

ART. V.—*On the Sensitiveness of the Eye to Colors of a Low Degree of Saturation* ;* by EDWARD L. NICHOLS, Ph.D.

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EVERY one who has had occasion to mix colors has noticed that an exceedingly small amount of any pigment will impart its hue to a very large quantity of white. One part of red lead, for instance, will color a million parts of a white powder like the carbonate of magnesium, and even a smaller proportion than that is distinguishable by the average observer, as will appear from the experiments to be described in this paper.

This observation is strikingly at variance with the results obtained by other methods of mixing colors. It has been shown, for example, by Aubert† that a disk, less than $\frac{1}{800}$ of which is painted (radially) with any pigment, the remainder being white, cannot when in rotation be distinguished from an entirely white disk.

We have attempted to measure the sensitiveness of the eye in this respect, by determining the smallest proportion of various coloring matters which, when mixed with a white powder, will

* This is one of a series of researches on the special senses by E. H. S. Bailey and E. L. Nichols.

† Rood: *Modern Chromatics*, p. 39.

give it a perceptible tint. The pigments selected were red lead, chromate of lead, chromic oxide and ultramarine blue. These were in the form of powder, the red and blue being the red lead and artificial ultra-marine of commerce, whereas the chromium compounds were freshly prepared by precipitation. Each of these pigments was mixed with white in the following manner. About ten cubic centimeters of the powder was mixed in the dry state with an equal volume of magnesium carbonate, the mixture was divided into two equal parts, half of it was again mixed with its own volume of the white powder, the product was again subdivided and the process of mixing with white by equal parts was repeated until all traces of color had disappeared. Since at each stage of the process only half the material was used for further dilution, there remained a series of colored powders of which the pure pigment formed the first, while the succeeding numbers were of less and less saturated hue, and finally could not be distinguished from white. These mixtures were put into small vials of white glass and labelled in such a manner as to ensure their recognition by persons acquainted with the code and at the same time to preclude the detection of the nature of their contents from the label, without such knowledge.

For the purpose of ascertaining the degree of saturation at which the presence of these pigments becomes perceptible to the eye, the four sets of bottles, containing mixtures of red and white, yellow and white, green and white, and blue and white, were mingled indiscriminately, and the observer whose eye was to be tested was requested to arrange those in which he could detect any trace of color, according to hue and degree of saturation. The bottles were afterwards inspected by some one acquainted with the code of labels, who threw out those not in the proper set and recorded the number of bottles remaining in each set and the number of each color which had been properly placed as to shade. From the former record the sensitiveness of the eye to colors of low saturation was determined; the latter data served to indicate the ability of the observer to detect small differences of shade.

Fifty four persons, all of them with two or three exceptions between the ages of fifteen and thirty, were examined in this way. The Holmgren worsteds had shown one of them to be completely green blind, three partially so and one partially red blind. Color-blindness was not found to affect in any marked way their ability to classify the colors.

This method of measuring the sensitiveness of the eye is not in all respects satisfactory. A method in which pure spectral tints mixed with white light could be compared with a field illuminated by white light alone and the amount of monochro-

matic light lessened until its effect was lost to the eye, would certainly be better; but ease and rapidity of execution were essential where so many individuals were to be tested and where the time of those who kindly presented themselves for the purpose was limited. Moreover, the study of spectral tints would not give results directly applicable to pigments, and it is the latter with which we have to do in many practical problems in the science of chromatics. An exhaustive study of this subject would involve the use of both methods.

Table I gives the general results of the fifty-four tests. The averages for males and for females are given separately for purpose of comparison. The numbers indicate in each case the amount of coloring matter present in one hundred million volumes of white, in the most dilute mixture which can be distinguished from a pure white by the average observer.

TABLE I.

Number of parts of coloring matter that must be mixed with 100,000,000 parts of white in order to affect the tint of the compound.

	Red lead.	Chromate of lead.	Chromic oxide.	Ultramarine
Average for 31 males.....	15.9	17.3	817.7	148.5
Average for 23 females	59.8	33.2	913.6	108.1
Average for both sexes....	25.2	23.9	864.2	126.5

The popular impression that in woman the special senses are more finely organized and delicate than in man,* a view considerably strengthened so far as color-perception is concerned by her well authenticated exemption from color-blindness, finds no support from these experiments. As will be seen from the above table the average male observer is measurably more sensitive to red, yellow and green, while the female shows superiority in the blue alone. Quite as interesting, perhaps, is the manner in which the relative sensitiveness of the eye varies with the wave-length. If the corresponding data for mixtures of white and monochromatic light were obtainable it would be possible to indicate by curves the variations of the sensitiveness of the eye in this particular. The light reflected by pigments, however, is so far from being monochromatic† that it is out of the question to attempt to assign them any place in a pure spectrum, and curves constructed upon the assumption that pigments are representative of definite wave-lengths would be of interest only as illustrating in a very imperfect way the general character of the curves which might be obtained by a more precise method.

* Some experiments upon the sense of smell, carried on at the same time as and partly in connection with the tests described in the present paper, indicate that in the case of many common odors also, delicacy of perception is much more marked among men than among women. (E. H. S. Bailey: Proceedings of the Kansas Acad. of Sciences, 1884.)

† See "A spectro-photometric study of pigments," American Journal of Science, vol. xxviii, Nov., 1884.

The variation from these averages, in the case of individual observers, was very marked. Of the fifty-four persons tested, eight (five males and three females), could distinguish the presence of yellow in a mixture of three parts of that pigment in one hundred millions, while two individuals, both of them females, failed to detect it in mixtures containing less than one hundred and ninety parts in one hundred millions. Like differences were met with in the sensitiveness of the eye to other colors, and the relative sensitiveness to different colors was not the same for all observers.

The lack of delicacy in respect to green was a very general trait. Only three observers were as sensitive to green as to blue, and in the case of but one individual was the power of detecting the former color equal to the sensitiveness to yellow. The thought suggests itself that the failure to detect green may be due to a blunting of the nerves which respond to that color by continual exposure to green foliage. An investigation of the relation between the sensitiveness of the eye to colors mixed with white and the form of the three primary color-curves of the eye would add to our knowledge of this subject.

The striking discrepancy between these results and those obtained by the method of rotating disks, the eye recognizing with ease and certainty one part of coloring matter in many millions when mechanically mixed with white, and failing to detect one part in a few hundred parts (i. e., 360 parts) when mixed by rotation, shows, in our opinion, that the eye while watching a revolving disk is in an abnormal condition, and that quantitative results obtained by this favorite method of combining colors are not always comparable with those which we get by the actual mixture of white and colored light, or by the mechanical mixture of pigments. In view of the large number of researches upon Chromatics and Physiological Optics in which the revolving disk has been used, a special study of the condition of the eye during the observation of the disk, and a comparison of the results of this method with those obtained in other ways is greatly to be desired. In this manner alone can the limits of usefulness of this exceeding simple and convenient method be determined.

The tests of the power of recognition of small differences of shade were undertaken chiefly as a further means of comparing the attainments of the sexes in delicacy of color perception. The method was not adapted to the direct determination of the smallest difference of saturation which can be perceived, but our experience with the series of colors already described showed that the neighboring members were quite as closely allied in shade as was compatible with their recognition. Indeed, of fifty-four observers not one succeeded in placing all

the vials, the colors of which were perceptible to him, in their proper places in the series. The two nearest approaches to complete accuracy consisted in the correct arrangement of ninety bottles out of ninety-two in the one case and of ninety out of ninety-three in the other. Although these records were made by male observers, the *average* for the other sex was noticeably higher than that of the males. It was found that of all the mixtures possessing appreciable color the average observer of each sex placed the following proportions correctly :

TABLE II.

Average accuracy of male and female observers in detecting the degree of saturation of mixtures of pigments with white. (Complete accuracy would be indicated by 100·00.)

	Red lead.	Chromate of lead.	Chromic oxide.	Ultramarine.
Males -----	86·86	87·16	92·81	78·13
Females -----	90·81	93·24	98·28	82·92

A comparison of tables I and II shows that the color (green) to which the eye is least sensitive, so far as the ability to detect small amounts of color is concerned, is the one in which the least difficulty is met with in noticing differences of shade. Possibly the circumstance already suggested as the cause of the deficiency in the one respect, i. e., continued exposure and consequent loss of sensitiveness to green, may be looked to as the cause of the increased facility in the other. If the detection of colors of low saturation depends upon the *delicacy* of the eye and the recognition of differences of shade upon *practice*, it would account equally well for both peculiarities.

An examination of some of the mixtures used in the foregoing tests under a half-inch objective magnifying about two hundred diameters, showed that the pigments consisted of well-formed, glistening crystals about $\frac{1}{100}$ mm in diameter. These crystals were mingled with the magnesium carbonate without imparting *any trace* of their own color to the latter. Under the microscope the separation was perfect and the contrast of color a striking one. In the more dilute mixtures it was often necessary to search for some time before a single crystal of the pigment could be found, and the portion placed upon the slide did not contain, in some cases, more than five or six crystals altogether. To the naked eye, nevertheless, the mass appeared perfectly homogeneous, and unmistakably colored. Doubtless the power of a few isolated points of color, too small to be recognized individually by the eye, to impart their own hue to the entire colorless field in which they lie, is due to the persistence of the color-impression they produce upon the retina; this impression being fused with the impression of white from the remainder of the field of view by the continual movement of the eye in the process of observation.

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