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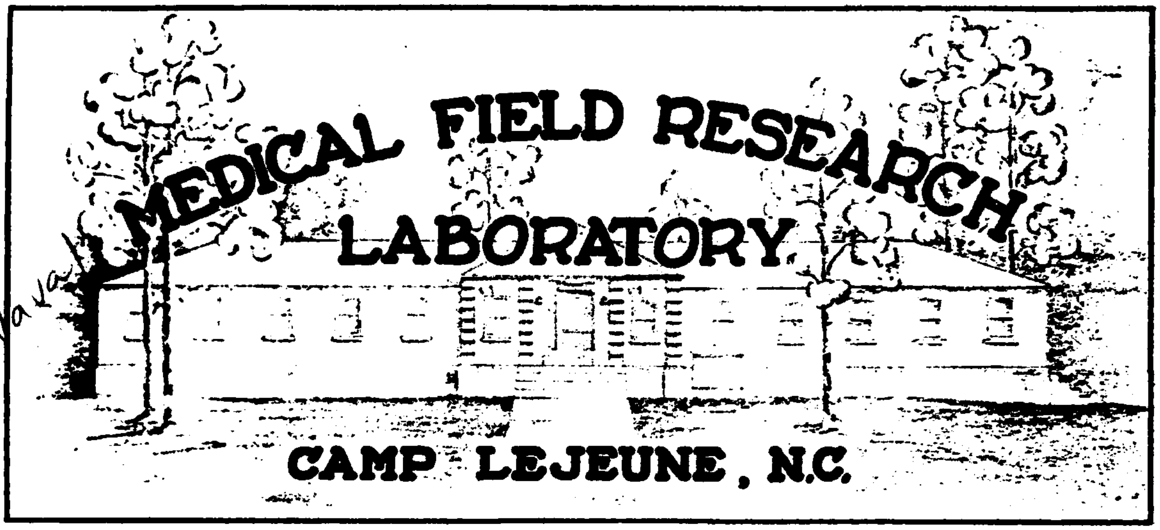

INFLUENCE OF EXPOSURE TO INTENSE SUNLIGHT ON SUBSEQUENT NIGHT VISION

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OBJECT

The object of this study was to investigate the temporary and cumulative effects of exposure to bright sunlight on night vision.

SUMMARY

1. Exposures to ordinary sunlight produce temporary and cumulative effects on night vision. A single exposure of two or three hours delays the onset of rod dark adaptation by ten minutes or more, and slows the process itself so that the normal night vision threshold is not reached for several hours.

2. After repeated daily exposures to sunlight, the delay in reaching the normal threshold persists overnight. The threshold, after complete dark adaptation, rises higher each day for about ten days. It then remains at the higher level.

3. This elevated threshold corresponds to an average deterioration of about fifty per cent in visual acuity, range of visiblity, contrast discrimination, and in the frequency of picking up a target when it is barely visible. The effect shows considerable individual variation, but the average loss in night vision is nearly the same as is suffered by flying at 12,000 feet at night without oxygen.

4. This chronic effect does not disappear even after ten days of protection from sunlight.

5. Sunglasses should be used by all persons who, while working in bright sunlight during the day, will be expected to perform critical night duties soon afterward. Adequate sunglasses are those

which transmit at most ten per cent of the visible light; however, for general service conditions this may have to be raised to 10 to 15% transmission.

I. BACKGROUND

Reports from North Africa and the South Pacific have suggested that night vision deteriorates after exposure to the strong sunlight on beaches, water, and particularly on coral islands. These reports have been confirmed by the study of fifty cases of night blindness in the Turkish Army, apparently due to bright light (Derman, 1943; cf. also McCartney, 1943).

To test such effects several English investigators worked one day on the roof of the National Physical Laboratory at Teddington, England, and compared the speed of their dark adaptation after exposure to a standard illumination with a similar test after staying indoors on a dull day. They found no significant difference (A.R.L., Teddington, 1943). However, these negative findings are not surprising because (a) Teddington can hardly be considered a very sunny location, and (b) roof tops generally are not regions of high reflectance.

In view of this, and of the persistence of reports from the South Pacific, we decided to reinvestigate the whole question.

The problem is three-fold. First, is the onset of dark adaptation delayed after exposure to bright sunlight? Second, is the process slowed up so that the threshold is still above normal even after an hour or two in darkness? Third, is the effect of daily exposure cumulative?

The first aspect of this problem may be answered in terms of previous information. The speed of dark adaptation is strongly influenced by the brightness of the preceding light adaptation (Winsor and Clark, 1936; Hecht, Haig, and Chase, 1937; Haig, 1941). Thus after light adaptation to a hundred millilamberts, the rod portion of dark adaptation appears almost at once, whereas after light adaptation to 40,000 millilamberts, rod adaptation does not become evident for 12 minutes. However, this aspect of the phenomenon is probably not important in military work since it is rare that any one needs to become dark adapted immediately after exposure to high light intensities.

Previous work also shows that after light adaptation to high intensities the final threshold may be delayed out of all proportion to the delay of the onset of rod adaptation. For instance, 40 minutes after exposure to approximately 40,000 millilamberts the eye is still about 0.3 log unit above its normal final threshold (Hecht, Haig, and Chase, 1937, Fig. 2). However, these data are fragmentary, and additional measurements are needed. No data on the cumulative effect of sunlight are known. We therefore decided to find out how long the final threshold remains above normal after exposure to sunlight, and whether such effects accumulate when people are exposed to sunlight day after day.

II. APPARATUS AND METHODS

The arrangements for the experiment were simple. Two communicating rooms were made completely light-proof and supplied with adequate ventilation by means of a blower and ducts. One served as a ready room, the other as a testing room. Entrance to the ready room from the outer hallway is by means of a maze light-trap. The room was illuminated with very dim red light, and had 14 comfortable chairs for the subjects to sit in while becoming dark adapted. The entrance from this ready room to the testing room was through a maze. The testing room had a few benches to receive the subjects awaiting their turn at the instruments.

The measurements were made with two Hecht-Shlaer Adaptometers, Model 3, such as are in regular use by the Royal Canadian Navy. Both were arranged to measure the binocular threshold of a retinal area 7° above the fovea and 3° in diameter flashed for 1/5 second. One instrument used only blue light of dominant λ 480 mu; the other used white light. Since the intensities are given as micro-microlamberts in terms of photopic brightness, the threshold values on the two instruments will not be the same because of the Purkinje phenomenon. We made many comparisons of the thresholds of the same people on both instruments, and found the average threshold to be 1.20 log units higher on the white instrument, with little variation from this average. All measurements in this report will be referred to the blue instrument regardless of which instrument was used in the experiment. With only a very few exceptions, a subject was always measured with the same instrument.

In determining a threshold the operator controls the brightness of the stimulus by means of a neutral wedge, while the subject operates the shutter. The wedge is first set to give a brightness about 1 log unit above threshold. This is seen by the subject, and the brightness is then reduced in steps of 0.5 to 0.2 log unit, until he fails to see even a faint flash of light. With the threshold roughly determined in this way, the operator varies the brightness in a random way above and below the threshold, always by even tenths of a log unit. The point at which about 3 out of 5 exposures are detected as flashes of light is chosen as the threshold.

The following sample case will illustrate the procedure. At 2.4 log uul the subject saw 2 out of 2 flashes; at 2.3, 3 out of 3; at 2.2, 2 out of 4; at 2.1, 1 out of 4; and at 2.0, 0 out of 2. The threshold, as defined, obviously lies between 2.2 and 2.3; in this case it is nearer 2.2, which is therefore chosen.

After a minute's rest, the procedure is repeated and the threshold redetermined. Usually the two agreed to 0.1 log unit. Occasionally, the difference between the two measurements was greater than 0.1 log unit; more determinations were made after a longer rest, until a satisfactory threshold was obtained.

III. THE COURSE OF DARK ADAPTATION FOLLOWING BRIGHT OUTDOOR LIGHT

Preliminary to the work at Camp Lejeune, experiments were conducted in New York on the effect on dark adaptation of exposure to bright sky. The subjects were adapted by looking at the sky for periods of from 4 minutes to an hour. Previous to this, in some cases, the subjects were sent outdoors for 2 hours, with instructions to look at the sky as much as possible. The brightness varied from 3,000 to 12,000 millilamberts, the limiting factor being the subject's ability to look at the light without undue pain. One eye only was usually adapted in the final stage, since this reduced the discomfort, and made it possible to look at brighter light. Monocular observation was possible because the Hecht-Shlaer Model 1 Adaptometer was used. Seven subjects were measured, giving a total of 12 dark adaptation curves, extending from one minute to at least 2 hours in the dark. Both rod and cone thresholds were obtained.

At Camp Lejeune, a further study of comparatively short exposures to bright light was made, using 5 subjects in a total of 15 experiments. The brightness of the sky to which the subjects were adapted varied from 3,500 to 16,000 millilamberts, and the time from 2 to 35 minutes. For comparison, dark adaptation curves were obtained after exposure to 5 and to 50 millilamberts for short periods of time. In each case, the threshold after 1 hour dark adaptation was obtained before the start of the light adaptation experiment. If the subjects had to be outdoors before this initial measurement, they wore red goggles to prevent uncontrolled exposure to high brightness.

In Fig. 1 are shown the significant parts of four representative dark adaptation curves with one subject; because of the long time intervals the abscissas are on a logarithmic scale, and the early portions of the data have been omitted. Since the measurements were made on different days, the curves are adjusted so that the initial threshold before light adaptation is the same for all. Note that after 60 minutes light adaptation to 50 millilamberts, recovery is complete after 40 minutes in the dark, whereas even a two minute exposure to 7,000 millilamberts prolonged the recovery time by at least 10 minutes. After

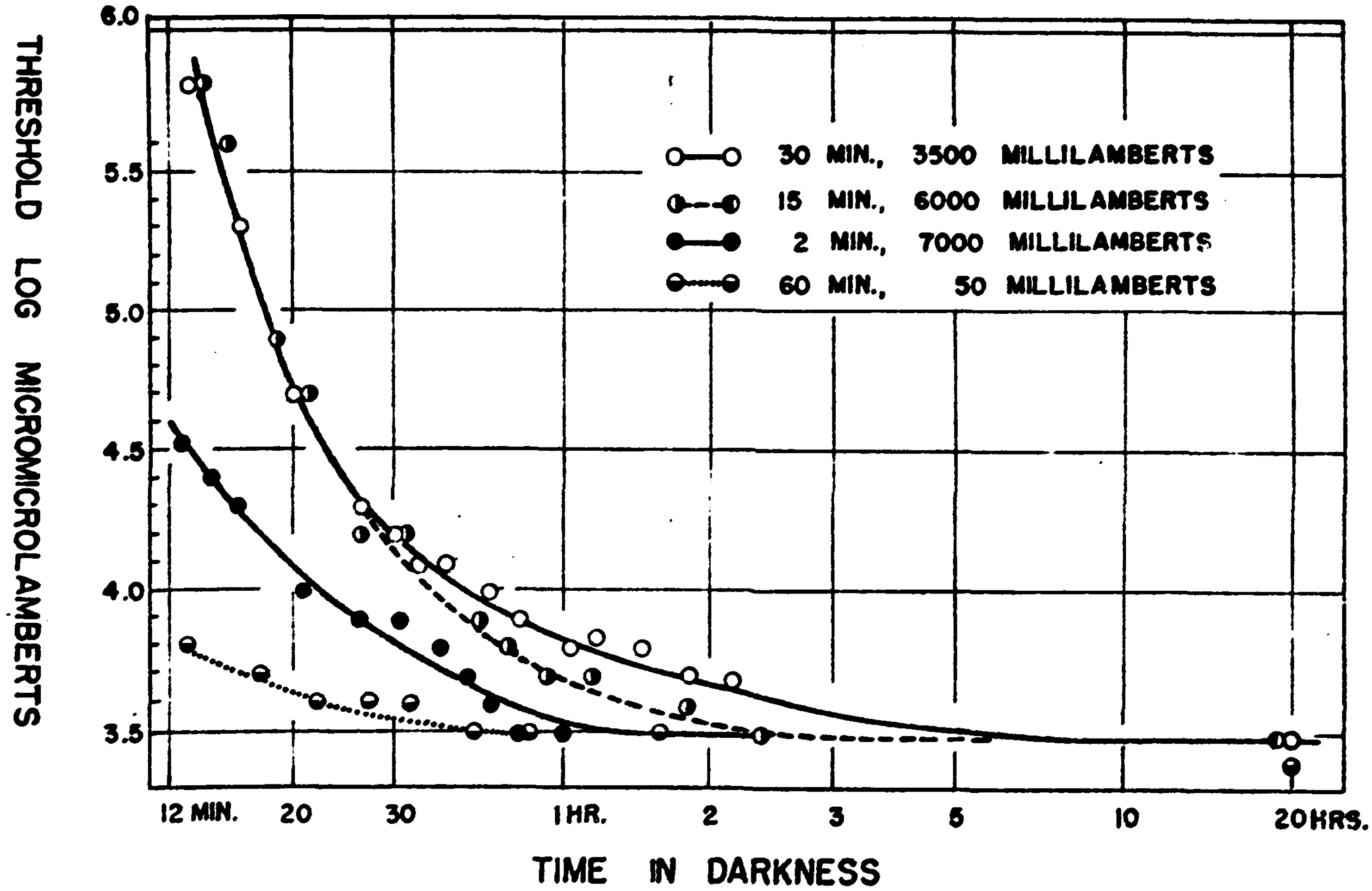

FIG.I DARK ADAPTATION AFTER EXPOSURE TO BRIGHT SKY light adaptation for 15 minutes to 6,000 millilamberts, it took over two hours for the eyes to recover completely. And after a 30 minute adaptation to 3,500 millilamberts it was over 5 hours before the threshold returned to normal.

Table I summarizes the main features of the Camp Lejeune and the New York experiments. Since different subjects were used in the various tests, and there is considerable individual variation, the results for different times and brightness are not directly comparable. However, it is clear enough that after exposure to bright skylight dark adaptation is considerably delayed. Far from being over in 30 minutes, dark adaptation may not be complete for two hours. An average of all the measurements in Table I shows that after 30 minutes, the threshold is 0.48 log unit above normal; after an hour it still has 0.20 log unit to go; and even after two hours the threshold is still 0.1 log unit above normal. These values in log units correspond to the threshold being 200, 60, and 26 per cent above normal.

IV. PRELIMINARY EXPERIMENTS ON PROLONGED EXPOSURE TO SUNLIGHT

These results are supported by measurements made at Camp Lejeune early in September preliminary to the main experiments to be described in the next section of this report. Each subject had his threshold measured, usually in the morning, after one hour dark adaptation. The group was then transported to New River Inlet on the Atlantic Ocean, and spent several hours on the beach in the sunlight. No special routine was provided, except that the subjects were requested not to shut their eyes or avoid the glare. After two to five hours the group returned to the laboratory and immediately entered the ready room. Each subject was then tested after various lengths of time in the dark. The subjects then left the building, but wore red goggles. They returned later, and were again measured after an hour's dark adaptation. With four groups we were also able next morning to measure the final threshold after one hour of dark adaptation.

Table II gives the results. It contains the number of subjects in each group, the time of exposure, and the average brightness of sky, water, and sand. The results are stated as the average rise in threshold compared to the threshold before exposure following a dark room stay of an hour. It is clear that exposure to sunlight delays the course of dark adaptation. After an hour the threshold is still between 0.12 and 0.27 log unit above normal, and there seems to be some residual effect even after several hours, and perhaps even overnight.

V. FINAL EXPERIMENTS AT CAMP LEJEUNE

After these measurements, we set up a series of systematic experiments to determine whether daily exposure to sunlight produced any cumulative effects on night vision. The experiments involved two groups of men; one was protected from sunlight and served as controls, while the other was exposed daily to sunlight for comparison. At regular intervals the thresholds of the men were determined after an hour of dark adptation. It was soon apparent that there was indeed a cumulative effect of the daily exposures.

1. Procedure

We worked with 51 volunteers from a group of petty officers in the Coast Guard detachment at Camp Lejeune. A larger number of men had their thresholds measured on two successive days; we then eliminated those with poor night vision, and those who were poor observers. The remaining 51 were divided into two sections.

One group of 20 men was kept at indoor tasks to prevent exposure to bright light. They were issued red dark adaptation goggles, which they wore whenever they went outdoors during the day. Saturday afternoons and Sundays they were free to go outdoors more often, but were instructed to wear goggles as much as possible. This group served as a control.

The other group of 31 men was sent outdoors every day except Sunday to the beach near New River Inlet, on the Atlantic Ocean. On sunny days near noon, the illumination was about 10,000 f t-candles; but because the sand was rather dark -- having a reflectance of 0.3 at best -- the brightness of the beach was less than 3,000 millilamberts. Viewed from the beach the water was usually darker than the sand. The sky varied from about 500 to 15,000 millilamberts depending on the weather and on the position of the sun. At the beach the men played, swam, or walked. They did not close their eyes, or protect them from the light in any way. During the first two weeks the men were exposed to the sun for about 4 hours, of which 2 hours were spent in an open boat going to and from the beach. The boat left at 9:30, returning at 11:30 for dinner. The men then went out again about 1:15, returning at 3:30. Later arrangements were made for the noon meal at the beach, and the subjects thus had about 6 hours exposure, of which only 1 was spent in transit.

It was not possible to measure all the men every day. The two groups were therefore divided into three sections each, and the measurements were rotated for the sections. Calling the sunlight sections X1, X2, and X3, and the indoor sections C1, C2, and C3 we arranged the following sequence. Sections X1 and C1 were measured Monday morning, Monday afternoon, and Tuesday morning. Sections X2 and C2 were measured Tuesday morning and afternoon and Wednesday morning. Sections X3 and C3 were measured Wednesday morning and afternoon and Thursday morning. It was then again the time for X1 and C1, and they were measured Thursday morning and afternoon and Friday morning. Friday morning X2 and C2 were again measured and the routine continued. Thus each section was measured twice a week in the sequence morning-afternoon-morning.

The subjects were dark adapted for one hour before their thresholds were measured. During the last 10 days thresholds were also taken after 1/2 hour of adaptation. In the afternoon, after the measurements of the sunlight subjects, they left for supper, but wore their red goggles, and returned immediately for another hour of dark adaptation and another measurement. The next morning, 1/2 hour and 1 hour thresholds were also obtained. Thus the recovery from exposure could be measured at 1/2 hour, 1 hour, 3 hours, and 17 hours.

These procedures began September   and continued through September 30. After the morning measurements on September 30, the indoor and sunlight groups were exchanged. The men who had been going outdoors every day, the X group, now remained indoors. The C group, on the other hand, took off their goggles and went outdoors on the beach. This continued until October 10 when the experiment was terminated. The measurements of the whole experiment are given in the Appendix.

2. Cumulative Effects

The simplest way of finding out whether daily exposure to sunlight produced any cumulative effect on night vision is to study the morning one-hour threshold after a night's sleep and before any exposure to sunlight. From the detailed data in the Appendix we give in Table III these morning measurements.

There are several ways in which these measurements may be treated, from following each small group to making weekly averages of all groups. We have tried a number of ways, and find that the results are much the same any way the data are examined: compared to the control group, the sunlight groups shows a steady rise in threshold which reaches a maximum in about ten days, and then remains roughly constant. A simple way of demonstrating this is as follows.

It is apparent from Table III that after the first two days, we measured 2 sunlight groups and 2 control groups each day, except at the beginning and end of the week when only one group each was measured. In the table we have combined the measurements of the daily two groups; these are in columns 5 and 9 and they are shown graphically in Fig. 2. The data for the sunlight group and for the control group are drawn separately.

Initially the two groups were selected so as to have almost identical thresholds; actually they differed by only 0.02 log unit. After this almost identical beginning, the morning thresholds of the two groups follow divergent courses. The control group threshold decreases, at first rapidly and then more slowly, while the sunlight group threshold rises rapidly and then settles to a level maintained approximately.

The decrease in the control group represents the improvement which comes with practice in measurements by untrained individuals. It occurs regularly, and is of the same order of magnitude as found here. This is shown by the threshold data for 37 aviation cadets at Randolph Field who were measured over a period of weeks; their "learning" curve is included in Fig. 2 for comparison. The control group continued to show a slight improvement as long as it stayed indoors.

The sunlight group, on the other hand, began to show higher thresholds a week after the start of the experiment, even though 4 of these days had been overcast or rainy. At the end of 2 weeks, the average threshold of the sunlight group came down slightly and then levelled off.

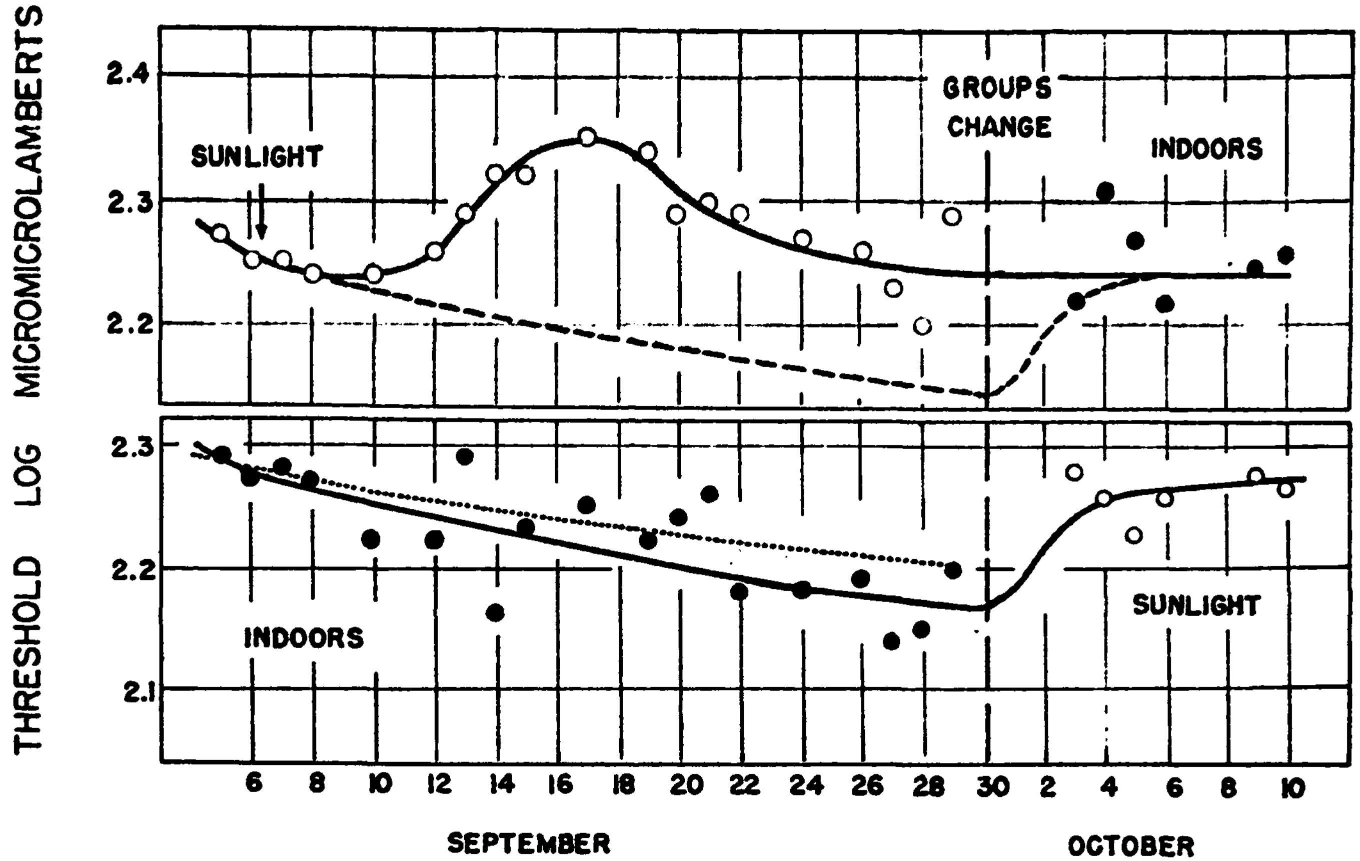

FIG.2 EFFECT OF SUNLIGHT ON MORNING THRESHOLD

SUNLIGHT GROUP
INDOOR GROUP
CONTROL GROUP CURVE ADJUSTED TO LEVEL OF SUNLIGHT GROUPS AT START
RANDOLPH FIELD CADETS

When the groups were reversed on September 30 the old control group threshold (now the sunlight group) began to rise. After 3 days of bright sunlight the rise was almost 0.1 log unit and further exposure caused only a slight additional rise. The original sunlight group (now the indoor group) showed practically no change for the 10 days they were indoors.

In making a quantitative estimate of the changes caused by sunlight, we must include the improvement in threshold shown by the control group. There is no reason to suppose that the sunlight group did not improve in a similar way; indeed this is apparent from the behavior of the first few points of this group, which show a decrease. Thus the control data form a base line for the sunlight data; this is indicated by the dotted line under the sunlight measurements.

Another way to show the cumulative effect of exposure to sunlight is to compare the distribution of thresholds before the experiment with those after the two groups diverged. In Fig. 3 these comparisons are made, the sunlight group being drawn on the left, the indoor group on the right. Since the number of subjects is small, 2 thresholds from successive morning measurements are included for each subject. This brings the total number of measurements to 60 for the sunlight, and 40 for the indoor group.

As before, the sunlight group shows a small but definite rise in threshold after 9 days outdoors even though 4 of these days were overcast. The indoor group shows a decrease of about the same magnitude.

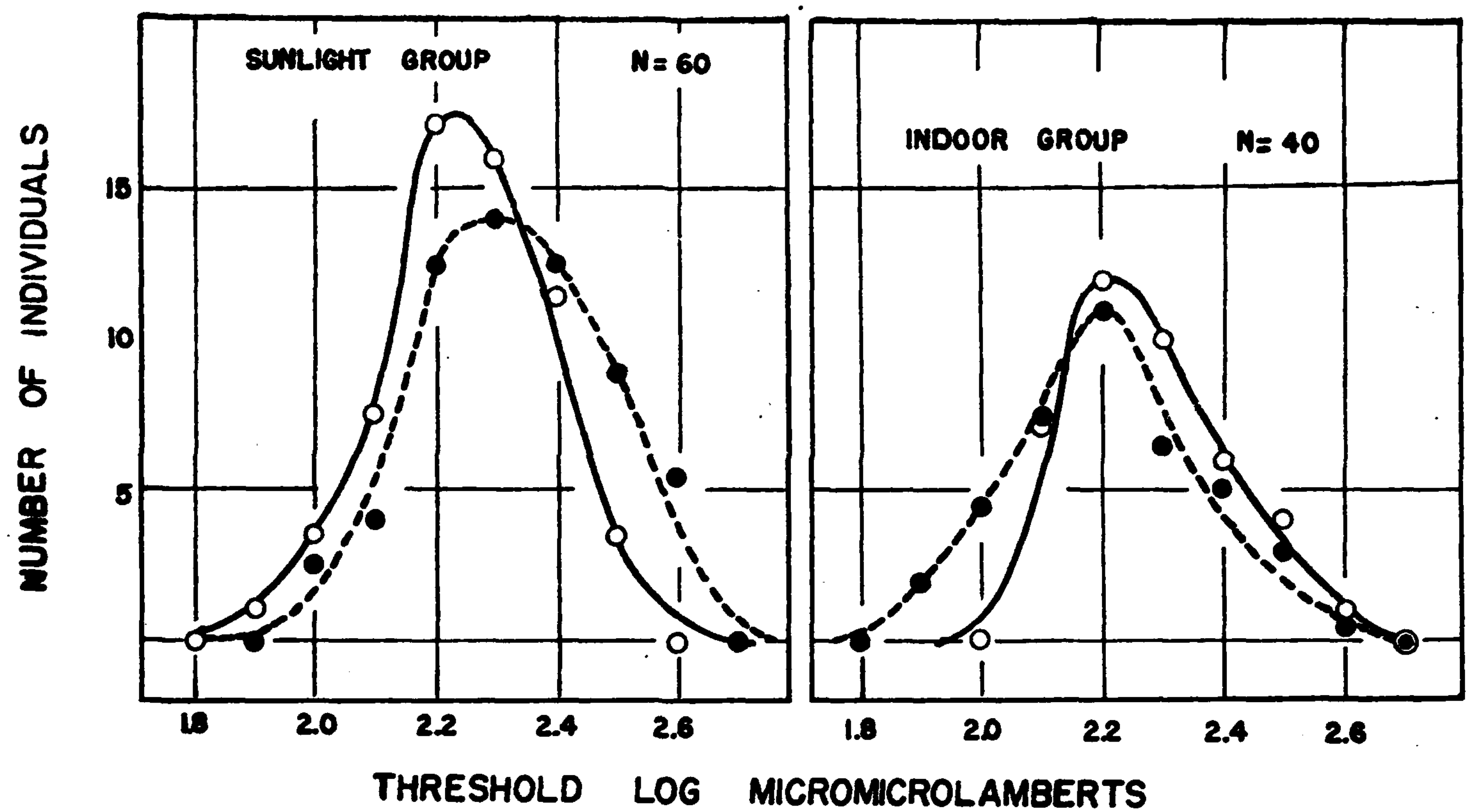

FIG. 3 DISTRIBUTION OF THRESHOLDS

o—o AT START OF EXPERIMENT

●--● AFTER 9 DAYS

When the means of the two groups are compared, the sunlight group is found to be lower than the control by 0.02 log unit at the start, but is 0.12 log unit higher after exposure. This change of 0.14 log unit is equal to 4.3 times the standard error of the difference between the two means after exposure. The probability that this difference is due simply to chance is therefore about 0.00002, and the difference is certainly significant by this test.

3. Daily Effects

The measurements in the Appendix may also be used to define more continuously than in Section III the changes in night vision which occur in the course of the day as the result of the exposure to sunlight on that day. For 9 days between September 26 and October 5 for each group which was exposed to sunshine, we measured the threshold after one hour dark adaptation in the morning before the exposure, in the afternoon after returning from the beach, in the evening after supper, the next morning before exposure to sunlight. Similarly with each indoor group we measured the one-hour threshold in the morning, in the afternoon, and next morning.

The averages of these 9 series of determinations are shown on Fig. 4. It is apparent that the one-hour threshold is raised by 0.14 log unit due to sunlight, and that this rise does not completely disappear until some time in the night. By the next morning the one-hour threshold is practically the same as the day before.

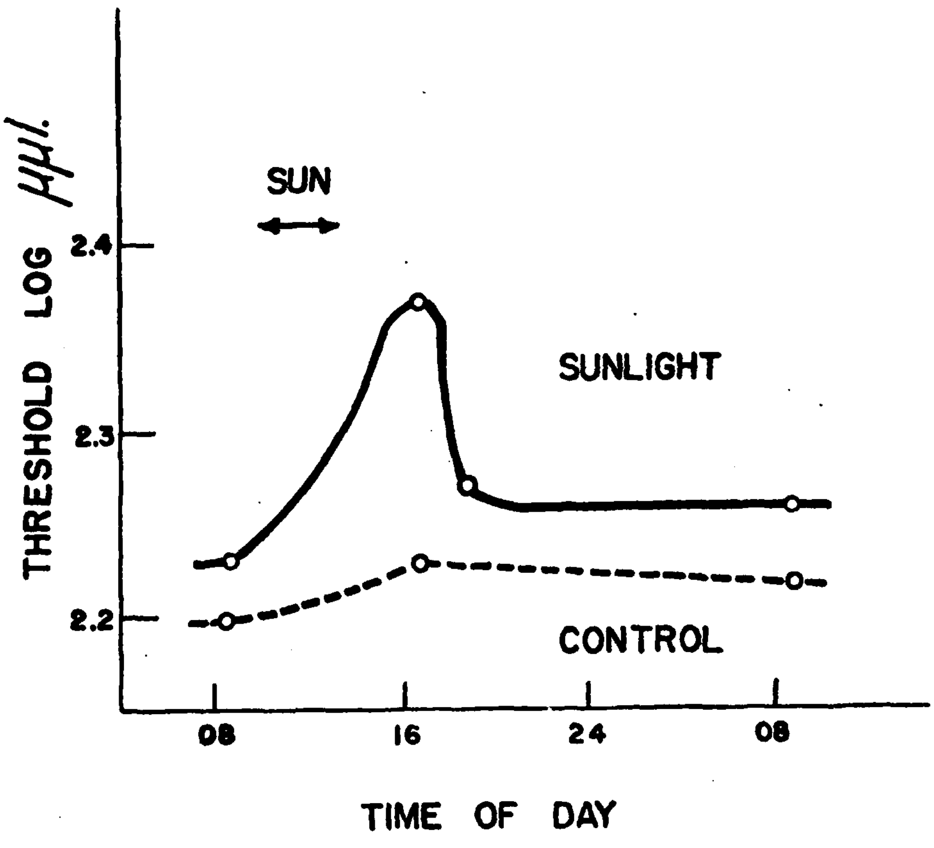

FIG. 4 THRESHOLD AFTER 1 HOUR IN DARKNESS

VI. MEANINGS

From all of these experiments we may conclude two things. One is that night vision is interfered with significantly but not drastically for a period of several hours after a single prolonged exposure to sunlight. The other is that daily exposures to sunlight produce a cumulative chronic effect on night vision which after ten days has about the same magnitude as the maximal temporary effect of a single exposure.

These disturbances, though not spectacular, are real and significant. They could easily be made more striking by considering what happens after half-hour dark adaptation. However, half-hour thresholds after sunlight, while interesting physiologically, have no great meaning for service conditions. The advantage of measuring hour thresholds is that dark adaptation is complete and if one finds an influence of sunlight on them, one can be sure that results are meaningful.

We may now consider what changes these threshold rises produce in night visual performance. The average morning threshold rose nearly 0.15 log unit above normal after ten days. Individuals varied in this respect; some showed only a slight rise, while 12 out of 30 men showed rises of 0.21 to 0.50 log unit. Calling the average rise of 0.15 log unit the chronic effect, we must remember that on any given evening there will be also a temporary effect due to the exposure to sunlight on that day. In the early part of the night, say 4 or 5 hours after exposure, this additional effect is about 0.05 log unit, which when added to the chronic 0.15 log unit rise gives a total rise of 0.2 log unit.

Such a rise of 0.2 log unit has a substantial influence on night visual performance. Fig. 5 shows the relationship between illumination and the frequency with which a target is seen, when it is presented repeatedly. This relation holds not only at the absolute threshold but at various levels above the threshold, as has been ably demonstrated by Hartline and others. The effect of raising the threshold by 0.2 log unit is to shift the whole curve to the right to higher intensities by a distance of 0.2 log unit. The result of such a shift may be clarified by examples.

Suppose the brightness and other conditions are such that a normal observer can pick up a ship or an airplane nine times out of ten. This brightness is shown by the vertical line at the right on Fig. 5. It is at once apparent that an observer, on whom exposure to sunlight had produced an average effect, will be able to pick up the same target under the same conditions only four or five times out of ten. This represents a loss of 50 per cent in visual effectiveness.

Another way of showing the injury produced by sunlight is in Fig. 6, which reproduces Koenig's data for the relation between visual acuity and brightness for night vision only. The same relationship holds for brightness discrimination and also for the range at which an object becomes visible. The dotted line to the right of Koenig's curve represents the same curve displaced 0.2 log unit to the right. At the lower levels representing dark nights and starlit nights, the shift results in a loss in visual acuity between 0.12 and 0.25 log unit depending on the

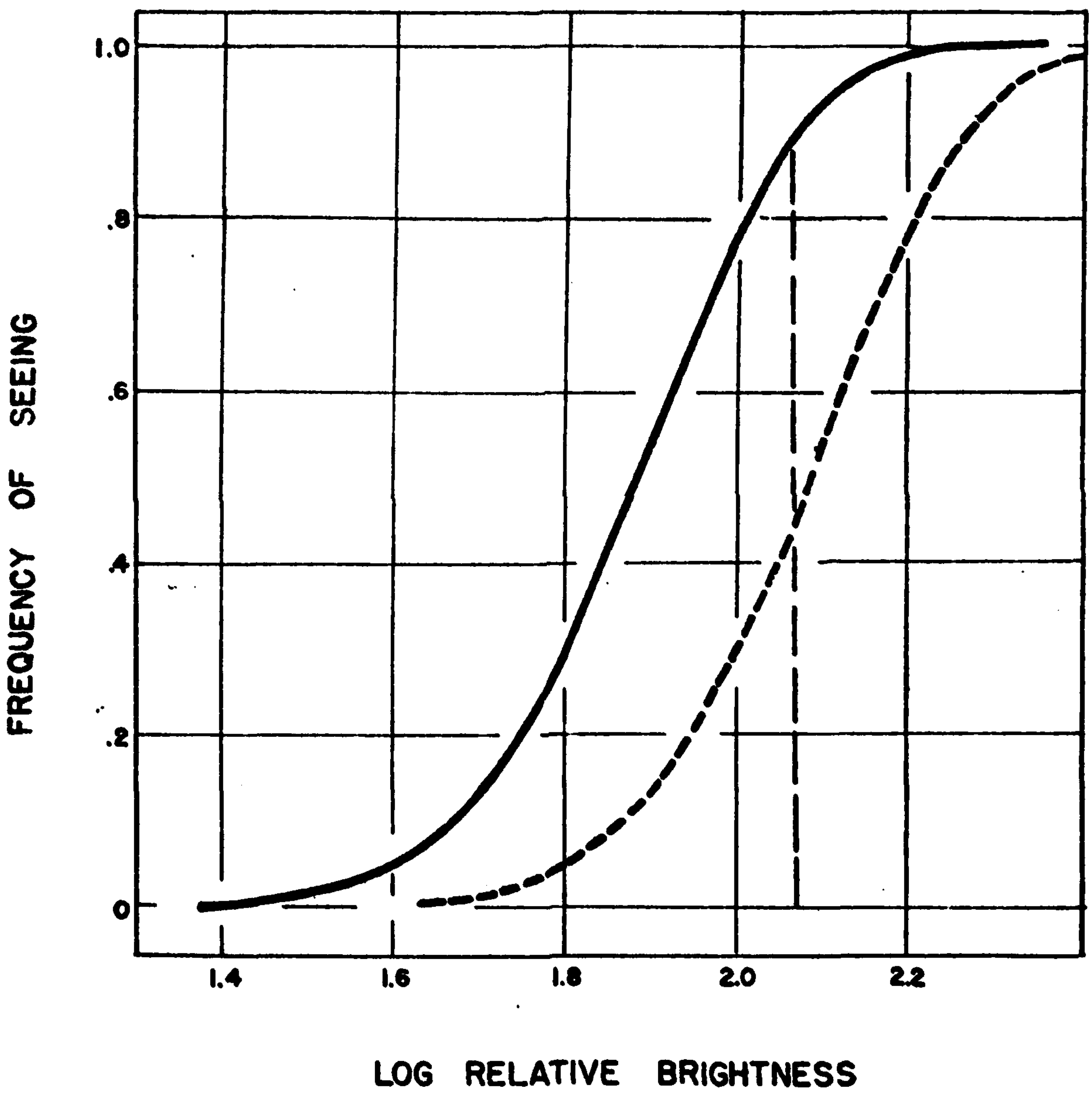

FIG. 5 BRIGHTNESS AND FREQUENCY OF SEEING

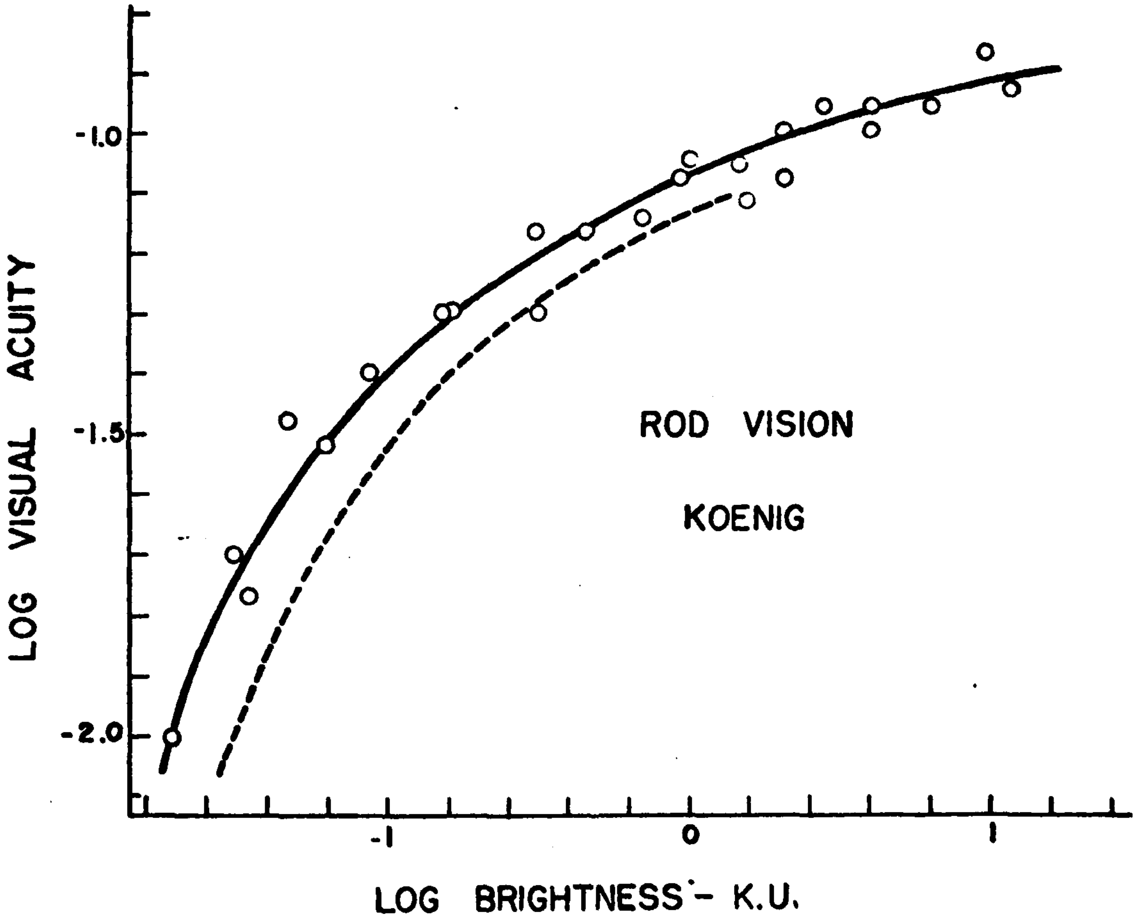

FIG. 6 VISUAL ACUITY AT LOW BRIGHTNESS

place on the curve. This is a loss varying between 32 and 78 per cent in visual acuity, and may be roughly averaged as 50 per cent. This means that a person affected by sunlight has his night vision impaired so that his visual acuity is cut in half, his range decreased to half, and the contrast which he can just recognize be increased by 50 per cent by comparison to his normal self.

All these deteriorations in visual function are of about the same order of magnitude as that suffered by an aviator flying at night between 12,000 and 15,000 feet without oxygen.

VII. SUNLIGHT, ULTRAVIOLET, NIGHT VISION TESTS

In considering the magnitude of sunlight effects, it is well to remember that September and October are not very sunny months at Camp Lejeune and a number of overcast and rainy days interrupted the exposures. Moreover, the men were actually at the beach only 2 hours a day for the first two weeks, and 5 hours a day later on. It may be that brighter sunlight as in the tropics, white coral sand as on atolls, and more prolonged exposures as under service conditions might produce much greater effects. It would indeed be desirable to investigate this, because even greater precautions might then be necessary for protecting individuals who are designated for night duty. Our experiments alone do not warrant extrapolation of this kind, since the injurious effect of exposure was just as great during the first two weeks as it was later on even though the exposures were shorter in the beginning. Clearly further work is indicated.

While it is not our object to inquire into the physiological mechanisms involved, we are inclined to believe that it is the visible part of the radiation that is effective. Ultraviolet forms only a small part of the radiation reaching the cornea, and while it can burn this part of the eye, as in snow blindness, it does not reach the retina to any appreciable extent, because of the great absorption of the lens and eye media. Nevertheless, if any further sunlight studies are made, it would be well to exclude the ultra-violet, merely to have the information.

Infra-red rays, though they comprise over half the radiation on a sunny day and do get through to the retina, are probably also not responsible. We know of no evidence that infra-red radiation is harmful unless many times as intense as it is in the brightest daylight. There are cases reported of retinal burns from staring at the sun, but this did not occur in our experiments.

Usually there are no service conditions in which one is required to become dark adapted immediately after exposure to sunlight. However, there is a situation in which this happens often which deserves to be pointed out. This is during measurements for the classification of personnel for night visual capacity. Such tests are most often made during the day, and unless special precautions are taken to avoid previous exposure to sunlight, or even to a very bright sky, individuals may show spuriously high thresholds in their tests, especially if they have been given only half-hour dark adaptation.

It would not be surprising if this were a factor in some of the curious results occasionally obtained in surveys of night vision and in studies of test-retest correlation of various testing devices.

VIII. THE USE OF SUNGLASSES

There exists an extremely simple preventative for avoiding the ill effects of exposure to sunlight, namely adequate sunglasses. Not merely sunglasses, but adequate sunglasses.

The best known and most expensive sunglasses now available are designed for maximum transmission of visable radiation, while cutting out as much as possible of the ultra-violet and infra-red. As a result, they transmit 50 or even 75 per cent of the light. Such sunglasses would be of little value in preventing injury to night vision.

Adequate protection ordinarily can be afforded by glasses having 10% light transmission, but, to meet general service requirements, transmission may have to be set at the slightly higher level of 10 to 15%. On the bright tropic atolls and in the sunny, snow covered regions, it would be better to have them transmit no more than 5 per cent of the light. Such glasses would transmit ample light for virtually maximum visibility, provided the day is moderately bright. Naturally they should not and need not be worn on heavily overcast days, indoors, or at night.

Sunglasses should be secured and distributed to all persons who, while working in bright sunlight during the day, will be expected to perform night duties soon afterward. It should be remembered that whereas the transient effect of exposure to sunlight disappears overnight, it has a chronic cumulative effect, which does not disappear even after ten days protection.

As a guide to what we call "bright sunlight" the subjective response is probably reliable: light which causes squinting or discomfort falls in this category.

ACKNOWLEDGEMENT

The measurements were made at Court House Bay in a building of the Coast Guard Detachment. To Lieutenant Commander Eugene Kiernan, USCG, the Commanding Officer, we express our thanks for putting the necessary space at our disposal and for supplying personnel and facilities without which the experiments could not have been accomplished.

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Table I

The Delay in Dark Adaptation Following Exposure to Bright Sky

Subject	Time of Preliminary Light Adaptation	Time of Final Light Adaptation	Brightness of Sky during Final Light Adaptation millilamberts	Rise in Rod Threshold 1/2 hr. in the dark	Rise in Rod Threshold 1 hr. in the dark	Rise in Rod Threshold 2 hrs. or more in the dark
A. B.	3 hours	4 minutes	3000 to 10,000	0.28	0.10	0.12
M. Y.	3 "	4 "	" "	0.45	0.09	0.04
B. L.	6 "	none	none	0.09	0.00	0.00
B. L.	4 "	4 minutes	3000 to 10,000	0.55	0.16	0.16
D. H.	23 minutes	9 "	1000 to 4000	0.27	0.08	-----
C. H.	2½ hours	5 "	10,000	0.20	0.00	0.00
C. H.	30 minutes	5 "	10,000 to 12,000	0.43	0.38	0.32
C. H.	20 "	10 "	10,000 and over	0.61	0.23	0.34
Y. H.	25 "	5 "	3000 to 10,000	0.19	0.17	0.17
Y. H.	25 "	5 "	5000	0.40	0.33	0.11
Y. H.	25 "	7 "	3000 to 6000	0.23	-0.04	-----
S. H.	none	20 "	not determined	1.2	0.15	0.05
W. N.	7 minutes	4 "	6500	0.55	0.25	-----
W. N.	10 "	8 "	5000	0.35	0.10	0.00
W. N.	none	30 "	3500	0.70	0.34	0.20
W. N.	15 minutes	15 "	6000	0.65	0.20	0.00
W. N.	10 "	10 "	9000	0.60	0.19	0.00
W. N.	none	10 "	5000	0.60	0.16	0.00
G. L.	none	30 "	8000	0.30	0.30	0.02
G. L.	none	37 "	9000	0.48	0.25	0.20
A. C.	none	25 "	16,000	1.05	0.84	0.57
Average				0.48	0.20	0.1

Table II

Effect of Sunlight on Night Vision

Sky Brightness $3-5 \times 10^3$ ft. lamberts
Water " 1-3 " " " "
Sand " 1-2 " " " "

No. of Subjects	Hours Exposure	Threshold Rise ---- log units				
		Hours after Exposure				
		1/3	3/4 - 1	1 1/2	4 1/2 - 5	16+
6	2		+0.25	+0.20		-0.02
6	5	+0.85	+0.25		+0.09	
4	2		+0.27		+0.27	+0.16
6	2 1/2		+0.23			
11	2 1/2		+0.19			+0.09
10	5		+0.12			-0.05

Table III

Morning Thresholds after One Hour in Darkness

Date	X - 1	X - 2	X - 3	Average of X Groups	C - 1	C - 2	C - 3	Average of C Grou
Sept. 5	2.27	2.25	2.30	2.27	2.29	2.26	2.31	2.29
6	2.23	2.24	2.29	2.25	2.29	2.22	2.29	2.27
7	2.30	2.20		2.25	2.26	2.29		2.28
8		2.23	2.25	2.24		2.28	2.27	2.27
9			2.24				2.21	
11	2.24			2.24	2.23			2.22
12	2.26	2.27		2.26	2.23	2.20		2.22
13		2.32	2.26	2.29		2.28	2.31	2.29
14	2.32		2.32	2.32	2.16		2.16	2.16
15	2.36	2.29		2.32	2.18	2.28		2.23
16		2.25				2.26		
18			2.44	2.35			2.24	2.25
19	2.22		2.47	2.34	2.18		2.25	2.22
20	2.27	2.31		2.29	2.23	2.25		2.24
21		2.28	2.32	2.30		2.32	2.21	2.26
22	2.27		2.31	2.29	2.17		2.18	2.18
23	2.25				2.14			
25		2.28		2.27		2.23		2.18
26		2.24	2.29	2.26		2.21	2.16	2.19
27	2.12		2.34	2.23	2.13		2.16	2.14
28	2.17	2.22		2.20	2.09	2.21		2.15
29		2.27	2.32	2.29		2.28	2.12	2.20
30			2.36				2.15	
Oct. 1	X Groups come indoors; C groups go out to beach.							
2	2.27				2.16			
3	2.22	2.22		2.22	2.25	2.31		2.28
4		2.28	2.35	2.31		2.31	2.20	2.26
5	2.14		2.40	2.27	2.22	2.28	2.19	2.23
6	2.18	2.25		2.22	2.27	2.29	2.23	2.26
7		2.22			2.29			
9	2.15		2.38	2.25	2.29	2.39	2.17	2.28
10	2.16	2.26	2.36	2.26	2.24	2.33	2.23	2.27

Table IV

Average Thresholds of Experimental and Control Groups

Date	Min.	Group X-1		Group C-1		Group X-2		Group C-2		Group X-3		Group C-3	
Sept.	in Dark	No. of Men	Threshold	No. of Men	Threshold	No. of Men	Threshold	No. of Men	Threshold	No. of Men	Threshold	No. of Men	Threshold
5 am	60	10	2.28	7	2.29	10	2.25	6	2.26	10	2.30	7	2.31
6 am	60	11	2.23	7	2.29	10	2.25	6	2.22	10	2.29	7	2.29
6 pm	60	11	2.41	7	2.31								
7 am	60	11	2.30	7	2.26	9	2.16	6	2.29				
7 pm	60					10	2.31	6	2.23				
8 am	60					9	2.23	6	2.28	10	2.25	7	2.27
8 pm	60									10	2.29	7	2.26
9 am	60									9	2.20	6	2.21
11 am	60	11	2.24	7	2.23								
11 pm	60	9	2.28	7	2.19								
12 am	60	10	2.26	7	2.23	9	2.27	6	2.20				
12 pm	60	11	2.41			6	2.36	6	2.24				
13 am	60					9	2.32	6	2.28	10	2.25	7	2.31
13 pm	60									10	2.37	7	2.23
14 am	60	11	2.32	7	2.16					10	2.32	7	2.16
14 pm	60	10	2.34	7	2.19								
15 am	60	11	2.36	7	2.18	9	2.29	6	2.28				
15 pm	60					9	2.32	6	2.23				
16 am	60					7	2.28	6	2.26				
18 am	60									10	2.44	7	2.34
18 pm	60									10	2.46	7	2.24
19 am	60	10	2.22	6	2.18					10	2.47	7	2.25
19 pm	60	10	2.32	7	2.16								
20 am	60	11	2.27	7	2.22	8	2.30	5	2.25				
20 pm	60					7	2.35	5	2.27				
21 am	60					9	2.26	5	2.32	9	2.31	7	2.21
21 pm	60									10	2.43	7	2.22
22 am	60	11	2.27	7	2.16					10	2.31	7	2.18
22 pm	60	11	2.39	7	2.68								
23 am	60	11	2.25	5	2.16								
25 am	60					9	2.28	4	2.16				

Table IV (Continued)

Date.	Min. in Dark	Group X-1 No. of Men	Group X-1 Threshold	Group C-1 No. of Men	Group C-1 Threshold	Group X-2 No. of Men	Group X-2 Threshold	Group C-2 No. of Men	Group C-2 Threshold	Group X-3 No. of Men	Group X-3 Threshold	Group C-3 No. of Men	Group C-3 Threshold
Sept.													
25 pm	30					9	2.53						
25 pm	60					9	2.36	5	2.26				
25 eve	60					9	2.2[illegible]						
26 am	30					10	2.3[illegible]	5	2.22	10	2.33	5	2.26
26 am	60					10	2.23	5	2.21	10	2.29	7	2.15
26 pm	30									10	2.50	7	2.21
26 pm	60									10	2.44	7	2.20
26 eve	60									10	2.39		
27 am	30	9	2.21	7	2.21					9	2.36	7	2.16
27 am	60	9	2.12	7	2.12					9	2.34	7	2.16
27 pm	30	9	2.35	6	2.11								
27 pm	60	9	2.33	6	2.12								
27 eve	60	9	[illegible]										
28 am	30	9	2.24	5	2.04	10	2.27						
28 am	60	9	2.17	7	2.09	10	2.2[illegible]	5	2.21				
28 pm	30					10	2.22	5	2.22				
26 pm	60					10	2.40	5	2.23				
28 eve	60					9	2.22						
29 am	30					10	2.26	5	2.32	9	2.35	6	2.67
29 am	60					10	2.24	5	2.28	9	2.32	6	2.14
29 pm	30									9	2.62	6	2.20
29 pm	60									9	2.42	6	2.16
29 eve	60									9	2.34		
30 am	30									9	2.50	5	2.24
30 am	60									9	2.36	5	2.15
Oct.													
2 am	30			3	2.33								
2 am	60	9	2.27	7	2.16								
2 pm	30			7	2.28								
2 pm	60	9	2.27	7	2.28								
2 eve	60			7	2.22								

Table IV
(Continued)

Date	Min. in Dark	Group X-1		Group C-1		Group X-2		Group C-2		Group X-3		Group C-3	
Oct.		No. of Men	Threshold	No. of Men	Threshold	No. of Men	Threshold	No. of Men	Threshold	No. of Men	Threshold	No. of Men	Threshold
3 am	30			7	2.43			5	2.36				
3 am	60	9	2.21	7	2.25			5	2.31				
3 pm	30					9	2.33	5	2.50				
3 pm	60					9	2.25	5	2.41				
3 eve	60							5	2.33				
4 am	30					9	2.35	5	2.34	9	2.45	5	2.22
4 am	60					9	2.30	5	2.31	9	2.34	5	2.13
4 pm	30					9	2.54			9	2.54		
4 pm	60					9	2.40	5	2.44	9	2.40	5	2.39
4 eve	60											5	2.30
5 am	30			7	2.31			5	2.30	7	2.47	5	2.38
5 am	60	9	2.13	7	2.21			5	2.28	9	2.40	5	2.19
5 pm	30	9	2.20	7	2.37							5	2.36
5 pm	60	9	2.17	7	2.35							5	2.32
5 eve	60			7	2.23								
6 am	30			7	2.34								
6 am	60	9	2.17	7	2.27	10	2.24	5	2.29			5	2.23
6 pm	30			3	2.30	9	2.24	3	2.40				
6 pm	60			6	2.36	10	2.21	5	2.39				
6 eve	60							2	2.49				
7 am	30			5	2.36	6	2.35	3	2.23				
7 am	60			5	2.31	6	2.25	3	2.25				
9 am	30	9	2.21	7	2.31			5	2.50	9	2.51	6	2.18
9 am	60	9	2.15	7	2.29			5	2.39	9	2.38	6	2.16
9 pm	30	9	2.22	7	2.54			5	2.56	6	2.41	6	2.40
9 pm	60	9	2.13	7	2.38			5	2.45	9	2.41	6	2.25
9 eve	60	9	2.18	7	2.37			4	2.36	8	2.32	4	2.26
10 am	30	5	2.42	3	2.37			1	2.20	3	2.53	1	2.15
10 am	60	9	2.16	7	2.24	10	2.26	5	2.33	8	2.36	6	2.19