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EFFECT OF STIMULUS SIZE, DURATION, AND RETINAL LOCATION UPON THE APPEARANCE OF COLOR

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SUMMARY PAGE

THE PROBLEM

To investigate the appearance of red, green, blue, and yellow color in the central and peripheral regions of the retina, when the colors are seen under circumstances of reduced size or short duration.

FINDINGS

Reduction of size or duration of the colored fields results in the replacement of full color recognition by a form of blue-yellow blindness when viewed contrally, and a form of green-yellow blindness when viewed peripherally. Red is the ideal color, giving high probability of recognition at all retinal locations.

APPLICATION

The data of this investigation will be of assistance in determining the proper colored signals to employ in signal systems and comples displays when the signal lights are small or brief, or when displaced from the central field of view.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF12.524.004-9013D - Optimization of Visual Performance in Submarines. The present report is No. 5 on this Work Unit, and has been designated as Submarine Medical Research Laboratory Report No. 606.

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ERRATUM

Weitzman, Donald O., and Jo Ann S. Kinney, "Effect of Stimulus Size, Duration, and Retinal Location upon the Appearance of Color."

P. 641: The diagrams marked Fig. 1 and Fig. 2 should be interchanged.

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Effect of Stimulus Size, Duration, and Retinal Location upon the Appearance of Color*

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The names given to spectral stimuli from 480 to 610 mμ and to a white-light test stimulus were obtained using 11′ or 21′ diam stimulus fields, exposed for 20 msec in the fovea and for 20 and 200 msec at 5° and 10° in the periphery. The experiment was designed to test the hypothesis that normal color vision is replaced by tritanopic vision in all parts of the retina if the total luminous energy is sufficiently reduced. The results obtained with four observers confirm the presence of tritanopia when small brief stimuli are viewed foveally but fail to confirm it in the periphery. Rather, reduced color vision in the periphery is more nearly characteristic of deuteranomaly which ends ultimately in colorless vision. These results are discussed as giving support to the notion that foveal tritanopia is due to the depressed sensitivity of the blue receptor mechanism found in the central fovea.

INDEX HEADING: Color vision.

In an earlier investigation,[1] an account was given of the appearance of small, brief centrally fixated spectral stimuli. The data, obtained by means of a color-naming technique, revealed that the eye behaved as if tritanopic.

König[2] was the first to describe this effect as though it were peculiar to the central fovea, and other writers have made a similar assumption.[3,4] Nevertheless, Hartridge[5–7] found that a similar loss of color discrimination can be produced by viewing sufficiently small fields when seen 2° to one side of central fixation. He concluded that the small size of the test field rather than the location of its image on the retina determines whether vision shall be tritanopic. Subsequent experiments in the parafoveal[8,9] and peripheral[10–12] regions of the retina appeared to confirm Hartridge's view.

As a possible explanation for this behavior, Farnsworth[13] suggested that the discrimination loss is not primarily a foveal or small subtense phenomena but is constant for a given total luminous energy ($A \times I \times t$). Brown[14] and Middleton and Mayo[15] did, in fact, find that tritanopic-like dichromacy can be produced by reducing the luminance when viewing a photometric field of larger size (2°). Also Weitzman and Kinney[1] showed data which confirmed, for the central fovea, that a tritanopic effect would be produced with brief stimulation. Similarly, Kaiser[16] found a reciprocal relation between luminance and stimulus duration for a constant tritanopic effect (the transition of yellow to white) in the central 12-min area of the fovea. If Farnsworth's

* From Bureau of Medicine and Surgery, Navy Department, Research Work Unit MF12.524.004-9013D. The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the view of the Navy Department or the Naval Service at large.

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[16] P. K. Kaiser, J. Opt. Soc. Am. **58**, 849 (1968).

explanation is correct for the foveal area, then it should also hold for the extra-foveal retina, but this has not been put to an experimental test. The present experiment was designed to investigate this phenomenon by studying the appearance of color as a function of stimulus size and duration when the peripheral region of the retina was directly stimulated.

The response to small, brief spectral stimuli seen at 5 and 10 deg from fixation was measured by a color-naming technique. The actual target sizes employed were 11 and 21 min, the durations were 20 and 200 msec. In addition, the same stimuli were presented foveally using the 20-msec exposure, to insure that the expected tritanopic response was obtained under these specific experimental conditions. Besides the theoretical interest of this paper, the data taken here should provide information of practical importance, on the perception of color by peripheral vision.

APPARATUS

The apparatus employed in this investigation has been described already.[1] The surround for the monochromatic stimuli had a luminance of 0.17 mL, 3800K. To provide stimulation at 5 and 10 deg in the periphery, fixation points were placed on the surround to the right side of the stimulus.

Bandwidths were varied with wavelength to equate the brightness of the stimulus field with the brightness of the surround. The bandwidth of the stimuli from 610 to 540 mμ was 5 mμ; at 530 mμ, 6.3 mμ; at 520 and 510 mμ, 7.5 mμ; at 500 mμ, 10 mμ; at 490 mμ, 17.5 mμ; and at 480 mμ, 20 mμ.

PROCEDURE

Details of the procedure were the same as described previously.[1] The observer responded by naming the color seen as either red, green, blue, yellow, or white or any combination of the two most dominant of the above color names when he was sure he could name the color. Very often, with peripheral stimulation, two or three presentations, separated by 15- to 20-sec intervals, were required to obtain a judgment. If after three presentations, the observer was still unable to name the color, a new wavelength was exhibited.

Data were obtained by recording the frequency of color names given to spectral lights at each 10 mμ from 480 to 610 mμ, to 575 mμ, and to a white-light test stimulus. These were presented with a 15- to 25-sec pause between flashes. The frequency of color names given to each spectral stimulus was scored according to the procedure used by Boynton and Gordon.[17] Four experimental Os with normal color vision participated.

RESULTS

The relative frequency of red, green, blue, yellow, and white reports are plotted against each test wavelength in Figs. 1–4. Each data point represents 80 responses—20 single response determinations for each of the four Os. Sample variability representative of each color is shown on the right.

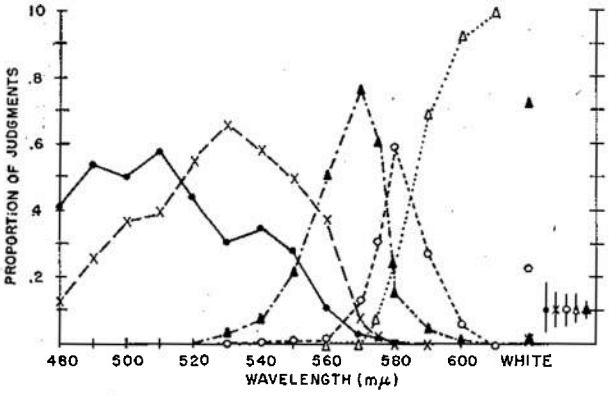

FIG. 1. Average response curves of four observers, for foveal presentation taken with a 21′-diam stimulus; frequency of color response plotted against wavelength. Colors indicated by blue (●); green (×), yellow (○); red (△); white (▲).

As can be seen from Figs. 1 and 2, the color names obtained for 0° show features of tritanopia, in agreement with previous findings for small fields and short durations.[1] Thus, wavelengths of 570 and 575 mμ were reported as white more often than as yellow green, while wavelengths in the middle of the spectrum were called green blue rather than green or green yellow. These color changes were accompanied by an increasingly reduced sensitivity to the shorter wavelengths (below 500 mμ) particularly at the smaller field used.

A comparison of the data taken at 5° (Fig. 3) with the foveal data shows increases of the proportion of "blue" responses to short wavelengths and of "yellow" responses throughout a wide range of mid-spectral wavelengths. At 5°, the green curve is shifted toward short wavelengths. The distribution of "white" responses covers most of the spectrum rather than centering on the 560- to 580-mμ band as it does in the fovea.

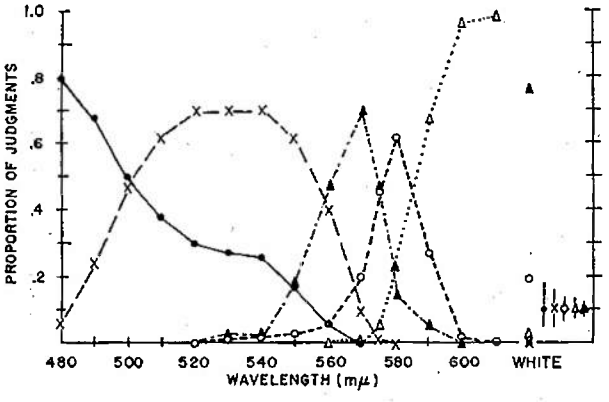

FIG. 2. Same as Fig. 1, taken with a 11′-diam stimulus.

[17] R. M. Boynton and J. Gordon, J. Opt. Soc. Am. 55, 78 (1965).

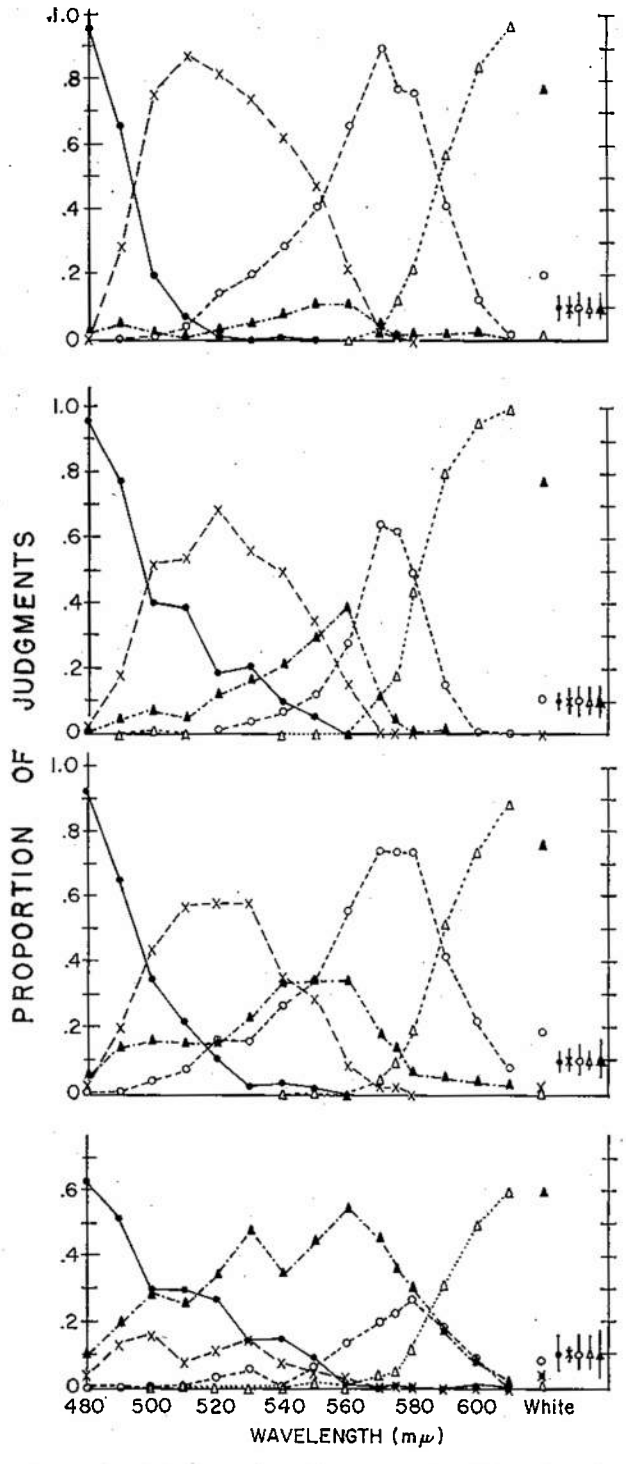

FIG. 3. Average response curves of four observers, taken at 5° from central fixation; frequency of color response plotted against wavelength. Colors indicated by blue (●); green (×); yellow (○); red (△); white (▲). The size of field and the exposure duration in the four curves, from top to bottom, are 21′ at 200 msec; 21′ at 20 msec; 11′ at 200 msec; 11′ at 20 msec.

The most striking feature of the results for the 5° position is the change of the over-all shape of the curves with change of field size and duration. The data show increasingly reduced green and yellow responses as field size and duration decrease. This reduction is accompanied chiefly by an increase of "white" responses; however with reduced duration some of the "green" judgments are replaced by "blue" and some of the "yellow" responses by "red."

Similar statements can be made about Fig. 4, which gives the results obtained at 10°. The principal difference between the two sets of curves at 5° and 10° is that in the latter case the deterioration of color vision has

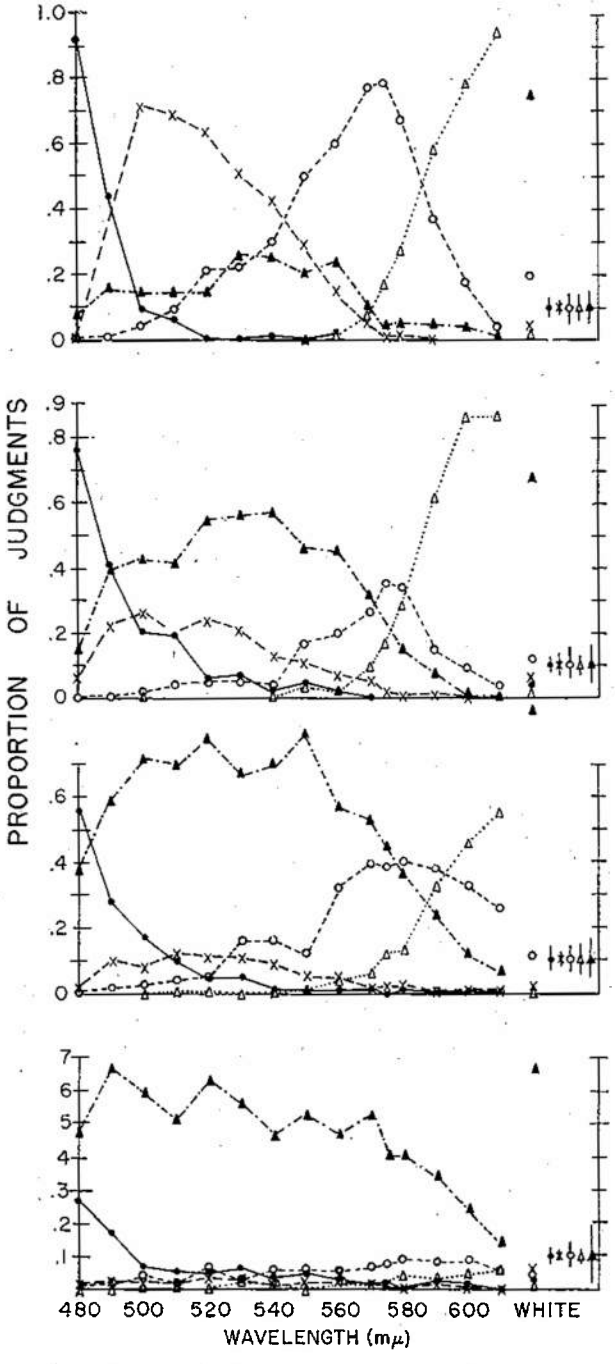

FIG. 4. Same as Fig. 3, taken at 10° from central fixation.

progressed further. With decreased visual angle and duration, colors between blue-green and green-yellow (490–575 mμ) changed chiefly to white. On the other hand, for long- and short-wavelength stimuli colors remained relatively constant as test area and exposure duration decreased. Responses to longer wavelengths than the yellow greens (beyond 570 mμ) were more often yellow and red but failed to emerge at the smallest stimulus size and duration. Short-wavelength stimuli (480–490 mμ) continued to elicit blue responses at progressively reduced conditions though at markedly reduced frequencies.

DISCUSSION

The findings of this experiment fail to support the reports that tritanopia, as observed in the normal eye, is characteristic of small fields rather than of the central fovea. The foveal data exhibit all the usual characteristics obtained in large-field data on congential tritanopes: reduced sensitivity to short wavelengths, confusion between blue and green, the presence of a well-defined neutral region around 570 mμ, and a decreased proportion of yellow responses.[18] On the other hand, the peripheral data, obtained under identical experimental conditions, clearly show a different pattern of color loss as stimulus size and duration are reduced. There is never a well-defined neutral area but rather a broad region of the spectrum called "white"; this region includes those wavelengths normally perceived as green. In addition, sensitivity to short wavelengths, below 500 mμ, increases; yellow responses, proportionally very large at first, decrease rapidly with stimulus reduction; and under extreme stimulus reduction, blue and red are the only remaining color responses. Thus, while reduced color vision in the fovea and congenital tritanopia are strikingly similar, reduced color vision in the periphery seems more nearly similar to dueteranomaly, since the deterioration of color vision first takes place at about 500–560 mμ.

It is of considerable interest that these changes of color names conform to changes previously found in measuring peripheral color sensations at greater eccentricities, using relatively larger fields (up to 3°). Thus, the demonstration of deuteranomalous responses with very small fields and short exposure durations found at 5° and 10° is similar to that found in the far periphery (between 20° and 40°) with larger test stimuli, both in color-naming experiments,[19,20] and in perimetry studies.[21,22] The color loss could arise, of course, from the scarcity of receptors belonging to the green mechanism.

The reduced color vision at 10° further indicates a shift to rod sensitivity. The increased sensitivity to short wavelengths, the reduced sensitivity to long wavelengths, plus the considerable desaturation in the region of maximum rod activity support this suggestion. In part then, the deterioration of color vision in the periphery must also involve the increased activity of rods, in view of the fact that the density of rods increases while the number of cones per unit area changes very little beyond 5°.

Despite the marked differences between the foveal and peripheral responses, it is evident that blue-green confusion occurs in the extra-foveal retina just as it does in the central fovea, although it is somewhat reduced. There is a region between 500–550 mμ where the confusion is maximal. It seems most likely, in view of our results for the other spectral colors, that blue–green confusion in the periphery is due to the enhanced sensitivity to blue and the attenuation of green sensitivity rather than some form of tritanopia adding its effect. Moreover, it may be that the tritanopia previously reported to occur with small fields falling on the peripheral retina[10–12] is due to the enhanced sensitivity to light of short wavelengths in the periphery. Thus the blue–green confusions seen in the periphery are not due to the same mechanism as that in the central fovea.

These results support the assumption that foveal tritanopia is caused by loss of the blue receptor mechanism. If the absence of blue-sensitive cones is the major determinant, then it would ordinarily follow that at retinal locations containing relatively fewer blue receptors than either red or green receptors, stimuli which are minimal in either area, luminance, or time, would arouse the blue sensation relatively less than the red and green sensation. This would mean that the data previously discussed, which have shown that the tritanopic effect is a consequence of the total energy involved, result because they were all concerned with an area of the retina where the sensitivity of the blue receptors relative to the other color receptors is greatly reduced.[23–25]

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13. ABSTRACT

The names given to spectral stimuli from 480 to 610 mμ and to a white-light test stimulus were obtained using 11' or 21' diam stimulus fields, exposed for 20 msec at 5° and 10° in the periphery. The experiment was designed to test the hypothesis that normal color vision is replaced by tritanopic vision in all parts of the retina if the total luminous energy is sufficiently reduced. The results obtained with four observers confirm the presence of tritanopia when small brief stimuli are viewed foveally but fail to confirm it in the periphery. Rather, reduced color vision in the periphery is more nearly characteristic of deuteranomaly which ends ultimately in colorless vision. These results are discussed as giving support to the notion that foveal tritanopia is due to the depressed sensitivity of the blue receptor mechanism found in the central fovea.

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Recognition of colored signals						