elapsed between successive flashes to the same eye. At any given minute during dark adaptation the experimenter simply noted whether or not the subject correctly identified the direction of grating lines. By this method it was, of course, impossible to determine a dark adaptation curve in a given session, and thresholds had to be estimated for a given acuity on the basis of data for several sessions. In any case, the results obtained by this method seem to be reliable and they are little influenced by light adaptation due to the threshold light. (See the discussion of results.)

Before each run the subject was light adapted for five minutes to a luminance of 1500 millilamberts. During light adaptation the subject's chair was tilted back and the head was placed in a head rest. At 10 and 5 seconds before the end of the five minute period, warning signals were given. At the end of the five minute period the chair was quickly tilted forward, the chin placed in the left hand chin rest and the red cross fixated with the right eye. With practice both subjects were able to accomplish this within five seconds. Ten seconds after the end of light adaptation a warning was given, at 14 seconds a ready signal, and at 15 seconds the test field was flashed on. All flashes were of 0.04 second duration.

At the end of 45 seconds the experimenter said "left eye," at 55 seconds "five seconds," at 59 seconds "ready," and on the minute the next flash was given. This procedure was repeated once each minute for 31 minutes of dark adaptation, the subject alternating eyes for each flash. The grating was presented in any one of its three positions

according to a randomized order. The subject responded "right," "left," or "vertical" if he saw the grating, and "no" if he did not see the grating.

On the first run for any one of the five gratings used, an effort was made to adjust the luminance of successive flashes so that frequent alternations of negative and affirmative responses occurred, thereby signalling that the flashes were near, and on both sides of, the subject's threshold. Sufficient runs were taken with each grating (usually three or four) to obtain both positive and negative responses differing by not more than 0.1 or 0.2 log unit of luminance for each of at least 15 of the 32 times at which flashes were presented.

The threshold for any point in time during the period of dark adaptation was determined by taking the midpoint between the highest luminance at which a negative response was obtained and the lowest luminance at which a correct affirmative response was obtained. The few incorrect responses (as to line direction) were treated as negative responses.

RESULTS

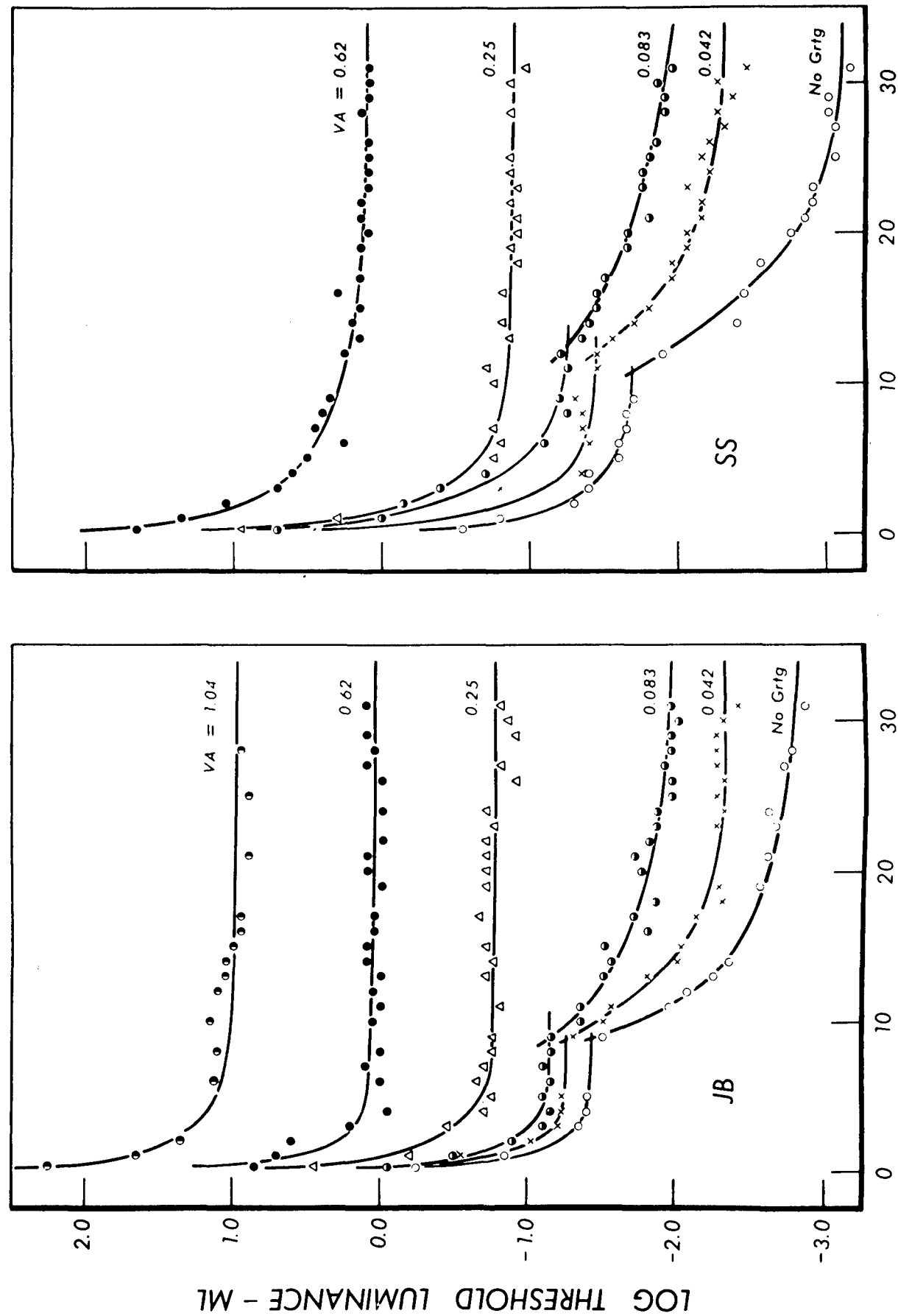
The data of the experiment are presented in Figure 1 and Table 1. Visual acuity values are given as the reciprocal of the visual angle subtended by the thickness of a line in minutes. These values are twice those computed by Shlaer's method (1937). Shlaer measured the angle subtended by the distance between the midpoints of two opaque lines. In order to make our data comparable to Shlaer's, our visual acuity values must be divided by 2.

Subject SS had considerable difficulty in reporting on the grating with the narrowest lines. For this reason the data for the highest acuity (1.04) are those of JB alone.

Subject JB's dark adaptation curves at the three highest criterion acuities (1.04, 0.62 and 0.25) are uncomplicated decelerating functions as are curves for subject SS at her two highest acuities (0.62 and 0.25). In fact, for corresponding acuities the final levels of the curves for both subjects are quite similar. Each curve starts at a high value of threshold and attains a final steady level within seven to ten minutes. Thus, the curves for the three highest visual acuities have the conventional appearance of cone dark adaptation curves (Hecht, 1937).

The curves for the visual acuities of 0.083 and 0.042, as well as the curve for no grating, differ considerably in appearance from the curves obtained with the higher visual acuities. Each of the lowest three curves for each subject starts off at a high threshold level, drops to a flat plateau, and then, after about ten to thirteen minutes, shows a secondary decrease that reaches a final level by about thirty minutes. The data for both subjects are comparable. We are unwilling to say that the change in direction of the curve at the "rod-cone break" varies in time with acuity level. There is some evidence for such an effect in the data of SS but none in the data of JB.

The three lowest curves of each subject of Figure 1 have the appearance of dark adaptation curves that show initial activity by the cones and



T I M E I N M I N U T E S

FIGURE 1: LUMINANCE THRESHOLDS FOR DIFFERENT ACUITIES DURING DARK ADAPTATION. THE NUMBER BESIDE EACH CURVE REFERS TO THE LEVEL OF ACUITY. DATA FOR SUBJECTS JB AND SS.

TABLE 1

Log threshold luminance in millilamberts at different times in the dark for different visual acuities and for no grating. 3 mm artificial pupil. Duration of flash: 0.04 second. Field diameter: 7.3 degrees. Brightness of preadapting light is 1500 millilamberts viewed binocularly without artificial pupil. Subjects JB and SS.

Time (min)	Log threshold luminance											
	Visual acuity = 1.04		0.52		0.25		0.083		0.042		No grating	
	JB	SS	JB	SS	JB	SS	JB	SS	JB	SS	JB	SS
0.25	2.25		0.85	1.65	0.45	0.95	-0.05	0.70		0.45	-0.25	-0.55
1	1.65		0.70	1.40	-0.20	0.30	-0.50	0.00	-0.55		-0.85	-0.80
2	1.35		0.60	1.05			-0.90	-0.15	-1.03			-1.30
3			0.20	0.70	-0.45		-1.10	-0.40	-1.20	-0.30	-1.35	-1.40
4			-0.05	0.60	-0.70		-1.15	-0.70	-1.23	-1.35	-1.40	-1.40
5				0.50	-0.75	-0.75	-1.10		-1.23		-1.40	-1.60
6	1.13		0.00	0.25	-0.65	-0.80	-1.15	-1.10		-1.40		-1.60
7			0.10	0.45	-0.70	-0.75	-1.10			-1.35		-1.65
8	1.10		0.00	0.40	-0.75		-1.15	-1.25		-1.35		-1.65
9				0.35	-0.75		-1.15	-1.20	-1.30	-1.30	-1.50	-1.70
10	1.15		0.05			-0.75	-1.35		-1.50			
11			0.00		-0.80	-0.70	-1.35	-1.25	-1.55	-1.45	-1.95	
12	1.10		0.05	0.25				-1.20		-1.45	-2.08	-1.90
13	1.05		0.00	0.15	-0.70	-0.85	-1.50	-1.35	-1.80	-1.55	-2.25	
14	1.05		0.10	0.20	-0.75	-0.80	-1.55	-1.40	-2.00	-1.70	-2.35	-2.40
15	1.00		0.10	0.15	-0.70		-1.50	-1.45	-2.03	-1.80		
16	0.95		0.05	0.30		-0.30	-1.80	-1.45				-2.45
17	0.95		0.05	0.15	-0.65		-1.73	-1.50	-2.13	-1.95		
18						-0.90	-1.85		-2.30	-1.95		-2.55
19			0.00	0.15	-0.70	-0.35		-1.65	-2.28	-2.05	-2.55	
20			0.10	0.10	-0.70	-0.30	-1.75	-1.65		-2.05		-2.75
21	0.90		0.10	0.15	-0.70	-0.90	-1.70	-1.80		-2.15	-2.60	-2.85
22			0.00	0.15	-0.70	-0.95	-1.80			-2.15		-2.90
23				0.10	-0.75	-0.90	-1.85	-1.75	-2.25	-2.05	-2.65	-2.90
24			0.00	0.10	-0.70	-0.95	-1.85	-1.75	-2.30	-2.20	-2.60	
25	0.90			0.10		-0.85	-1.95	-1.80	-2.25	-2.15		-3.05
26			0.00	0.10	-0.90		-1.95	-1.85	-2.30	-2.20		
27			0.10		-0.80		-1.90		-2.25	-2.30	-2.70	-3.05
28	0.95		0.05	0.15		-0.85	-1.95	-1.90	-2.25	-2.25	-2.75	-3.00
29			0.10	0.10	-0.90		-1.95	-1.90	-2.25	-2.35		-3.00
30				0.10	-0.85	-0.85	-2.00	-1.85	-2.30	-2.25		
31			0.10	0.10	-0.80	-0.95	-1.95	-1.95	-2.40	-2.45	-2.85	-3.15

delayed activity by the rods. Thus the data of our experiment, which uses a centrally fixated threshold area extending well beyond the limits of the fovea, are in accord with interpretations as to the course of dark adaptation made by other experimenters (see Hecht 1937 for a summary). The initial stage of dark adaptation for areas that contain both cones and rods is due to cones; later stages manifest the activity of rods.

Visual acuity is a parameter that sets the ordinate position of each curve. The curve for the highest visual acuity is highest on the ordinate, and curves for successively smaller visual acuities are displaced downward in a systematic way. This systematic displacement is true not only for the simple cone curves, but it is also true for the three lower curves that show both rod and cone segments. The threshold increases as visual acuity increases.

The lowest threshold is given by the condition of no grating, i.e., by an unlined configuration within the area defined by the field stop. Because of the fact that the area of retinal stimulation represents a heterogeneous population of rods and cones it is probably not worth while to relate the findings for the no grating condition and the lowest acuity to area-intensity considerations (Graham, Brown and Mote, 1939).

The shapes of the three highest curves for JB and the two highest for SS are similar. In fact, appropriate displacement along the ordinate axis would probably cause all of the cone curves to be superimposed.

There is some indication in the three lowest curves for each subject that the rod branch for the visual acuity of 0.083 descends more slowly than the rod branches for the two lowest curves. We are not ready to labor this point since influencing considerations (e.g., the fact that the critical duration of the threshold light may be affected by luminance) come to mind but do not diminish the significance of the qualitative result. A more appropriate choice of stimulus location and an experimental design specifically aimed at analyzing this problem would be desirable.

It will be recalled that our method of determining thresholds involves widely spaced presentations and computations based on data for successive days. Figure 1 shows that the results obtained by this method do exhibit some scatter but that, in general, a high degree of consistency emerges.

It seemed to be worth while to test the possible influence of light adaptation effects due to the presentation of the threshold light, particularly at the highest acuity level (i.e., 1.04).

To this end JB's thresholds at 12 and 13 minutes of dark adaptation were compared with his thresholds at 12 and 13 minutes of dark adaptation without preceding threshold flashes. Thresholds were estimated from the data of three successive sessions in the following way. In any single session, JB was light adapted for 5 minutes at the pre-adapting luminance of the experiment. He then became dark adapted for 12 minutes at which time a flash was presented to his right eye. He

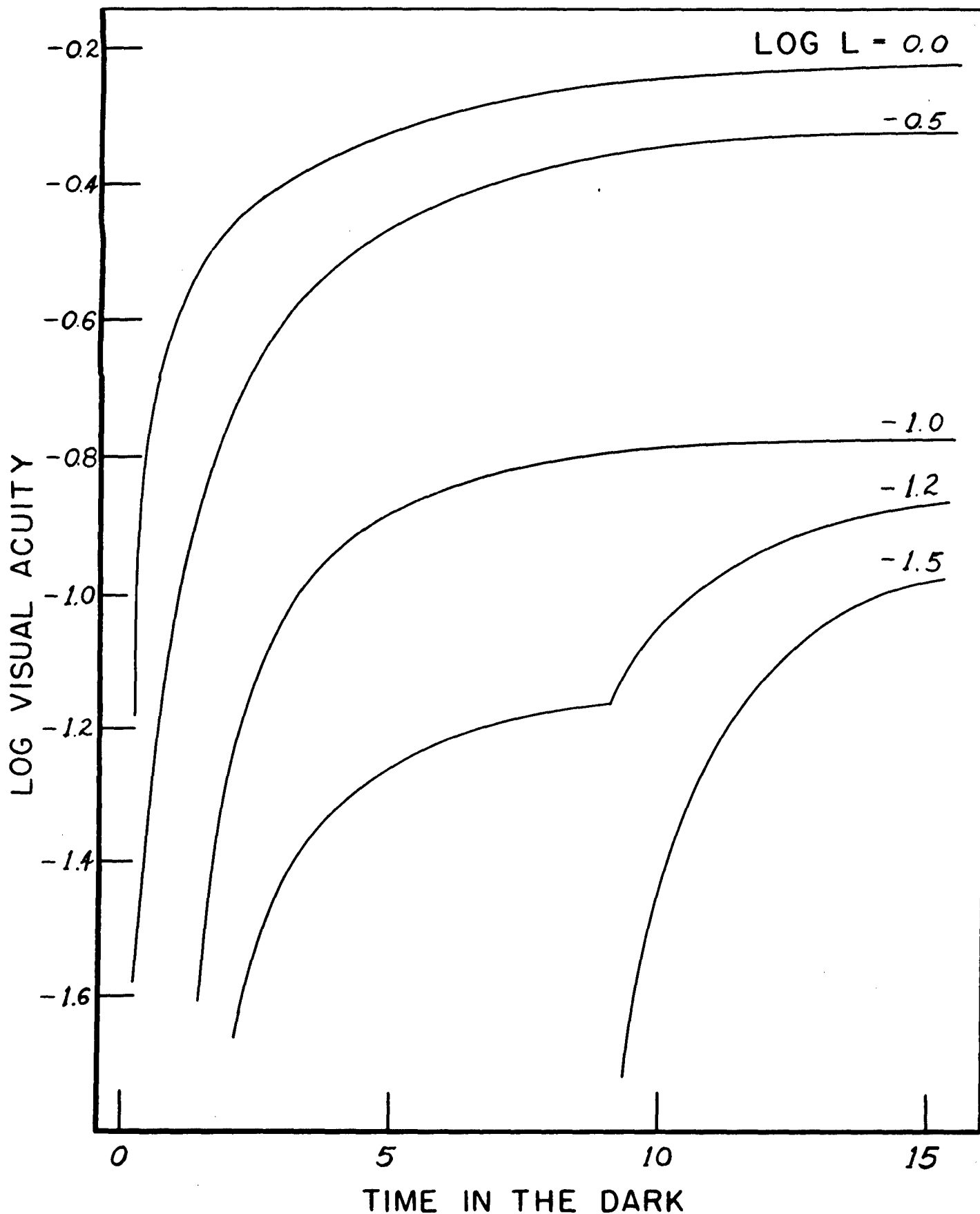


FIGURE 2: VISUAL ACUITY AT CONSTANT GRATING LUMINANCE AS A FUNCTION OF TIME IN THE DARK. CURVES ARE COMPUTED FROM THOSE OF FIGURE 1. THE NUMBER BESIDE EACH CURVE SPECIFIES THE CONSTANT VALUE OF GRATING LUMINANCE.

reported on the direction of the fine grating. At the 13th minute a flash was presented to his left eye and he made a similar judgment. The thresholds so obtained from the data of three successive sessions turned out to be 1.05 log millilamberts for 12 minutes, and 0.95 log millilamberts for 13 minutes. These figures are to be contrasted with those obtained in the regular series: 1.10 log millilamberts for 12 minutes, and 1.05 log millilamberts for 13 minutes. These results give no indication that preceding light adaptation due to the threshold light had any influence on the threshold at 12 and 13 minutes of dark adaptation. Light adaptation due to the method of determining threshold is probably not a factor in the curves of Figure 1.

DISCUSSION

The results of this experiment show that dark adaptation curves obtained at different criterion visual acuities have the characteristic shape observed in experiments on light detection thresholds. A high criterion visual acuity gives only the initial cone curve and a low visual acuity gives the cone curve and a delayed rod curve. Visual acuity is a parameter that sets the position of the given curve on the log threshold axis. The higher the visual acuity, the higher the dark adaptation threshold. All of these relations are shown in the curves of Figure 1.

It is possible to recompute the data of Figure 1 to show how visual acuity varies with time in the dark for a constant luminance of visual acuity object. This procedure may be carried out by observing how the visual acuity parameter of Figure 1 varies at different times in the dark along any one of a number of horizontal lines drawn at various log threshold values of the ordinate. Such data are given in Figure 2 which shows visual acuity as a function of time in the dark for four arbitrarily chosen levels of threshold luminance (results of JB). The curve for a medium threshold luminance value ($\log L = 0.0$) rises very rapidly and achieves a final high maximum in a relatively short time (about 10 minutes). The curve for a lower luminance ($\log L = -0.5$) rises less rapidly and achieves a lower maximum acuity. The curves for $\log L = -1.0$ and -1.5 show successively lowered maxima, slower rises to the maxima and, finally, increased delays in initial starting times.

Figure 2 shows that visual acuity rises earlier and more rapidly to a maximum and achieves a higher maximum during dark adaptation when the luminance of the threshold object increases. This means, practically, that "fine" instrument markings (that are analogous to our "fine-line" threshold object), should be illuminated as brightly as possible for conditions that exist when the pilot has been subjected to glare sources, e.g., the sky. If the markings are coarse, a lower degree of instrument illumination may serve. In any case, the data of Figure 1 show that visual acuity reaches a maximum that is dependent upon test patch luminance. Unless a minimum level of luminance is provided, visual acuity may never reach a (necessary) critical value for the seeing of a given detail.

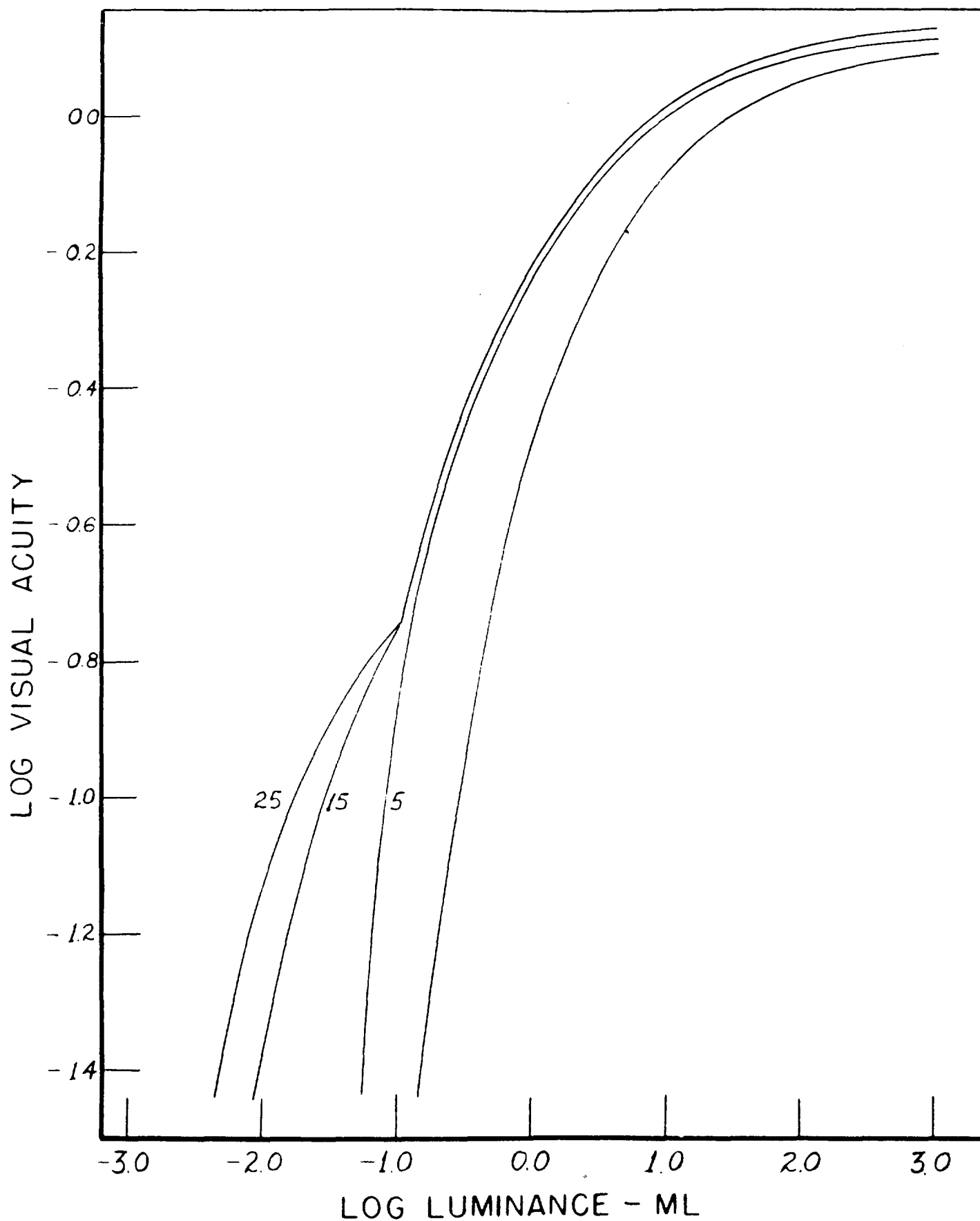


FIGURE 3: VISUAL ACUITY AS A FUNCTION OF GRATING LUMINANCE. DATA ARE COMPUTED FROM THE CURVES OF FIGURE 1. THE NUMBER BESIDE EACH CURVE REFERS TO A CONSTANT VALUE OF TIME IN THE DARK.

Figure 3 shows how log visual acuity varies with log luminance for constant, arbitrarily chosen periods of dark adaptation (data of JB). (These curves were obtained from those of Figure 1 by noting how the visual acuity parameter varies with log luminance along selected vertical lines that intersect the time axis at arbitrarily chosen positions.) Log visual acuity increases at all dark adaptation times with log luminance. Those curves of Figure 3 that were determined for the early stages of dark adaptation do not show a rod branch, but that branch is apparent in the curves for 15 to 25 minutes of dark adaptation. The luminance required to produce a given visual acuity decreases as duration of dark adaptation increases, but in general, the curves attributable to cone function alone (1 and 5 minutes) seem to be parallel on the log luminance axis, as do the cone branches of the duplex curves (15 and 25 minutes). The rod branches of the latter two curves differ slightly in slope.

SUMMARY

1. The luminance threshold for a subject's visual resolution of differently sized grating lines was determined at various durations of dark adaptation following exposure to a preadapting light. The preadapting illumination was a "white" light at a luminance of 1500 millilamberts; the subject was adapted to it for five minutes. The grating lines appeared for an exposure duration of 0.04 second within a centrally fixated circular area of 7.3 degrees in diameter. Each grating presented alternating light and dark lines of the same width; the width varied in the different gratings. Corresponding degrees of visual resolution were specified in terms of visual acuity, a measure that is equal to the reciprocal of the just resolvable line width in minutes of arc.
2. Each dark adaptation curve obtained at a given visual acuity has the characteristic shape observed in experiments on light detection thresholds. The finest gratings, representing high degrees of visual acuity, show only a single cone curve that drops from a high luminance threshold during the first moments of dark adaptation to a final steady level that is reached after about 7 to 10 minutes in the dark. Coarse gratings produce a duplex curve that shows the initial cone portion and a delayed rod portion, with a greatly lowered final threshold.
3. Visual acuity is a parameter that sets the position of a given curve on the log threshold axis. The higher the degree of resolution required, the higher the luminance threshold during dark adaptation.
4. At a constant grating luminance, visual acuity rises rapidly to a maximum during dark adaptation. The higher the luminance, the earlier and more rapid the rise and the higher the maximum. Some implications of this finding are discussed.
5. Log visual acuity increases at all dark adaptation times with an increase in log luminance. At short durations of dark adaptation, the log acuity vs log luminance function represents the activity of cones; at longer durations, the function shows a rod branch at low luminances.
6. The implications of these results for instrument illumination are discussed.

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