THE PROBLEMS OF COLOR-BLINDNESS.

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The past few years have witnessed an unprecedented activity in the investigation of the problems of vision. A necessary consequence of the extension of our knowledge has been a definitizing of our concepts, and a recognition of more and more minute distinctions. Hand in hand with this development has come the introduction of a complex technical vocabulary — a vocabulary which has grown to such proportions as to confuse and bewilder the reader. Meanwhile the scientific literature of the topic has become so voluminous that the psychologist can scarcely master it without neglecting other provinces of his domain. While these factors have contributed to hamper the progress of the general reader's knowledge regarding many of the phenomena of vision, the situation seems to be particularly unfortunate in the matter of color-blindness.

Only one hundred and fourteen years have elapsed since Dalton first called attention to the interesting group of phenomena which are now known to be symptoms of color-blindness.¹ And while it is remarkable that such a conspicuous abnormality had so long escaped notice, it is equally remarkable that, when once pointed out and described, it excited so little interest. During the next fifty years it was scarcely mentioned in the literature; and not until toward the close of the past century did scientists come to recognize the important part which it was to play in the explanation of the facts of normal color vision. Within recent years, however, they have come to regard color-blindness as an exceedingly significant biological variation which enables them to observe, if not the evolution, at least the disintegration of the color sense. Color-blindness is not a mere idiosyncrasy — the peculiar personal possession of a particular individual. It is a typical deviation from normality — an imperfection whose essential characteristics are uniformly present in a great variety of individual cases. It is, in all

¹An earlier reference to color-blindness dates from 1787. But in this earlier case the patient had died before an opportunity was afforded for a thorough examination, and the published account is meager and inadequate. Dalton's 'Extraordinary Facts relating to the Vision of Colors' appeared in 1794 (*Trans. of the Lit. and Philos. Society of Manchester*).

probability, the product of an arrest at a half-way stage in the development of sensory equipment. And it seems probable that a knowledge of the typical forms and of the essential character of this arrested development may throw light upon the nature of the retinal process by means of which normal color vision is accomplished. And it is for that reason that scientists have labored so assiduously in an attempt to obtain a complete description of the abnormality.

Color-blindness is still far from being a closed issue in the psychology of sensation. But while certain controverted points are still in dispute, it is possible, in the present status of our knowledge of the subject, to present numerous facts upon which all investigators are in agreement.

The individual who possesses a normal color system is capable of discriminating between a great variety of color-tones; he sees the spectrum as a continuous band — save for the Fraunhofer lines — in which each tone represents a gradual transition between its neighbor on the right and its neighbor on the left. When the conditions of presentation are no longer optimal, he may fail to discriminate between spectrally adjacent tones; but, unless the conditions be exceedingly unfavorable, he never confuses colors selected from widely separated regions of the spectrum. Now, we may regard any marked deviation from this normal capacity as a form of color-blindness. It must be borne in mind, however, that color-blindness is a defect of *color-sensing*, not of *color-naming*. The circumstance that one individual describes a certain spectral region as green or greenish, while another calls it blue or bluish, indicates nothing more than that, in the vocabularies of these two individuals, the same significance does not attach to these two color-names.

From the point of view of its origin, we may distinguish between congenital and acquired color-blindness. The congenital form is by far the more common; and it is to this form that investigators have most frequently directed their attention. Congenital color-blindness is believed to be common to about three per cent. of the human race; but in the absence of reliable comprehensive statistics one cannot do more than make a rough estimate as to its frequency. As to its distribution, it is more common in men than in women — a fact which may probably be referred to the circumstance that men for generations have had relatively little interest and little practice in the discrimination of colors. The defect is of frequent occurrence among the lower animals. Color-blindness is believed to be transmitted by heredity (Bateson, Nagel); and its prevalence among certain groups of individuals,

such as the Society of Friends, would seem to support this view. Acquired color-blindness may result from certain traumatic conditions, from disease and from the action of chemical agents. A wound in the region of the eye may produce an impairment of color vision, with little or no decrease of visual acuity for uncolored light. Certain neurotic conditions and diseases of the retina and optic nerve proper may be attended by similar changes. Doses of santonin and of other drugs produce typical disturbances of color vision. And it may be mentioned in this connection that a continuous chromatic stimulation, as when one sits in a colored illumination, reduces the sensitivity to that color, and hence produces an abnormal condition of color vision.

The tests which are employed for the detection of color-blindness have reached a high state of development. The earliest form of test still bears the name of Holmgren, although that investigator cannot claim priority for its discovery. This test, in all its various forms, consists in having the suspect select, from a variety of colored objects, those which match a given sample. While this procedure may be of service for practical purposes, provided it be superintended by an efficient examiner, its diagnostic and investigative value is limited. The Stilling plates consist of groups of vari-colored patches so arranged as to form more or less readily legible numerals. This test also is of slight value, save as a preliminary for a more thorough-going examination. These two, however, are the forms in common use; and Stilling's publication reached its eleventh edition during the past year. A much more adequate test is that recently devised by Nagel — himself a color-blind. It is unfortunate, however, that his scheme has recourse to color-naming — a capacity which may be subject to well-marked individual variation among persons who possess the same color sensitivity. For the purposes of the investigator, the test which employs 'Rayleigh's equations' possesses unequalled advantages. On account of the numerous variations in cases of defective color-vision it is impossible, by any system of unchanging stimuli, to provide colors which shall appear exactly alike to any considerable number of color-blinds. It is therefore essential to devise some means of gradual variation of stimulus. This condition has been met in the scheme which resorts to a determination of the laws of color-mixing for the abnormal retina — a scheme which also provides for the expression of its results in most illuminating form. This method is essentially an extension of a plan which was introduced by Lord Rayleigh in 1881; it is usually referred to as the method of Rayleigh's equations (or confusion equations). It may be described as a systematic attempt to determine

what proportions of given color-tones must be combined to produce a mixture which shall be indistinguishable, in color and in brightness, from another color stimulus. For example, the examination may consist in matching a spectral yellow by an appropriate combination of spectral red and spectral green.

Every attempt to present a detailed characterization of color-blindness must encounter an obstacle in the matter of terminology. It may be stated at once, however, that two chief types of color-blindness are found. Total color-blindness consists in an inability to distinguish any color from gray. Those individuals who are able to distinguish certain colors only are said to be partially color-blind. The most frequent errors made by partial color-blinds consist in confusions between red and green, although a few cases have been reported in which yellow was confused with blue. Inasmuch as all the tones in the color system of the partially color-blind may be reproduced from mixtures of two colors (yellow and blue in the former case, red and green in the latter) such a system may be said to be dichromatic. Trichromatism would refer to a normal color system, since all possible tones may be reproduced from the mixture of three colors, appropriately chosen and appropriately combined. In the scientific literature, particularly that of Germany, color systems are usually described in terms of dichromatism and trichromatism. It seems unfortunate that a more significant terminology has not found favor; for one finds it quite as easy to speak of red-green blindness, blue-yellow blindness and normal color vision.

The red-green blind sees no difference, save in brightness alone, between a certain red, a certain green and gray. The green which confuses him has a bluish hue. It lies between the *b*-line and the *F*-line, having a wave-length which varies, for different observers,¹ between 500 $\mu\mu$ and 490 $\mu\mu$. His other missing color is a (non-spectral) purplish red, the complement of the bluish-green. For the blue-yellow blind the neutral bands appear in the vicinity of the *D*-line, and at the region of the complementary blue.

The examination of red-green blinds has revealed the existence of a well-marked individual difference. And indeed the variation seems sufficiently great to justify the division of this group into two subtypes. The most striking difference appears in matches between red and gray — certain members of the group selecting a light gray while the others as uniformly select a dark gray. Von Kries has suggested

¹ It is probable that this variation in the 'neutral band' may be referred to variations in the pigmentation of the lens and of the macula.

that the latter form of abnormality be called *protanopia* and the former *deutanopia*. Here again let us pause to enter an objection to the choice of non-significant terms. The Rayleigh equations emphasize the essential difference between the two sub-types. When red and blue are mixed to match blue-green the protanope requires a relative excess of red in his purple mixture; and in similar determinations with red and yellow the protanope may demand five times as much red as the deutanope.

Besides the types of abnormality which have been described, certain less conspicuous deviations from the normal are occasionally found. The least serious of these has been called anomalous trichromatism (König). Although not fully understood as yet, anomalous trichromatism seems, when brought into relation with normal sensitivity, to present points of qualitative similarity but of quantitative dissimilarity. Attempts have been made to trace its origin, not to a retinal source, but to an individual variation in lenticular and macular pigmentation. This interesting and baffling variant was first reported by Rayleigh in 1881. In an investigation where several individuals were asked to match a mixture of spectral red and spectral green with spectral yellow, Rayleigh found that the results of most observers group themselves around a common average. Certain individuals, however, make their mixtures much redder, and other individuals much greener than the average. Here again then we must distinguish between a protanopic and a deutanopic sub-type. Investigations since Rayleigh's pioneer publication have shown that the former sub-type is much more numerous than the latter.

Another variation from normal color vision has been designated by the exceedingly inappropriate name of 'color weakness.' At an early stage in the development of our knowledge of this defect, investigators believed that it consisted in nothing more serious than a slight but uniform blunting of sensitivity to all colors. And this view still persists in the popular mind — probably as the result of the misleading character of the name by which it is commonly known. Investigation has shown, however, that the defect is much more intimately related to the typical forms of dichromatism than its name implies. The individual who suffers from 'color-weakness' is unable to pass even the least searching tests of color-blindness; and his abnormality is most strikingly revealed in the presence of reds and greens. The defect becomes most conspicuous under relatively unfavorable conditions of stimulation. Confusions are most numerous when color-stimuli subtend small visual angles; it has been established, however, that reduced

brightness and decreased saturation also make discrimination more difficult.

The practical application of the results of investigations in this field has come up for discussion in recent years. The æsthetician and the painter have interested themselves in these as in other visual problems. But the most natural direction in which to turn to find a practical application has proved to be toward the field of railway signaling. In developing means of control over railway trains, a complex system of signaling has been evolved. Here, as in the marine service, colored lights are employed for night signaling. A superficial consideration of certain defects of color vision has inspired the fear that this method of signaling is a menace to public safety. It is to be noted, however, that the objector has brought forward no evidence to show that his objection has any other than a purely fictitious foundation. Nor is it difficult to determine that the alarming conditions which he has conjured up have no counterpart in the practical affairs of railway operation. Railways, the world over, make use of colored signals; and the governments of several countries publish statistical reports of the numbers, the fatalities and the causes of railway wrecks. Now, such a country as England furnishes ideal conditions for a crucial test of the efficiency of the present system of signaling, because the English railways have to cope with an unusual combination of adverse conditions of operation, — congestion of traffic, high speed of trains, and the prevalence of fogs. Yet the English railways are noted for the infrequency of their accidents. Their fatalities have averaged so low as one per one hundred and sixty-nine millions of passengers carried; and a full year has elapsed without a single fatality. These data refer to accidents *from all causes*; and a commission recently appointed by the Royal Society reports that no accident, railway or marine, can be traced to anomalous conditions of color vision. Practical experience then shows that colored lights constitute a safe means of signaling, and that their results are in the highest degree successful even when the conditions of operation are relatively unfavorable. Is it not clear that if railway disasters are more frequent in America the cause is to be sought elsewhere than in a defective system of signaling? The Inter-State Commerce Commission (America) reports great numbers of railway disasters which may be traced to disobedience and drowsiness of employees, to defective road-bed and rolling stock, to obstructions upon the track, to the American tendency to take hazardous risks, etc. And the reader who cares to consult the Commission's reports will find that these are the causes to which the lesser safety of railway travelling in America must be ascribed.

Although we are now in possession of a goodly accumulation of facts regarding the phenomena of abnormal color vision, there are still a number of points upon which additional light is desirable. Certain technical problems still remain unsolved: What is the relative distribution of spectral brightness in normal and abnormal color systems? What is the relation of lenticular and macular pigmentation to variation from normal color vision? What are the mutual relationships of 'color weakness,' anomalous trichromatism and normal color vision?

If, however, some beneficent magician should grant the boon of an answer to but a single question, the investigator would undoubtedly demand to know just what is the character of the sensations which are possible to the abnormal. If we had a perfect description of the color systems of the various types of abnormality, few obstacles would remain in our path. Then we should be prepared to give a definite answer to the general question: Do these various types of abnormality represent a continuous series of gradations, without interruption or lacuna, between normality and complete color-blindness? Indeed, the suspicion is gaining ground that even this most extreme form is not a color-blindness at all, in the literal sense of that term. There seems reason to believe that at least the color system of the typical red-green blind contains red and green sensations; and that he may distinguish between red and green if only the stimuli be presented under sufficiently favorable conditions. Whether the hypothesis of continuous gradation, or the hypothesis of isolated types will ultimately dominate our envisagement, remains for the investigator of the future to determine.