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A Clinical lecture delivered before the Senior Class at the Jefferson Medical College, Philadelphia, April 5, 1895.

BY WILLIAM THOMSON, M.D.
PROFESSOR OF OPHTHALMOLOGY IN THE JEFFERSON MEDICAL COLLEGE; OPHTHALMIC SURGEON TO THE PENNSYLVANIA RAILROAD, ETC.

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Gentlemen:—Your Clinical Professor of Ophthalmology has invited me to address you on the subject of color-blindness. I must suppose that you have been made acquainted with the anatomy and physiology of the eye, by the teaching of my friend and colleague, Professor Hansell, who is so well qualified to instruct you upon this subject. Taking, therefore, your familiarity with these preliminary matters for granted, I will proceed at once to tell you what is meant by color blindness; and how the condition may be recognized. I will also explain the tests, and give you clinical illustration of their application. In this way, you will get a practical demonstration of the methods of examining patients who are suspected of having a defective color sense.

When we speak of congenital color-blindness, we mean that the eye may be perfectly normal in its structure, have no anomaly of refraction, and be a perfect optical instrument, except for one defect, and that is the inability to distinguish the difference between colors, which to ordinary, normal eyes is very obvious, such as red and green. It is precisely these colors, however, which have been selected for signals on the railroads and on shipboard, where failure to recognize them may cause serious loss of life and property. You will appreciate this better when I tell you that there are cases of total color-blindness in which the solar spectrum looks to the patient like a lead-pencil drawing of it; where, from red to indigo, the spectrum looks as if drawn in different shades of gray. Such cases, however, of total color-blindness are rare; indeed, I have never met with a case of this kind. On the other hand, cases of partial color blindness are common. For instance, there is blue, yellow, red, and green blindness. What is most commonly meant, at the present day, by color blindness, on occount of its wide-spread and far-reaching consequences, is the inability to distinguish between red and green, or green and gray. When you realize that the individual presenting this defect to the examiner would show the same in ability to distinguish between red and green flags or lights, which are commonly used as signals at sea or on railroads, you will understand the great importance of testing the eyes of all pilots, and of engineers and brakemen particularly. The correct interpretation of those signals depends upon the ability of the engineer or lookout to recognize certain colors at sight. The white light or flag on the railroad means: "Go ahead;" the green, "Proceed with caution;" the blue, "Do not move it;" but the red light or flag means imperatively, "Halt." It is important to recognize lights at sea, for another reason, because by their aid the course is indicated in which a ship is sailing. The red light is hung at the port and the green at starboard, with a white light on the masthead. By the relative positions of these lights the direction may be known. In the recent calamity by which the steamship *Elbe* was injured in a collision in the North Sea and foundered with all on board, I am not sure that it was not due to the defect in vision of which I speak to-day. The accident occurred at night when there was no storm, and the atmosphere was clear enough for ships to see each other for a long distance before they met. It might have been due to the fact that the lookout on the *Craithie* could not tell which way the *Elbe* was going, owing to color-blindness, which prevented him from correctly interpreting the signals on the *Elbe*. So, you see that this is a matter of very great importance, especially to all of us who may have occasion to travel by land or water.

Now, we will see if we can approach this subject in some way so that you will get a clear idea of the color sense and of the relations of colors. Here, on this plate I show you a colored representation of what is commonly known as a "spectrum" "or solar spectrum." This teaches you that if you go into a dark room and make a small hole in a shutter, that the beam of light (or if passed through a prism) will break up into this arrangement of colors upon a screen, with blue light at one end and red light at the other, as everybody knows. The reason why the spectrum is formed is because a beam of white light is made up of a number of rays having different wave lengths, or rates of vibrations. Thus, the red rays at one end of the spectrum have about four hundred million millions of vibrations per second, while the violet at the other end have over seven hundred and fifty million millions. All rays under four hundred billions of vibrations per second are not perceptible as light and are known as heat rays, while those higher than the violet can not be appreciated by the human eye and are only recognized by their chemic and physical effects. Between these extremes of red and violet are found the orange, yellow, green and blue rays with rates of vibration of four to eight billions per second.

You may ask why it is we see only a small portion of the spectrum, and that the higher and lower rays are not luminous. It is because the human eye has been evolved from lower forms of animal life, and its condition is the result of the action of external forces of nature upon it during the course of its development to fulfill the needs of the human organism. We will suppose that the light falls upon the cornea and passed through the crystalline lens and that impact takes place upon the retina. A commotion is set up among its rods and cones, the red rays and violet rays make a different impression upon the nerve endings in the cones, and this is carried backward through the optic chiasm to the part of the brain which we have ascertained, by pathologic and other observations, to be the center for vision, which is situated in the occipital lobe of the brain in the cuneus. From here it is carried on to consciousness, and if any of you, gentleman, can tell me where that is and how these impressions become conscious sensations, I shall be very much obliged to you for the information. Having traced the impression to the cortical center in the occipital lobe, there we must leave it for the present; all we know is that it is carried to the cuneus and thereafter it becomes to us conscious sensation.

Case 1. Congenital Color-Blindness.—Now, gentlemen, I will show you this case of color-blindness, in order to demonstrate the nature of this phenomenon to you. I will first give him fine print to read and thus test each of his eyes, to prove to you that they are perfect as optical instruments, and that vision is acute and accommodation normal. He says that he first learned that he was color-blind when he bought what he thought was a blue necktie, and when he brought it home he was laughed at for buying a green one. This led to conversations upon colors, which showed him there were differences recognized by others, but which he could not appreciate.

It is of interest to mention that it is to Dalton, who was himself afflicted in this way, and who a hundred years ago was a distinguished professor of chemistry, that we owe our first exact views on the subject of color-blindness. He also ascertained the peculiarity by accident. He was living at Oxford, and when he went up to take his degree he was informed that he must wear a red coat, and it being against the rule of the religious society to which he belonged, he was much troubled about it. When the coat was brought home, he thought that they had changed it for a mouse-color or drab and he was very much pleased with the shade. He thought so well of it that he not only wore it to the ceremony when he received his degree, but he also wore it in the street until his friends spoke to him about it, when he learned for the first time that the coat was red. He investigated this subject and taught the use of the spectroscope in diagnosis. After Dalton came Dr. Thomas Young, who made observations upon the color sense, which have become classic. Now, coming down to our own time, Holmgren taught us that color-blindness was comparatively common among the railway employes in Sweden, and devised a very practical test for the examination of their color sense.

Now, let us suppose that you will be called upon to examine a suspected case. It will be useless to ask him to name colors, for he has learned to apply these names which he will use in speaking, although he could not distinguish the green from the red, perhaps except by a slight difference of shade, both appearing as dark gray. Now, according to the doctrine of probabilities, if you take a large number of men, you will find that 4 men out every 100 will not be able to distinguish between red and green, or will be color-blind; whereas there are only about 4 women out of 6,000 who are color-blind. This would really show on this point, a superiority of the female sex, in the ratio of 1 in 25, in males, to 1 in 1,500 females possessing this defect of color-blindness.

We will now proceed to the test for color-blindness. The best way to ascertain the existence of this condition is to ask the subject of the test to match certain colors. Here is a mass of over a hundred small bundles of wool of different shades of green, pink, blue, orange, etc. In making then, what is known as Holmgren's test, three test colors, viz., light green, rose or purple, and red are placed in turn before the person to be examined, and he is told to select from the mass a number of skeins and to sort them according to the color.

This test will now be made upon our patient. Observe that he takes a rose-pink and lays upon it the light blues and hesitates about the grays. In assorting the colors, as requested, you can see, without asking him any questions, that he is unable to distinguish between certain colors, and especially green and red, and makes ludicrous mismatches. He reminds me of a young man who happened to be color-blind, and who describing his ladylove said that her cheeks (pink) were the same color as the sky (blue). I have no doubt that there are a number of gentlemen in this class who are color-blind, and if so, they should know it, in order that they may avoid errors and thus succeed in their professional lives. There are many things that appear differently to the color-blind physician, and we often depend upon full appreciation of color for our diagnoses. For instance, a rash upon the skin would not look the same to such an individual as to others with a normal color-sense. Chemic tests, dependent upon color changes, would be rendered uncertain and difficult to a color-blind doctor.

Here is a bundle of skeins of wool of neutral colors which our patient selects. Here is a pink, which this man calls a dirty white. If he were an engineer and should make such a mistake confusing a red with a dirty white flag, the results might be serious. Now, if we confront this man with the picture of the spectrum, we find that he can distinguish blue and yellow better than red or green. Therefore, if we divide the spectrum into four colors, red, yellow, green and blue, he can distinguish yellow and blue well and fails on the other two colors, and he has hence that form known as red-green color-blindness.

Some difficulty arises owing to the partial education of the color-sense in these cases, so that we can not ask them to name the colors, or to select colors by name. But we must ask him to match skeins of worsted by placing him before this box filled with many colors, from which he must select those corresponding in color to the test skeins, but lighter or darker in shade.

The rose-pink, as you may know, is a mixture of red and blue. Therefore if he matches this with a blue, he is red blind: and if he matches it with green or gray, he is green blind. Now, you see he gives himself away in two ways; he not only matches the rose-pink with a blue, but fails to pick out the other pinks in the mass right before him. He then picks out a bright red and throws it upon the green test. This shows that his eye is incapable of responding to the four hundred million millions of vibrations in a second, which correspond with the red color. Now, if he were a doctor, and were to examine the eye-ground with the ophthalmoscope, the field would look to him as if bright green or dark yellow.

One other point should be mentioned. Nature is very miserly in her gifts and, while our color-sense is most acute in the very center of the posterior segment of the retina, outside of this portion of the retina we are all relatively color-blind. The response to the color rays becomes less decided as we pass from the center to the periphery of the field of vision in normal eyes.

As our color-blind subject sees in the spectrum only blue and yellow, he has a dichromatic color-sense, that is to say, a color-sense limited to two color sensations only. The normal sense is trichromatic: red, green and violet, which are the three color sensations necessary to produce white light. If this man should attempt to paint the solar spectrum, he would place blue at one end and yellow at the other end, with a neutral gray band between, as he has only two color perceptions. His entire color scheme of nature most correspond to this fact, and would necessarily be very different from that of other persons who have all three sensations. Therefore, his appreciation of nature is much more limited than that of those with full perceptions of color. He would not be able to pick strawberries out of a patch, or cherries from a tree, except by the form of the fruit; and in his eyes a red rose would not be very different in color from its leaves.

This examination which I have made by Holmgren's test can be very much facilitated and shortened by that instrument known as "the color-stick," which was invented by me in 1879, for testing the employes of the Pennsylvania Railroad. The simplicity of this instrument and the positive character of the results, make it valuable also for preserving records, and it has the great advantage that the test can be made with it by laymen and non-professional people. I think that it is always better to have a trained surgeon to supervise the examinations; but at the time that this system was introduced it was impossible to find a sufficient number of ophthalmic surgeons to supply the demands of the Pennsylvania Railroad, where there were about forty thousand men in the employment of the company, scattered over thousands of miles of railroad. To accomplish this result, I devised this instrument. It consists of forty skeins of worsted, arranged in a single row, upon two sticks joined together, but which can be taken apart. Each skein has a ring and a little bangle upon which is stamped its number. Twenty of these skeins are affirmative and twenty are negative; all the affirmative bear odd numbers, all the negatives are *confusion colors* and have even numbers. Now, if a person's color-sense is normal, he will select all the odd numbers, while the color-blind person will select a portion of the even numbers. As each skein is selected, it is turned backward so as to hang over the top of the stick. At the end of the examination the results are read off and entered upon a printed blank form, which is then sent to the superintendent, who can tell at a glance whether the man is or is not deficient in color-sense, by an inspection of his odd or even numbers.

Now we will give this man a skein of green to hold in his hand and he is told to pick up some others from the stick that look like it. Observe, now, that the even-numbered skeins show his mistakes. He is now given a rose-pink and told to pick out skeins to match it. The former test is confirmed by his selection again of even-numbered skeins. The result is read off immediately and recorded on the blank, and color-blindness is the diagnosis.

The new system recently adopted by the Pennsylvania Railroad is the following: The stick has been discarded and the test consists of two different sets of worsted skeins which must always be kept apart, not only in their corresponding parts of this box, but also in testing the men. The first set consists of twenty skeins, numbered 1 to 20 on bangles, these numbers being so concealed that the men can not see them. Among these numbers the odd ones (1, 3, 5, etc.) are greens, while the even numbers (2, 4, 6, etc.) are grays or light browns. The second set consists also of twenty skeins, but they are numbered from 21 to 40. Here the odd numbers (21, 23, 25, etc.) are all different shades of rose color, while the ten even numbers (22, 24, 26, etc.) consists of four blues, three greens and three grays.

The following directions are to be observed in the use of this test:

1. Examine only *one* eye at a time, by covering the other eye with a handkerchief or some other means, that will exclude it from vision.

2. Spread a white cloth, like a towel, on a table in a good light.

3. Take out all the worsteds from the green part of the box and put them on the cloth at random.

4. Take from this heap the large light green test skein which is marked *A*, and laying it to the side in a good light direct your man to select ten skeins from the heap. Tell him

that they are not to be exactly like it in every respect, but that they are to be of the same color, only a little lighter or darker in shade.

5. Write down on your blank the numbers of the ten skeins selected by your man to match the test skein *A*. If only odd numbers appear which he selected promptly, then he is not color-blind; but if even numbers have been chosen, he must be more or less color-blind.

6. Ask him the name of the color he has been matching, or any other worsted, and register his answer on the blank.

7. Remove now all the worsteds and put them back in the green part of the box.

8. Now take out the second test and expose it on the table in the same way as before.

9. Show him the large rose-colored test skein, marked *B*, and ask him to match this with ten worsted in the same sense as before the first test.

10. Register his ten selections on the blank. Now any even numbers selected betray and determine definitely his color-blindness. If your man selects *blues*, with the test skein *B*, he is *red-blind;* if he selects *grays* or *greens*, he is *green-blind.*

11. Ask him the name of the test skein, or any other skein, and register it.

12. Put down whether his selection was prompt or hesitating.

13. Finally, as a control upon the test and as a substitute for the second and third color-test of the old system, there have been arranged especially for the surgical expert, two more large test skeins, one *c*, yellow, and the other *d*, blue. The test *c* is exposed and you ask your man to match it, if possible, by the skeins from 1 to 20. If normal in color-sense, he will decline or at the most only take the yellow-green skein, but if color-blind he will select a number of the green skeins, which should be recorded. Then use test *d*, the blue skein, and let him match it from skeins 21 to 40. If normal or green blind he will select blues only, but if red blind he will pick out a series of roses, which should be recorded.

The old system is now in actual use by more than forty of the principal railway corporations in this country and Europe, and over fifty-two thousand miles of railroad are now protected by it. It is used not only for those actually in service of the railroads, but also for all applicants who seek such employment. To make the examination of vision complete, records are also kept of the results after testing by Snellen's test types for sight and power of accommodation.

In Holmgren's test as originally conducted, the examination took considerable time and required an accurate knowledge of the subject on the part of the examiner. By this system of mine, the tests are quickly made and recorded, and the results are equally positive.

Now, gentlemen, I think that you are satisfied that I have exhibited to you a typical case of marked congenital color-blindness. This was probably inherited either from his father or grandfather, possibly from his maternal grandfather, since, as already mentioned, the females usually escape color-blindness. I think, moreover, that you would not like to ride in a train behind a locomotive in charge of this man as engineer, who would then be called upon to recognize all kinds of signals at a glance by night as well as by day, when as he has just told you he sees green as dirty white, and red is indistinguishable from green.

There is another easy test known as the cobalt blue test, which I will demonstrate to you. A lighted candle is held about ten feet from the patient and a piece of cobalt blue glass is held before each eye in succession, the other being closed. Now to the normal eye, the flame of the candle should be pink or rose surrounded by a blue halo, but this man tells us that he sees only one color which he calls blüe, and thus demonstrates his inability to see any red color, since this glass transmits both red and blue rays.

Case 2.—Acquired Color-Blindness of Toxic Origin. I will now refer to this other case in which the color-blindness instead of being inherited has been acquired. This man for twenty years has used tobacco to excess, and he has, as the result, a central scotoma, or partial loss of vision with color-blindness over a limited area of the retina, involving the yellow spot, which is the center of most acute vision. In this large colored plate of the eye-ground, I now show you a very fine delineation of what we see at the back part of the healthy eye by the aid of the ophthalmoscope. Here is the optic disc or the entrance of the optic nerve, and here is the yellow spot, about 8 degrees to the outer side of the disc. Immediately at this point is the *fovea*, the seat of most acute vision and likewise of the highest development of the color-sense. When a man has any lesion in this region, it reduces his appreciation of both color and form very materially, if not totally. Outside of this central region everybody is relatively color-blind, the periphery of the retina being less responsive to color vibration than the center.

To prove to you the color defect, I take this red glass from the test case and place it in front of a lighted candle at six feet away; now by replacing it with green we find him unable to distinguish between green and red. I now measure the diameter of the test glass and find it 33 mm. I now bring the candle to 33 cm. (or thirteen inches) from his eye and he begins to feel the red color of the glass, and distinguishes it quite promptly if the lighted candle is moved a little from its position. When it is removed farther from the eye he is color-blind, but when it is approached, say to 25 cm. (or ten inches) he at once perceives either red or green colors, properly. Now, at 33 cm. this stick in my hand, of 33 cm. in length, covers 60 degrees of his retinal surface; the red or green glass is 33 mm. or one-tenth the size, and hence covers 6 degrees of his retina, and as he is color-blind for an object of this size, we are able to prove that within 6 degrees at his fovea he is color-blind, but if a larger portion of the retina is covered by the image of the test, it responds in a normal manner. From this, you will infer that this man would be incapable of seeing the signal-lights at night and would mistake red for green, or white for green, but that he would escape detection perhaps if tested by any colored wools, since each skein would form an *image* of more than 6 degrees upon his retinal center, and would touch rods and cones with normal sensation. Such cases are rare, and should be remembered by those who have the charge of lookouts on the water, or on railways on land. Accidents, alcohol, some of the fevers, may cause this condition and would render reëxamination of suspected men necessary even after they had once passed the color-blind examination.[1]

This, then, is a case of acquired color-blindness wieh central scotoma only, due to excessive use of tobacco; and it differs from the preceding case in being amenable to treatment by tonics, such as strychnin, etc.

Case 3.—Traumatic Color-Blindness. I have another case to show you but the termination of the hour will permit me only to advert to it very briefly. This patient sustained a severe injury some months ago. He fell down twenty or thirty feet into an elevator shaft and suffered a concussion of the brain. At this time he probably sustained a lesion of the cuneus in the cortex of the occipital lobe of the right hemisphere. It was ascertained recently that he has hemianopsia for color only. One-half his field of vision in each eye, is color-blind, while he has a perfect appreciation of color and form in the other half.

I show him to you as a case of traumatic color-blindness limited to one-half of each eye, following an injury to the occipital region. I am indebted to Dr. A. G. Thomson for this case.

With this case, I conclude the clinical remarks I wished to make upon these three patients, which will illustrate the congenital, the acquired and the traumated forms of this very interesting and very important condition of so-called color-blindness.

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[1] This man recovered his full sight both for form and color under disuse of tobacco, and internal use of strychnia. His color scotoma extended for 6° and involved the central or macular band of nerve fibers only.