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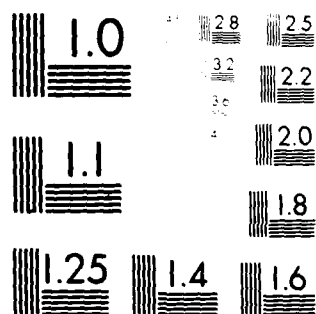
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USAARL REPORT NO. 82-1



**DIRECT AND NEIGHBORING SENSITIVITY CHANGES PRODUCED
BY RED AND BLUE-WHITE ADAPTING FIELDS**

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By
Franklin F. Holly
Virgil R. Rogers

SENSORY RESEARCH DIVISION
Visual Science Group

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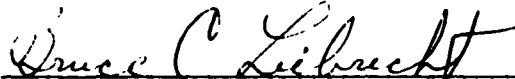
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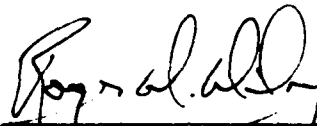
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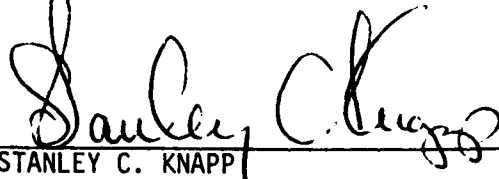
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Observers viewed Army instrument panel lighting red and Air Force instru- ment panel lighting blue-white adaptation fields and their thresholds were determined both within the adaptation field and outside of it. In some cases, thresholds were determined while the adaptation field was still on and in other cases they were determined after the adaptation field had been off for 10 sec- onds. Also, some trials were performed under otherwise totally dark ambient conditions and other trials were performed under an ambient illumination which		

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20. ABSTRACT (Contd)

simulated that produced by a full moon on a clear night. It was found that under ambient conditions of total darkness thresholds were lower with the red adaptation field than with the blue-white. With the full moon ambient illumination the results were more varied. When the trials were performed after the adaptation field had been turned off, there were generally no differences between the thresholds produced by the red adaptation field and those produced by the blue-white adaptation field. On the other hand, when trials were performed with the adaptation field still on, there was an interaction such that thresholds were lower with the blue-white field at the smallest adaptation field intensities but were lower with the red field at the greatest adaptation field intensities. The results were discussed in terms of their significance for aircraft lighting and the possible roles played by stray light and other underlying processes.

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PREFACE

Virgil R. Rogers is presently employed by Technical Engineers, Inc.,
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TABLE OF CONTENTS

	<u>Page No.</u>
List of Illustrations	4
Introduction.	5
Method.	6
Observers	6
Apparatus	6
Procedure	8
Results and Discussion.	9
Implications For Aircraft Lighting.	9
Theoretical Implications.	14
Conclusions	16
Recommendations	16
References.	17

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page No.</u>
1	Air Force instrument panel lighting IPL chromaticity limits.	7
2	Diagram of adaptation and test fields	8
3	Thresholds of subject FH with adaptation field off. . . .	10
4	Thresholds of subject VR with adaptation field off. . . .	11
5	Thresholds of subject FH with adaptation field on	12
6	Thresholds of subject VR with adaptation field on	12
7	Thresholds of subject FH with adaptation field off and moonlight field added	13
8	Thresholds of subject FH with adaptation field on and moonlight field added	13

INTRODUCTION

Red lighting has been used in Army aircraft cockpits since before the days of World War II to preserve scotopic (night) visual sensitivity. Recently, this practice has been questioned by some members of the hardware development community because of the increased expense of red lighting over unfiltered white and because of the incompatibility of single-color lighting with the multicolored displays which have been suggested for Army aircraft use. While conceding the marked adaptation advantage provided by red lighting at high luminance levels, some have suggested that at the low luminance levels at which aviators normally set their instruments the advantage provided by red is so small as to be not worth the added expense and inconvenience. Even more recently, the advent of the latest generation of night vision goggles has again raised the whole question of the use of red lighting in Army aircraft cockpits. This is because these goggles are extremely sensitive in the long-wavelength end of the visible spectrum and the red cockpit lights tend to cause "blooming" in them and to activate the automatic gain control which reduces their sensitivity for outside viewing. The present study and another study to be performed later were designed to determine just how much of an adaptation advantage red lighting provides at low luminance levels so that a decision can eventually be made concerning its continued use in Army aircraft cockpits. The blue-white lighting selected for comparison is the one currently used in Air Force cockpits (MIL-L-271160B).

This study was also intended to be a first step towards examining an aspect of dark adaptation that has not often been studied in the past. Most previous studies of dark adaptation either used whole-field adaptation followed by a threshold probe or used partial-field adaptation followed by a threshold probe presented within the area just stimulated (Hecht, Haig, and Chase, 1937; Hecht, Haig, Wald, 1935; Wald and Clark, 1937). However, under operational conditions, adapting lights do not usually occur in such an orderly fashion; we are often concerned with the question of how does an adapting light at Point A affect sensitivity at Point B or how do adapting lights at Points A and B affect sensitivity at Point C. What is needed is a basic understanding of the process by which adaptation effects spread laterally across the retina if, indeed, they do at all.

In the work to be described, threshold probes were presented both inside and outside the adaptation area and the curves for the two points were compared in order to gain an insight about any possible spreading effects. The threshold probes were also presented both during the presence of the adapting field and after its offset. The ambient conditions were either total darkness or a luminance level which simulated that produced by a full moon on a clear night.

METHOD

OBSERVERS

Two male observers were used. Both exhibited normal dark adaptation processes as determined by the Goldmann-Weekers adaptometer.* One observer (FH) is deuteranomalous; the other observer (VR) has normal color vision as determined by the Nagel anomaloscope* and the Dvorine pseudoisochromatic plates.†

APPARATUS

The apparatus consisted of a two-channel Maxwellian view optical system in which the right channel was used to present the red or blue-white adaptation field and the left channel was used to present the unfiltered white threshold stimulus. The sources for these channels were tungsten-halogen bulbs. In addition, a third, non-Maxwellian, channel was provided by a light box situated off to the right of the apparatus and directed to the eye by means of an additional beamsplitting cube at the eye. This channel was used to simulate the luminance (2.4×10^{-3} ftL) of grass on a clear night with a full moon. Its chromaticity coordinates were $x = 0.199$ and $y = 0.586$. The fixation point was provided by means of an optical fiber with a grain-of-wheat bulb at one end and the other end situated at the right edge of the right channel field aperture. The red adaptation field was provided by means of a Wratten No. 29[§] filter and the blue-white adaptation field was provided by a Wratten No. 78[§] filter. The location of the blue-white light within the chromaticity limits established for Air Force blue-white lighting, shown graphically in Figure 1, page 7, is $x = .4477$ and $y = .4074$. The coordinates of the red light are $x = .7116$ and $y = .2883$. The limits established by MIL-C-25050A for instrument panel red lighting are: x not less than .693, y not greater than .306, and z not greater than .001.

The threshold pulses had a duration of 35 msec and were generated by a Vincent Associates UniBlitz Model 100-2B Electronic Shutter# and an electronic timing system. This electronic timing system consisted of a Tektronix PG508 Pulse Generator** which was triggered by the subject by means of a hand-held pushbutton switch and which fed into a Tektronix FG502 Function Generator.** The function generator produced a ramp which fed into a Tektronix PG505 Pulse Generator** and triggered an output pulse from it which was adjusted to 35 msec and fed into the shutter control unit.

The adaptation field (large field in Figure 2, page 8) provided by the right channel consisted of a 13° , 15' diameter circular field. The fixation point was located at the extreme right edge of this field and one of the threshold probes (small fields in Figure 2, page 8) was located 10° , 15' to the left of this fixation point (inside the adaptation field) and the other threshold probe was located 16° , 15' to the left of the fixation point

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† Scientific Publishing Company, 7901 Liberty Road, Baltimore, MD 21207

§ Eastman Kodak Company, 343 State Street, Rochester, NY 14650

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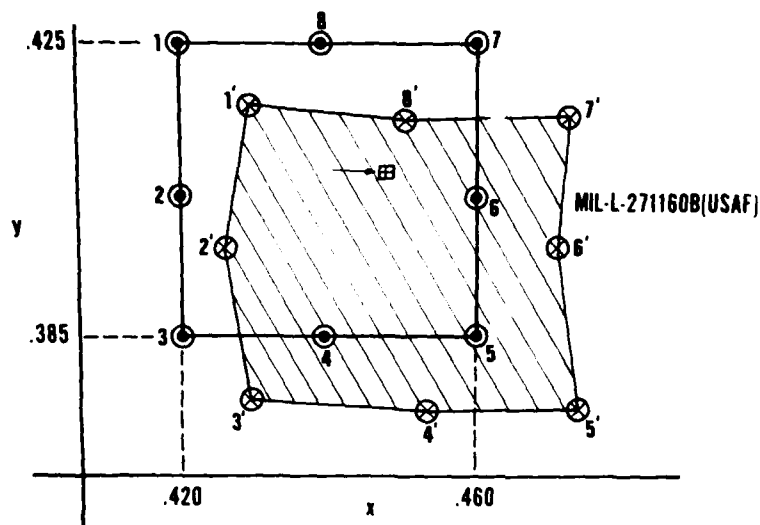


FIGURE 1. The chromaticity limits of Air Force blue-white lighting are indicated by the crosshatched area. The chromaticity coordinates of the blue-white adapting field used in the study are indicated by the inclosed crosshair.

(outside of the adaptation field). The threshold probe location inside the adaptation field will be referred to as Point 1 and the threshold probe location outside the adaptation field will be referred to as Point 2. In the conditions where the moon simulation was added, this moonlight field extended for 40° of vertical visual field and 30° of horizontal visual field thus covering the adaptation field and both threshold probes.

The light level measurements were all made with a Photo Research Model 1980 PL Pritchard Photometer* with the photopic[†] filter in place. The chromaticity measurements were made with the Tektronix Rapid Scan Spectrophotometric System.[§]

* Photo Research, 3000 No. Hollywood Way, Burbank, CA 91505

[†] Photopic rather than scotopic equivalence for the red and blue-white adaptation fields was appropriate since photopic vision is required to see the fine details of the instruments (Brown and others, 1953). Aviators normally set their instruments just above photopic threshold but they try not to set them any higher than necessary because they are a potential glare source and can create reflections from the canopy.

[§] See page 6.

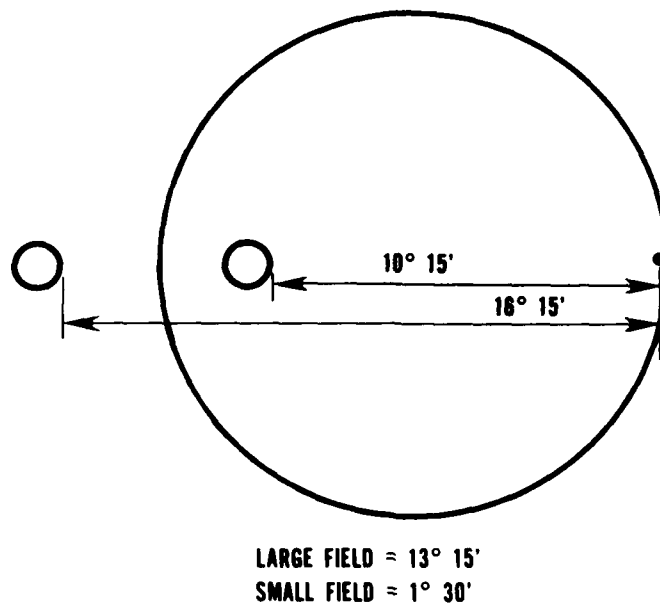


FIGURE 2. The large circle represents the adaptation field. The small circles represent the threshold probes both inside and outside of the adaptation field. The dot at the right edge of the adaptation field represents the fixation point. Dimensions are as shown. In the cases where the moonlight field was added, it covered the entire area.

PROCEDURE

The experimental design was an AXBXCXDXE(2X2X2X2X6) design in which Factor A was the location of the test stimulus (either inside or outside of the adaptation field), Factor B was the color of the adaptation field (either red or blue-white), Factor C was the presence or absence of the adaptation field during the presentation of the test stimulus, Factor D was the presence or absence of the moonlight field, and Factor E was the intensity of the adaptation field.

After the head-stabilizing device --the bite-bar-- had been aligned for an observer, he was first dark-adapted for 45 minutes and then exposed to the lowest intensity of the red adaptation field for 5 minutes. At the end of this time, the adaptation field was turned off and 10 seconds later he used the method of adjustment (ascending trials only) to determine his threshold at Point 1. The observer was then reexposed to the same adaptation field for two minutes and a second threshold judgment was obtained in the same way.

After this, two more threshold judgments were made at the same adaptation field intensity but on these two trials the threshold probe was presented at Point 2. Next, the intensity of the adaptation field was increased to the next highest level and the same procedures were repeated. After threshold judgments had been obtained at all adaptation field intensities, the same pattern was repeated in another session except that this time the adaptation field remained on while the threshold judgments were made. In still other sessions, judgments were obtained for the blue-white adaptation field under the same conditions described above. Finally, the moonlight field was added and all of these procedures were repeated.

RESULTS AND DISCUSSION

PRACTICAL IMPLICATIONS

The intensities of the adaptation fields were converted from photopic trolands to photopic footlamberts by measuring the pupil sizes at the various retinal illuminances and then calculating the luminance of a target in footlamberts that would produce an equivalent retinal illuminance. These luminances and pupil sizes are listed in the following table:

<u>FOOTLAMBERTS</u>	<u>PUPIL SIZE (mm)</u>
100	3.5
10	5
1	5
.1	7
.01	7
.001	7

This conversion was performed so that the findings could be more easily related to the luminance levels used in aircraft cockpits. In Figures 3 through 8, these equivalent luminances of the adaptation fields are displayed on the abscissae and the thresholds are displayed on the ordinates. The area of greatest interest for aircraft lighting is the range of from .01 to .1 ftL for the adaptation fields since this is the luminance range within which aviators normally set their instruments.

These data for Point 1 in Figure 3 (subject FH) show a superiority for red of from approximately .3 to .5 log units in the range of .01 to .1 ftL. This represents the case in which the aviator has just been looking at his instrument panel and then looks outside to see something with the same part of his retina that has just been stimulated by the instrument panel. The data for Point 2 in the same figure represent the case in which the aviator has just been looking at his instrument panel and then looks outside to see something with a part of his retina that has not just been stimulated by the instrument panel. This data shows a superiority for red of from .2 to .5 log units in the range of .01 to .1 ftL. The same data for subject VR are shown in Figure 4, page 11. The data for Point 2 of Figure 5, page 12, (subject FH)

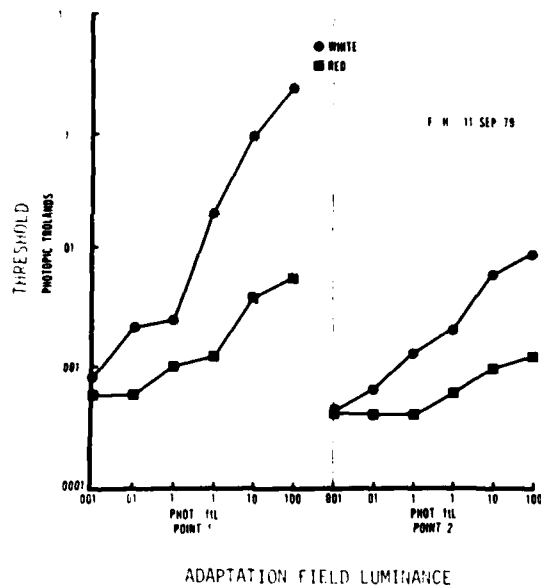


FIGURE 3. Threshold performance of subject FH at Points 1 and 2 following exposures to red and blue-white adaptation fields of various intensities. The adaptation field was off during the judgments.

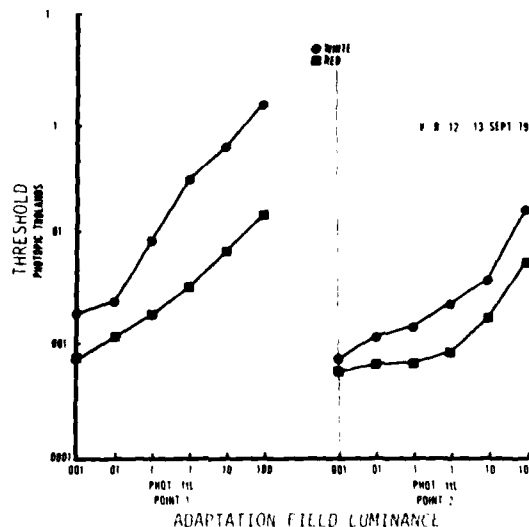


FIGURE 4. Threshold performance of subject VR under the same conditions described in Figure 3.

(adaptation field on) represent the case in which the aviator is looking at his instrument panel while, at the same time, attempting to see something outside of his aircraft out of the corner of his eye. Here, the red shows a superiority of from .8 to 1.2 log units in the range of .01 to .1 ftL. The data for subject VR under this condition are shown in Figure 6, page 12.

All of the results described so far were obtained under ambient conditions of total darkness. In the aviation environment, conditions close to this could exist, for example, when the aviator is flying on a very dark night, when he is flying close to a ridge or large hill which is blocking the moonlight, or when he is flying Instrument Flight Rules (IFR) at night and then breaks out beneath the cloud cover into darkness. Figures 7 and 8, page 13, show the results for the opposite ambient conditions, i.e., full moon and clear sky. The data for Point 1 of Figure 7, page 13, (subject FH) correspond to the condition described above in which the aviator has just been looking at his instrument panel and then views outside with a part of his retina which has just been stimulated except that this time the moonlight has been added. It can be seen that there is no difference between the results for red and blue-white in this case. The results for Point 2 (subject FH) represent the case in which the aviator has just been looking at his instrument panel and views outside with a part of his retina which has not just been stimulated (with moonlight added). It can be seen that, again, there is no difference between the red and blue-white. Finally, Point 2 of Figure 8, page 13, represents the condition, with moonlight added, in which the aviator is looking

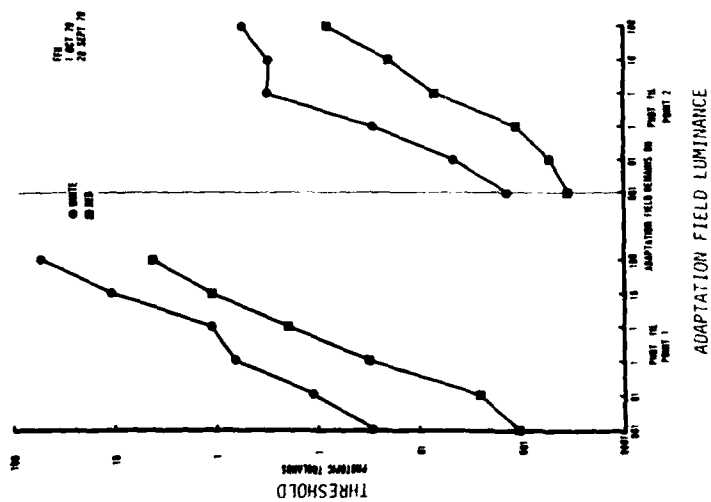


FIGURE 5. Threshold performance of subject FH at Points 1 and 2 following exposures to red and blue-white adaptation fields of various intensities. The adaptation field was left on during the judgments.

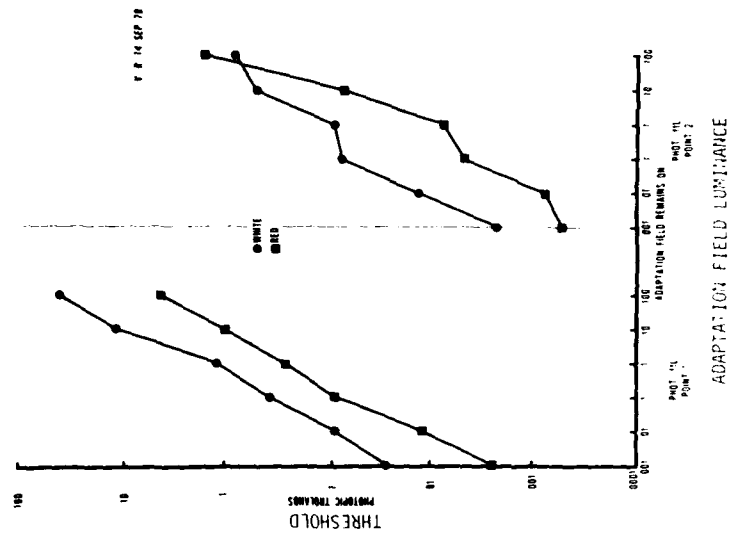


FIGURE 6. Threshold performance of subject VR under the same conditions described in Figure 5.

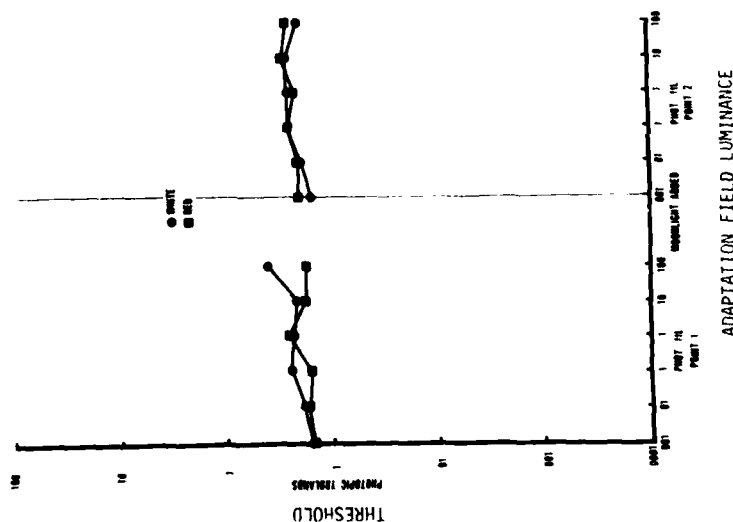


FIGURE 7. Threshold performance of subject FH at Points 1 and 2 following exposures to red and blue-white adaptation fields of various intensities with the moonlight field added. The adaptation field was off during the judgments.

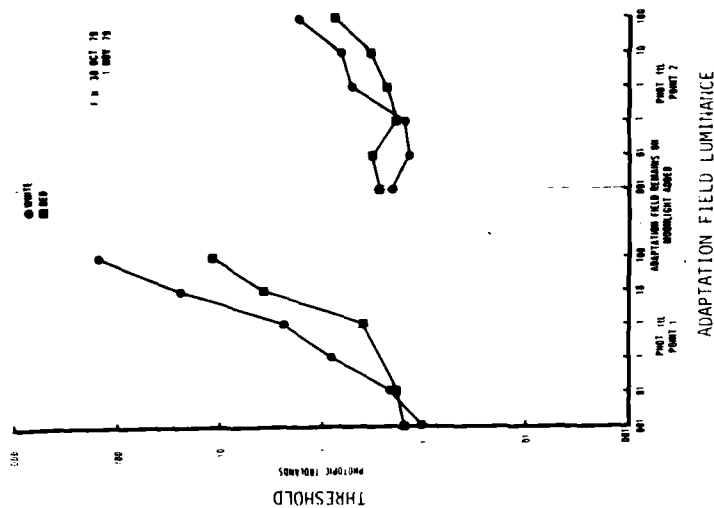


FIGURE 8. Threshold performance of subject FH at Points 1 and 2 following exposures to red and blue-white adaptation fields of various intensities with the moonlight field added. The adaptation field was left on during the judgments.

at his instrument panel and, at the same time, attempts to see something outside the aircraft out of the corner of his eye. In this case, there is actually a superiority for the blue-white at .01 ftL and virtually no difference between the red and blue-white at .1 ftL.

THEORETICAL IMPLICATIONS

First of all, it will be noted that when the adaptation field remains on (Figures 5, 6, and 8) the performance at Point 1 is somewhat more linear than the performance at Point 2 perhaps indicating a more straightforward threshold-determining process at Point 1. Secondly, the thresholds at Point 1 and Point 2 are generally more similar with red adaptation than with blue-white adaptation perhaps indicating a greater amount of adaptation pooling among rods than among cones since the red adaptation thresholds are, in most cases, rod determined. Thirdly, one can see that the curves at Point 1 generally tend to rise more steeply than the curves at Point 2. This is especially true in the case where moonlight is added and the adaptation field remains on (Figure 8, page 13).

In our attempt to learn something about the underlying processes producing this data one of the most obvious factors that must be considered is the influence of stray light, i.e., to what extent is the performance at Point 2 determined by light scattered within the eye. The image formed on the retina is never a sharp one but rather shows a fuzziness or gradual tapering off at the edges due to optical aberrations and light scattering within the eye. Since this stray light at any given point will be a constant proportion of the adaptation field intensity, to the extent that stray light is determining the thresholds at Point 2, the curves at Point 1 and Point 2 will be superimposable by simply shifting the Point 2 curves a certain constant amount to the left. Before considering other hypotheses, let us first determine the extent to which such a stray light hypothesis is consistent with the data. It will be seen that in a number of instances a leftward shift of about one log unit of the Point 2 curves produces some similarities to the Point 1 curves. For example, in the condition where the adaptation field remains on and the moonlight is added (Figure 8, page 13) the crossover point of the Point 2 curves is about one log unit to the right of the crossover point of the Point 1 curves. Furthermore, in one condition where the adaptation field remains on (Figure 5, page 12) the temporary levelling-off of the blue-white curves at Points 1 and 2, which probably represents the rod-cone break, occurs about one log unit later (to the right) in the Point 2 curve than in the Point 1 curve. Finally, in one case where the adaptation field does not remain on (Figure 3, page 10) it can be seen that a movement of the Point 2 curves to the left about 1 log unit would produce approximately the same initial difference between the red and blue-white curves as occurs in the Point 1 curves.

However, in none of these instances does a leftward shift of the Point 2 curves produce complete superimposition with the Point 1 curves; the curves vary considerably in overall shape. For example, in the case where the adaptation field remains on and the moonlight is added (Figure 8, page 13) even though a leftward shift of the Point 2 curves of one log unit produces

superimposition of the crossover points the Point 1 and Point 2 curves have very different shapes overall. Also, in two cases where the adaptation fields do not remain on (Figures 3 and 4) both observers show at Point 1 a sharp upward turn (at approximately .01 fTL for subject VR and at approximately .1 fTL for subject FH). However, at Point 2 this sharp upward turn does not occur until about 3 log units later for subject VR and never occurs for subject FH. Thus, we must conclude that even though there is certainly stray light in the eye and it must have a considerable effect upon threshold, a simple stray light hypothesis alone cannot adequately explain the threshold performance at Point 2. Instead, it would seem that the performance at Point 2 must be determined in part by lateral connections* within the retina.

The crossovers at both Points 1 and 2 in Figure 8, page 13, are intriguing. At the lower intensities, the usual relationship is reversed; performance is better following the blue-white adaptation than after the red. However, as the adaptation field intensity increases while the intensity of the moonlight field remains constant the adaptation field eventually reestablishes its predominant influence and the usual relationship obtains. This effect may be related to the finding by Ronchi (1960) and Cavanus and Hilz (1970) that the thresholds for photopic detection tasks can actually be lowered by the addition of a small amount of short-wavelength light to the preadapting field. Viewed in these terms, we can say that under the present conditions the effect is maximal at Point 2 when .01 fTL of short-wavelength light is added to the moonlight adapting field.

The Point 2 curves are generally somewhat flatter than the Point 1 curves even if one shifts them laterally to compensate for the stray light effect. What sorts of things could cause such a flattening? To cite an extreme (and certainly untrue) example, if there were no stray light and no neural spreading then the Point 2 curves would be perfectly flat and at absolute threshold. More interestingly, if some of the adaptation occurred after a certain amount of form processing** had taken place one would also expect some flattening since such processing serves to improve the image by, among other things, cancelling the effects of stray light. Formally, we can say at this point only that a simple model consisting of stray light effects plus neural spreading by multiplicative constants of less than 1 could roughly account for most of the Point 2 curves.

* Another potentially significant factor whose importance we are not able to assess from this study is that of retinal locus per se; some of the differences between the Point 1 and Point 2 curves could be due to the fact that they were obtained at different retinal loci. Hopefully, in the future we will be able to extend the study to a balanced design in which the Point 1 and Point 2 probes fall both within and outside of the adapting field.

** The term "form processing" is being used here only in the simple sense of lateral inhibitory effects, edge effects, etc. It is not being suggested that a significant proportion of light/dark adaptation occurs centrally.

CONCLUSIONS

Under conditions of total or nearly total darkness, red lighting preserves visual sensitivity for outside viewing to a greater extent than does blue-white lighting. This is true even when the instrument lights are set at the low levels (.01 to .1 ftL) at which aviators normally set their instruments.

Under conditions of full moon illumination with a clear sky, the difference between the sensitivity preserved by red lighting and blue-white lighting at .01 and .1 ftL vanishes and, in one case, even shows a superiority for the blue-white lighting.

Stray light effects alone cannot explain the spatial distribution of adaptation. That is, adaptation levels must, to some extent, spread laterally by either a neural or photochemical process.

RECOMMENDATIONS

Dark adaptation tests need to be performed under operational flying conditions with a variety of ambient lighting conditions. This will allow us to expand our conclusions beyond simply the two extremes of ambient illumination studied in the present work.

Basic research needs to be performed on the lateral spreading of adaptation in the retina.

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