NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 1045

IMMEDIATE VISIBILITY
AFTER RED AND WHITE ADAPTATION

by

S. M. Luria and D. A. Kobus

Naval Medical Research and Development Command
Research Work Unit M0100.001-1023

Released by:

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Commanding Officer
Naval Submarine Medical Research Laboratory

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RESEARCH PROJECT M0100.001-1023

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SUMMARY PAGE

PROBLEM

To measure visibility within the first 10 seconds after looking away from red or low level white light of equal brightness.

FINDINGS

There were no differences in the ability of observers to detect silhouettes or shadows against the starlit or moonlit sky after adapting to red or low level white.

APPLICATION

These results support the proposal to substitute low level white light for red light in submarine control rooms.

ADMINISTRATIVE INFORMATION

This research was conducted as part of the Naval Medical Research and Development Command Work Unit M0100.001-1023 "Enhanced visual performance on submarines." It was submitted for review on 14 Mar 1985, approved for publication on 26 Apr 1985, and designated as NSMRL Rep. No. 1045.

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ABSTRACT

The ability to see simulated ship silhouettes and shadows within 10 seconds of looking away from either red or white light of equal brightness was measured. There were no significant differences in the ability to see such targets after adaptation to red or white light at either 0.1 or .01 fL, or when the background illumination was .09 fc or .006 fc.

INTRODUCTION

As is well known, exposure to red light results in faster dark adaptation once the light is turned off than does exposure to any other color (1,2). Submarine compartments have for this reason been illuminated with red light to maintain a level of dark adaptation primarily for the officer of the deck who must be prepared to look through the periscope at night. This has provided a limited amount of dark adaptation while at the same time permitting the crew to carry out most of their duties.

In the modern submarine, the red light is used only as a preparatory condition prior to extinguishing all lighting before going to periscope depth. However, the officer of the deck (OOD) is required to wear red goggles during his entire watch at night. Consideration is now being given to doing away with red light altogether (3). The red light has always been unpopular. It makes it difficult to read and write, makes it impossible to read color-coded charts, and tends to increase eye-fatigue. The planned implementation of extensive color-coded CRT displays makes it even more desirable to eliminate chromatic ambient illumination.

The advantages of red light for subsequent dark adaptation have been the subject of many investigations (4). As mentioned, red light has been used because it is well established that subsequent dark adaptation is faster than with any other color. However, the magnitude of this advantage depends on the intensity of the adapting light. As intensity decreases, the advantage of red for pre-adaptation also decreases. Moreover, the measure that has typically been used to show this phenomenon is the time required to detect pinpoints of light at absolute scotopic threshold--that is, the individual's maximum sensitivity. Although this is undoubtedly of great importance at times, it is probably true that in most practical situations the observer is required to operate at something less than maximum sensitivity and to detect targets quite different from spots of light. The submarine periscope operator, for example, may need maximum scotopic sensitivity only on those nights which are overcast and dark. Even on a clear night when there is no moon, the brightness level of the starlit sky is an order of magnitude greater than the level required for absolute dark adaptation of a young observer. In addition, the targets the periscope operator is often looking for are ship silhouettes, or the shadows of ships seen on the surface when coming to periscope depth rather than pinpoints of light.

Although the periscope operator must still dark adapt, the unpopularity of red lighting has led to numerous attempts to replace it (5). Recently, investigations exploring the feasibility of eliminating red lighting have suggested low level white (LLW) ambient illumination matched in brightness to the red lighting as a substitute (6-8). It has been suggested that other workspaces that have previously used red lighting be converted to the LLW system (9). Luria and Kobus (4) have suggested that the additional time required to dark adapt after pre-exposure to LLW rather than to red is probably not of operational importance because additional time is typically spent under the no-light condition before making observations. However, one possibility that was not considered was that of an emergency condition. That is, there may be times when it is necessary for the ship to go to periscope depth or to the surface without time for the usual procedure for fully adapting. What are the differences in performance between the two lighting systems in such a case? Eventually the observer will adapt to the background he is viewing, but how different is visual performance within the first few seconds of exposure after adapting to red or LLW? The goal of the present study is to measure differences in performance to see if they are of operational significance.

EXPERIMENT I

In the first experiment, we simulated targets along a nighttime horizon and measured the size of the smallest low contrast rectangle that could be detected against a dimly lighted background.

Method

Subjects Eight staff members of the laboratory served as subjects.

Apparatus The subjects sat in front of a large sheet of white cardboard (120 x 100 deg visual angle) which served as the adaptation field. In the center was a shutter with an aperture 1.5 in. in diameter. The subjects looked through this aperture at a light box 20 ft away which subtended 3 x 5 deg visual angle and served as the background.. This was illuminated to .09 fc, which is equivalent to the brightness of the sky between a full and a quarter moon.

Adaptation lights The subjects adapted by looking at the large sheet of white cardboard which was illuminated by red or white light. The red light was produced by mounting a standard Navy red filter in front of a tungsten lamp. The white light was produced by mounting a bluish correction filter in front of a tungsten lamp. The intensity of the lights was attenuated with neutral density filters. The white light was first dimmed to .01 fL as measured by a Spectra-Pritchard Model 1980 photometer. This is approximately the lowest intensity which was found in a survey of sonar rooms illuminated for red light (10).

Since the intensity of colored lights cannot be measured accurately with a photometer, particularly at mesopic or scotopic intensities (11), the red light was matched in brightness to the white light by six observers. Both lights were turned on at the same time to illuminate the cardboard. The cardboard was divided by another piece of cardboard perpendicular to the field of view. Each judge viewed the two halves of the field simultaneously as the intensity of the red light was varied until it matched the white light in brightness. The mean setting proved to be acceptable to all.

Targets The targets were rectangular neutral density filters (ND=.09) which transmitted 81% of the light. When mounted in front of the light box, they produced a low contrast target which was slightly darker than the background. The length of each rectangle was twice that of its height, and at the viewing distance of 20 ft, the horizontal viewing angles of the various targets ranged from less than half a degree to more than one degree in about 0.1 deg increments.

Procedure Half the subjects observed first under the red light, half under the white. The two colors were tested on different days. The subject was first adapted to the light for 15 minutes by gazing at the cardboard. The target threshold was then obtained by the method of constant stimuli. One of the rectangles was randomly chosen and placed somewhere on the surface of the light-box. The adaptation light was extinguished, and the subject immediately put his eye to the viewing port which was opened for 10 seconds. At the end of 10 seconds, the port was closed and the adaptation light was turned on. The subject then reported whether or not he had seen the target and, if so, its location. The subject re-adapted to the light for 50 seconds while a new target was positioned, after which the procedure was repeated. The subject's threshold was determined by plotting the percentage of detections for each size target on probit paper and taking the 50% point as the threshold.

Results

The mean visual angle of the target length at threshold was .49 deg under the white light and .46 deg under the red light, a difference which is not statistically significant according to the Wilcoxon matched pair signed-ranks test (12). Two of the subjects saw better under the red light, three saw better under the white light, and three had thresholds which were essentially the same for both conditions. These threshold values correspond to those of a 500 ft ship at distances of 19,600 yards after white adaptation and 20,800 yards after red adaptation.

EXPERIMENT II

In the second experiment, we sought to simulate the shadow of a surface ship lying above a submarine. When a submarine is coming to the surface, it must be concerned about the presence of a ship above it. The periscope operator may therefore be looking for large shadows in his field of view. We measured the ability of our observers to detect such large shadows randomly oriented across the field of view after adaptation to both colors of light.

Method

Subjects Twelve staff members of the Laboratory served as subjects.

Targets The shadows were produced by positioning neutral density filters between the observer and the lighted background such that approximately half the background was occluded by the filter. The filter could be oriented either vertically or at an angle and could occlude either the left or right side of the field. The neutral density filters were in 0.1 density increments and were shown against a background of .006 fL, equivalent to the brightness of the sky between starlight and a quarter moon.

Adaptation lights The adapting lights from Experiment I were used.

Procedure The procedure was identical to that in Experiment I. The neutral density filters were presented in random order and random orientation on each trial. The subject was given 10 seconds to look through the viewing port and report the position and orientation of the shadow. In between each trial he adapted to the light for 50 seconds. The threshold was calculated by plotting the percentage of detections for each density of filter on probit paper and taking the 50% point as the threshold.

Results

The lower the density of filter which could be detected, the greater the sensitivity of the observer. The mean density by the 12 observers after adaptation to white light was 0.111 (transmittance = 77.45%). After adaptation to red light, the mean density which could be detected was 0.125 (transmittance = 74.99%), somewhat less, but not a statistically significant difference, according to the Wilcoxon matched pairs signed-ranks test.

EXPERIMENT III

The results of the first two experiments showed that the observers were equally sensitive both to the rectangular silhouettes and the large shadows after adaptation to red or low level white light. In this experiment, we tested the visual performance of the observers through a periscope as they attempted to detect the silhouette of an approaching ship.

Method

Subjects Ten staff members of the laboratory served as subjects.

Target The subjects viewed a high quality computer simulation of a scene at sea, produced at the Submarine Periscope and Navigation (SPAN) Trainer at the Naval Submarine School. The computer simulated a ship approaching the periscope directly ("zero angle on the bow"). The subject was told that the ship would appear in the center of the field of view. The time simulated was night, the atmosphere was clear, the brightness of the sky was between starlight and quarter moon, and the horizon was clearly visible.

Procedure The adaptation level was increased in this experiment to 0.1 fL, the highest intensity level measured in the forward part of the control room of the USS BOSTON (SSN703) when it was rigged for red. Half the subjects adapted first to the red, half to the white. Each subject adapted to the illumination on white cardboard for at least 15 minutes.

At a signal from the experimenter, the subject quickly went to the periscope and the target ship began to move toward him at a constant speed. The initial range of the target ship was randomly varied to avoid anticipatory error. The subject was allowed 10 seconds of viewing time, after which the ship movement was stopped and he had to resume gazing at the adaptation field for 30 seconds. At another signal from experimenter, the ship movement resumed and the subject looked through the periscope again. The subject was thus never more than 10 seconds removed from the adaptation field. This continued until the subject detected the ship. After three detections with the first light, the subject adapted to the other color for at least 15 minutes and then made three detections with the second color.

Results

The mean distance at which the ship was detected after red adaptation was 31,195 yards. After white adaptation, the mean detection distance was 31,021 yards. There was very little variability in these results between subjects; the standard deviations of the red detection thresholds was only 452 yards; that of the white thresholds was 722 yards. The difference between the two mean thresholds is not statistically significant, according to the Wilcoxon matched pairs signed-ranks test.

DISCUSSION

There is no evidence in these three experiments that the ability to see such relatively large targets as rectangles, shadows, ship silhouettes--as opposed to spots of light--is worse after adaptation to low levels of white light than after adaptation to red light of equal brightness. This was true for two intensities of adaptation, 0.1 and .01 fL, and for two levels of background intensity, despite the fact that as the adaptation level increases, the effectiveness of the red light in promoting subsequent visibility should increase.

Thus, although there is no question that maximum scotopic sensitivity can be shown to be better after adaptation to red than to white light, and that this advantage increases as the adaptation level increases, these results show that after adaptation to low intensity levels observers do not suffer losses of visibility when tested under conditions which are above threshold and with targets which have some appreciable spatial extent.

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