THE EFFECT OF VARIATIONS OF THE INTENSITY OF THE ILLUMINATION OF THE PERIMETER ARM ON THE DETERMINATION OF THE COLOR FIELDS

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Field study is coming to have a very important place in office and clinic work. By field study is meant the determination of the limits of light and color sensitivity; the mapping of scotomata and the blind spot; determinations of sensitivity and of disturbances in the distribution of sensitivity; etc. It is perhaps the most sensitive and valuable means at the disposal of the medical profession for the diagnosis and the study of the advance and recession of many pathological conditions of the eye, of the sinuses, and of the brain and its conducting paths. For the successful development of this work there is great need of the coöperation of the laboratory worker with skill and experience in devising, standardizing and applying functional tests.

The importance of the functional test in the medical work on the eye seems to be generally conceded. All seem agreed that in the diagnosis and the checking up of the advance and recession of pathological and other disturbing conditions the functional test is the most sensitive that has yet been proposed. Difficulty has been encountered, however, in applying it with the sensitivity and precision that is needed, particularly in office and clinic work. In some fields great advancement has yet to be made in delicacy and sensitivity; in others the more important need is greater precision and reliability. In all fields a more careful scrutiny of the functions affected is needed. Many attempts to apply functional testing have failed because the wrong function was selected to be tested. At one time it was held that a difference in the effect of good and bad lighting on the eye

could not be found by test merely because the eye functions most affected by bad lighting conditions were not tested. And today the acuity test is rendered needlessly insensitive, partly because the test is not applied under the most sensitive conditions obtainable, but mainly because the aspects of acuity most affected by ocular defects and special and disturbing conditions of work—namely, speed and power to sustain, are not included in the conventional method of testing acuity. In the pathological field we have yet to find out what are the most important functions to be tested.

The theory and practice of clinic field taking for color seems up to the present time to have been based on the following assumptions: (1) The far periphery of the retina is blind to color, that is, there are definite limits or boundaries of the sensitivity to colored light. These may be called the *actual* limits of sensitivity. The limits as determined, the apparent limits, may or may not agree with the actual limits depending upon the conditions under which the work is done. (2) The factors affecting the apparent limits when the fields are taken with pigment colors are the size and coefficient of reflection of the stimuli employed. A contraction of the fields taken under standard conditions of control for these two factors means then an actual change in the distribution of sensitivities. (3) Sensitivity decreases from the center towards the periphery of the retina in a fairly regular manner in any given meridian and the rate of decrease for the same color is approximately uniform from meridian to meridian over a considerable range near the limits of sensitivity. Irregularity of contraction, resulting in a change in the shape of the field, is not therefore to be expected to any considerable extent as a phenomenon of the normal eye. And (4) the field of sensitivity is wider for blue than for red. The limits of the fields should not then be expected to interlace or to reverse their order of ranking as to breadth without some pathologic or other disturbance in the distribution of sensitivities.

A study of the distribution of sensitivities in the peripheral retina and of the factors which affect the apparent limits of sensitivity shows that these assumptions are not correct.

The far periphery of the retina is not blind to blue and red, nor is the sensitivity in this part of the retina greater for blue than for red (at some points it is greater for blue, at others for red); the decrease of sensitivity from the center towards the periphery of the retina is very irregular in any given meridian and the rate of decrease is very different from point to point in the different meridians; the apparent limits of sensitivity are a function not of two but several variables; all of the field changes noted above as pathologic may occur and do occur as the result of nothing more serious than a defective control of the variable factors which affect the sensitivity of the peripheral retina to color.

The variable factors which affect the sensitivity of the peripheral retina to color are, so far as we have been able to discover, the wave-length and purity of the stimulus, the intensity of the stimulus and the visual angle, length of exposure of the eye, the method of exposure (moving or stationary stimulus), accuracy and steadiness of fixation, the intensity of the general illumination of the retina and its state of adaptation, breadth of pupil, and the brightness of the preexposure and of the background or surrounding field. The most important of these factors, from the standpoint of the work of the office and clinic, are perhaps the intensity of the stimulus and the precision of its control, the brightness of the preexposure and of the surrounding field, the intensity of the general illumination and the accuracy and steadiness of fixation. Some of these factors have been discussed in previous papers; some will be discussed in later papers. The present paper is an additional study of the effect of variations of the intensity of the stimulus on the determination of the color fields. When the color fields are determined with pigment stimuli of a given coefficient of reflection, the intensity of the stimulus light is of course dependent upon the amount of light received on the perimeter arm.

In a discussion of the factors influencing the determination of the color fields, intensity may be considered as typical. That is, whatever is true of the effect of intensity should be true also in a general way of the effect of any other uniformly

acting factor which produces large variations in the breadth of the color fields. The common factor underlying the effect of any condition of work on the size and shape of the color fields and their order of ranking as to breadth is the type of distribution of sensitivity in the peripheral retina. It is this, for example, which determines how much contraction or shrinkage of the field shall take place with a given value of factor and whether shrinkage shall be accompanied by a change in the shape of the field or a reversal in the order of ranking of the fields as to breadth.

The Intensity of the Stimulus.—By a sufficiently wide variation of this factor alone, the fields of color sensitivity may be made to have almost any breadth in the field of vision, to differ radically in shape, and even to change or reverse their order of ranking as to breadth,—changes of a type and magnitude to which the clinician might ascribe a grave and important pathologic significance. For example, with very high intensities of stimulus the limits of red, yellow and blue are coincident with the limits of white light vision. Green cannot be made to have so wide an extent. With stimuli of medium intensity and of the relative energies found in the prismatic spectrum of a Nernst filament, for example, the limits are concentric and in the order from widest to narrowest of red, yellow, blue and green. With stimuli of medium intensities of equal energy (equal physical intensities) the limits of red, yellow and blue interlace or crisscross. The limits for green again are narrower. The limits for pigment stimuli may be either interlacing or concentric in the order from widest to narrowest of red, blue and green; or blue, red and green, depending upon the pigments used and the intensity of light falling on the perimeter arm. It seems only fair to conclude, therefore, that the conventional clinic rating of the limits from widest to narrowest in the order of blue, red and green is a function of the relative and absolute intensities of the stimuli employed as well as of the actual distribution of sensitivities. A change in the intensity of the stimulus not only changes the limits but, because of the irregular distribution of sensitivities in the different meridians,

causes a marked change in the shape of the fields; and because of changes in the ratio of sensitivity to the different colors in the same meridians, a change in their order of ranking as to breadth. Without great precision in the control of intensity, it is obvious that reproducibility of result cannot be obtained and little significance can be attached to extent or shape of field, to order of ranking as to breadth of field or to any variations from time to time or from person to person in these important features.

The effect of changes in the intensity of the stimulus both on the extent and shape of the color fields varies with the order of magnitude of intensity employed. For medium and low intensities the effect of a given amount of change is very much greater than for high intensities. This is an obvious corollary of the type of distribution of sensitivities found in the peripheral retina. That is, in passing from the center towards the periphery the decrease in sensitivity is comparatively slow and gradual in the paracentral retina; it is much faster and more abrupt in the mid-periphery; and very abrupt in the far periphery. It requires, therefore, comparatively large changes of intensity of stimuli of high intensity which carry the limits of sensitivity into the far periphery, to produce a significant change in the limits; not so great a change in the stimuli of medium intensity; and a still smaller change in stimuli of low intensity. This effect varies greatly, however, for the same color in the different meridians and for different colors in the same meridians. For the stimuli of medium and low intensities used in the office and clinic, the effect of change of intensity is very marked indeed both on the extent and shape of the fields of sensitivity.

We have stated that the order in which the fields may be found to occur, ranked with regard to breadth, depends both upon the actual distribution of sensitivities and upon the relative and absolute intensities of the stimuli employed. That it depends upon the relative intensities should be more or less obvious, provided of course that the relative differences of intensity are great enough to overcome or reverse the

actual differences in sensitivity. In support of the statement that it depends also on the absolute intensity, maps will be shown in which for the same eye and a constant ratio of intensity of stimuli, the limits for red and blue in some cases interlace or crisscross; in others they are concentric or nearly so—the limits for blue lying outside of the limits for red; or conversely the limits for red lying outside of the limits for blue—the difference in result depending solely upon the absolute intensities of the stimuli employed. The determinations were made with the Hering standard pigment papers presented to the eye by means of the perimeter¹ described in a preceding paper, with the preëxposure and surrounding field of the brightness of the color, the only variable being the intensity of the illumination of the perimeter arm.

The Chromatic Thresholds of Sensation from Center to Periphery of the Retina.—As we have already intimated, the effect of such factors as intensity on the extent and shape of the color fields and their order of ranking as to breadth can be understood better when a thorough knowledge is had of the actual distribution of sensitivities from point to point from center to periphery of the retina. In order to show this distribution we have made determinations² of the threshold of sensation in energy terms using spectrum lights and proper conditions of control, for the different colors at near-lying points from center to periphery of the retina. A graphic representation of the results of these determinations for two meridians, the temporal and nasal, is given in Charts 1-4, "Chromatic Thresholds of Sensation from Center to Periphery of the Retina and their Bearing on Color Theory," *PSYCHOL. REV.*, 1919, 26, 28-32. The following points of importance to this paper may be noted from these charts.

1. The great range of sensitivity from the center to the extreme periphery of the retina. For example, in the nasal meridian the sensitivity to red is 900 times as great at the center as at the extreme periphery of the retina; for yellow 1,650, for blue 3,280 and for green 3,380 times as great.

¹ *J. of Exp. Psychol.*, 1922, 5, 46-67.

² The stimuli used were red (670 m μ); yellow (581 m μ); green (522 m μ); and blue (468 m μ).

2. The great irregularity of decrease of sensitivity which is found in passing from the center to the periphery of the retina. This irregularity moreover differs greatly in the different meridians. From these irregularities it is obvious why the shape as well as the extent of the fields of sensitivity changes with the change of intensity of the stimulus light. That is, depending upon the different rates of decrease of sensitivity in the different meridians, a given increase or decrease of intensity of the stimulus light causes respectively different amounts of extension or contraction of the fields in these meridians. The result is of course a change of shape of the field proportionate to the amount of irregularity of distribution of sensitivity in the different meridians.

A further obvious corollary of irregularity of distribution of sensitivity in the different meridians is the interlacing or crisscrossing of the limits when the stimuli are so graded in intensity as to give the limits for all of the colors approximately the same degree of excentricity. That is, a condition of coincident or concentric limits would presuppose regularity of distribution of sensitivity from meridian to meridian; irregularity inevitably leads to an interlacing or crisscrossing when the conditions under which the determinations are made are such that the fields have approximately the same breadth. A frequent crisscrossing of the limits occurs for red, yellow and blue when stimuli of medium intensity and of anywhere near equal energies are used.¹

3. A third point is the great irregularity in the ratio of sensitivity to the different colors which is found in the same meridians in passing from the center to the periphery of the retina. At some points, for example, the sensitivity to red is greater than the sensitivity to blue; at others the reverse is true. An obvious corollary of such a shift in relative sensitivity is a reversal of the order of ranking of the color fields as to breadth—a reversal which we have every reason to believe is not pathological. This does not mean, of course, that reversals in the order of ranking as to breadth may not

¹ 'The Absolute Limits of Color Sensitivity and the Effect of Intensity of Light on the Apparent Limits,' *PSYCHOL. REV.*, 1920, 27, 17-19.

be of pathological origin. It does indicate, however, that they may occur in case of the normal eye as the result of no more serious condition than a change in the absolute intensity of the stimulus light, or translated into terms of ordinary office and clinic practice, a change in the intensity of light falling on the perimeter arm at the point of work—a change moreover no greater than may occur in the illumination of a daylighted room from noon to four o'clock on any bright winter day. That is, as the intensity of the stimulus light changes, the limits fall at different distances from the center of the retina. If they happen to fall in a region where the sensitivity is greater to red than to blue, the limits for red will be outside the limits for blue; and conversely if they happen to fall in a region where the sensitivity to blue is greater than to red, the limits for blue will lie outside of the limits for red. There is, moreover, no reason to believe that these irregularities are the same in kind or degree from person to person. Obviously the only safeguard against misinterpretation either in establishing a norm or in making comparisons with an established norm is always to work with the same conditions of control. A difference in result will then mean an actual difference in sensitivity or in the relative distribution of sensitivities, as the case may be. Working under these conditions we have a chance really to find out what is normal with regard to breadth and shape of the fields of sensitivity and their relation for the different colors, and to check up their variations from time to time as result of the advance or recession of a pathological condition.

A further corollary of the change in the ratio of sensitivity to the different colors in passing from the center to the periphery of the retina is the change in hue of red and green. This change is towards yellow when the observation is made with a preëxposure and surrounding field of the brightness of the color and there is a proper control of all other variable factors. If the observation is not made under these conditions the change may be still more complicated. The change towards yellow depends upon two facts: (a) The red and green wave-lengths of light have the power to arouse not

only the sensations of red and green but also weakly the sensation of yellow; and (b) sensitivity to red and green falls off more rapidly than to yellow in the mid-periphery of the retina. In the center of the retina, which is fully sensitive to red and green, the weakly aroused yellow excitation is below the threshold of sensation, *i.e.*, too weak to be sensed in the presence of the strongly aroused red and green sensations. However, in those parts of the retina in which the loss of sensitivity to red and green is greater than to yellow, the yellow component of the sensation comes above the threshold and the red and green stimuli are sensed as yellowish red and yellowish green. For example, in passing from the center to the periphery of the retina in the nasal meridian, the red stimulus was sensed as red from the center to about 60° , by the observer whose threshold results are given in Charts 1-4; from 60° to about 86° it was sensed as yellowish red or orange; from 86° to the limits of sensitivity it was sensed again as red. Corresponding to this it will be noted (Charts 1-4) that there is in this meridian a fairly close agreement in sensitivity to red and yellow from the center to about 60° (stimulus sensed as red), at which point there is a relatively sharp decrease in sensitivity to red. That is, from 60° to 86° there is much less sensitivity to red than to yellow (stimulus sensed as yellowish red or orange). At about 86° there is a sharp decrease in sensitivity to yellow, and from this point on to the limits, a fairly close agreement again in sensitivity to the two colors (stimulus sensed as red). In the temporal meridian the red stimulus was sensed as red from the center of the retina to about 30° ; from there to about 47° as yellowish red or orange; and from 47° to the limits of sensitivity, as red. Similarly in this meridian there is a fairly close agreement in sensitivity to red and yellow from the center to about 30° ; from 30° to about 47° there is a considerably greater sensitivity to yellow than to red; and from this point on to the limits greater sensitivity to red than to yellow. In case of the green stimulus in the nasal meridian the greater loss in sensitivity to green as compared with yellow begins about 51° ; and in the temporal

meridian at about 26°. Correspondingly at these points the green stimulus began to be sensed as yellowish green and continued to be sensed in this hue until the limits of sensitivity to green were reached, from which point on for a short distance it was sensed as unsaturated yellow.

These changes of hue are the normal changes for spectrum or pure red and green in passing from the center to the periphery of the retina when, as we have already stated, there is no achromatic effect of preëxposure and surrounding field, that is when the preëxposure and surrounding field are a gray of the brightness of the color and when the general illumination of the room is held constant. In a later paper the changes produced by a preëxposure and surrounding field lighter or darker than the color and by a variable illumination will be given.

The Effect of Variations of the Intensity of the Stimulus on the Size and Shape of the Color Fields and their Order of Ranking as to Breadth.—Results have been obtained for two sets of conditions: high intensities, the fields having been taken with our rotary campimeter and spectrum lights;¹ and medium and low intensities, the fields having been taken with our rotary campimeter and spectrum lights; and medium and low intensities, the fields having been taken with the illuminated perimeter described in a former paper and pigment stimuli.

The results for the first series of determinations have already been given.² In the second series of determinations, five intensities of light reflected from pigment stimuli were used: the Hering standard pigment papers under 51, 17, 7, 3 and 0.03 foot-candles of light. In order to show how these illuminations compared with the daylight illumination falling on the perimeter arm in an ordinary room, measurements were made of the daylight at the level of the perimeter arm in a room with southern exposure, six windows the lower sills of which were somewhat higher than the level of the perimeter

¹ 'A Spectroscopic Apparatus for the Investigation of the Color Sensitivity of the Retina, Central and Peripheral,' *J. of Exp. Psychol.*, 1916, 1, 247-283; also 'Description of a Rotary Campimeter,' *Amer. J. of Psychol.*, 1912, 23, 449-453.

² 'The Absolute Limits of Color Sensitivity and the Effect of Intensity of Light on the Apparent Limits,' *Psychol. Rev.*, 1920, 27, 1-24.

arm when placed in the horizontal position. These measurements were made on a bright day, Jan. 14, 1921. It was found that our highest intensity of illumination, 51 foot-candles, was the same as that falling on the perimeter arm at the fixation point when facing one of the windows at 1 P.M.; our second highest illumination, 17 foot-candles, was

FIG. 1. Fields taken under 51 foot-candles of light—an illumination equal to the daylight falling on the perimeter at the fixation point when facing a window on a bright day, 1 P.M., Jan. 14, 1921.

the same as that falling at the fixation point at 2.30 P.M.; the third highest illumination, 7 foot-candles, the same as that falling on the fixation point at 3.45 P.M.; and the fourth, 3 foot-candles, the same as that falling at the fixation point at 4.15 P.M.

Measurements were also made with the perimeter placed parallel to this window. Our second illumination, 17 foot-candles, was the same as that falling at the fixation point at

11 A.M.; the third, 7 foot-candles, the same as at 1.30 P.M.; and the fourth, 3 foot-candles, the same as at 2.30 P.M. In making the photometric measurements, a test-plate covered with magnesium oxide deposited from the burning metal was set up at the fixation point and its brightness measured

FIG. 2. Fields taken under 17 foot-candles of light—an illumination equal to the daylight at the fixation point, on the same day at 2.30 P.M., perimeter facing window; or at 11 A.M., perimeter parallel to window.

with a Sharp-Millar illuminometer. From these brightness measurements, the value of the incident light in foot-candles was computed. The fields were taken with all of the controls described in our previous paper, 'A New Laboratory and Clinic Perimeter.'¹ They are shown in Figs. 1-6.

The decrease of illumination from 51 to 3 foot-candles narrowed the limits for red by an amount ranging from 11 to 27 degrees; for blue from 13 to 37 degrees; and for green

¹ *J. of Exp. Psychol.*, 1922, 5, 46-67.

from 10 to 19 degrees—a result which it will be remembered was produced by a change of illumination equal to that which occurred from 1 to 4.15 P.M. in a well-lighted room on a bright winter day. The decrease of illumination from 51 to 0.03 foot-candles narrowed the limits for red by an amount

FIG. 3. Fields taken under 7 foot-candles of light—an illumination equal to the daylight at the fixation point, on the same day at 3.45 P.M., perimeter facing window; or at 1.30 P.M., perimeter parallel to window.

varying from 27 to 72 degrees; for blue from 29–61 degrees; and for green from 22 to 45 degrees.

Average Fields for 35 Normal Observers.—Since the perimeter referred to in the preceding section with its pigment stimuli different from those now in use in office and clinic work and its standardization and control of variable factors introduces a new situation in perimetry, it becomes necessary to determine a norm for the color fields under the new con-

ditions to serve as a standard or basis for comparisons. This work is in progress but has not yet been finished. Average fields (Fig. 7) for red, green and blue have been determined for 35 normal observers just as the perimeter stands, *i.e.*, with 17 foot-candles of light on the test-object and with the controls described.

FIG. 4. Fields taken under 3 foot-candles of light—an illumination equal to the daylight at the fixation point, on the same day at 4.15 P.M., perimeter facing window; or at 2.30 P.M., perimeter parallel to window.

The observers used in making the determinations, the average results of which are shown in Fig. 7, were all under 24 years of age. No astigmatisms were present of a value greater than 0.50 diopter; and no myopias of a value greater than 2 diopters. A value of myopia greater than 3.3 diopters would throw the colored stimulus at a distance of 33 cm. (the radius of curvature of the perimeter arm) outside of the

range of accommodation. There were no ophthalmoscopic or other evidences of pathological or abnormal conditions. The intensity of illumination of the stimulus, as already stated, was kept constant at 17 foot-candles. Had the intensity of illumination been different, the fields would of course have

FIG. 5. Fields taken under 0.03 foot-candles of light.

been different. If, as we believe, it will be found advisable to provide for field taking at more than one intensity of illumination, norms will have to be established for each illumination.

The fields given in Fig. 7, it will be noted, are interlacing for red and blue and otherwise differ from those accepted as standard by the medical profession. The interlacing of red and blue is a characteristic of normal limits in the mid-periphery and for periphery of the retina when stimuli of

Fields for blue

Fields for red

Fields for green

FIG. 6. Showing variations in both the extent and the shape of the color fields when taken under 51, 17, 7, 3 and 0.03 foot-candles of light.

anywhere nearly equal energy are used. The generally accepted clinic rating of the fields as to breadth is in the order from greatest to least of blue, red, green. The interlacing of the red and blue has been claimed by some medical writers to indicate a pathological condition. This may be true for

FIG. 7. Average color fields for blue, red and green for 35 normal observers.

the stimuli ordinarily employed by the medical profession, *i.e.*, a dark unsaturated red and a well-saturated blue, and for the conditions under which their work is done. It is not true when stimuli of more nearly equal energy are used and the determinations are made with a proper control of variable factors.