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ADAPTATION TO A HOMOCROMATIC VISUAL WORLD

by

Jo Ann S. Kinney, Ph.D.

and

Jane C. Cooper, B.A.

Bureau of Medicine and Surgery, Navy Department

Research Work Unit MF011.99-9002.05

Approved and Released by:

C. L. Waite, CAPT MC USN
COMMANDING OFFICER
Naval Submarine Medical Center

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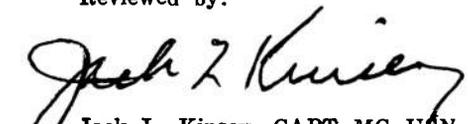
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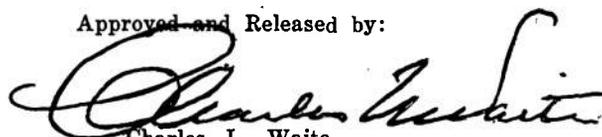
Reviewed by:


Charles F. Gell, M.D., D.SC
Chief Scientist

Reviewed by:


Jack L. Kinsey, CAPT MC USN
Director, SubMedResLab

Approved and Released by:


Charles L. Waite
CAPT MC U. S. Navy
Commanding Officer, SMC

SUMMARY PAGE

PROBLEM

To determine the effects on behavior of remaining in a visual world of restricted color, analogous to that found underwater at great depths.

FINDINGS

The results showed that, after the eye was adapted to blue-green, there was a shift in the appearance of other colors; targets that are normally white appeared yellow-red. At the same time, the subject's reaction-time to red, blue-green, or white targets did not change.

APPLICATION

The shift in color appearance explains the reports of divers that they see yellows and reds underwater, even when there is no physical stimulus for yellow or red. However, their responses to true red targets will not be facilitated nor will there be any impairment in response to blue-green targets.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF011.99-9002—Effects of Unusual Environments on Visual Functions. The present report is No. 5 on this Work Unit. It was approved for publication on 28 July 1967, and cleared for unlimited distribution, and designated as Submarine Medical Research Laboratory Report No. 499.

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ABSTRACT

In a simulation of the underwater visual world, subjects adapted to a diffuse visual field of blue-green light and, for a control, of red light. Measures were then made both of the shift in color appearance of objects and of the subject's speed of reacting to these shifted colors. The amount of change in the appearance of colors was sizable, easily accounting for the reports of SEALAB divers who said they could see yellows and reds when there were none present. There was however no change in the subjects' speed of reacting to the colors.

ADAPTATION TO A HOMOCHROMATIC VISUAL WORLD

INTRODUCTION

Adapting the eye to a specific color, or to a restricted portion of the spectrum, results in obvious changes in the appearance of colors. The amount of change depends upon a number of factors such as the size, intensity, and duration of the colored stimulation. Generally, with increasing adaptation time, the color will gradually lose saturation and fade toward gray. Normally neutral or achromatic stimuli, presented to a subject in this adapted state, will appear to be a color complementary to the background.

Under extreme conditions of completely homogenous stimulation without form or pattern — called the visual Ganzfeld — profound changes occur. Subjects report a visual impression of a dense fog whose color rapidly disappears and complete cessation of vision, periodically, for brief intervals.¹

This entire adaptation process is thought to take place rather quickly, the major changes occurring within approximately five minutes. The phenomenon is generally explained as a loss of sensitivity or reduced response by the color mechanisms primarily affected by the stimulation.² The change in appearance of neutral colors thus reflects the diminished contribution of the adapted color mechanism to the new stimulation.

Reports from divers taking part in SEALAB I indicated that such color adaptation was common there. The water around SEALAB was exceptionally clear and at a depth of 200 ft, most of the natural light is filtered out with the exception of wavelengths that appear blue-green. The visual scene to divers swimming at any distance from SEALAB (away from the artificial illumination) would thus be a complete field of diffuse, blue-green light. Conditions here are nearly ideal for almost complete color adaptation to take place, i.e. for the sea background to take on a colorless appearance and for normally neutral colors to appear yellow-red.

There were some reports, however, that indicated the color changes were not simply

the result of reduced sensitivity to blue-green light but actually represented an enhanced sensitivity to the long wavelengths—wavelengths which are not present to any extent in the diver's underwater world. These subjects reported they could see red colors, after a period of time, that were not visible originally.

Such reports are somewhat at variance with the main body of adaptation theory and may represent nothing more than a subjective response to the blue-green adaptation. There are, however, several reasons for giving credence to the possibility. First, it has been shown that individuals display remarkable adaptive capacities to transformations and distortions of their visual world.³ Not only can they adjust so that they make appropriate visual-motor responses to inverted, curved, or displaced retinal images, but some say the distorted images eventually appear normal.⁴ Second, at least one major theory of color views contrast effects not as a reduction of sensitivity of one mechanism but as an enhancement of response in the opposite or opponent color mechanism.⁵ Third, enhancement of cortical evoked potentials (increased amplitude of response) has been demonstrated in situations of adaptation to large colored surrounds.⁶

This study was designed to provide information on two aspects of color adaptation, (1) the change in the appearance of colors, and (2) change in motor response to colors. Reaction time was chosen as the motor response since it has been shown to be a reliable measure of an individual's sensitivity to stimulation, and furthermore is directly related to the amplitude of evoked cortical response.⁷ The underwater world was simulated by use of a type of visual Ganzfeld into which chromatic light could be projected. Although primary interest was focused on blue-green stimulation, red and white illuminations were also included for control purposes.

APPARATUS

Visual Ganzfeld

A surround of homogeneous diffuse light was achieved by means of a large hemisphere, 3 ft in diameter, painted flat white. The hemisphere was illuminated by a 200-w projection bulb mounted in a housing on the top of it. Light from the bulb passed through a Fresnel lens onto a white matte surface from which it was reflected into the hemisphere and spread evenly over the surround. The subject's head could be positioned in the middle of the hemisphere on a chin rest; at this location the only visibly differentiated part of the surround was a small hole, 1° in diameter, in the hemisphere, through which the stimuli were presented.

The color of the light in the hemisphere was controlled by Wratten gelatin filters mounted in cover glass; the chromaticities of the filters are given in Table I. The luminance of the hemisphere was maintained at 0.1 ft-L for all three colors by appropriate neutral density filters. Measures of the unfiltered light in the hemisphere were made with a Spectra Brightness Spot Meter and checked periodically throughout the course of the experiment. Luminance values for each colored condition were calculated from the spectral transmission curves of the filters as measured on a GE Spectrophotometer, and the luminance of the hemisphere.

TABLE I.

Chromaticity values of colors used in the surround

Color	x	y	z
Blue-green (Wratten #44A)	0.1290	0.3337	0.5373
Red (Wratten #29)	0.7125	0.2874	0.0001
Neutral (Illum. A)	0.4476	0.4075	0.1449

Stimulus for Color Appearance

A MacAdam wide-field colorimeter was used to provide the stimulus for measuring color appearance. Light from one half of the colorimeter was used to illuminate the hole in the hemisphere. The color com-

position of the light, or the proportion of three filters used in the mixture in the MacAdam colorimeter, can be varied by the subject by means of a remote control unit.

Stimulus for Reaction Time

The source for the study of reaction time was a Sylvania strobe light 1131C, stabilized at 271-v and 38-ma. Light was projected through diffusing glass into the hole in the hemisphere. The same three colored filters, red, blue, and white,—were used for the reaction time stimulus as for the hemisphere; luminance of each was maintained at 0.1 ft-L. The strobe light and microswitch for the subject were connected with a Hewlett-Packard Model 522B electronic counter which automatically registered the time, in milliseconds, between the onset of the light and the release of the microswitch by the subject.

PROCEDURE

Color Appearance

The subject, seated at the hemisphere with his left eye occluded, first adapted to a particular color in the hemisphere, blue, red, or white, for five minutes. A colored stimulus was then presented in the hole in the surround. The subject was instructed to manipulate the dials, controlling the amount of three primaries in the mixture, until the stimulus appeared white. He was also told at the same time to try to match the surround as closely as he could in brightness.

The subjects were given as much time as they required to make these settings, but they were told to look back at the surround frequently in order to maintain their color adaptation. After a subject was satisfied that the mixture was white, the stimulus was removed for ten seconds while the subject gazed at the surround; following this the subject checked his settings and adjusted them if necessary. Ten such mixtures were made for each of the red, blue, and white surrounds. Four subjects were tested, all of whom have normal color vision.

Reaction Time

The experimental situation for the reaction time portion of the study was the same as for the adaptation portion except that the subject was required to respond to the 1° stimulus by releasing a microswitch rather than by adjusting its color.

After a given period of adaptation, the subject sat in position with the microswitch in his hand. At a ready signal he depressed the switch; after a pause of two to seven seconds, the stimulus was turned on and the subject told to release the microswitch as soon as he saw it. The counter automatically recorded the time between the onset of the light and the release of the microswitch. Ten readings were taken in one session, with six sessions (or a total of 60 reaction times) for each experimental condition.

The experimental conditions were a white, blue, and red 1° stimulus each presented against the blue and the red hemispheric surrounds after adaptation of zero and five minutes. For the five-minute adaptation duration, the subject looked into the hemisphere for five minutes prior to the measurement of his reaction time. For the zero duration of colored adaptation, he viewed the white hemisphere for five minutes before the color was inserted, in order to minimize the influence of uncontrolled prior stimulation. The measurement of ten reaction times/session took about 1.5 minutes, so the zero condition actually refers to a time interval between 0 and 1.5 minutes after the color was turned on, and the five minute duration, to the time interval 5-6.5 minutes.

Two of the four subjects used in the color appearance study were used in the reaction time study. They were given considerable practice in the reaction-time apparatus and then tested in the main experiment in which six sessions of ten trials each were given for each of the twelve conditions in a random order of presentation.

In a further attempt to measure long-range effects, one subject wore red goggles for six hours one day and blue goggles another day. Reaction times were measured with a red stimulus after ½, 1, 2, 4, 5, and 6 hours of red goggles, and with a blue stimulus after ½, 1, 2, 3, 5, and 6 hours of blue goggles.

RESULTS

Color Appearance

The change in color appearance due to the presence of the colored hemispheric surround is illustrated in the CIE (Commission Internationale de l'Éclairage) diagram in Fig. 1. The individual colorimeter settings for one subject are plotted for each of the three colored surrounds. When the subject adapted to the white surround, the values fall in the center of the diagram in an area normally perceived as white. After adaptation to the blue surround, however, these "white" stimuli appear reddish and considerably more blue has to be added to the stimulus before it appears an acceptable white. Similarly, after adaptation to the red surround, "white" stimuli appear blue-green and more red has to be added.

The CIE diagram in Fig. 2 gives the average values of the settings of the four observers. An ellipse has been drawn around the mean for each surround representing the area included within one standard deviation from the mean. The average functions are very similar to the sample data of Fig. 1, indicating sizable and distinct differences in color appearance due to the colored surround.

Reaction Time

Tables II and III give the average reaction times for the two subjects under each of the stimulus conditions. Differences among conditions are small, 5 to 10 msec, while the standard deviations for single conditions are around 30 msec. There is no indication that the response to the long wavelengths is changed or enhanced by adaptation to the blue-green surround. An analysis of vari-

ance, triple classification factorial design, yielded no differences that were significant for both subjects.*

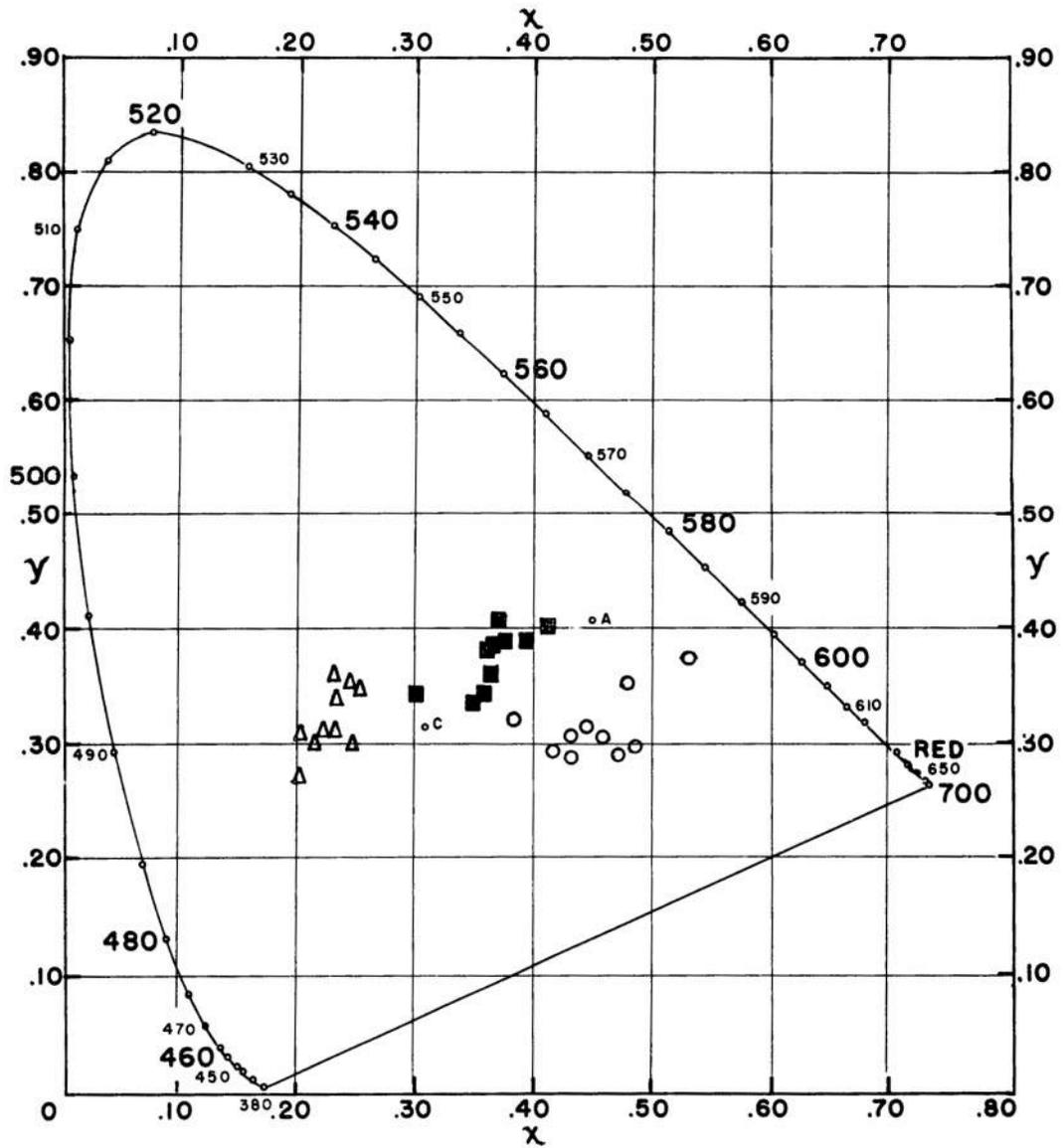


Fig. 1. Data on one subject, plotted on a CIE diagram, illustrating the colors chosen as "white" under different surround conditions: ○ red; ■ white; △ blue.

*For JK, reaction times after 5 min. were significantly shorter than after 0 min. of colored adaptation; however, the effect was the same for all combinations of colors. For AR, reaction times for the red surround were significantly shorter than for the blue, but this was also true for all stimuli; there are thus no interactive effects.

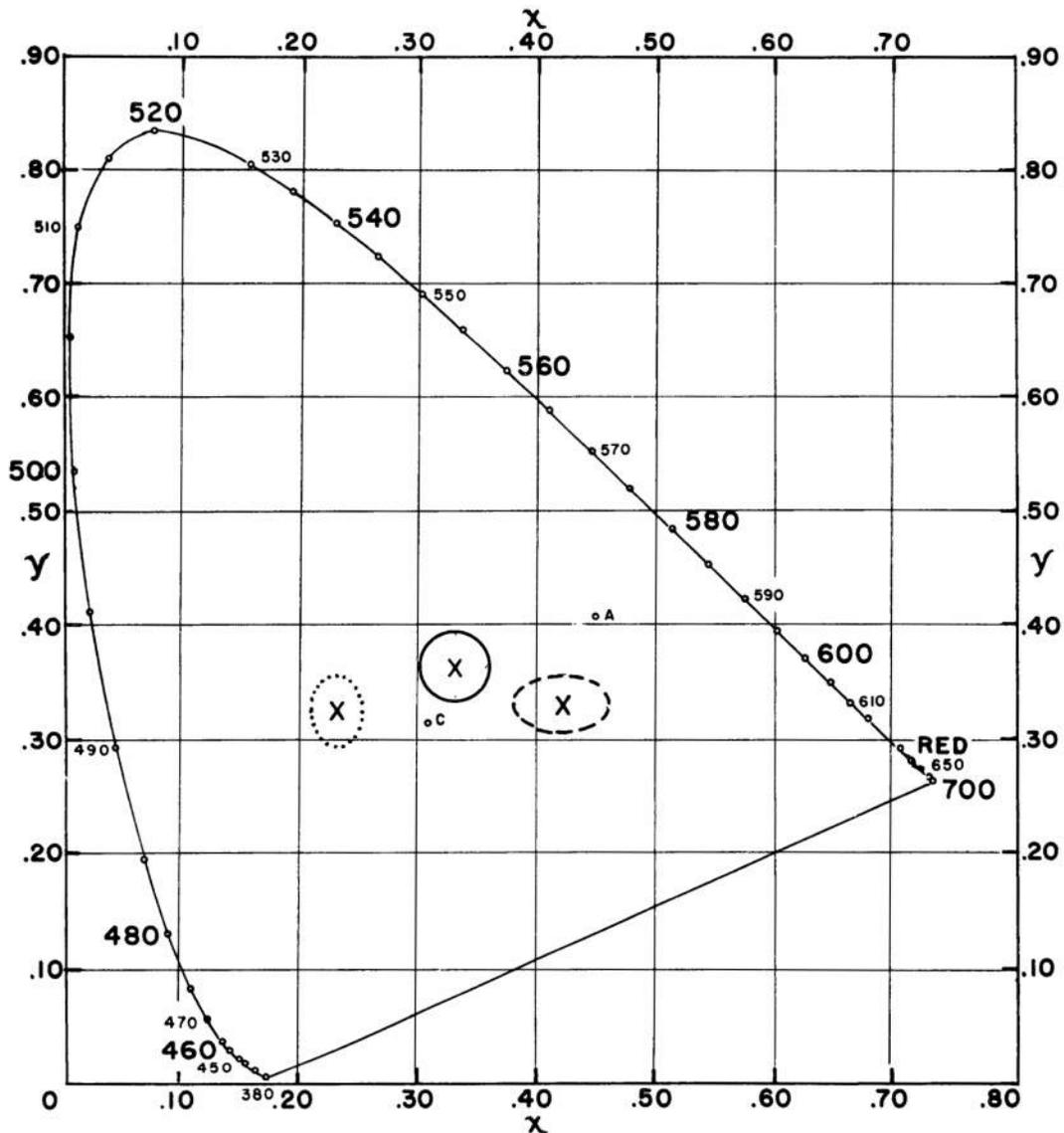


Fig. 2. The average "white" settings for the four observers with surrounds of red — — — —; white — — — —; and blue..... The means, x, are surrounded by ellipses representing one standard deviation.

The results of the long-term adaptation to red and blue surrounds are shown in Figs. 3 and 4. Mean reaction times are plotted as a function of length of adaptation time; the standard deviations are shown by the vertical lines. Once again there is no indication of change attributable to the prolonged adaptation, since the variation within sessions is so much larger than those among sessions.

DISCUSSION

The results of this investigation of the effects of adaptation to homochromatic visual worlds have shown that sizable changes in the appearance of colors take place within five minutes. On the other hand, no reliable differences in the subject's overt responses to these colors could be shown, even after 6 hours of adaptation.

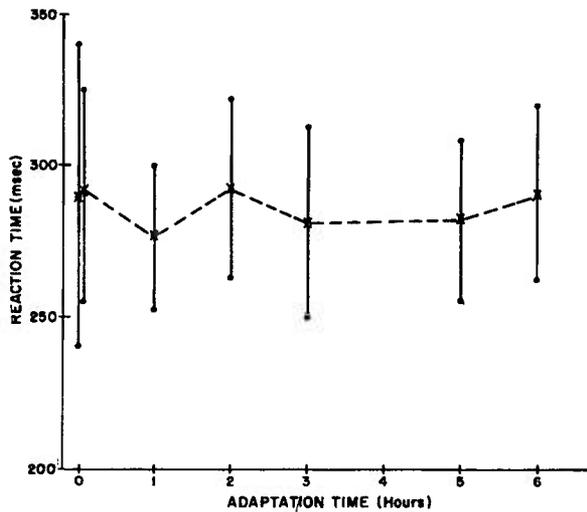


Fig. 3. The reaction times of one subject after adaptation to blue-green for various lengths of time. The horizontal line connects the means and the vertical lines show the extent of one standard deviation above and below the mean.

TABLE II.

Mean reaction times and standard deviations for the red surround for each subject

Stimulus/ S	Adaptation Time		
	0 min	5 min	
Red	JK	271.3 \pm 33.6	260.6 \pm 24.2
	AR	280.8 \pm 32.5	270.8 \pm 32.3
White	JK	256.9 \pm 33.1	247.1 \pm 25.8
	AR	276.4 \pm 33.8	276.0 \pm 41.1
Blue	JK	260.9 \pm 25.6	251.4 \pm 26.5
	AR	268.3 \pm 33.6	283.0 \pm 29.0

TABLE III.

Mean reaction times and standard deviations for the blue surround for each subject

Stimulus/ S	Adaptation Time		
	0 min	5 min	
Red	JK	264.8 \pm 29.8	258.6 \pm 19.9
	AR	282.4 \pm 31.5	285.2 \pm 36.7
White	JK	258.0 \pm 28.5	262.5 \pm 22.6
	AR	288.1 \pm 36.3	286.3 \pm 38.8
Blue	JK	266.5 \pm 33.8	259.6 \pm 33.3
	AR	290.7 \pm 49.6	291.0 \pm 35.1

The change in the appearance of colors due to adaptation is generally thought to reflect a change in the balance of sensitivity among color receptors. One might speculate that this imbalance should be reflected by increased speed of response to some colors and impairment of response to others. The failure to find motor manifestations of changes in color appearance obviously does not support this view.

At the theoretical level, the result is not surprising. The dramatic changes in visual-motor performance following transformed visual stimulation, which have been repeatedly demonstrated, involve adjustment to conflicting stimulation between different senses, as, for example, the visual and tactual/kinaesthetic systems.⁸ No such conflict is characteristic of adaptation to the homochromatic visual world. The major study that runs counter to such a view is the report by Ivo Kohler⁹ of profound perceptual-motor changes following long-term adaptation to colored goggles. His findings however were not replicated in a recent attempt by Celeste McCulloch¹⁰ who wore colored goggles for three months.

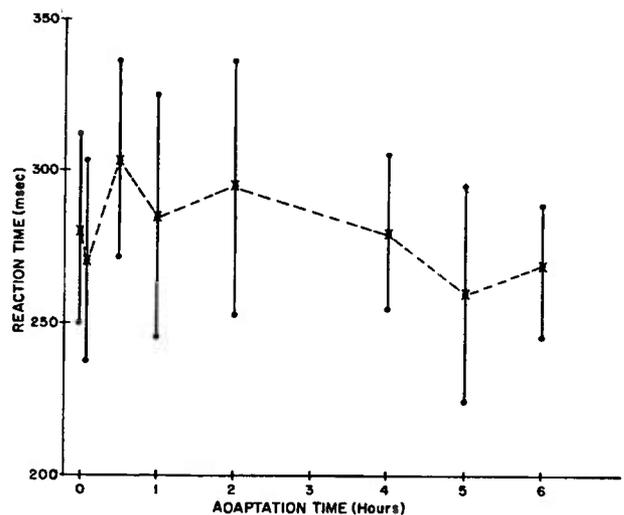


Fig. 4. The reaction times of one subject after adaptation to red for various lengths of time. The horizontal line connects the means and the vertical lines show the extent of one standard deviation above and below the mean.

For the diver, the results of this study mean that the adaptation to a blue-green visual world will result in a shift of all the colors he perceives. He will see yellow-reds for which there is no physical stimulus present, and the normally blue-green objects will appear whitish. It is important to impress this fact on divers who may use or search for colored objects underwater. On the other hand, the diver will not respond any more efficiently to the reddish objects nor should his reactions to blue-green targets be impaired.

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