MEDICAL EVALUATION OF NUTRITIONAL STATUS[1]

II. MEASUREMENT OF VISUAL DARK ADAPTATION WITH THE ADAPTOMETER

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INTRODUCTION

THE measurement of visual dark adaptation described in this report was part of a cooperative nutrition study, which was directed toward an appraisal of methods of investigating the nutritional status of apparently well persons. The purpose and scope of the study and procedures employed have recently been described (1).

In nutritional examinations, dark adaptation measurements are a basis of inference regarding the presence of nyctalopia, a condition of impaired retinal sensitivity under dim illumination, arising from avitaminosis A. The sensory phenomenon of dark adaptation, as expressed in threshold measurements, reflects the synthesis of photosensitive pigment and the corresponding recovery of sensitivity of the retina after exposure to light. The regression of threshold upon time in the dark describes the course of the individual's retinal recovery.

The present report on dark adaptation represents an attempt to obtain information on the accuracy of threshold measurements obtained with a particular adaptometer. The demarcation between adequacy and deficiency in vitamin A nutrition, we believe, cannot be defined satisfactorily until the accuracy of threshold measurements has been evaluated and the major factors other than vitamin A, contributing to the variability of threshold measurements are

[1] This paper is the second of a series from a cooperative investigation by the Milbank Memorial Fund; the New York City Department of Health; the United States Public Health Service, Division of Public Health Methods; and the Cornell University Medical College, Department of Public Health and Preventive Medicine and Department of Pediatrics.

The cooperating agencies have been assisted in carrying out this investigation by the Work Projects Administration for the City of New York, Official Project No. 65-1-97-21, W.P. 24, "Medical Evaluation of Nutritional Status."

identified. Such preliminary evaluation of the technique of measurement provides essential information whereby experimental error can be minimized and discriminating observations can be made with respect to such nutrition categories as may later be defined.

MATERIAL AND METHODS

The Adaptometer. Measurements of dark adaptation dealt with in this report were made with the adaptometer designed and described in detail by Hecht and Shlaer (2). This adaptometer is a device for exposing one eye of a subject to a light of standardized brightness (preadaptation) and for measuring the dark adaptation of that eye by determining, at specified intervals of time, the threshold of perception of light stimuli of measured intensity. An instrument, constructed according to the specification of Hecht and Shlaer, can be purchased in the commercial market.[2] So obtained, the adaptometer is considered complete for routine measurement of dark adaptation. Three of these adaptometers, carrying the manufacturer's serial numbers 5, 9, and 16, were obtained and used in the present study.

Procedure of the Test. Except for certain details which will be considered later, the test procedure used in the present study was that described by Hecht and Shlaer (2). The right eye of the subject was always tested unless it was missing or presented an obvious abnormality. The location of the retinal field involved both in preadaptation and in dark adaptation was determined by adjusting the light and dark fixation points so that the points were viewed 7° nasally. Preadaptation time was held constant at 3 minutes and covered a retinal area of approximately 35° in diameter. The flashes of light used during dark adaptation were adjusted at 0.2 second and covered an area 3° in diameter. The violet filter (Corning 511) was always used for the threshold determinations so that only wave lengths below 460 millimicrons were transmitted. Threshold

[2] From Mr. O. C. Rudolph, 55 Van Dam Street, New York, N. Y.

measurements were made during the first minute following pre-adaptation and thereafter at intervals of from 2 to 4 minutes for a period of from 30 to 40 minutes. The brightness of the adaptation light and of the test flash during dark adaptation was expressed in the logarithm of micromicrolamberts ($\mu\,\mu\,l$).

The classification of the several observations during a given adaptation into rod or cone, was accomplished by a consideration of the speed and velocity of adaptation during the first 15 minutes as well as the reported color of the image. We have found color reports under field conditions too inconsistent with expected results to serve as a certain basis for distinguishing cone and rod thresholds. The terms, cone and rod, are used in this discussion to refer respectively to thresholds before and thresholds after the first apparent plateau during adaptation, without implication as to its reality or its physiological significance.

The three adaptometers used in the study were operated in a dark room in which separate booths were arranged for each instrument. A partition in each booth, through which the eye piece of the adaptometer projected, furnished two cubicles, one for the subject and the other for the technician and adaptometer. By this arrangement the subject was completely shielded from stray light during the test. An adjustable chair, and an arm rest placed below the eye piece of the adaptometer, were provided for the subject.

The procedure of determining a threshold during dark adaptation was to obtain a series of verbal responses from the subject to a number of flashes of light given in fairly rapid succession. The threshold was the brightness, between narrow limits, which corresponded, respectively, to images seen ("Yes," response), and images not seen ("No," response). The technician reduced the limits as much as possible by varying the intensity of illumination in relation to the subject's verbal responses. In general, the brightness of the test flash was decreased when the subject's response was "Yes," and increased when the response was "No." The brightness recorded as the threshold was the critical level dividing "Yes" and "No" responses. The time, at which the critical level was obtained, was recorded as the observation-time of the threshold.

Before the beginning of the test, the technician explained its characteristics to the subject, mentioning the preadaptation period, and the subsequent dark adaptation in order to familiarize the subject with the test and his rôle in it. The technician also exhibited several flashes at different intensities and the subject was given some preliminary experience in responding, after each operation of the shutter, as to whether the test light had been seen or not. The subject was instructed also to view the dark point during light adaptation and the light point during dark adaptation, and inform the technician, in the latter case, when the point was more than just perceptible in order that the technician might maintain the light fixation point at the just perceptible level.

Technicians. The instruments were operated by three laboratory technicians under the supervision of a senior technician of the field service of the United States Public Health Service. Each of the technicians was instructed in the procedure of the test by the same supervisor and had field experience before making regular examinations.

Instrumental Variations

Experimental work with the three commercially procured adaptometers clearly indicated that comparable dark adaptation data would not be obtained from the three different instruments if they were used as purchased. For example, it was found that repeated tests made on the same subject with the same adaptometer were very similar. Other tests, on the same subject, made on a different adaptometer, were grossly and significantly different from those made on the first adaptometer. Since it was essential that data from the several adaptometers be directly comparable, a study was made of the sources of these instrumental variations. As a result of this study, and the changes subsequently made in the instruments, it was found possible to obtain comparable results with the three different adaptometers. The elimination of differences between the adaptometers is of interest as a special case of the more general problem of maintaining comparability of data from different laboratories using this type of adaptometer. Uniformity of apparatus and procedure will promote the collection of comparable data and minimize the purely technical sources of difference which are often confounded with nutritional, biological, or regional factors.

Differences in Optical Parts. The first source of instrumental variation involved differences in the composition of the "neutral" wedge and filters which are parts of the intensity control assembly. The adaptometers having serial numbers 5 and 9 were found to be equipped with Wratten gelatin-between-glass wedges while the wedge in instrument number 16 was made of Jena glass. The set of "neutral" filters for adaptometer 5 were Wratten gelatin-between-glass while those for instruments 9 and 16 were Jena glass. After some use, the gelatin-between-glass wedge and balancer of adaptometer 5 were found to have become noticeably faded and the cementing material was affected. It is well known that the physical properties of gelatin-between-glass units are impermanent and their calibrations accordingly unstable. Since the calibrations of glass wedges and filters can be depended upon, all gelatin-between-glass parts were replaced by glass parts.

Calibration of Violet Filters. The second source of instrumental variation involved the density factors of the violet (Corning 511) filters which are used during the dark adaptation part of the test. According to the data supplied by the manufacturer these factors for the filters in instruments 5, 9, and 16 were, respectively, 3.011, 2.721, and 2.723. A check of the calibrations at the United States Bureau of Standards[3] resulted in the following values: 2.932, 2.932,

[3] The method of calibration used at the United States Bureau of Standards depends on a determination of spectral distribution of transmission on a recording photoelectric spectrophotometer. The transmission factors for incandescent lamp light at 2700°K were computed from these data and using I.C.I. luminosity factors. (3)

and 2.943 for the filters from instruments 5, 9, and 16, respectively. Differences between the maker's density factors and those obtained at the Bureau of Standards apparently derive from different methods of calibration. The practical results of adopting the new calibrations were: threshold values obtained on instruments 9 and 16 were dropped to the lower level characteristic of instrument 5 and the calibration of the chromatic filters was placed on a standard and more reliable basis.

Calibration of the Light Source. A third type of variation arose in connection with the problem of estimating the brightness of the light source in the adaptometer. This source, which is used both in preadaptation and in the dark adaptation phase of the test, is a fixed ground-glass window of the lamp housing which is illuminated by an ordinary commercial 40-watt, inside-frosted tungsten filament lamp operated on a definite current, 115 volts. A precise measurement of the brightness of the light source is a necessary part of the operation of the adaptometer since the brightness value figures directly in the calculation of each threshold determination. The measurement of brightness is necessary also whenever a lamp burns out, or is replaced, and is desirable from time to time as a check on changes in the lamp. Obviously, it is necessary that the user of the adaptometer be able to measure this brightness accurately. For this purpose, each commercial adaptometer is provided with a "standard reference lamp." The procedure of measurement involves a matching of the brightness of the light source of the standard lamp with that of the adaptometer. In actual practice this entails a heterochromatic match. In instrument 9, for example, the half of the field illuminated by the light source of the adaptometer was greenish in hue, whereas the other half of the field illuminated by the standard lamp appeared to be orange. The difficulty of matching brightness when the sources compared are different in color is well known (3).

Study of the use of the standard reference lamp in calibrations of the adaptometer light source showed that estimates of brightness obtained by different observers were highly variable. It was found, for example, that three different observers estimated the brightness (log of μ μ l) of the source light of instrument number 16, as 12.606, 12.689, and 12.817, respectively. For instrument number 5, the same observers reported 12.364, 12.072, and 12.316 as the brightness. These results are mentioned to illustrate the range of results when the brightness of the adaptometer light source was repeatedly matched to that of the standard lamp as reference by different observers.

Table 1. Variance of measurements of brightness of the source when calibrated with the standard lamp of the adaptometer.

Source of Variation	Degrees of Freedom (Number)	Mean Square (log of μ μ l)^2
TOTAL	239	1.429
Between Different Observers	14	21.655*
Between Repeated Readings by Same Observer	222	.006
Combined Error of Observation	236	1.291

* $p<.01$.

To obtain a measure of error of this method of calibration of the source, an analysis of variance was made of 240 observations contributed by five different observers for light sources whose brightness was in the neighborhood of 12.00 log units. Each observation involved a match of the brightness of the source of the adaptometer with that provided by the standard lamp, by variation of the wedge setting of the adaptometer. Table 1 shows the variance of the observations for the same observer and for different observers. From this analysis it appeared that the variance of observations repeated by different observers, is 1.291. This estimate included the variance between different observers as well as the variability of repeated readings by the same observer. Since the variance of such observations was large, it follows that the actual brightness was subject to considerable uncertainty. Thus, for theoretical sample means of fifteen repeated observations by different observers the chances were 19 to 1 that the actual mean brightness was within the interval ± .572 log units. The value ± .572 serves to indicate the extent to which the inferred brightness could vary and still be consistent with the sample observations.

The inability of different observers to arrive at results which correspond more closely made it necessary to find a more reliable method for the calibration of the light source of the adaptometer. Use of the Macbeth illuminometer, in place of the standard reference lamp supplied with the adaptometers, appeared to be satisfactory. An analysis of variance similar to that described above was made for observations obtained with this illuminometer. For theoretical sample means of fifteen repeated observations by three observers, the chances were 19 to 1 that the actual mean brightness was within the interval ± .01 log units. Observations with the Macbeth illuminometer provided, therefore, the highly discriminating information which is necessary regarding the brightness of the source of light in the adaptometer despite plurality of observers.

Other ways of obtaining reliable estimates of the light source in the adaptometer are of course possible. Thus the standard reference lamp might be modified to eliminate the heterochromatic comparison. Suitable filters would reduce the discrepancy in color between reference field and the light source of the adaptometer. The color difference between the reference and the adaptometer source would be reduced if the standard lamp were operated more nearly at rated current. If the latter expedient were adopted, the reference lamp of the standard would need to be housed so that its position could be varied. A combination of these or similar modifications would increase the reliability of results with the standard lamp.

Differences of Brightness in Preadaptation. Specifications for the adaptometer indicate that the 40-watt lamp operated at 120 volts will provide a source for preadaptation whose brightness is in the neighborhood of 12.176 log units of $\mu\ \mu\ l$ (1,500 millilamberts). It is generally agreed that such small differences as might be found in the brightness of commercial 40-watt lamps would not materially affect the thresholds of light perception determined during dark adaptation. However, the effective brightness of the light source from such lamps may vary under operating conditions.

Estimates of the brightness of the preadaptation lights in adaptometers numbers 5 and 16 were made with the Macbeth illuminometer and found to be, respectively, 11.793 log units (approximately 620 millilamberts) and 12.024 log units (approximately 1,060 millilamberts). While this difference is not large, it is greater than could be explained by the random variation alone, of 40-watt, commercial tungsten filament lamps. Two questions are raised by this finding: First, what instrumental factors bring about the variation in different adaptometers? Secondly, do differences of this magnitude give rise to physiologically significant differences in dark adaptation?

A partial answer to the second question was obtained from an analysis of tests of 175 children made with instrument number 16 and of 179 children made with instrument number 5. Data from this analysis are shown in Table 2 and Figure 1. The means of threshold at successive minutes in the dark, following the slightly greater preadaptation of 12.024 log units on instrument 16, were consistently higher than the corresponding means after preadaptation on instrument 5 with 11.793 log units, except after 20 minutes in the dark.

If the difference in preadaptation brightness was much greater than in the above tests (0.231 log units), the differences in threshold values before 20 minutes in the dark were larger, and significant differences were found as well after 20 minutes in the dark. A number of individuals were tested with varying preadaptation brightness. Figure 2 illustrates, for two individuals, the course of dark adaptation following differences in preadaptation bright-

Minutes in the Dark	Instrument 16		Instrument 5	
	Preadaptation Brightness (μ μ l) 12.024 Log Units		Preadaptation Brightness (μ μ l) 11.793 Log Units	
	Cases Observed at Time Specified	Mean Threshold (Log of μ μ l)	Cases Observed at Time Specified	Mean Threshold (Log of μ μ l)
Cones				
.5	172	6.436	179	6.217
1.5	3	6.145	0	—
2.5	157	5.847	163	5.651
3.5	15	5.722	14	5.693
4.5	94	5.561	94	5.360
5.5	52	5.420	60	5.309
6.5	26	5.337	27	5.145
7.5	24	5.254	33	5.107
8.5	9	5.168	4	5.075
Rods				
7.0	58	4.693	54	4.406
8.0	46	4.230	52	4.046
9.0	50	4.051	46	3.779
10.0	81	4.006	88	3.852
11.0	56	3.678	74	3.475
12.0	52	3.719	46	3.396
13.0	84	3.470	82	3.366
14.0	63	3.352	65	3.186
15.0	46	3.218	55	3.114
16.0	78	3.181	75	3.024
17.0	56	3.100	56	2.994
18.0	49	2.902	48	2.811
19.0	61	2.936	59	2.907
20.0	54	2.831	60	2.833
21.0	48	2.779	53	2.698
22.0	51	2.714	49	2.740
23.0	56	2.656	54	2.631
24.0	56	2.607	66	2.629
25.0	51	2.597	49	2.598
26.0	58	2.552	54	2.569
27.0	55	2.508	54	2.511
28.0	50	2.511	61	2.510
29.0	59	2.457	50	2.493
30.0	56	2.463	65	2.447
31.0	48	2.436	43	2.496
32.0	51	2.409	60	2.438
33.0	50	2.445	59	2.436
34.0	58	2.423	51	2.469
35.0	50	2.398	62	2.437
36.0	53	2.414	56	2.424
37.0	47	2.422	35	2.434

Table 2. Mean threshold during dark adaptation after preadaptations differing in brightness by 0.23 log units.

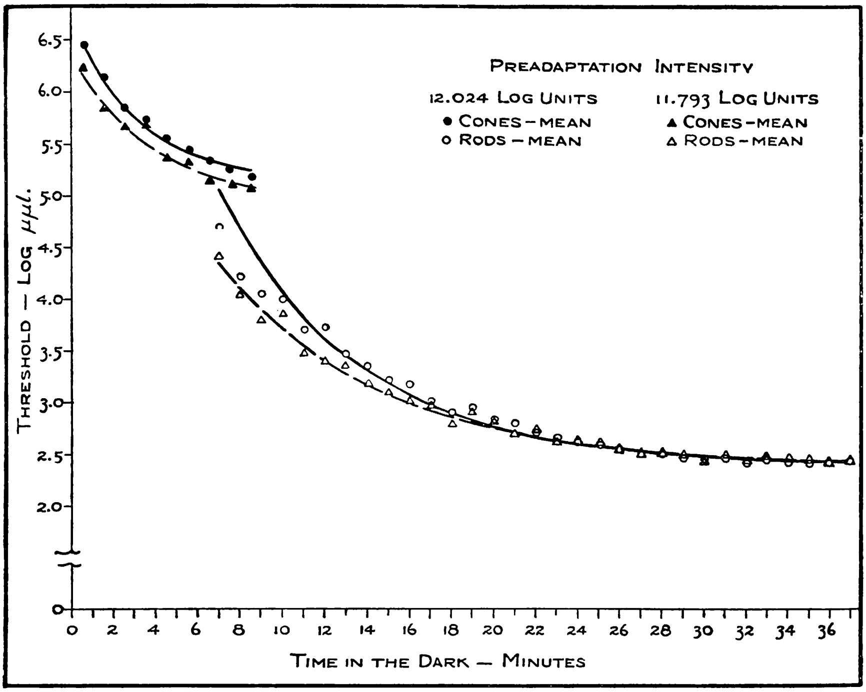


Fig. 1. Regressions of mean threshold during dark adaptation after preadaptation with lights differing in brightness (intensity) by 0.23 log units.

ness of approximately 0.5 log units. In the case of one subject (T. Z.), the differences in threshold, presumably due to preadaptation difference, were evident and large, until 28 minutes in the dark. The response of the other subject was similar. The discrepancy in the threshold curves illustrated by these subjects was representative of the results obtained for other subjects in a series of such tests. The analysis of this question in general indicated that if thresholds earlier than 30 minutes are to be used and compared, uniform preadaptation is indispensable.

Adjustment and Control of Brightness in Preadaptation. Since it appeared necessary, an attempt was made to adjust the preadaptation brightness of the three adaptometers to a uniform value. To date, this attempt is not considered entirely satisfactory.

A priori considerations indicated that the differences among the

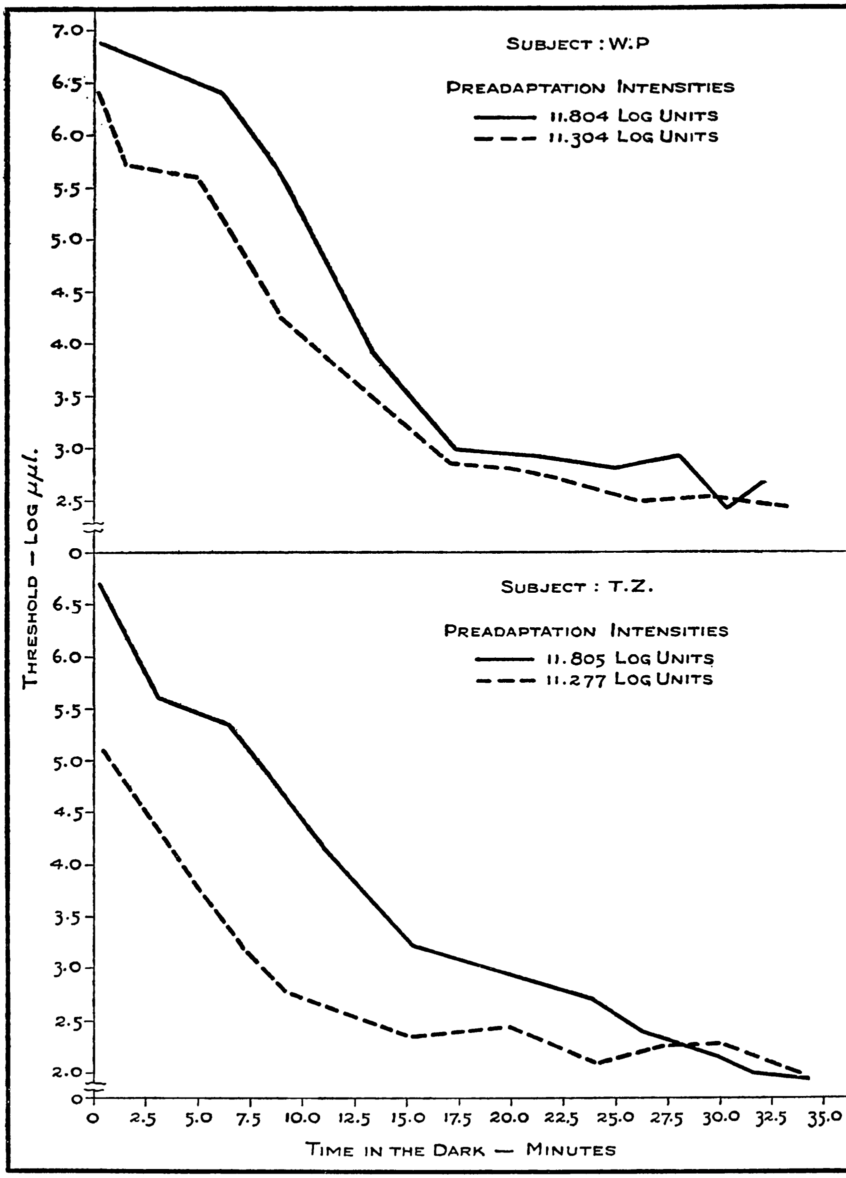


Fig. 2. Dark adaptation curves for two subjects (W.P., T.Z.) after preadaptations with lights differing in brightness (intensity) by approximately 0.5 log units.

three adaptometers were due to some combination of the following factors: (a) differences of one-quarter transmitting "neutral" filters used during preadaptation, (b) position of the lamps as placed in their sockets, (c) distances of the lamps from the ground-glass windows of the housings, (d) differences in the thickness or composition or installation of the ground-glass windows. Although no study of the relative importance of these factors has been made, it was likely that they accounted for a major part of the observed difference in the brightness of the preadaptation lights. While it probably would be most desirable to equalize the preadaptation brightness of the several instruments by varying the distance between the lamp and the ground-glass window of the housing, the structural changes required did not appear feasible without considerable alteration of the present design of the adaptometer.

The method finally adopted to equalize preadaptation brightness for the present study was an adjustment of the operating current by means of a manually-controlled rheostat and voltage regulator assembly attached to each adaptometer. It was found that the maximum uniform brightness to which the three adaptometers could be adjusted, by variation of operating current, was 12.002 log units (1,004.4 millilamberts). The reference standard of brightness, while adjusting the operating current of the individual adaptometers, was the Macbeth illuminometer, set to provide 1,004.4 millilamberts. The one-fourth transmitting "neutral" filter was in its position for preadaptation, while the brightness of the adaptometer light source was matched to that of the reference standard, by the requisite adjustment of operating current. Thus, the adjusted current compensated differences between the one-fourth transmitting "neutral" filters as well as those from sources previously mentioned. When illuminated by a 40-watt lamp, the window of the lamp housing of adaptometer 5 did not yield the desired 12.002 log units of preadaptation brightness. A 50-watt lamp has been installed in this adaptometer. Table 3 summarizes the details of the operating conditions.

In the case of instrument 16, the adaptometer lamp was operated

Instrument Number	Working Lamp (Watts)	Operating Current (Volts)	Brightness of Source (Log of μ μ l)	Density of ¼ Transmitting "Neutral" Filter (Log of μ μ l)	Preadaptation Brightness (Log of μ μ l)
5	50	111.4	12.522	.520	12.002
9	40	109.1	12.512	.510	12.002
16	40	106.7	12.529	.527	12.002

Table 3. Operating conditions of different adaptometers, modified to obtain uniform brightness of preadaptation.

at approximately 13 volts below rated current. The respective operating currents of the other instruments fell short, also, by smaller amounts of the rated voltage. A change of 10 volts causes a change of about 100 degrees in color temperature for the 40-watt, 120 volt, inside-frosted lamp and a corresponding slight decrease in the transmitting factor of the violet filter. The color temperature of the 40-watt lamp, such as that installed in adaptometer 9, for example, is in the vicinity of 2,700°K when rated current of 120 volts is applied to the terminals. The density assigned to the violet filter at this color temperature was 2.932. At 2,600°K the density of the same filter would be 2.971. The small change in density was a negligible source of variation in threshold compared with the differences attributable to discrepancy in preadaptation brightness when the adaptometers were operated without compensating adjustments of current. The adjustment of current alone was adopted temporarily as the most feasible expedient to bring about uniform preadaptation brightness.

A preadaptation brightness of 12.00 log units (approximately 1,000 millilamberts) was selected primarily because of structural characteristics of the adaptometers and certain operating conditions which obtained in the present study. In order to make possible the direct comparison of dark adaptation data from different laboratories, there obviously must be general agreement among workers in the field to use this or some other standardized brightness value.

Errors of Measurement

The accuracy of the dark adaptation test, like other physiological tests, is dependent upon a complex of factors which may be grouped together under the general heading of "errors of measurement." For example, the accuracy of a particular threshold during dark adaptation is dependent upon the accuracy of the technician's reading of the wedge setting, upon the subject's attention at the moment of the flash of light, upon the precision with which the subject followed instructions during the preadaptation phase of the test, and upon many other variable factors. An attempt has been made to measure several of the more obvious sources of errors of measurement in the adaptometer test.

Variation in the Perception of the Test Light During Dark Adaptation. Determination of the threshold during dark adaptation must depend to some extent on the subject's interpretation of how bright the test light must be before he reports that he is just able to see it. That is, subjects probably differ considerably with respect to their definition of perceptible and nonperceptible flashes of light. Further, the same subject may change during the course of a test his definition of what is perceptible. A limited set of observations was made with a carefully trained subject to determine the magnitude of this source of variation.

After a period of 30 minutes in the dark, the subject was asked to respond to each of four successive series of flashes according to the following four respective grades of perceptible test flashes:

1. Images which were just perceptible as a presence, or perhaps a glow, but without form and without luminous effect.
2. Images which were definitely perceptible, more than a glow, but still without form and only a slight luminous effect.
3. Images which were characterized by a slight form effect, not well defined, and only faintly luminous.
4. Images which were bright and with form sufficiently well defined to be described as approaching a circle.

For each class of image the subject was shown the usual short series of flashes. The threshold was determined for each of the image groups in the order given. The results show that there was a gradual elevation of the threshold as the definiteness of the image increased with respect to form and luminous effect. The means of these thresholds, in each image group, are summarized in Table 4.

Table 4. Mean threshold according to subject's definition of perceptible image.

Definition of the "Image Perceived," Controlling "Yes" Response of the Subject	Number of Observations	Mean Threshold (Log of $\mu\mu l$)
1. Just Perceptible, Form and Color Absent	9	2.647
2. Definitely Perceptible	9	2.879
3. Form Present	13	3.134
4. Bright Image with Form	12	3.298

The means differ significantly although the number of observations in each group was small. After 30 minutes in the dark a trained subject reported the threshold of just perceptible images to be 2.647 log units. The average of definitely perceptible images was 2.879 log units, or 0.232 log units above the average of just perceptible images. The average for images that were definitely bright with form (Class 4) was 3.298, or 0.651 log units above the average of just perceptible flashes.

At the present time no information is available on the extent to which untrained individuals may change their subjective definition of a just perceptible flash during the course of a single dark adaptation test; nor is there information on the differences among different individuals as to their personal criteria of how bright a flash of light must be before they report it as being just perceptible. It seems possible, however, that in routine dark adaptation tests a difference among different individuals of as much as .5 log unit in the threshold after 30 minutes may be due to differences in subjective criteria of perception.

The above analysis and interpretation is of special interest in connection with the distribution of threshold responses for different individuals. Lindquist (5), Hecht and Mandelbaum (6), and others have presented data which indicate that the variability of threshold values of presumably normal persons after 30 minutes in the dark covers a range in the neighborhood of 1.0 log unit. A substantial proportion of this range, therefore, may be due to variation in the subjects' criteria of perceptible flashes.

Variation of Threshold Determinations for a Given Individual. To obtain information on variations characteristic of the subject, and his response to the test, duplicate tests have been made for eighty-three subjects. Each subject was tested twice, the second test following the first test after a lapse of 20 minutes, during which the subject was permitted to leave the dark room and move about at ease in the laboratory. In some instances, subjects sat quietly in the laboratory between repeated tests. The instrument, observer, and test procedure were identical for first and second tests of the duplicate set. The only difference between the first and second tests was one of order. To obtain an estimate of difference in threshold values at several observation times, the observations were made at certain specified times during the test. They were at .5, 3.5, 6.5, 9.5, 12.5, 15.5, 18.5, 21.5, 24.5, 27.5, 30.5, and 33.5 minutes in the dark. The actual observation time of the threshold might vary by ± 30 seconds from the time specified. This range of tolerance was more than sufficient, and in practice the actual observation time corresponded to the specified time within a few seconds.

One or two of the eighty-three subjects had had previous experience with the adaptation test. For the other subjects, the duplicate tests were the only adaptations experienced. There were sixty-one men and twenty-two women in the group. Their ages ranged from 20 to 65 years. It is likely that the response of this group to the test may be regarded as typical of the performance of lay subjects who are average in interest and intelligence.

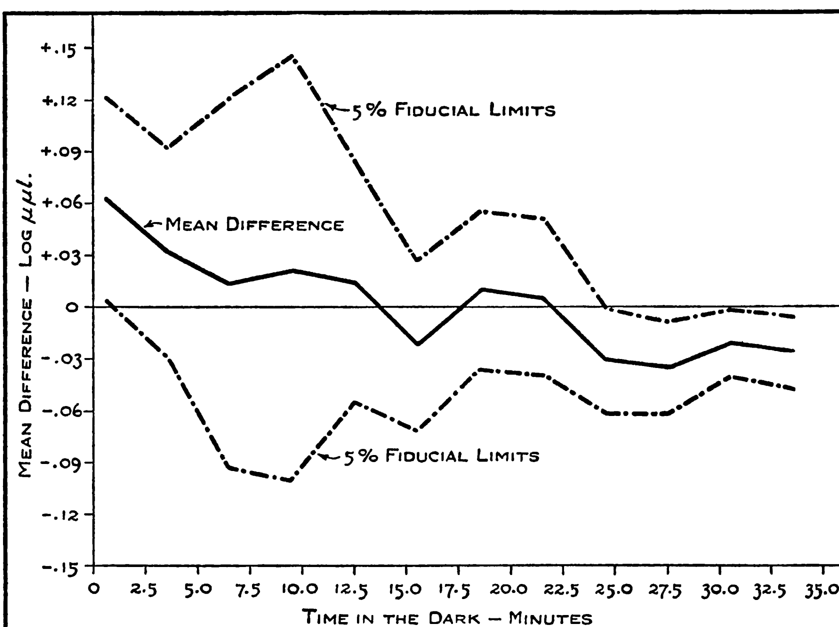
In Table 5 are shown the mean difference, its standard error

Minutes in the Dark	Cases Observed at Time Specified	Difference in Thresholds (Log of $\mu\mu l$)					
		Mean	Standard Deviation (s)	$\frac{s}{\sqrt{2}}$	Standard Error	Range	Fiducial Limits 5 Per Cent
.5	83	+.063	.2657	.1879	.0292	−1.44 + .73	+.005 +.121
3.5	83	+.032	.2772	.1960	.0304	−1.23 +1.00	−.028 +.092
6.5	83	+.014	.4899	.3464	0538	−1.95 +1.48	−.093 +.121
9.5	83	+.022	.5636	.3985	.0619	−2.01 +1.62	−.101 +.145
12.5	83	+.014	.3161	.2235	.0347	− .84 + .97	−.055 +.083
15.5	83	−.022	.2276	.1609	.0250	− .73 + .64	−.072 +.028
18.5	83	+.010	.2155	.1524	.0236	− .49 + .43	−.037 +.057
21.5	83	+.006	.2072	.1465	.0227	− .48 + .56	−.039 +.051
24.5	83	−.031	.1387	.0981	.0152	− .50 + .34	−.001 −.061
27.5	82	−.035	.1212	.0857	.0134	− .52 + .21	−.008 −.062
30.5	83	−.021	.0872	.0617	.0096	− .34 + .17	−.002 −.040
33.5	82	−.026	.0912	.0645	.0101	− .43 + .12	−.006 −.046

Table 5. Difference in threshold, at corresponding times in the dark, between determinations in two consecutive dark adaptation tests.

and the standard deviation of the distribution of differences, and other data, according to the time in the dark at which the thresholds

Fig. 3. Mean difference in threshold, at corresponding time in the dark, between duplicate dark adaptation tests. (First test minus second test.)

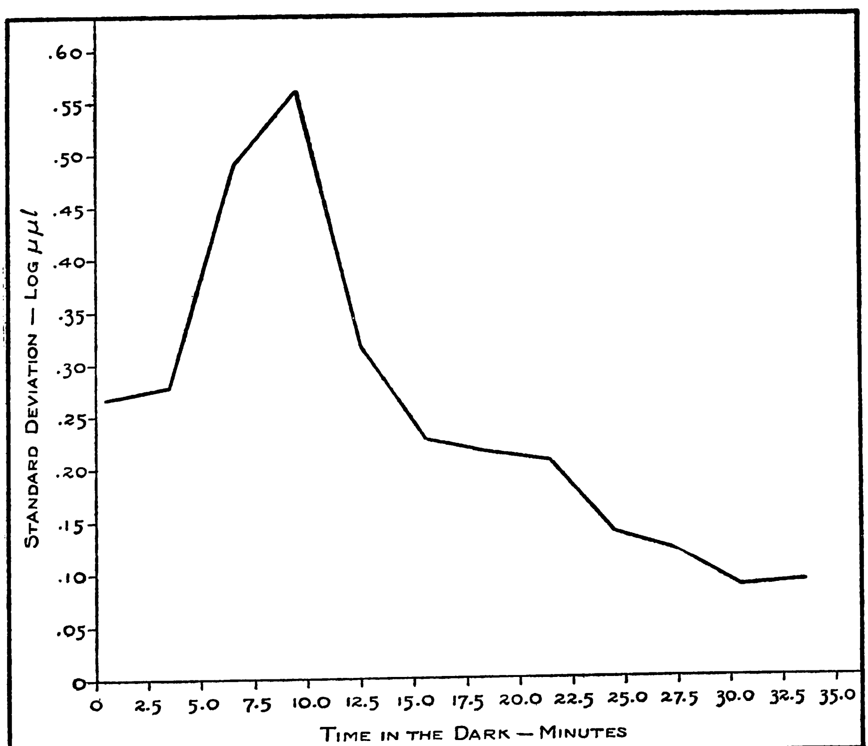


were determined. In computing the difference, at any given time, between the first and second tests, the value of the threshold obtained for the second test has been subtracted from the value obtained during the first test.

In Figure 3 the mean difference and its 5 per cent fiducial limits, at successive observation times, are shown. At 0.5 minute the threshold was significantly higher in the first test of the pair of duplicates. At 24.5 minutes and later, the threshold was significantly higher in the second test.

Figure 4 shows the trend of the standard deviation of the difference between duplicate tests. The variability increased rapidly to a maximum of 0.56 log units at 9.5 minutes, after which there was an equally rapid decline to approximately 15.5 minutes, and a con-

Fig. 4. Standard deviation of the difference in threshold, at corresponding time in the dark, between duplicate dark adaptation tests. (First test minus second test.)



tinued slower decline to a minimum of 0.09 log units at 30.5 and 33.5 minutes. Thus, relatively large differences were common earlier in the test. If the extreme variations are considered as shown in the range, it is found that the discrepancy between duplicate readings for the same individual may equal or exceed a whole log unit at 9.5 minutes or earlier. At 30.5 and 33.5 minutes the total range of observed differences did not exceed .5 log unit and the majority of differences were in the interval ± .10 log units.

From the standard deviation of the difference, at each observation time, the variability of a hypothetical population may be estimated from which the repeated observations may have been drawn. Such variabilities are shown in column 5 of Table 5. If these variabilities are regarded as a measure of experimental error, it is evident that only larger differences in threshold can be distinguished from error before approximately 25 minutes. When judging changes in the individual's threshold, or when attempting to evaluate individual and group differences, more discriminating observations can be made after 30 minutes in the dark.

The observed differences and their variabilities are conditional upon the standard routine of the test in these examinations. A less detailed standardization of procedure would be expected to lead to even greater and more variable differences. Also, if preadaptation brightness, the size and position of the test field, duration and color of test object, and other specifications of the test were altered, the correspondence between duplicate tests would no doubt vary widely from the present findings.

It is worthy of note that the larger differences between duplicate thresholds and therefore the less reliable observations were obtained at the time when cone adaptation was slower and rod adaptation was presumably most active.

The significantly lower value of the threshold at 0.5 minute for the second test may well reflect a learning process during the duplicate tests.

By the end of the first test, the subject had experienced the just perceptible flash of the nearly dark-adapted eye. Such flashes lack form and color and the image is often a presence without other well-defined characteristics. It is not unlikely that persons who have experienced the image of the just perceptible final flashes, do, on retest, revise their concepts of seen and not seen, so that at the time of the second test, affirmative responses are given earlier to marginal images which would at first have been reported as not seen. It should be considered also that the subject may become conditioned to the sound of the shutter and doubtful images may be reported as seen when actually the response is to the sound of the shutter.

Summary

In the present study, field experience with the adaptometer described by Hecht and Shlaer indicates that certain modifications and extensions of the original specifications are desirable if comparable results are to be obtained for different instruments within a given investigation and for different instruments in different laboratories. In brief, the following suggestions are made:

1. To ensure stable calibrations of the wedge and "neutral" filters, these parts of the intensity control system should be made of glass. The impermanence of gelatin-between-glass is well known and no assurance can be given, even if the original calibrations are accurate that they will remain so.

2. A check of the calibration of chromatic filters in commercially procured instruments is desirable. The error of calibration of these filters can be reduced by employing a standard procedure of calibration, less dependent upon the visual idiosyncracies of the individual observer.

3. Use of the "standard reference lamp" supplied with the adaptometer indicates that estimates of the brightness of the light source, obtained with this standard, differ significantly according to the observer. Either another reference standard should be used or the present one modified. In the present study, estimates of brightness with the Macbeth illuminometer appeared to be satisfactory.

4. As now constructed, the preadaptation brightness of the adaptometer cannot be controlled conveniently. Adjustment of the operating current, by means of a manually-controlled rheostat and voltage regulator assembly attached to each adaptometer, was adopted temporarily in the present study as the most feasible expedient to bring about uniform preadaptation brightness. Data are presented which show that uniform preadaptation brightness is essential if comparable results during dark adaptation are to be obtained with different instruments.

Under the heading of "errors of measurement," the results of two experiments are reported:

1. Variation in the subjective criteria of perceptible light flashes may be of sufficient magnitude to account for a considerable proportion of the variation among different individuals in final threshold values obtained after 30 minutes of dark adaptation.

2. Study of duplicate adaptometer tests indicates that there is a marked difference in the reliability of threshold measurements for different periods during dark adaptation. The variability of duplicate tests increases rapidly from 30 seconds to a maximum at 9.5 minutes and thereafter declines to a minimum of $\pm$ 0.09 log units after 30 minutes of dark adaptation.

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