The Hunterian Lectures
ON
COLOUR VISION AND COLOUR BLINDNESS.

DELIVERED AT THE ROYAL COLLEGE OF SURGEONS OF ENGLAND,
BY

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[ABSTRACT]

COLOUR blindness is not a good name for the condition to which it is applied, and still worse is the use of the term "red blindness" or "green blindness." In the majority of cases of colour blindness there is no blindness to colours in the ordinary acceptation of the term; a green, red, or yellow light produces a very definite sensation of colour. Those who confuse red and green do so not because they see red as green or green as red, but because both give rise to a similar sensation of colour.

I propose to divide the subject into two parts, and in the first lecture to deal with the theory and facts of colour vision and colour blindness, and in the second lecture with the detection of colour blindness from a practical point of view.

I. THE THEORY AND FACTS OF COLOUR VISION AND COLOUR BLINDNESS.

The following is the theory which I have propounded in order to explain vision and colour vision.

A ray of light impinging on the retina liberates the visual purple from the rods and a photograph is formed. The rods are concerned only with the formation and distribution of the visual purple, not with the conveyance of light impulses to the brain. The ends of the cones are stimulated through the photo-chemical decomposition of the visual purple by light (very probably through the electricity which is produced), and a visual impulse is set up which is conveyed through the optic nerve fibres to the brain. The character of the stimulus differs according to the wave length of the light causing it. In the impulse itself we have the physiological basis of the sensation of light, and in the quality of the impulse the physiological basis of the sensation of colour. The impulse being conveyed along the optic nerve to the brain stimulates the visual centre, causing a sensation of light, and then passing on to the colour-perceiving centre, causes a sensation of colour. But though the impulses vary in character according to the wave length of the light causing them, the retino-cerebral apparatus is not able to discriminate between the character of adjacent stimuli, not being sufficiently developed for the purpose. At most seven distinct colours are seen, whilst others see in proportion to the development of their colour-perceiving centres—only six, five, four, three, or two. This causes colour blindness, the person seeing only two or three colours instead of the normal six, putting colours together as alike which are seen by the normal sighted to be different. In the degree of colour blindness just preceding total, only the colours at the extremes of the spectrum are recognized as different, the remainder of the spectrum appearing grey.

Though my own opinion is that the ordinary form of congenital colour blindness is caused by a defective development of the portion of the brain whose function is the perception of colour, we must not exclude any portion of the retino-cerebral apparatus, defect of which would have exactly the same result.

It will be noticed that the theory really consists of two parts, one concerned with the retina, and the other with the whole retino-cerebral apparatus. I shall in these lectures use the word cerebral in this sense. I am not aware of a single fact which does not support this theory, and I have used it to predict facts which have subsequently been rediscovered by others, and now form a part of our common knowledge.

The Visual Purple the Essential Factor in Vision.

I will now state very briefly the evidence which supports the view that the visual purple is the essential factor in the retina which enables it to transform light into visual impulses.

1. *Anatomical.*—In the fovea of the retina only cones are to be found. Immediately external to this each cone is surrounded by a ring of rods. The number of rings of rods round each cone increases as the periphery is reached. The outer segments of the cones are situated in a space which is filled with fluid. The external limiting membrane retains this fluid in its place. I find[1] four depressions or canals which lead into the larger depression of the external fovea. These canals appear to have smaller branches and serve to conduct the visual purple into the part of most acute vision. The cones which are present in the fovea have very long outer segments which would present a greater surface for photo-chemical stimulation. The visual purple is only to be found in the rods and not in the cones. I determined to ascertain whether the visual purple could be seen between the cones in the fovea. I have examined under the microscope the retinas of two monkeys which had been kept previously in a dark room for forty eight hours. The yellow spot was the reddest part of the whole retina, and the visual purple was seen to be between and not in the cones.[2]

2. *Physiological Analogy with other Body Cells.*—It is far more probable that the rods should produce a secretion which would affect other cells rather than themselves. The liver cells do not form bile in order to stimulate themselves, and the internal secretions are produced to affect other parts of the body. I am not aware of a single instance in which a cell produces a secretion which has the function of stimulating the cell producing it. The visual purple is regenerated in the rods by the pigment cells in connexion with them.

3. *The Relation between the Foveal and the Extra-foveal Regions.*—As the fovea only contains cones, if any of the older theories of the relative functions of the rods and cones were true, we should expect to find qualitative differences between the foveal and extra-foveal regions. This is not the case, but, as we should expect if the visual purple were the visual substance, all the phenomena which have been attributed to the visual purple should be found in the fovea. Von Tschermak, Hering, Hess, Garten, and others have found the Purkinje phenomenon, the variation in optical white equations by a state of light and dark adaptation, the colourless interval for spectral lights of increasing intensity and the varying phases of the after-image in the fovea only gradually diminished.

4. *The Varying Sensibility of the Fovea.*—The fovea is in some conditions the most sensitive part of the whole retina, and with other conditions the least. Helmholtz has recorded some of these facts, and regarded them as quite inexplicable. We have, however, an easy explanation of the facts on the assumption that when there is visual purple in the fovea this is the most sensitive part of the whole retina, but when there is none there time must elapse before it can diffuse into the spot, and in the meantime it is insensitive to light. I have devised several experiments which show the visual purple flowing into the foveal region. The following simple experiment shows this very well. If on awaking in the morning the eyes be directed to a dull white surface, as for instance the ceiling, the region of the yellow spot will appear as an irregular black spot and light will appear to invade this spot from without inwards. If the eyes be now closed and covered with the hands purple circles will form round the centre of the field of vision, and gradually contracting, reach the centre. When the circle reaches the centre it breaks up into a star-shaped figure and becomes much brighter. It then disappears and is followed by another contracting circle. Now it will be noticed that if one eye be opened when the circle has broken up a brilliant rose-coloured star much brighter than any other part will be seen in the centre of the field of vision. This has the exact hue of the visual purple. If we wait until the star has disappeared before opening an eye the macular region appears as a black spot as before. This conclusively shows that the central portion of the retina is sensitized from the peripheral portions.

5. *Chemical Analogy.*—The visual purple gives a curve which is very similar to that of many other photo-chemical substances. We know that with photo-chemical substances the chemical effect is not proportional to the intensity of

the light. That is, a different curve is obtained with weak light from that which is formed with light of greater intensity.

6. *Illusion of Moving Light.*—If a small light be looked at fixedly in a dark room it will appear to move until it comes apparently so close that it could be grasped. The reason of this is that the eye moves so that the light falls upon a more peripheral part of the retina. I find that the movement takes place as if some photo-chemical substance acted under the influence of gravity. For instance, when standing the light appears to travel upwards; resting the head on one side it appears to travel in the opposite direction. The light appears as if we were looking straight at it, and the eye which is covered up remains directed straight at the object.

7. *Currents Seen in the Field of Vision not due to the Circulation.*—It occurred to me that if there were canals in the retina which promoted the easy flow of the visual purple into the fovea, we ought to obtain evidence of the currents flowing along these channels entoptically. I found that this was the case, and that the currents could be seen in numerous ways.[3] If one eye be partially covered with an opaque disc while both eyes are directed forwards in a not too brightly illuminated room, and special attention be paid to the covered eye, an appearance of whirling contents will be seen with this eye. These currents appear to be directed towards the centre, and have a very similar appearance to a whirlpool which is fed by four main branches. These, again, are fed by smaller branches which continually change their paths. On closing both eyes all the portion in which the whirling currents are seen appears as dull purple. These currents cannot be due to vessels, because we know that the centre of the retina corresponding to the point where the greatest movement is seen is free from vessels. The appearance is also very different from that of the movement of blood in vessels. The currents can also be seen in the light, in the dark, through yellow-green glass, and with intermittent light. The main branches form a star-shaped figure with four rays. The currents carry the visual quality, colour and brightness, from whence they come into an after-image. They also tend to move an after-image towards the centre. The currents behave as if they ran in definite channels, but could also overrun, on any further stimulus, the banks of the channels. For instance, a thin bright line with a little more light appears as a broad band, and the central star figure will enlarge into a rhomboid, oval or disc. Movements of the eyes affect the broad currents in the outer part of the field of vision.

8. *Pressure Figure.*—Pressure on the front of the eye causes the star-shaped figure to be seen, and this changes into a rhomboid with a little more pressure.

9. *Macular Star.*—It occurred to me that we ought to obtain evidence of the canals in the retina in cases where the outflow from the retina is obstructed as by tumour. I find this is the case; the star-shaped figure given by Sir Victor Horsley in his paper on tumour of the frontal lobe[4] is almost exactly the same as that seen subjectively.

10. *Entoptic Appearance of Cone Mosaic.*—Appearances corresponding to the cone mosaic of the retina may be seen in several ways.[5] The appearance seen corresponds to the cone distribution of the retina as viewed from its outer side, the portions occupied by rods appearing as dark spaces.

11. *Visual Acuity.*—Visual acuity is most acute with the fovea and diminishes from within outwards. It corresponds very fairly with the cone distribution of the retina.

On the other hand, there is not one single fact which points to the rods as being light sentient organs. This is well recognized by those best qualified to judge.[6]

II. The Detection of Colour Blindness from a Practical Point of View.

Requirements of a Test for Colour Blindness.

A test for colour blindness, when it is to be employed for some definite and specific purpose as, for instance, excluding dangerous persons from certain callings, should be such as to show definitely that the persons rejected are dangerous. It is very useful to demonstrate to the men and their fellows that a rejected candidate is dangerous. The colleagues of a rejected candidate would refuse to risk their lives with a man who before their eyes called a red light green. I was expressing these views when a superintendent of a railway company who is using my lamp told me that he had adopted this method with great satisfaction to himself and to the men. A man, for instance, who has been working twenty years on the railway, has been rejected for colour blindness. He has complained bitterly to the superintendent, at the same time declaring emphatically that he is normal sighted. The superintendent has replied, "You know red?" "Yes." "And you know green?" "Yes." "You will therefore agree that if you call green red, or red green, you ought to be rejected. Bring two or three of the other men in with you and I will test you." The man has readily agreed to this. The superintendent has then tested him by asking him to name various coloured objects in the room, and knowing by experience exactly the coloured objects which are miscalled by the colour blind, readily exposes his defect. It is noteworthy that on some occasions a colour-blind man has been tested by another person in the same room without making any of the mistakes which he subsequently made, because none but coloured objects which he could readily recognize were shown to him. This is an example of the necessity of a practical knowledge of colour blindness in an examiner.

On account of the arrangement of signals by sea and land it is necessary that persons employed in the marine and railway services should be able to recognize and distinguish between the standard red, green, and white lights in all conditions in which they are likely to be placed. An engine driver or sailor has to name a coloured light when he sees it, not to match it. He has to say to himself, "This is a red light, therefore there is danger"; and this is practically the same as if he made the observation out loud. Therefore, from the very commencement we have colour names introduced, and it is impossible to exclude them. The engine-driver is told that red is a "danger" signal, green a "caution" signal, and white an "all right" signal. Therefore it is absolutely necessary that he should know the meaning of these colour names. A test should be such as to make it impossible for the examinee to be coached through it. This is one of the most important requirements of a test for colour blindness, and one that is rarely fulfilled. Nearly every one of the tests in general use will fail on this account.

A test should be one which can be carried out as rapidly as is possible with absolute efficiency; of two equally efficient tests the one which takes the least time must be selected. A test, therefore, should have no unnecessary details which, though of theoretical interest, are not concerned with the object in hand. The test should be made as easy and as little complicated for the examiner as possible.

Persons to be Excluded.

We wish to exclude all those individuals who are included in the following three classes: (1) Those who see three or less colours in the spectrum; (2) those who, whilst being able to perceive a greater number of colours than three, have the red end of the spectrum shortened to a degree incompatible with their recognition of a red light at a distance of two miles; (3) those who are unable to distinguish between the red, green, and white lights at the normal distance through defect or insensitiveness of the cerebro-retinal apparatus when the image on the retina is diminished in size.

I will now explain why these three classes of persons should be excluded. The first class includes the trichromic, the dichromic, and the totally colour blind, in accordance with the facts previously stated. The trichromic never, in ordinary circumstances, mistake green for red, but confuse yellow with green or red. Colour is a feeble quality of objects to them, and nervousness or excitement may reduce them to the condition of the dichromic. The dichromic are liable to mistake a green light for red and vice versa. It is very important that persons belonging to the second class should be excluded, and yet none of the ordinarily used tests detect them. The rays of red at the extreme left of the spectrum are the most penetrating, as may be seen by looking at a light or the sun on a foggy day, or through several thicknesses of neutral glass. It is chiefly by these rays that we recognize a red light at a distance;

and it is therefore of greater importance that a sailor or engine-driver should be able to perceive them. The third class contains persons who are able to distinguish colours easily when they are close to, but fail to distinguish them at a distance owing to the nerve fibres supplying the central portion of the retina being impaired. As a light at a distance occupies the central portion of the visual field it is essential that the corresponding portion of the retina should be normal. There are cases of central scotoma for colours with perfect form vision; these would, therefore, not be detected by the test for visual acuity. This class also includes those who, without having a scotoma, are unable to distinguish between colours at the normal distance when the image on the retina is diminished in size.

The lantern shown has been constructed conformably with the requirements and facts of colour blindness. All the facts of colour blindness have been considered in constructing the lantern.

Objections to other Tests for Colour Blindness.

The tests which have been proposed for colour blindness are very numerous, but some are so defective that it is rare to detect a single colour-blind person with them. I have, for instance, tested men whom I knew to be colour blind with certain lanterns, with the result that not a single one was detected. In these so-called tests all the requirements of a test and facts of colour blindness have been neglected. I must, however, refer to three tests constructed by exceptionally able men, each with considerable knowledge of the subject. I refer to the tests of Professor Holmgren, Professor Stilling, and Professor Nagel.

All these tests can be passed at the first attempt and without coaching by certain dangerously colour-blind persons, chiefly varieties not known to the inventors; but the chief defect of each is that it is very easy to coach a colour-blind person to pass it. The surgeon to one of our largest railway companies told me that when they used Holmgren's test they rejected 1 man in 300, but with my lantern 12 in the same number. All these three tests are much better tests when the persons to be examined have not seen them before. A colour-blind man may make only one mistake; say, for instance, as in a case I examined the other day with Nagel's test (last edition), he passes the test perfectly with the exception of one mistake, that of calling a grey on one card, green. All he has to do is to look for some distinguishing mark on this card in order to go through the test with the ease and certainty of a normal-sighted person. It is the same with Stilling's letters, he has only to note the letter which he was not able to read and the appearance of the card. A normal-sighted man or woman would readily help him. The confusion of green and grey does not appeal to the average man as a serious defect, especially when he sees his friend go through the rest of the test perfectly. He says to himself, "I suppose he sees a tinge of green in that grey."

The same man would rightly regard it as a most iniquitous proceeding to endeavour to coach his friend through a test when he had seen him mistake a red for a green light.

Holmgren's test rejects a large number of normal-sighted persons, as may be seen by the reports of the Board of Trade; about 50 per cent. of those who appeal are found to be normal sighted and to have been rejected wrongly.

REFERENCES.

[1] *Journ. of Physiol.*, vol. xli, p. 274. [2] *Trans. Ophth. Soc.*, 1902, p. 300. [3] *Journ. of Physiol.*, vol, xli, p. 269. [4] BRITISH MEDICAL JOURNAL, 1910, p. 556. [5] *Journ. of Physiol.*, xli, p. 266. [6] Nagel, *Physiol. des Menschen*, vol. iii, p. 107.

THE French Medical Parliamentary Group, among its other activities, watches over the interests of the thermal and climatic stations of France. It has decided to take steps to secure speedy promulgation of the Governmental decree imposing a "cure tax" on visitors. It is hoped that this will be put into force during the coming season, and that in this way funds will be collected in sufficient amount to enable improvements to be made that will attract foreigners. It has also been decided to found a chair for the instruction in hydrology and climatology in the University of Paris. It appears that the syndicates of the various spas are quite willing to bear the expense on the understanding that the chair is established solely in the general interests of the country.

THE HISTORY OF YELLOW FEVER IN WEST AFRICA.

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(Concluded from page 250.)

VII.

HISTORY OF YELLOW FEVER IN THE GOLD COAST COLONY.

There can be little doubt that yellow fever was as prevalent on the Gold Coast in the early part of the nineteenth century as in Sierra Leone.

From the report of Staff Surgeon Tidlie, quoted by Boyle, it appears that in 1819, out of 9 new arrivals, 3 died; in 1820, out of 4 new arrivals, 2 died; and in 1821, out of 7 new arrivals, 2 died, or two-thirds of all newcomers within twelve months of arrival. In the same period 15 of the African Company had died. It is most probable that this fatal disease which attacked the newcomers was here, as elsewhere in the tropics, yellow fever.

In a report by Bell, upon the garrison at Cape Coast Castle for 1824, it is stated that 217 deaths occurred in the regiments, exclusive of women and children.

Of the first detachment of Europeans, numbering 128, which arrived in April, 1823, only 1 survived; out of 109 women and children who had arrived since October, 1823, 70 had died.

It is stated in the report that the cause of death was bilious remittent fever, which usually terminated fatally on the third, fifth, or seventh day. Many of the cases were as "yellow as an orange." Boyle also mentions that an epidemic occurred in 1824, similar to that which took place in Freetown in 1823.

In 1824, out of a third detachment of 131 men, disembarked in March, 1824, the majority had died, after a few months, from "remittent fever and dysentery," and the same occurred with numerous subsequent detachments. Then comes the usual pause, commencing from the middle of the nineteenth century, probably due to the withdrawal of the garrison, and therefore of large bodies of non-immune new arrivals.

At a later date, following on the commercial development of the colony and the growth of the coast towns, yellow fever again began to attract attention.

As had happened, however, in other British West African colonies, the disease was very frequently not recognized, and was more often wrongly diagnosed.

Examination of the casebooks of the European hospitals in the principal seaports are of very great interest, for they show, in the first place, the difficulties which medical officers experienced in making a diagnosis; and, secondly, the unwillingness, as in Sierra Leone, on the part of the medical authority of the colony, to admit that yellow fever existed, in spite of the fact, as the careful records amply testify, of the patients presenting all the classical symptoms of fatal yellow fever. The stumbling-block here, as in numerous other instances, being occasioned by the confusion brought about by the use of the word "contagious," as applied to yellow fever.

Examination of the medical reports of the colony show that cases of yellow fever were recorded in the following years: 1895, several cases; 1897, 4 cases; 1902, 2 cases.

Whilst on the Gold Coast I examined the hospital casebooks of Cape Coast, Saltpond, Elmina, Axim, and Accra, and I find that yellow fever was diagnosed as such, and entered in the hospital casebooks at Cape Coast in 1897, 1902, and 1903; at Saltpond in 1897 and 1902; at Elmina in 1895; and at Accra in 1899.

In 1899 Dr. Elliott, who had had four years' experience in the Gold Coast, published in detail 3 cases of yellow fever which he attended at Saltpond.

He alludes to the reluctance prevalent against the diagnosis of yellow fever and the tendency to regard all fevers as malarial.

In 1901 Dr. S. O. Browne published a case of yellow fever which he attended at Saltpond.

In addition to these well-marked cases which were diagnosed at the time by the physicians in charge as