U.S. NAVAL
MEDICAL RESEARCH LABORATORY

Submarine Base, New London, Conn.

Volume 9 1950 pp.258-277

THE RELATION OF DARK ADAPTATION TO DURATION OF PRIOR RED ADAPTATION

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Medical Research Laboratory Report No. 166

Report No. 1
BuMed Project NM 003 041.49

APPROVED: T. L. Willmon, Captain (MC) USN, OinC 6 Dec 1950

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Reference may be made to this report as follows: R. T. Mitchell, A. Morris and F. L. Dimmick, The relation of dark adaptation to duration of prior red adaptation. MRL Report No. 166, 9, 258-277, 1950

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OPERATIONAL INTERPRETATION

The dogma of dark adaptation and use of red light and red goggles as disseminated during the past ten years was based on estimates rather than upon scientific experimentation. This experiment covers that lack and adds quantitative data on the amount of red adaptation useful for seeing in specific levels of "darkness". It shows that the important effect of wearing red goggles is to improve the speed with which the eyes thereafter become sensitive in the dark. Red adaptation of itself does not greatly lower the brightness threshold. Wearing red goggles, therefore, is a valuable adjunct to, but never a substitute for, adaptation in the dark.

In service situations the following rules are recommended:

(1) When a period of alert precedes an assignment requiring dark adaptation, such as 'lookout', red goggles should be worn for a period up to 20 minutes or the same time should be spent in a red-lighted room. Following this, 2 to 10 minutes must be spent in total dark; the darker the night the longer the time in darkness.

(2) When a man is awakened to go on night watch he should immediately don red goggles. He will thereby salvage a portion of his dark adaptation. However, he must supplement this with 2 to 10 minutes in the dark as recommended under (1).

(3) When a man is subject to call to night duty at a moment's notice, he should wear red goggles at all times when they do not interfere seriously with his other duties. Supplementation of this red adaptation with 2 to 10 minutes in the dark is imperative.

(4) When the quickest possible dark adaptation is desired, a man should go immediately into complete darkness for a period of time dependent upon the outside darkness level, e.g. for starlight (5 log $\mu\mu$L) eight minutes; for overcast starlight (4 log $\mu\mu$L), 16 minutes.

(5) When some shortening of the period of adaptation in the dark is desirable, even at the expense of total time, five minutes in red goggles is most efficient, because it shortens the period in the dark by about four minutes. Longer periods in red goggles up to 20 minutes will shorten the adaptation time in darkness very little and at the cost of disproportionately longer total times.

(6) When total darkness is not available for adapting, additional time following the red adaptation must be spent at the working illumination before a man can see effectively.

ABSTRACT

The effects of duration of red preadaptation upon the immediate brightness threshold and upon the course of dark adaptation are presented. Measurements were made following seven adaptation periods of 0 to 40 minutes wearing red goggles under a preadapting brightness of 150 mL.

It was found that red adaptation increased the rate of subsequent dark adaptation so that the 5 log µµL threshold was reached in one half the time after wearing red goggles for five minutes, and in one fourth the time after 20 minutes in red. Forty minutes in red gave no further decrease in dark adaptation time.

In terms of the total time (red plus dark) required to dark adapt to a threshold of 5 log µµL, the first five minutes of red adaptation showed the greatest efficiency. Five minutes in red goggles followed by 3.8 minutes in darkness are equivalent to 8.2 minutes in darkness. Red preadaptation for long periods (20 minutes or more) produces relatively little dark adaptation compared with the same time spent in total darkness. The sensitivity reached by wearing red goggles for 40 minutes was still 2.75 log µµL above the 30 minute threshold in total darkness.

INTRODUCTION

During the last ten years the use of red illumination to aid in achieving or maintaining a degree of dark adaptation has become standard practice in the laboratory and under military operational conditions. Although the psychophysiological basis for the use of red has been stated in some detail[1], and a system of standards for evaluating red filters has been issued for the U. S. Navy[2,3], procedures have not been established with respect to duration of red adaptation and subsequent dark adaptation. Common practice is to wear red goggles for 20 minutes or longer, following that by 5 to 10 minutes in complete darkness. There is, however, no adequate experimental basis for this practice. If we are to establish standard procedures which will achieve maximum efficiency with respect to elapsed adaptation time and sensitivity level attained, it becomes necessary to determine the effect of duration of red adaptation upon the brightness sensitivity of the eye and its interrelationship with subsequent adaptation in darkness.

Practical dark adaptation situations are of two general types; first, those in which it is desired to achieve a given level of sensitivity as rapidly as possible; and second, those in which it is desired to perform visual tasks at photopic brightness levels while developing or maintaining as high a sensitivity as possible. Criteria for evaluating the effect of duration of red adaptation depend upon which of these two situations is involved. In the first, it is necessary to know only how the brightness threshold following various periods of red adaptation compares with that following adaptation in total darkness for an equal period of time. Miles' experiments[4] led him to state that red illumination would yield thresholds as low as those resulting from adaptation in darkness for equal periods. This conclusion has been contradicted by Lee[5] and by Schoen and Dimmick[6].

If it is true that red is less effective than total darkness, it becomes necessary to investigate further the effect of duration of red adaptation on immediate brightness sensitivity in order to establish criteria for the second situation. Previous studies do not preclude the possibility that scotopic sensitivity merely increases more slowly under red illumination and may eventually reach the same level as in darkness. If such proved to be the case, then working in red illumination for an extended period of time would, of course, accomplish total dark adaptation. If this is not true, the effect, if any, of varying the duration of red adaptation upon the course of subsequent dark adaptation must be investigated.

The present study was undertaken to investigate the effect of varying the duration of red illumination on the brightness threshold of the light adapted eye. The experiment was designed to measure (1) the immediate sensitivity level and (2) the course of dark adaptation following different durations of red adaptation, to the point where further increase in red adaptation time produced no further changes.

In order to have the results applicable to ordinary visual working conditions, it was desirable to choose a light adaptation level that falls within the range of normal indoor lighting. For our purposes therefore we selected a brightness between usual artificial room illumination and daylight illumination at the window, the highest brightness that is likely to be met indoors. At such levels previous experiments[7,8] have shown that a fast rate of adaptation might obscure the temporal separation of the effects sought. Consequently an observer was chosen whose adaptation rate was slow but who showed the expected minimum photopic level near 6 log $\mu\mu$L and the 30 minute scotopic level below 3.5 log $\mu\mu$L. In addition, the use of this light level and this observer assures that, in operational interpretations derived from the data, recommended time intervals will always be adequate.

APPARATUS

Light adaptation proceeded in an approximately circular booth 40 inches in diameter lined with white cloth having diffuse reflectance of 70%. Adaptation light was provided by incandescent projector flood lamps mounted in a chandelier above a Lumarith diffusing screen which covered the top of the booth, giving a brightness at eye level of 150 mL.

Brightness thresholds were measured with a Hecht-Shlaer Adaptometer using a 3° circular "white" stimulus centered at 12.5° on the nasal side of the fixation point. The standard shutter mechanism was replaced by a revolving, slotted disc providing a 1/5 second exposure once per second. The eye piece of the instrument projected into the adaptation booth so that threshold measurements could begin immediately after completing light or goggle adaptation.

The red goggles used were standard Navy Dark Adaptation Goggles*, having a spectral cutoff at 592 mμ. The photopic transmission was measured to be 10.5% and the relative scotopic transmission computed to be 0.8% with respect to incandescent illumination at 2848°K. At the level of 150 mL the goggles gave an effective photopic brightness of 16 mL.

PROCEDURE

The observer was light adapted for 10 minutes at the brightness of 150 mL and then wore red goggles for one of seven periods of time, 0, 2, 3.5, 5, 10, 20 or 40 minutes. When this period was finished, the lights were extinguished, goggles removed and sensitivity measurements begun. Observations were repeated at five different sessions for each duration of red adaptation.

* Stock No. 6-031-000 Army-Navy Catalog of Medical Material

At the beginning of the observation period the experimenter set the stimulus brightness slightly below the "instantaneous" threshold estimated from preliminary observations. The observer reported "Now" when he saw two successive stimulus flashes; the experimenter recorded the time and reduced the stimulus brightness to the next lower value in the series. The observer reported again when he perceived two successive flashes, and the procedure was repeated until brightness sensitivity approached a final level as indicated by a nearly flat curve.

Preliminary experimentation at this laboratory in 1948 by H. A. Knoll and A. Morris (unpublished) using the standard Hecht-Shlaer technique[9] indicated the desirability of combining data from a number of experimental sessions. This procedure is not possible with the usual Hecht-Shlaer technique of adjustment by the observer, in which neither stimulus intensity nor time of measurement is fixed. The method of predetermined stimulus intensities which we adopted permits the averaging of the times in all observation sessions to reach each level of sensitivity. The series of stimulus brightness levels was chosen with a spacing designed to give good definition of the adaptation curve.

The observer, R.T.M, was a 30 year old white male with hyperopia of .50 -.25 axis 90° but with no pathological defects of the eyes. Care was taken to avoid prolonged effects that might result from exposure to high outdoor brightnesses during the experiment.

RESULTS

Table I and Figure 1 show the mean periods in dark required to reach the experimental brightness settings, the parameter being duration of prior adaptation in red illumination.

TABLE I

Dark Adaptation Following Different Durations of Red Adaptation

Brightness Log μμL	Ave. time in minutes to reach brightness level (Each value is mean of 5 observations)						
	none	2	3.5	5	10	20	40
7.97	.05						
7.04	.16	.09	.08	.06			
6.93					.05		
6.42	.50	.40	.36	.28	.12	.07	
6.22	.98	.80	.58	.41	.23	.15	.09
6.02	4.29	2.10	1.54	.62	.35	.23	.18
5.90	4.80	2.90	1.84	.85	.47		
5.81	5.18	3.71	2.28	1.15	.58	.37	.37
5.70	5.45	4.03	2.60	1.58	.71		
5.60	5.99	4.50	2.95	1.87	.86	.55	.56
5.39	6.41	5.23	3.84	2.40	1.16	.85	.86
5.18	7.40	6.17	4.71	3.21	1.68	1.20	1.40
sigma	(1.56)	(.82)	(.74)	(.76)	(.40)	(.47)	(.63)
4.87	9.10	8.05	6.27	4.53	3.22	2.23	2.38
4.67	10.08	9.33	7.65	6.45	4.53	3.61	3.46
4.56	10.82	9.87	8.64	7.47	5.51	4.67	4.51
4.46	11.97	11.16		8.52	6.52	6.25	6.49
4.35	13.03	11.93		9.48	8.25	7.51	7.36
4.23	13.70	12.45		10.79	9.48	8.92	8.77
4.13	15.12	13.82		12.24	11.09	10.33	10.32
4.03	16.44	15.26		13.23	12.32	12.33	11.70
3.93		17.13		14.79	13.93	14.56	13.53
3.82	20.24	19.15		17.17	15.83	16.50	16.54
3.73	21.62	20.44		19.06	19.20	20.02	19.33
3.61	24.58	23.58		21.64	21.78	22.74	23.57
3.50	27.99	25.91		24.65	26.02	27.31	27.67
3.45	33.08	31.17		29.13	31.83	31.16	31.85

Answers to the two questions raised concerning the effects of red adaptation, namely, (1) on the immediate brightness threshold and (2) on the course of dark adaptation, are contained in these results.

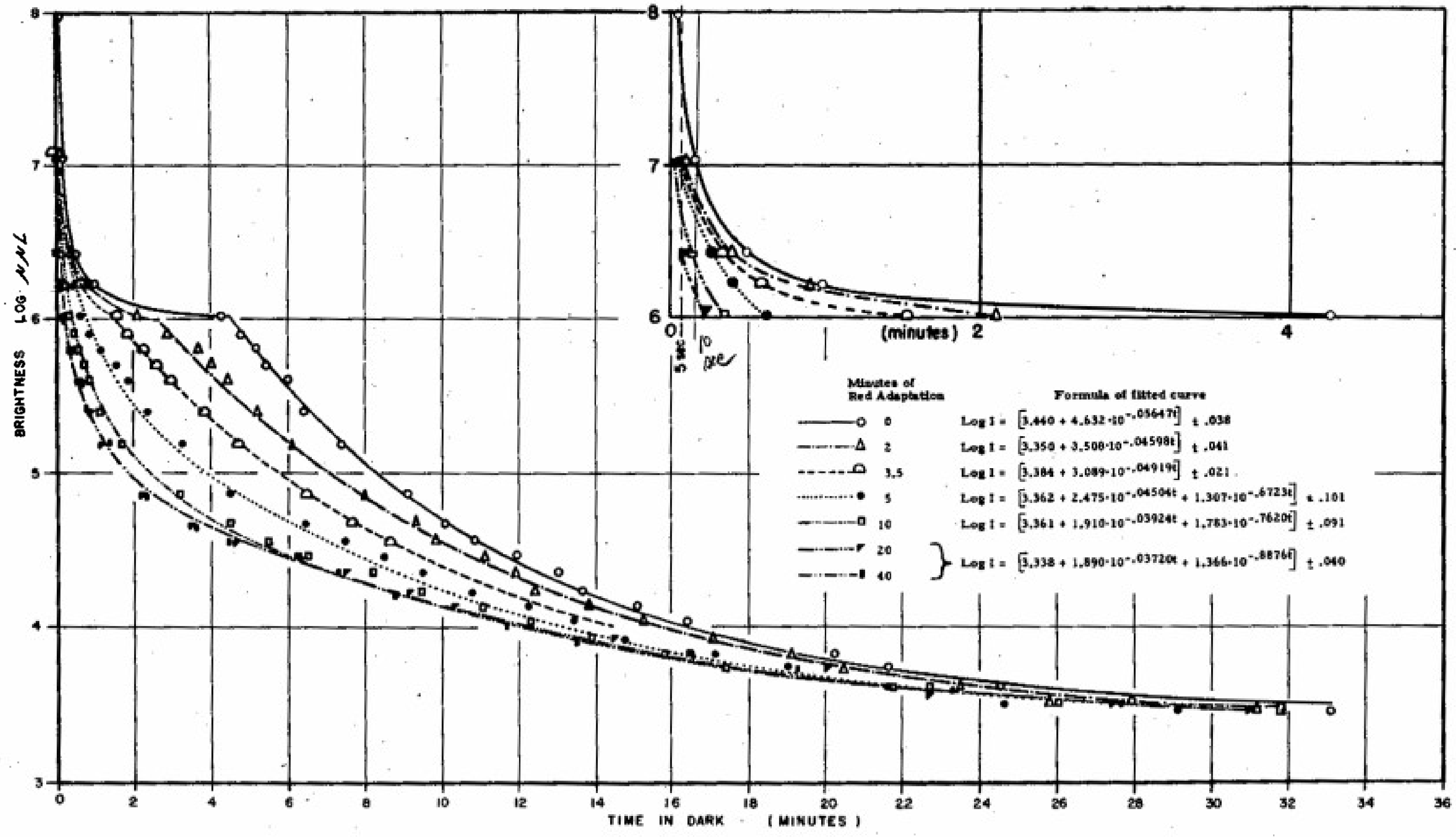

Figure 1

Dark Adaptation Following Different Durationa of Red Adaptation

Plotted points are means of five measurements for one observer. Curves were fitted to means by formulae given in legend. Insert shows the first portion of the curves expanded along the abscissa.

(1) The initial values on the adaptation curves (See insert, Fig. 1.) indicate the "immediate" thresholds after different periods of red adaptation.

With our experimental method an attempt to set the initial stimulus brightness so that the mean time of report would be zero minutes would have resulted in a positively skewed distribution since there could be no negative time values. It was, however, possible to select stimulus values which yielded symmetrical distributions with means of 5 seconds and less. In the following discussion this 5 second sensitivity level is considered conjugate with the "immediate" threshold. Table II and Figure 2 present the thresholds for five seconds in darkness. The values were obtained by graphical interpolation on an enlarged plotting of the data of Table I.

TABLE II
Effect of Red Adaptation on Brightness Sensitivity

Time in red goggles minutes	Sensitivity level after 5 sec. in dark log µµL
0	7.48
2	7.04
3.5	7.04
5	6.87
10	6.59
20	6.38
40	6.26

Two facts are apparent. First, red adaptation does not result in as great an increase in sensitivity as does adaptation in darkness for an equal time. At adaptation durations longer than 20 minutes the sensitivity has increased only about 1 log unit under red illumination compared with nearly 4 log units in darkness, a ratio of 1 to 1000. We find that the sensitivity level

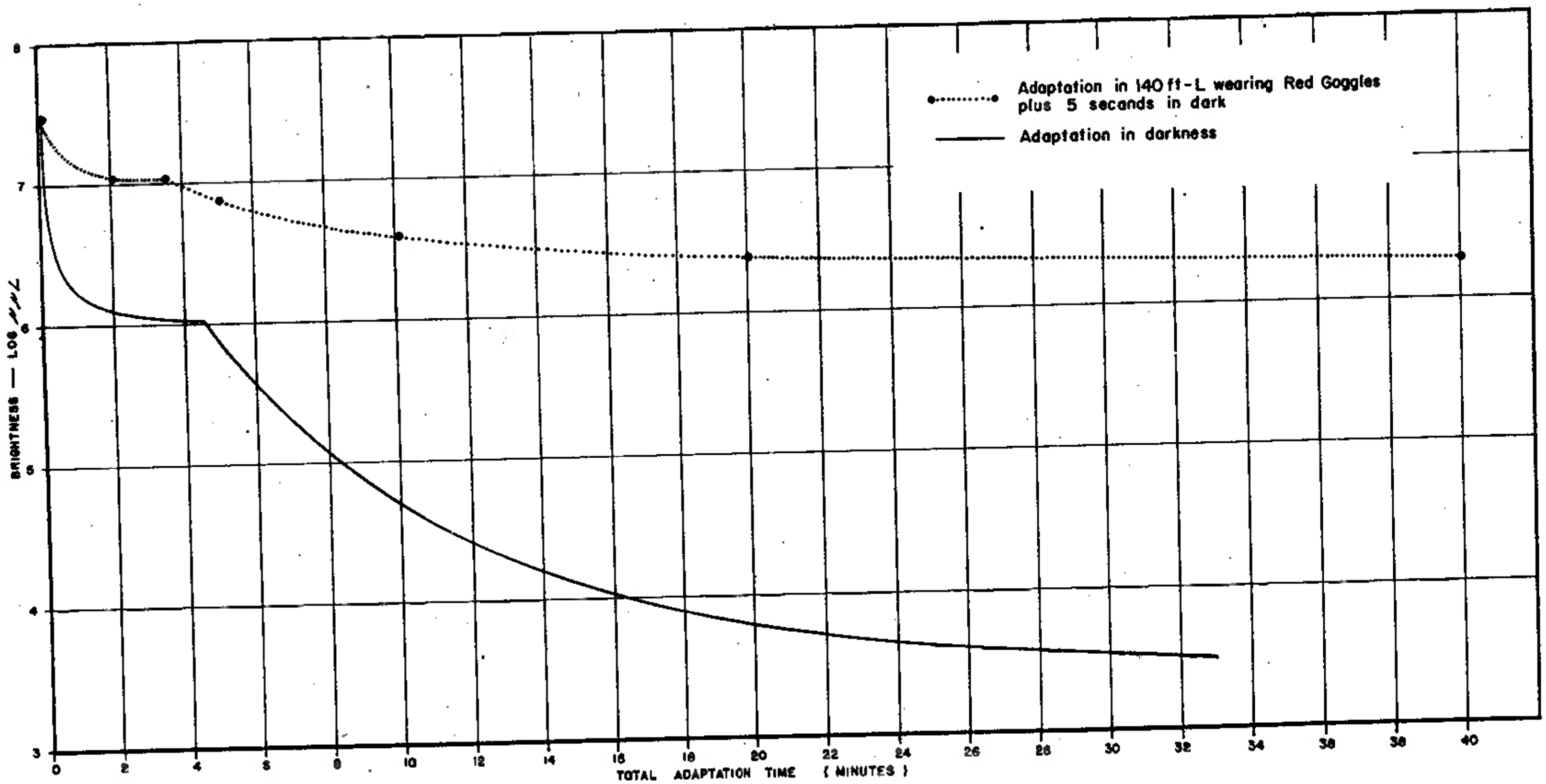

Figure 2

Effect of Red Illumination and of Darkness upon Brightness Sensitivity

The upper curve shows the change in hrightness sensitivity during adaptation to red light. Each of the plotted values includes an additional 5 seconds of adaptation in darkness. For comparison, the lower curve shows the change during adaptation in total darkness.

reached after 20 minutes of red plus 5 seconds in darkness is reached after only 35 seconds in darkness alone. Second, the amount of increase in sensitivity decreases with time and becomes negligible after 20 minutes of red adaptation.

(2) Increasing duration of red adaptation affects subsequent dark adaptation in two ways. For a brief period of red adaptation, i.e., up to $3\frac{1}{2}$ minutes, the effect is primarily the displacement of the curves toward the Y-axis. Longer periods, i.e., 5 min. or more, result also in a change in the shape of the curve by making it steeper during the first few minutes of dark adaptation. This change is progressive up to 20 minutes of red adaptation. Beyond that, increased red adaptation produces no additional effect, as shown by the coincidence of the 20 and 40 minute curves.

The change in the shape of the curves with increase in length of the period of preceding red adaptation is further specified by a change in the equation of the curves*. The scotopic data for goggle adaptation of 2 min. and 3.5 min. can be expressed as $Y = a + b \cdot 10^{-kx}$. Substituting the parameters of our problem,

$Y = \text{Log } I$, the brightness of the threshold,

$a = \text{Log } I_f$, the brightness of the final threshold,

$b = \text{Log } I_i - \text{Log } I_f$, the difference between the instantaneous threshold and the final threshold,

$k =$ a constant of slope,

$x = t$, the duration of dark adaptation,

the equation becomes

$$\text{Log } I = \text{Log } I_f + (\text{Log } I_i - \text{Log } I_f)10^{-kx} \qquad (1)$$

When, however, the red adaptation time is increased to 5 minutes or more, the simple form of the equation no longer holds,

*The authors are indebted to Dr. Hermann von Schelling of this laboratory for the mathematical treatment of the data.

and another term must be added. The equation thus becomes $Y = a + b_1 \cdot 10^{-kx} + b_2 \cdot 10^{-k'x}$ in which

b_1 = the difference between the Log I at 5 min. and the Log I of the final threshold: $(\text{Log } I_5 - \text{Log } I_f)$ or $\text{Log } \frac{I_5}{I_f}$

b_2 = b of the first equation minus b_1: $\left(\text{Log} \frac{I_i}{I_f} - \text{Log} \frac{I_5}{I_f}\right)$

k' = a second slope constant.

Thus

$$\text{Log } I = \text{Log } I_f \left(\text{Log} \frac{I_5}{I_f} \cdot 10^{5k}\right) 10^{-kt} + \left(\text{Log} \frac{I_i}{I_f} - \text{Log} \frac{I_5}{I_f} \cdot 10^{5k}\right) 10^{-k't} \quad (2)$$

Table III and Figure 3 show "time-in-dark" saved in reaching several representative sensitivity levels after the experimental red adaptation periods. For example, if 12 minutes in darkness is required to reach a sensitivity level of 5 log µµL after no prior red adaptation and 8 minutes after 5 minutes of red adaptation, a saving of 4 minutes in dark has occurred.

TABLE III

Time-in-Dark Saved Following Different Durations of Red Adaptation

Brightness level	Time in minutes saved*				
	Minutes of red adaptation				
Log µµL	2	3.5	5	10	20 & 40
6.0	1.83	3.00	3.67	4.13	4.25
5.5	1.55	2.92	4.35	5.35	5.58
5.0	1.17	2.65	4.33	6.20	6.50
4.5	.83	2.42	3.78	5.68	5.83
4.0	.27	1.50	3.10	4.10	4.00

* Values calculated from Equations (1) and (2)

Figure 3 demonstrates that the saving of time in the dark increases rapidly up to five minutes of red adaptation. Thereafter there is a decline in rate of increase and after 20 minutes there is no further increment of saving. The absolute level of sensitivity at which saving is measured has considerable influence on the amount of that saving when the longer periods of red adaptation are considered. Saving is greatest at 5 log $\mu\mu$L, falls off at levels above and below, and approaches zero near 3.5 log $\mu\mu$L.

In Table IV and Figure 4 the same values are shown as percentages of red adaptation time. In the example cited above the per cent of saving would be 80%, that is; four of the five minutes of red adaptation time were saved in the dark.

TABLE IV

Per Cent of Red Adaptation Time Saved in Dark Following Different Durations of Red Adaptation

Brightness level	Per Cent Saved					
	Minutes of red adaptation					
Log $\mu\mu$L	2	3.5	5	10	20	40
6.0	91.5	85.7	73.4	41.3	21.3	10.6
5.5	77.5	83.4	87.0	53.5	27.9	13.9
5.0	58.5	75.7	86.6	62.0	32.5	16.3
4.5	41.5	69.1	75.6	56.8	29.2	14.6
4.0	13.5	42.9	62.0	41.0	20.0	10.0

* Values calculated from Equations (1) and (2).

The relative efficiency of different durations of red adaptation can be expressed as the per cent of that red adaptation time which is subsequently saved from the time in darkness which is required to reach a given threshold. From Figure 4 it may be seen that this percentage is maximum at 5 minutes of red adaptation and falls off sharply for longer times.

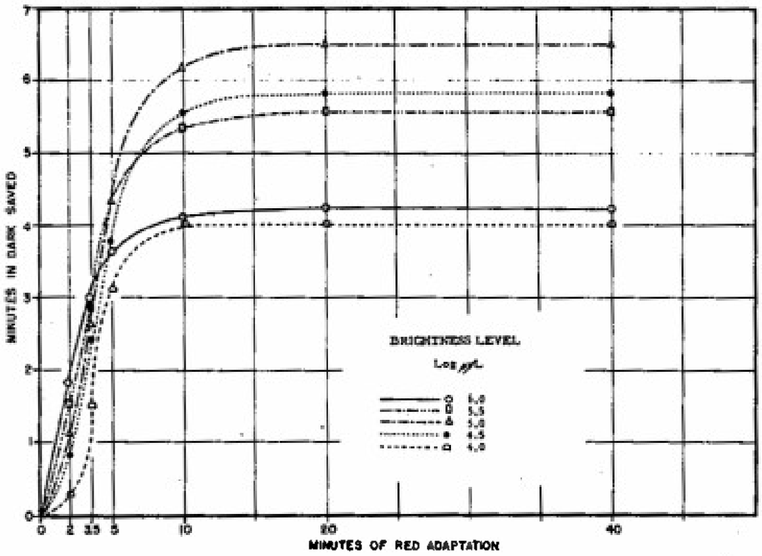

Figure 3

Time-in-Dark Saved Following Different Durations of Red Adaptation

Curves denote minutee in dark eaved at selected brightnees levels by adapting in red goggles for different duratione prior to adapting in darknees.

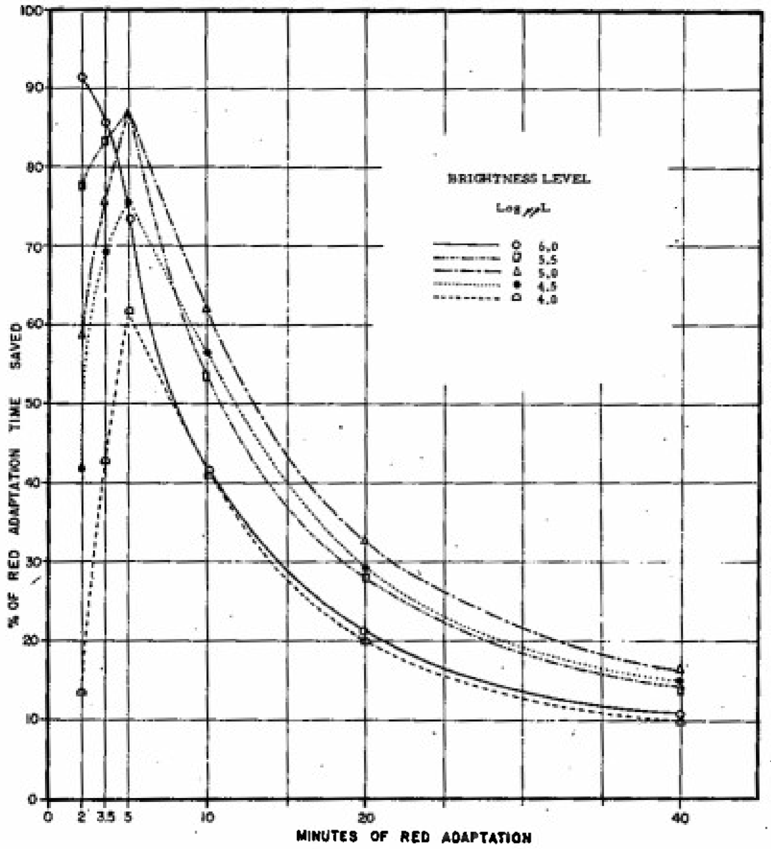

Figure 4

Per Cent of Time-in-Dark Saved

Plotted pointe are valuee from Table IV expreseed as per cent of red adaptation dnration.

Table V and Figure 5 show the improvement in the threshold at several times of dark adaptation, produced by the experimental red adaptation periods. For example, if with no prior red adaptation the observer reached a threshold of 5.07 log µµL, after 8 minutes of dark adaptation and with 5 minutes of prior red adaptation, he reached 4.46 log µµL, the improvement in threshold amounts to .61 log µµL.

TABLE V

Improvement in Brightness Threshold Following Different Durations of Red Adaptation

Time in Dark min.	Difference between threshold without and with red adaptation Log µµL					
	Minutes of red adaptation*					
	2	3.5	5	10	20	40
2	.06	.25	.63	1.06	1.13	1.12
4	.37	.69	1.03	1.34	1.36	1.36
6	.35	.61	.87	1.09	1.10	1.11
8	.21	.44	.61	.78	.78	.78
10	.14	-	.45	.57	.57	.56
12	.09	-	.34	.40	.41	.40
14	.05	-	.25	.29	.28	.28
16	.02	-	.18	.21	.19	.20

*Values calculated from Equations (1) and (2)

This arrangement of the data shows that the greatest improvement in the threshold occurs after a preadaptation with red of 10 min. duration. Longer times of red adaptation show virtually no further improvement. The time in the dark at which improvement is made determines further the amount of improvement. At 4 min. of dark adaptation the improvement is greatest for all times of red adaptation. As adaptation in the dark proceeds the improvement in threshold contributed by red adaptation diminishes. After 16 minutes in the dark there is little gain from having had a period of red adaptation.

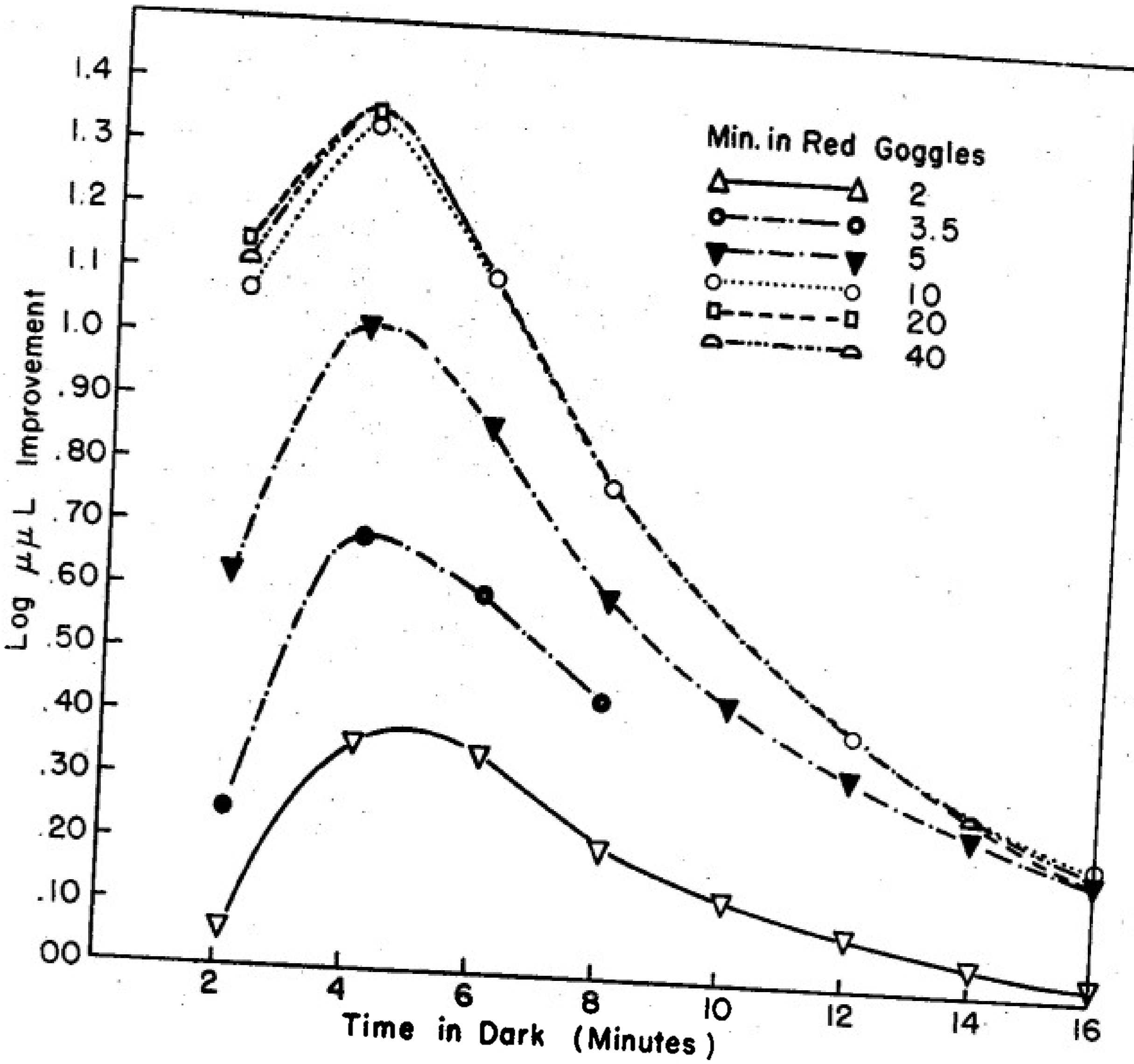

Figure 5

Improvement in Brightnese Threehold Following Different Duretione of Red Adeptetion

Curves indicete log $\mu\mu$L improvement in the threehold at varioue times in the derk after weering red goggles for the eeveral experimental periods.

When the question is not one of efficiency in the use of time, red adaptation for 10 minutes assures that the threshold will be a full log unit lower within two minutes after removal of the red goggles in the dark.

Since we worked with a single observer and at a high level of initial adaptation brightness, generalization from the absolute values of adaptation time and of brightness threshold requires an estimation of the influence on them of these factors.

A comparison of the adaptation of our observer with those of a small group taken under the same conditions, and with data cited in the literature[10] indicates that his sensitivity lies near the higher (less sensitive) limits of the normal range. Since the best indication of this range is that it covers about 1 log µµL at most adaptation times, thresholds of the most highly sensitive observer to be expected would fall no more than that amount--1 log µµL--below our data. The majority of individuals would have thresholds .5 log µµL lower than our thresholds.

The high initial adapting brightness is 1 to 1.5 log units above that commonly found in interiors. Previous experimental work has shown that lowering the level from 150 mL to 10 mL has two effects. (a) The immediate threshold is lowered by .75 log µµL[11]. (b) The difference between the dark adaptation curves diminishes with time in the dark and becomes negligible after about 10 minutes[7]. We verified these effects under our conditions by measurements on one observer.

We can assume then, that the relative changes in the dark adaptation curves which result from various time of red adaptation will hold for other <u>O</u>s and for initial adaptation levels below 150 mL. Absolute thresholds and absolute times of adaptation must be adjusted within the limits indicated for the particular observer and for the adaptation level.

CONCLUSIONS

Within the limits set by the conditions of our experiment we conclude:

1. Long adaptation to red illumination lowers the brightness threshold only to a level 2 to 3 log units above that obtained by adaptation in darkness for the same time.

2. Adaptation to red illumination for durations up to $3\frac{1}{2}$ minutes results in the earlier appearance of the scotopic adaptation process during subsequent dark adaptation but does not appreciably alter its rate.

3. Adaptation to red illumination for durations of 5 or more minutes increases the rate of the first few minutes of scotopic adaptation during subsequent dark adaptation.

4. As duration of red adaptation increases up to five minutes the saving of time in the dark required to reach a given sensitivity increases rapidly; thereafter the rate of increase in saving diminishes, becoming zero for durations of red adaptation longer than 20 minutes.

5. The maximum saving in duration of subsequent dark adaptation resulting from prior red adaptation occurs at an adaptation level of 5 log $\mu\mu$L, which is 1.5 log units above the 30 minute threshold.

6. Variation from these figures due to a more sensitive observer and to a lower light level is estimated to be within 1 log $\mu\mu$L.

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