

COLOUR BLINDNESS

A COMPARISON OF DIFFERENT
METHODS OF TESTING COLOUR
BLINDNESS.

by

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Ph. D. Thesis presented 1923.

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Colour Blindness

Chapter I
INTRODUCTION

The study of colour-blindness has been somewhat retarded by the concomitant study of colour theories. The majority of investigators have started out unduly biased by their favourite theory and have examined colour-blinds from this prejudiced standpoint. The result is that a great deal of unnecessary confusion has gathered round this subject which has ultimately caused an obscuring of the real issues. Attempts have been made from time to time to get away from theories but, on the whole, these have proved futile, and the results achieved are only gradually permeating the literature of the subject. Yet even in the highest authoritative references to colour-blindness, it is amazing to find that a description of the defect is inevitably given along the lines of some particular theory, although it must be admitted that some authors take the precaution of inserting a note to the effect that such a description holds only if that theory be accepted.

Dr. ^{who revolts} ~~Hayes~~ ~~a revolt~~ against this method, states that "the general topic of colour-blindness is still in such a state which many psychologists consider to be most disgraceful to their science. One reason for this backward condition is undoubtedly to be found in the extreme complexity of the subject, and the enormous variations from case to case; but an even greater obstacle to the progress of knowledge has been the almost universal practice of studying and classifying cases under the domination of some preconceived colour-theory" (1).

The division of partial colour-blinds into Red-blind, Green-blind, and Violet-blind, following the Young-Helmholtz theory, is the most noted example of this falsifying of results. It is a more or less established fact that the so-called red-blind is also blind to green, and the so-called green-blind, blind to red, yet this terminology is still frequently applied to describe this colour anomaly. And what is more surprising is that in detailing tests useful in examining colour-blinds, the tests are vitiated by the theory lying behind them. The Holmgren wool test, a splendid one for dichromates, is still seemingly employed to select out the red-blinds from the green-blinds, and Holmgren's coloured plate showing the matches which the two types of colour-blinds make is often referred to as authoritative. We still find in so recent a book as Abney's Researches in Colour Vision, instructions similar to Holmgren's own. "If in the second test, he selects with purple only green and grey, or one of

(1) American Journal of Psychology, "The Colour Sensations of the Partially Colour Blind" 1911, Vol. 22, p. 369.

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then, he is completely Green-Blind. The red-blind never selects the colours taken by the green-blind, and vice versa." (1) This division of the colour-blinds into groups which are totally ~~contradictory to~~ the known facts has done much to spread false ideas of the defect, and progress has been considerably impeded. The wool test, as we shall see later, is excellent for diagnosis if we leave aside the implications on ^{which} it was based and reject the idea of a rigid classification.

at variance with

The Helmholtz theory has been merely cited as an illustration of a theory predominating facts. ~~and is not intended as an attempt to deny the theory~~ as an explanation of the various phenomena of colour defect. It has been modified since Young and Helmholtz first ~~formulated~~ it, but what must be emphasized is that its influence is clearly visible in the reports of many of the cases of dichromasy which have been investigated.

There is no intention

formulated



Run on

(1) Helmgren's own words. Quoted from a Translation by Jeffries in Colour Blindness: Its Dangers and Detection, p. 213.

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Clarendon

Brief Historical Survey

It is interesting to trace the illumination which has been gradually thrown upon this curious defect. As the experiments which are to be described later deal only with colour-blindness in its most common form, ~~namely~~ blindness to red and green, ^{only a brief} account will be ~~given~~ of blue-yellow blindness and of total colour-blindness.

Hal. → gives / 1. Red-Green Colour-Blindness

The earliest case on record seems to be that of Harris the shoemaker reported in 1777 by Mr. Huddart in a letter to the Rev. J. Priestley. Mr. Huddart writes "The account he (Harris) gave was this: that he had reason to believe other persons saw something in objects which he could not see; that their language seemed to mark qualities with confidence and precision which he could only guess at with hesitation, and frequently with error. His first suspicion of this arose when he was about four years old. Having by accident found in the street a child's stocking, he carried it to a neighbouring house to enquire for the owner. He observed the people called it a RED stocking though he did not understand why they gave it that denomination, as he himself thought it completely described by being called a stocking". This seemed to ~~be~~ a blindness to red, although Abney explains the defect as being one of green-blindness. "He observed also, that when young, other children could discern cherries on a tree by some pretended difference of colour, though he could only distinguish them from the leaves by their difference of size and shape. He observed also, that by means of this difference of colour, they could see the cherries at a greater distance than he could, though he could see other objects at as great a distance as they; that is, where the sight was not assisted by the colour." This seems to be the first scientific account of any abnormality in ^{colour} vision, although it must have been a defect common to the large majority of mankind; evidently it had existed undetected. This first account appears to be a description of a case of confusion of both red and green. It is interesting to note that Harris had two brothers who were similarly affected.

P.c. ital.

imply

2/1

always detected

fairly common

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In 1794 Dalton's description of his own case appeared and attracted considerable attention- so much so that Daltonism became for long the name by which colour-blindness was described. He first became acquainted with his defect by observing a pink geranium in candle-light. "The flower was pink, but it appeared to me almost an exact sky-blue by day. In candle-light, however, it was astonishingly changed, not having then any blue in it, but being what I called RED- a colour which forms a striking contrast to blue." He found on examination that his brother suffered from the same defect- showing as in the case of Harris the hereditary nature of the phenomenon. He further states that while

P.c. ital.

4.

he found that most people could distinguish six colours in the solar spectrum- his colour sensations were reduced to two, blue and yellow, or at the most three, blue, yellow, and purple. "My yellow comprehends the red, orange, yellow, and green of others; and my blue and purple coincide with theirs. That part of the image which others call red appears to me little more than a shade, or defect of light; after that, the orange, yellow, and green seem one colour, which descends pretty uniformly from an intense to a rare yellow, making what I should call different shades of yellow.

The difference between the green part and the blue part is very striking to my eye, they seem to be strongly contrasted. That between the blue and purple is much less so. The purple appears to be blue much darkened and condensed." This is an excellent description of a colour-blind. Dalton's defect was said to be due to an inability to see red, and Daltonism accordingly sometimes stands for this particular form of colour-blindness. Dalton attributed his defect to the fact that one of the humours of his eye, probably the vitreous humour, was a colour medium, probably some modification of blue. But an examination of his eye after death ~~disclaimed~~ any such theory.

did not support

Goethe in 1812 in his "Theory of Colours" (1) described this defect of colour-blindness in the following manner. "We will here advert to a very remarkable state in which the vision of many persons is found to be. As it presents a deviation from the ordinary mode of seeing colours, it may be classed under morbid impressions; but as it is consistent with itself, as it often occurs, may extend to several members of a family, and probably does not admit of cure, we may consider it as bordering only on the nosological cases." The two cases which Goethe was acquainted with saw white, grey, and black in the usual manner, They also saw yellow, red-yellow, and yellow-red, but they confused blue with pink, green with dark orange, green and brown. "These persons saw fewer colours than other people; hence the confusion of different colours."

the colour

The next cases reported are in 1816-17 by Dr. Nichols;- one of a boy aged eleven, the other of a man aged forty-nine. They are both reported as making the typical mistakes of the red-green colour-blind. "The colour I am most at a loss with is green; and in attempting to distinguish it from red, it is nearly guess-work. The different shades of red and green, I know not to which they belong; but, when they are before me, I see a difference in the shade. Though I see different shades in looking at a rainbow, I should say it was a mixture of yellow and blue - yellow in the centre and blue towards the edge."

In 1837 Seebeck gave a detailed analysis of the several cases which he had investigated. He found

(1) Translation by Eastlake.

he could divide his subjects into two classes based on the difference in the length of the spectrum which was visible to them. This led later to the classification of deuteranopes whose colour system is reduced to blue and yellow but who have a normal length of spectrum and protanopes who likewise see blue and yellow but whose spectrum is shortened at the red end. This is the most marked differentiation of the present day and has been generally accepted.

Sir John Herschel, however, was the first to put forward the dichromic explanation of colour blindness. He pointed out in his well-known article on "Light" written for the Encyclopedia Metropolitana that certain individuals could only distinguish two colours, blue and yellow. This seems to have been the first positive statement of the diagnosis of the defect- the former cases reported being merely descriptive. Herschel considered Dalton's case as coming under this category but this explanation was objected to by Prof. George Wilson. Wilson had taken particular interest in Dalton's case, and considered that Dalton did not show signs of blindness to red.

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(1)

C/D/

In Wilson's book (published in 1855)

Researches on Colour Blindness, he describes a large number of cases which he had personally studied. He discusses the various theories which had been postulated at that time and examines many of the phenomena which had been observed to accompany the defect. He points out, for example, that some Daltonians, as he calls them, can distinguish colours by other means than vision, "Slight differences in shape, accidental rough points, folds, wrinkles, and the like" and touch. "Wools, dyed with certain compounds are much harsher to the touch than those dyed with others; the mineral pigments, such as Prussian blue, or chromate of lead, in general producing rougher surfaces than the organic dyes, such as indigo. A wool dyed with a mineral might thus be distinguished by the touch, from one dyed with a vegetable red, although the colour-blind eye could detect no difference between their tints." An important step was taken by Wilson in testing the colour-blind. He employed a large number of samples of coloured wool, coloured paper and glasses, which the examinee arranged in groups- this is the method so splendidly adapted later by Holmgren in his investigations.

formulated

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Clerk Maxwell in the same year, in a communication to the Royal Society of Edinburgh, on "Experiments on Colour as Perceived by the Eye, with Remarks on Colour Blindness" seemed to agree with Prof. Wilson in regarding dichromic cases of colour blindness as not firmly established. "In experiments made with the pure spectrum, it appears that though the red appears much more obscure than the other colours, it is not invisible." He adopted a new method of experiment, by revolving colour discs and forming colour equations. The discs were slipped on a top or teetotum which consisted of a flat disc of tin plate and a vertical

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- (1) 1845, ~~557~~ Parag 3507.
- (2) ~~page~~ 116.

one hundred

axis of ivory. The axis passed through the centre of the disc, and the quantity of each colour exposed could be measured by a graduation on the rim of the disc, which was divided into 100 parts. "The principal use of the top is to obtain colour equations. These are got by producing, by two different combinations of colours, the same mixed tint. For this purpose there is another set of discs, half the diameter of the others, which lie above them, and by which the second combination of colours is formed." (1) Prof. Clerk Maxwell was an upholder of the theory first postulated by Thos. Young in 1801, and later adopted by Helmholtz. (2) This theory postulated to explain the general facts of colour vision, assumed there were three elementary colours corresponding to which there were three nerve fibres in the retina. The stimulation of the first aroused the sensation of red, of the second green, and of the third violet. In other words, the action of the long wave end of the spectrum affected the first, of the middle wave length, the second, and of the short wave end the third, but light of all kinds excited all three fibres though in varying degrees. In the modern exposition of the theory the nerve fibres have been replaced by three photochemical substances. Young's theory received scant attention until it was revived by Helmholtz, and later upheld by Clerk Maxwell. It was easy to assume in the case of colour blindness the simple explanation that absence of one of the fibres was sufficient to cause the defect. The absence of the red element caused an inability to see reds, lack of the green element a corresponding inability to see greens, and possibly a third case existed in which the lack of the third element gave rise to violet blindness. For a time the facts of colour blindness were strongly in favour of this classification. Colour-blinds were either red-blind, green-blind, or violet-blind. The red-blind were blind to red, but could see the remaining two colours, green and violet; the green-blind were blind to green, but could see red and violet. Maxwell's colour equations seemed to be consistent with this explanation.

adherent

At an early stage however, doubts began to arise and in an account by Dr. Pole of his own case (he was a red-green colour-blind) we find ^{that he} vigorously protesting against the prevailing beliefs, and giving a careful analysis of his own colour vision as evidence. He had been pronounced red-blind by Maxwell, and green-blind by Holmgren, who based his conclusions on his wool test. Dr. Pole repudiated both suggestions and claimed that the true solution was that he was blind to both colours. He based his evidence on a large array of facts. (4) First, the testimony of the

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- (1) Quoted from a letter written by Clerk Maxwell to Dr. G. Wilson, 1855.
- (2) See later reference, page 42.
- (3) Royal Society of London. 1856.
- (4) Transactions of the Royal Society of Edinburgh. 1893.

Vide infra p. 44

Proceedings

colour-blind themselves, who, whether they were acclaimed as red-blind or green-blind, unanimously asserted that their colour sensations were confined to blue and yellow.

Secondly, the study of acquired colour blindness.
Thirdly, colour blindness of one eye only.

Von Hippel's case, reported in 1880, attracted considerable attention. The subject, a young man who knew nothing of his defect, and who came to Von Hippel for spectacles to cure double vision was found to be colour-blind in one eye. His left eye was normal - his right was dichromic. His peripheral vision was tested and he was found to confuse red and green with yellow with the right eye. Further tests with Stilling's pseudo-isochromatic tables, Holmgren's wools, and Von Hippel's photometer confirmed the result. The colour sensations which the subject experienced with his right eye were blue and yellow. Von Hippel diagnosed this case as one of red-green blindness - with spectrum of normal length.

4. Holmgren diagnosed the same case and proclaimed it to be one of red-blindness with shortened spectrum. According to the Helmholtz theory as presented in the first edition of the Physiological Optics, 1867, he was able to see a greenish yellow and a blue tending to violet.

verified by Von Hippel retested his subject and substantiated his claim that the spectrum was not shortened and that the colours seen by the colour-blind eye and compared with the normal eye were blue and yellow. This was the first case of monocular vision reported verifying the dichromasy of colour blindness. ~~It attracted considerable attention.~~

Holmgren ultimately agreed that blue and yellow were the only colours seen, and von Kries, also a staunch supporter of the Young-Helmholtz theory, noted the result. They refused to admit, however, that such a case affected the validity of the theory but agreed that the application of it to explain dichromatism was no longer tenable.

Fourthly, the analogy of Peripheral Colour-Blindness.

The result was overwhelming evidence that the colour system of the colour blind was composed of blue and yellow. As Dr. Pole so justly remarks, "Not a fact of any kind to lead to the belief that the sensation is not yellow, but red or green. Nothing but a peculiar inference drawn empirically from a certain theory which, though commanding the greatest respect in regard to colour vision generally, does not in the least necessitate the form of application to colour-blindness under which this inference has been drawn." (I)

We find Helmholtz in 1892 referring to the former explanation as an "old attempt to explain colour-blindness." He adopted blue and yellow as the two fundamental sensations of the colour-blind, and declared that the absence of one of the elements no

Ibid.
(I) Pole, ~~Transactions of the Royal Society of Edinburgh.~~ 1893.

Ibid.

longer explained the defect. The three fundamental colours red, green, and violet, were changed as regards their degree of excitability. The sensation of yellow was said to arise from the fact that the red and the green elements were equally stimulated.

This solution was objected to by Hering (1) who had postulated a different theory to explain the facts. His theory of ^{colour} vision assumed six simple visual sensations, white, black, yellow, blue, red, and green. These can be arranged in pairs, white black, yellow blue, red green, which are complementary to each other, and at the same time antagonistic. The mixture of these six colours in different proportions gives rise to all the colour sensations.

From an examination of different cases, Hering concluded that the division into red and green blinds was a false one - that the red-blind was also blind to green. His explanation was, therefore, that the absence of the red green elements would meet the case, leaving blue and yellow, black and white as the sensations of the colour blind. The spectrum would appear in accordance with the known facts - yellow and blue with different degrees of saturation. "The red-green blind patients always point out pure yellow and blue correctly, and no two colours in which blue, on the one hand, and yellow, on the other, are prominent, are ever mistaken for each other." (2) Hering explained the two varieties of red-green colour blindness as due to differences in the macular pigmentation.

L offered

Hering alluded to the new explanation of colour blindness ~~proffered~~ by Helmholtz, ~~namely~~ that the red and green curves had become identical, and concluded "on the whole, that if the Young-Helmholtz theory had not been bequeathed to physiologists as a venerable legacy, it would certainly never have been drawn from the examination of the colour-blind." (3)

The results of these two great theories have been that partially colour-blinds have been divided into classes - three classes by the advocates of Helmholtz, red, green and violet - two classes by the advocates of Hering, red-green blindness and blue-yellow blindness.

von Kries suggested the terms deuteranopes and protanopes to mark off the different types exclusive of any particular theory. The deuteranopes are those whose colour system is reduced to yellow and blue but who see colour throughout the whole length of the spectrum; the protanopes are those whose colour system is reduced to yellow and blue, but whose spectrum is shortened at the red end. In this second type the point of maximum brightness has been found to be shifted towards the green; in other words, they show the Purkinje phenomenon in ordinary light. Dr/ Rivers suggested the two terms photerythrous and scoterythrous (4) to de-

(1) An Essay towards the Explanation of Colour Blindness by the Theory of Opposite Colours.

(2) From a translation by Pole - ~~Phil Mag~~ 1893. Vol. 30

(3) ~~Ibid.~~ p. 194.

(4) ~~Schäffer's~~ Physiology text-book of Physiology. "Vision", in Schäffer's

Philosophical Magazine

scribe the two groups. He adopted the terms from Dr Verral of Trinity College, Cambridge, but unfortunately they have not met with general acceptance.

The two however are not found sufficient to describe all cases which show deviation from the normal. Seebeck, even in 1837, found certain cases which he was reluctant to classify as colour-blinds, and yet which showed signs of abnormality. They seemed to be weak cases of colour vision. It was not until 1881, when Rayleigh reported the results of his experiments, (1) that these cases were understood. Rayleigh found that a number of individuals with otherwise normal vision were unequally sensitive to red and green. In equating red and green equal to yellow (since known as the Rayleigh equation) some were found to require far more red than the normal, others required an excess of green. von Kries, in an extensive series of experiments, applied the name "anomalous trichromates" to them, and this term has gained universal currency. The anomalous trichromates see the three fundamental colours of Helmholtz in the spectrum but are unequally sensitive to red and green. Guttman advocated the terms 'red-weak' and 'green-weak' and distinguished seven characteristic symptoms which they manifested: small area and low intensity, a decidedly heightened colour contrast, difficulty in comparing colour tones of unequal brightness or saturation, and quick fatigue to colour stimuli. These seven inter-related symptoms form a complex state so that the abnormality varies considerably with different individuals.

Describing

a reduced sensitivity to colour stimuli especially when the stimulus is of short duration

Nagel rejects the term colour-weakness as being too wide and prefers the term anomalous trichromatism. It is customary to divide these anomalous trichromates into two groups corresponding to the two groups of dichromatism- deuteranomalous trichromates whose sensitiveness to green is below normal and protanomalous trichromates whose sensitiveness to red is below normal.

Research on colour-blinds since have been carried out in the hope of solving various problems, or are merely descriptive. The advocates of Helmholtz, such as Abney, have adopted new methods of studying the defect, all with a view of proving the favoured theory. It is interesting to note that Abney's luminosity test was adopted by the Board of Trade in 1912. The ~~up~~ holders of Hering have been equally assiduous in supporting their claims. New theories have arisen each claiming ^{to be} a better interpretation of the facts and a number of them have explained colour-blindness as a regression ~~back~~ to a previous stage of colour evolution.

adherents

One large advance which has been made has been the devising of tests for practical use. It has long been recognized that red-green colour-blindness may be a danger to the community in such occupations where the distinction between red and green is of paramount importance, and accidents on sea and rail have often been attributed, and in some cases traced, to this cause.

One of the largest contributors of tests (1) Nature, 1881. 25, 64-66,

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devised to pick out dangerous colour blinds has been Professor Edridge-Green. In his capacity as Examiner to the Board of Trade, he has examined a large number of candidates and has embodied his results in numerous publications. He rejects the simple classification of colour-blinds into dichromates, for he finds many grades and varieties of severity of the defect. The ^{INDIVIDUAL} normal vision can see Δ colours in the spectrum (sometimes Δ) and he accordingly is ranked as a unit (or a ^{seven} unit). According to the number of colours he can perceive ^{an individual} is a ~~1, 2, 3, 2~~ or a Δ unit. The two extreme ends of the spectrum are the first to be seen red and violet - the dichromate therefore can see red and violet. But Edridge-Green points out that ~~it is not really red and violet which he sees but blue and yellow.~~ Yellow is the centre colour of the red unit and blue the centre colour of the violet unit. The three unit ~~sees red and violet,~~ and a third colour, green, makes its appearance. The ^{four} unit can see red, yellow, green, and violet, the Δ unit, red, yellow, green, blue, and violet, and the normal ^{six} unit, red, orange, yellow, green, blue, and violet. The ^{two} unit ~~corresponds to the dichromate and he may have a normal spectrum or a shortened spectrum;~~ the ^{three} Δ and ^{two} Δ units are anomalous trichromates. This theory is interesting in showing the Grading deterioration of the colour sense from the Δ or ^{seven} normal unit to the ^{two} Δ , ^{one} Δ , or none unit class which represents total colour-blindness.

Edridge-Green bases his results, published in Colour Blindness and Colour Perception, on an examination of ~~10~~ cases. He has devised a pocket wool test; a classification test; a colour perception Spectrometer, and constructed a lantern specially devised to detect dangerous colour-blinds. He ~~rejects~~ ^{attaches} great importance to the colour names which the colour-blind employ. The dangerous colour-blinds, according to Edridge-Green are:

1. Those who see ^{three} Δ or less colours in the spectrum.
2. Those who, whilst being able to perceive a greater number of colours than ^{three} Δ , 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 ⁽¹⁾ (i.e.) those of central scotoma.)

Collins who, in 1918, ⁽²⁾ carried out an examination of a thousand persons with the Edridge-Green Lantern, confirms these results and marks as dangerously colour-blind the three classes enumerated above. His final judgment is, that the dangerous colour-blinds can be satisfactorily discovered by means of the Edridge-Green Lantern.

(1) Hunterian Lectures, ^{on Colour Vision and Colour Blindness,} p. 41.
 (2) Public Health Bulletin No. 92, Wash. Govt. Printing Office, 1918.

six/seven

five

(* In addition to these classes, there are others distinguished by shortening either ^{of the red or} the violet end of the spectrum

6

five, four, three, two, one
 as the colour perception improves, the red and violet will invade the grey and approach each other. When the whole of the grey has disappeared, the colours seen will not ^{be} red and violet but ~~orange~~

a hundred and sixteen

11.

Professor Hayes, in the American Journal of Psychology, 1911, gives the results of a series of experiments which he carried out with the intention of showing that dichromatism should be regarded as a limiting case. He asserts that there are mild cases of colour-blindness who can see red or green under favourable conditions- that there are protanopes who can see some greens, and deuteranopes who can see some reds. His main results are based on a case of monocular protanopia, and he gives convincing evidence that his subject in certain experiments could distinguish green. "If we grant that Von Hippel's patient saw only blue and yellow, must we not also grant that Miss G. S. sees green, blue, and yellow? This assumption is supported by abundant indications that many of our colour-blinds possess a similar sensation to red or to green. In confirmation he adds, in a footnote, that Nagel reported that, among thirty dichromates, both protanopes and deuteranopes, examined by him, none failed to recognize various shades of red when a sufficiently large area of the retina was stimulated. Professor Hayes' ultimate conclusion is, that there is a large mass of evidence which points out the presence of sensations of red or green in the colour systems of the partially colour-blind. He asserts that a strict classification of colour defectives is necessarily artificial, and that there are numerous transitional cases between normality and total colour-blindness. Dichromasy should be regarded as an extreme variation, and not as a typical condition of the partially colour-blind.

2. Blue - Yellow Blindness

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Chapter II

Colours Theories with Special Reference to Colour-Blindness

Theories of Colour-Vision in so far as they Explain Colour-Blindness.

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In all theories it seems more or less agreed that colour-blindness is a reduction system of normal colour vision. Again and again it has been found that equations valid for the normal eye are equally valid for the colour-blind eye. This points to the conclusion that the dichromate lacks something which the normal eye has - but has nothing which the normal eye does not possess.

Left hand side
Colours Theories
and Colour
Blindness

Right hand side
Young Helmholtz
Theory

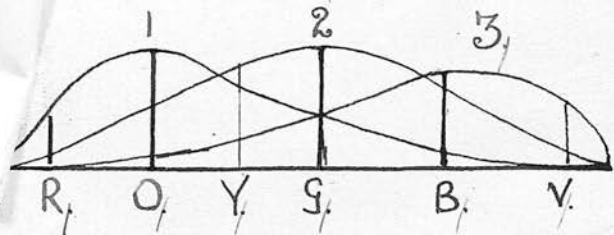
Young - Helmholtz Theory (Ital)

(The Three Components Theory)

This theory first propounded in 1801 by Thos. Young and resuscitated in 1860 by Helmholtz is one of the most important.

The colour sensations are reduced to three fundamental colours, red, green, and violet, corresponding to which there are three nerve fibres in the retina - now replaced by three photochemical substances. Stimulation of the first fibre produces red, of the second, green, and of the third, violet. But homogeneous light excites all three in different proportions according to the wave lengths.

Figure I



(after Helmholtz)

Fig I

The three curves represent the proportional stimulation of each set of nerve fibres with pure light (1) is red nerve fibre. (2) green. (3) violet.

<u>Red.</u>	Stimulates strongly the red, less the other two.	<u>Sensation is Red.</u>
<u>Yellow.</u>	Stimulates moderately the Red and Green, feebly the Violet.	<u>Sensation is Yellow.</u>
<u>Green.</u>	Stimulates strongly the Green, much less the other two.	<u>Sensation is Green.</u>
<u>Blue.</u>	Stimulates moderately the Green and Violet, feebly the Red.	<u>Sensation is Blue.</u>
<u>Violet.</u>	Stimulates strongly the Violet, feebly the other two.	<u>Sensation is Violet.</u>

q.c.
l.c.
l.c.
l.c.
l.c.

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Chapter II

Colours Theories with Special Reference to Colours-Blindness/

(Small Caps)

Theories of Colour-Vision in so far as they Explain Colour-Blindness.

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Figure I

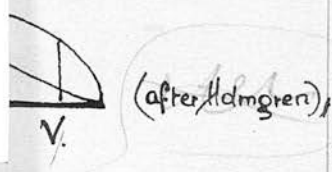
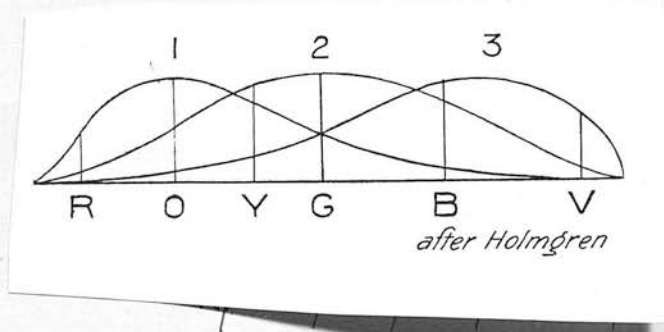


Fig. I

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- Blue. Stimulates moderately the Green and Violet, feebly the Red. Sensation is Blue.
- Violet. Stimulates strongly the Violet, feebly the other two. Sensation is Violet.

l.c.
l.c.
l.c.
l.c.
l.c.

✓

Equally strong stimulation of all the fibres gives the sensation of white. Absence of stimulation gives the sensation of black.

The red now adopted is a carmine red (a red bluer than the extreme red of the spectrum) the green, a yellowish green, and the third element an ultramarine blue.

as primitive

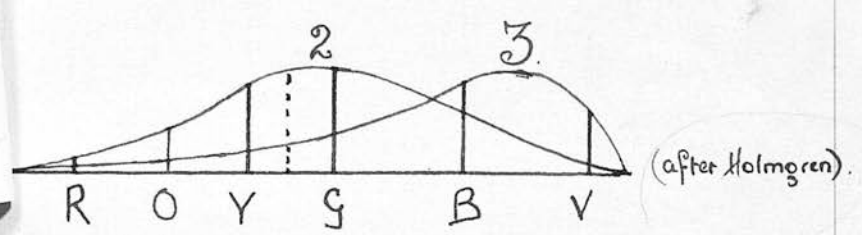
Colour-Blindness

According to this theory the partial colour-blinds may be divided into the following classes:

1. Partial colour-blindness in which one of the three fundamental sensations is completely absent.
 - A. Red-blindness.
 - B. Green-blindness.
 - C. Violet-blindness.
2. Incomplete colour-blindness where one or all of the three fundamental elements are inferior in excitability.

Red-blindness

~~Figure II~~



(after Holmgren)

Fig. II

In red-blindness, the colour sensations of the individual are reduced to green and violet.

- Red. Appears as a saturated green of very feeble intensity.
 - Feeble Red. Does not sufficiently stimulate any of the fibres; therefore it appears black.
 - Yellow. Appears as a saturated green and intensely luminous, and as it constitutes the precisely saturated and very intense shade of that colour, it can be understood how the red-blind select the name of that colour, and call all those tints that are properly speaking green, yellow.
 - Green. Appears as a more intense but whitish shade of the same colour as yellow and red.
 - White. Is composed of the two elementary colours and appears blue-grey to normal vision.
- The colours between green and blue are seen therefore as grey. The rest of the spectrum appears blue or violet.

(1) Quoted by Holmgren. See Smithsonian Report, 1877.

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Red-blindness

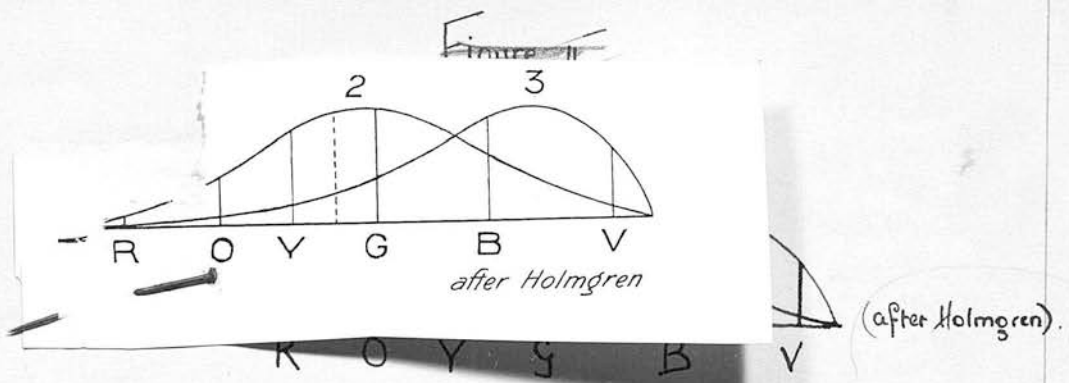


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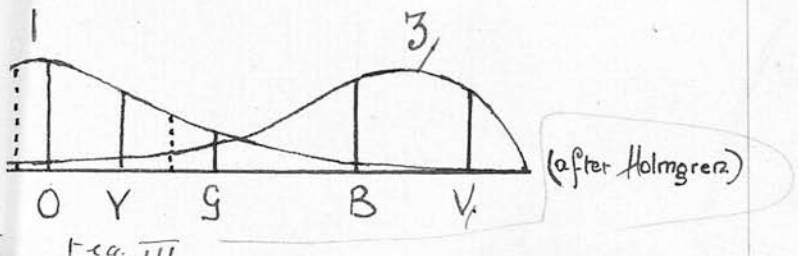
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 - Green. Appears as a more intense but whitish shade of the same colour as yellow and red.
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Green-Blind

~~Figure III~~



In the case of the absence of the green element - the colour system is derived from the other two elements, Red and Violet. e/c.

- Red. Stimulates strongly red fibre and faintly the violet one. It appears to the green-blind as a strongly saturated red.
- Orange. Also a saturated red.
- Yellow. A more intensely luminous red than spectral red.
- Green. Is the grey of the colour-blind because it is composed of equal parts of red and violet.
- Blue. Is an intense violet.

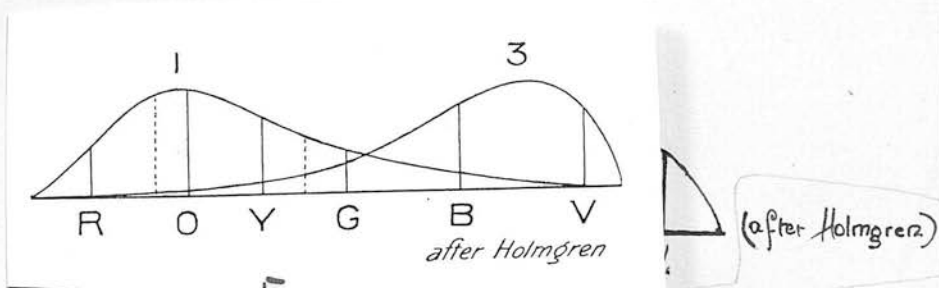
12

This explanation of the two common types of red and green blindness was accepted for some time, and experiments which were carried out seemed to fit in with the theoretical hypotheses. The first objection to the theory as an explanation of colour-blindness was raised by Edmund Rose, who from his own personal experience, based on observation of colour-blinds, found the theory to be incompatible with fact. He found that both types of colour-blinds declared their fundamental sensations to be yellow and blue. Helmholtz noted Rose's results, but thought they were insufficient to alter his theory although he admitted that "in the case of congenital colour-blindness, it might well be imagined that the activity of the nerve fibres might not be removed, but that the intensity curves of the three kinds of light-sensitive elements might change, whereby a much greater variability in the effect of objective colours on the eye might arise." (1)

John Aitken, F.R.S., of Falkirk, in a paper on colour sensation (2), suggested that "the nerves might be so constructed that the red nerves might be sensitive to all the rays to which the ~~red~~ nerves are sensitive" so that, both nerves being excited by either red or green rays, "the sensation produced would be what we call yellow."

(1) Handbuch der Physiologischen Optik, 2nd Edition.
 (2) Scottish Society of Arts, 1892. Quoted from Pole's Article in Transactions of the Royal Society of Edinburgh, 1893.

Figure III



In the case of the ^{the} absence of the green element - the colour system is derived from the other two elements, Red and Violet. e/c.

- Red. Stimulates strongly red fibre and faintly the violet one. It appears to the green-blind as a strongly saturated red.
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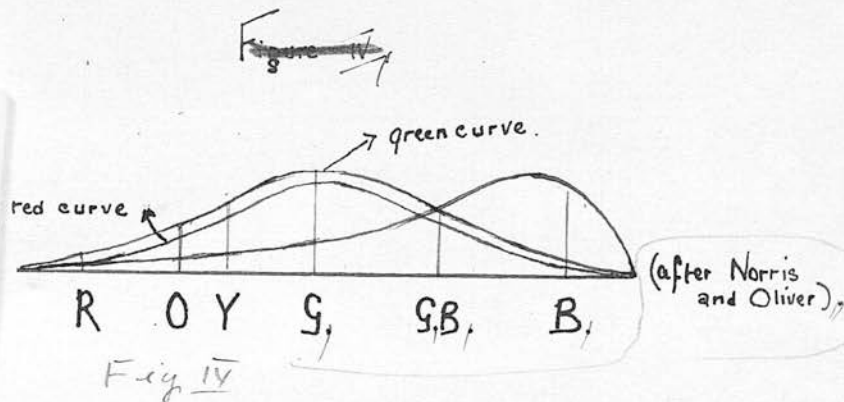
Green

Leber in 1873 in an independent publication confirmed these results asserting that yellow was the sensation of the dichromic, because the red and green fibres were equally stimulated.

This explanation was later adopted by Fick, and König in 1888 expounded the same view at a meeting of the British Association in Birmingham.

Helmholtz in 1892 in the second edition of his Physiological Optics confirms this new modification of the theory, and further points out that the former division into red and green blinds is no longer advisable. "One of the greatest stones of stumbling for years past has been the division, consequent on the "old" explanation, of dichromic patients into the two theoretically distinct classes of "red-blind" and "green-blind." It is obvious that this division naturally disappears when the old explanation is abandoned; but Helmholtz takes pains to show geometrically that his new theory gives no place for such a division. And he, moreover, expresses the opinion that such a division does not seem to have been fully justified by observation." (1)

According to this new explanation red-blindness would be explained thus:



The red element has become equal to the green element.

The spectrum consists of yellow and blue but the yellow begins not in the red but in the orange. Blue-green excites all three elements and therefore is seen as grey; the neutral band therefore lies towards the violet end of the spectrum. The red and green curves equally excited, give sensations of yellow.

similar in sensitivity

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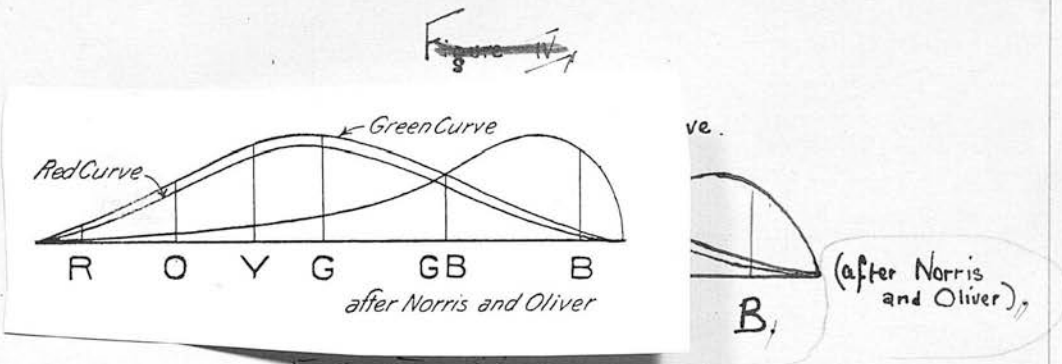


Fig. IV

The red element has become equal to the green element.

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Figure V₁

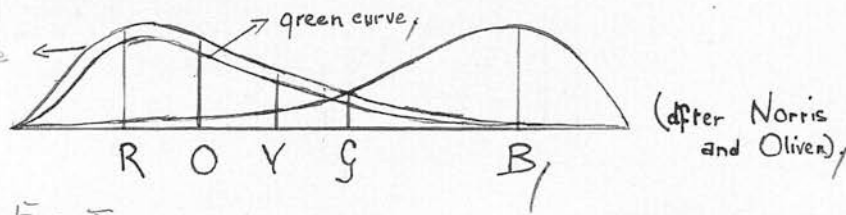


Fig. V

The green element has become equal to the red element.

The spectrum is seen as shades of yellow and blue.

The green excites all three elements and therefore will be seen as grey. (Note the difference from the case above where the neutral band lay in blue-green.)

Again Red and Blue are stimulated equally at this point, giving the purple of the normal eye, therefore, purple is equal to grey, which in turn is seen as green.

Similar in sensitivity

e/c.

Light-
reaction
re Dougall's
Theory

2. McDougall's Theory (Hald)

McDougall has modified this theory. (1) He accepts the three fundamental colours, Red, Green and Blue, but adds ~~fourth~~ an independent mechanism for white having its retinal seat in the rods. He bases his theories firstly on a large number of observations carried out on the fading and "mutual inhibitions" of visual images, and secondly, he demonstrated that the hypothesis of a special black-exciting process is unnecessary, such as is postulated with Hering's theory. McDougall, therefore, adopts the duplicity theory of von Kries. He writes "von Kries has brought together evidence that makes it appear in the highest degree probable that the rods are the retinal elements of an independent white apparatus, which functions alone in the normal eye when affected by light of low intensity only, and in the monochromatic eye. This view of the functions of the rods had been suggested thirty years before to Max Schultze by his studies in comparative histology. This hypothesis of an independent white-exciting function of the rods must then be taken up into and incorporated with Young's theory, and then, when this is done the difficulty in representing the development of the visual processes in terms of this theory at once fades away." (2)

In the first place, argues

McDougall thus assumes a separate retino-cerebral apparatus for each of the three photopic colours of red, green and blue, and for the scotopic white element. He further assumes that each eye has its

(1) See Mind, N.S., Vol. 10, 1901.

(2) Ibid., p. 211-2.



Green-Blind

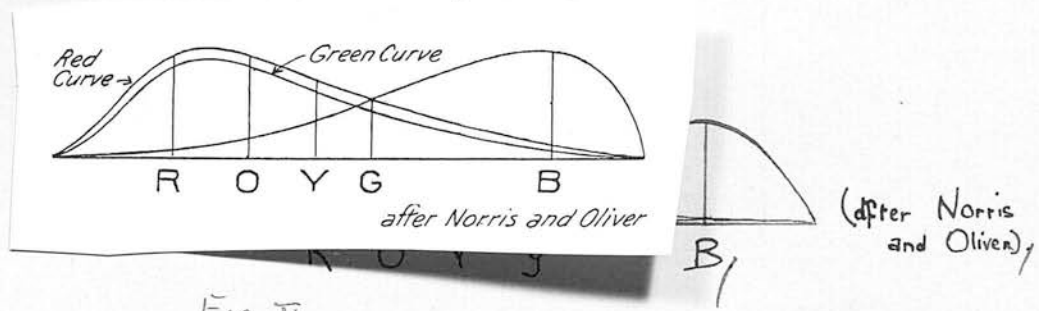


Fig. V

The green element has become equal to the red element.

The spectrum is seen as shades of yellow and blue.

The green excites all three elements and therefore will be seen as grey. (Note the difference from the case above where the neutral band lay in blue-green.)

Again Red and Blue are stimulated equally at this point, giving the purple of the normal eye, therefore, purple is equal to grey, which in turn is seen as green.

Similar in sensitivity

e/c.

Light-
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Mc Dougall's
Theory

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 (2) Ibid., p. 211-2.

✓

own set of four such systems quite independent of the other. *The sensation of black is experienced when "complete fading" occurs and the visual cortex is at rest.*

13
Colour-Blindness. His explanation of colour-blindness follows from his theory of the evolution of the colour sense. Vision begins first, and exists in the lower animals, as monochromatic, varying only in brightness, and similar to our white or grey sensation. The first stage is the differentiation of the rays of light of the warm and cold ends of the spectrum. The cold rays in addition to setting free a white exciting substance would begin to set free "a substance that by the excitement of a concurrently differentiated retino-cerebral apparatus would add the sensation of blue to that of white; (1) similarly, the warm rays would effect a sensation of yellow. If mixed light stimulates the retina at this stage of development, all three systems will be excited. McDougall points out that it would be advantageous for the yellow and blue to fuse and form white and thereby reinforce the sensation of white caused by the excitation of the older apparatus. If yellow and blue fused to give a new sensation- the result of stimulation by mixed light would be a sensation composed of this new colour added to white- the pure sensation of white would then be lost for ever. All that would be possible would be yellow and blue and a yellowish blue probably.

The peripheral zone of the retina is still a relic of this primitive stage of monochromatic vision while the totally colour-blind are cases of a total reversion to "this remote ancestral condition."

The middle zone of the retina shows the second stage of differentiation in which yellow, blue, and white are all that are experienced, and the "frequent cases of bichromatic vision, in which yellow and blue and white seem to be the only sensations that can be aroused by stimulation of the retina, are cases of reversion to or arrested development in this more recent ancestral condition."

otherwise
McDougall, tracing the stage of evolution further, shows how for advantageous reasons, the differentiation would next proceed in the region of the yellow, giving rise to the sensations of red and green. These when stimulated simultaneously fuse in a yellow sensation; ~~the~~ the primitive white and the original yellow will be lost. As the red and green developed (and the development takes place from the fovea centralis outwards) yellow would disappear from the central region just as white itself no longer is found in the fovea. The white, however, remains in the other parts of the retina, probably because it assists vision in dim illumination. e/c.

This view, McDougall claims, especially when it is remembered that the rods are the end organs for the white apparatus, brings the Young theory, as he prefers to call it, into harmony with all the known facts, especially with regard to those of colour-blindness.

(1) ibid.

Right-headed

3. Hering Theory

(Hals)

(The Opponent Colours Theory,)

The Hering theory rivals the Young- Helmholtz in importance. Hering bases his theory on six elementary colours, elementary so far as introspection can discover. These are Red, Green, Yellow, Blue, White, Black. Red, green, yellow, and blue are the toned or bright (bunte) colours; white and black are the toneless colours. The toneless colours can be arranged in a graded series from the most intense white to the deepest black, forming, when combined in different proportions, various shades of grey; the toned colours can be arranged in a circular series with the four elementary colours forming four divisions. The colours, therefore, can be arranged in two pairs, yellow and blue forming one pair; red and green the other. We cannot pass directly from yellow to blue, we have to pass through green, a member of the other pair. In other words we cannot have a reddish green nor a yellowish blue. The yellow may combine with the red and form a new compound colour in which both elements are recognizable, or with green and form a yellow-green, but it cannot combine with the other member of the same pair, blue, and form a compound colour. For no matter what proportions of yellow and blue are combined, no new hue will appear; the mixture will appear either yellow or blue except where the two colours are neutralized, and then neither colour will be recognizable. These complementary colours forming a pair are, therefore, opposed or antagonistic colours.

Corresponding to these two pairs of antagonistic colours, there exist two elementary systems somewhere in the retino-cerebral apparatus, one of which gives rise to red and green, the other to yellow and blue. A third system gives the colourless sensations of black and white. The physiological action of a colour and its complementary is antagonistic. Each of the substances can undergo a building up or an anabolic process, and a breaking down or a katabolic process.

Red is caused by Katabolism in the red-green apparatus

Orange	''	{ Katabolism	''	red-green	''
		{ Katabolism	''	yellow-blue	''
Yellow	''	Katabolism	''	yellow-blue	''
Green	''	Anabolism	''	red-green	''
Blue	''	Anabolism	''	yellow-blue	''
Violet	''	{ Katabolism	''	red-green	''
		{ Anabolism	''	yellow-blue	''
White	''	Katabolism	''	white-black	''
Black	''	Anabolism	''	white-black	''

In most kinds of stimulation all three systems are set in action and the resultant sensation depends upon the relative amount of excitation of each substance. Thus orange is composed of red and yellow, and in Hering's terminology we should say that orange has a red "value" (valenz) and a yellow "value". Further all spectral colours contain white so that each colour has a white "value" in addition. This white is most

Indent
space
top and
bottom

(is not) distinct in the yellow and the yellow-green. All coloured lights except the four primary colours have therefore three values corresponding to their action on the three different substances. All rays from the extreme red end of the spectrum have in addition an effect on the yellow process as far as the pure or fundamental green. These rays are said to have a yellow value. All rays from the green to the violet end of the spectrum affect the blue process - they are said to have a blue value. The yellow is so weak at the beginning of the spectrum that the red overpowers it, and the ultimate sensation experienced is red -- the yellow is invisible to the normal eye. The four divisions of the spectrum may thus be represented:

First	1st division	contains	Red and Yellow and White.
	Pure Yellow	"	Yellow and White.
Second	2nd division	"	Yellow and Green and White.
	Pure Green	"	Green and White.
Third	3rd division	"	Green and Blue and White.
	Pure Blue	"	Blue and White.
Fourth	4th division	"	Blue and Red and White.

The spectrum, therefore, can be divided according to the excitation of the yellow-blue substances and we get yellow in the first half, blue in the second half; these two divided by pure green with a white value.

Hering ~~is a~~ ^{theory of the} believer in the "specific brightness of colours". Certain colours possess an inherent brightness or darkness of their own. The brightness of a colour sensation depends, therefore, on two causes (1) on the inherent brightness (or darkness) of the colour itself. (2) on the amount of excitation of the white-black process. The warm colours, red and yellow possess an inherent brightness [the cold colours, green and blue possess an inherent darkness (Eigendunkelheit)].

substituted for his former explanation of luminosity as wholly due to the black-white component.

(Eigenthelligkeit)

"A toned colour may generally be regarded as made up of four fundamental components, two toned and two tone-free (white and black). It is only in colours of the tone of a primary that a single toned component is present. In any red-yellow colour, eg. orange, we have, therefore, to distinguish three fundamental components (red, yellow, white) and one dark (black); in any green-blue, on the other hand, three dark (green, blue, black) and one bright (white). The red-blue and the green-yellow colours would contain two bright and two dark fundamental components.

"From what has been said the following rules can be deduced: n

"If two colours of equal tone and equal purity differ in brightness, this is due to a difference in their black-white components.

"Two colours differing in tone may, notwithstanding equal degrees of purity and equality as regards their black-white components, differ in brightness.

"With equality of conditions as to the black-white components, a yellow, a red, or a yellow-red colour is so much the brighter, a blue, a green, or a blue-green so much the darker, the more distinct the colour tone in comparison with the black-white components."

(1) Quoted from Greenwood ^{special} Physiology of the Senses. (1)

Colour-Blindness

Red-green blindness is due to the absence of the red-green substance. As we have already seen, if the red and green elements are removed, the sensations of yellow, blue, black and white still remain. The sensations of the red-green colour blinds are accordingly yellow and blue. Red, orange, yellow and some of the green will appear as yellows of different degrees of saturation; part of the green and blue and violet will appear as blues of different degrees of saturation. The pure green will be colourless.

The peripheral zone of the retina according to Hering shows the same conditions as in colour-blindness. In the outermost zone of the retina as in total colour-blindness, only the white-black substance is present. Red-green blindness corresponds to the middle zone of the retina where yellow and blue are the only colours experienced. The investigations which Hess⁽¹⁾ has carried out along these lines have been strong confirmation of Hering's views.

Hering's greatest difficulty has been to account for the two varieties of red-green colour-blindness. Undoubtedly both types see yellow and blue in the spectrum, but they vary in regard to what part of the spectrum appears the brightest yellow. Hering explained this difference as due to differences of pigmentation of the macula and lens, and ~~offered~~ offered the same explanation to account for the differences in normal vision of anomalous trichromates. The yellow pigment in the macula absorbs the warm end of the spectrum very little, is at its maximum in the yellow-green region^{and} diminishes in action towards the cold end of the spectrum.

Hering in 1888⁽²⁾ examined a number of cases and found he could divide them into two groups. One group matched spectral red with spectral blue in the ratio of 1.15:1. the other group in the ratio of 7 to 1. He found the position of pure green to differ in the two groups - the green requiring to be ~~longer~~ of greater wave-length in the case of the first group. In colourless mixtures of red and bluish-green, greenish yellow and violet, and yellow and blue, the first group required larger quantities of the shorter wave-length component. The first group was said to be relatively yellow-sighted, the second group relatively blue-sighted, based on their responsiveness to these colours, Hering examined two marked cases of individual variation in pigmentation - Professor Biedermann and Dr. Singer. Professor Biedermann with little macular pigmentation he termed relatively yellow-sighted, Dr. Singer with greater pigmentation he termed relatively blue-sighted. Hering therefore suggested that the two classes of red-green colour-blindness were extreme cases of yellow and blue-sightedness, combined with greater or lesser pigmentation of the macula. The protanopes or scoterythrous group would be regarded as relatively blue-sighted (or blue anomalous); the deuteranopes or photerythrous would be regarded as relatively yellow-sighted.

of greater wave-length

the distinction being based...

(1) Pflüger's Archiv, Vol. 71, p. 105, ~~§~~ seq.
(2) Lotos, 6th N.F. ~~112~~

15

If the explanation is correct, one would expect to find gradation cases - passing gradually from protanopia to deuteranopia - but such does seem to be the case. von Kries and Abney, by experimentation have shown that the basis of differentiation between scoterythrous and photerythrous cannot be a physical one. Tschernak, a staunch upholder of Hering's theory is also inclined to give up this explanation. (1) *adherent*

Dr. Rivers, however, states that the variations of pigmentation may be discontinuous; and in the absence of direct investigation of the question the existence of two distinct groups by no means destroys the validity of the proposed explanation. It seems probable to Hering that there is a relation between macular (and lens) pigmentation and development of the colour sense. In cases of red-green blindness, it seemed as if the group with more pigmentation (yellow-sighted or photerythrous) had a more highly developed blue-yellow sense, and Hering supposes that the shortening of the spectrum in the scoterythrous group may be due to weakness of the yellow sensation. (2) *up*

Ryft headline
4. Müller's Theory *Hals*

Müller is an exponent of the Hering theory and has suggested some modifications. (3) He accepts as fundamental the colours red, yellow, green and blue of Hering and the white-black apparatus. These four chromatic processes and the two achromatic processes are at the periphery; but in addition to these there are six central values. The red process excites the red, yellow and white values; the yellow process excites the yellow, green and white; the green process excites the green, blue, and black; the blue process excites the blue, red and black. The yellow process excites the red and the yellow processes, thereby exciting the red, green, yellow and white values. The red and green neutralise one another, leaving the sensation of yellow.

Müller substituted a reversible chemical process for Hering's antagonistic process of anabolism and katabolism.

Müller was dissatisfied with Hering's explanation of the two types of red-green colour-blindness and gives the following explanation.

"The red light of the spectrum he assumes, besides its effect on the red-green substance, may have also an effect on the yellow-blue substance, and it may even have two such effects - it may act upon it in the first place, directly, by producing out of the decomposition of the red-green substance some one or more of the constituents of the yellow material (with which, in the original form of the hypothesis, red light had nothing to do). The first type of the red-green blind - those formerly called red-blind - are totally lacking in the red-green substance; these are the

- (1) Tschernak, *Textbook of*
- (2) Article in Schäffer's *Physiology*, p. 1118-1119.
- (3) *Zeitschrift für Psychologie und Physiologie der Sinnesorgane*, 10, 1896;

*Ergebnisse der
 Physiologie,
 902.*

typical yellow-blue visioned. But the second type—those formerly called green-blind—see yellow in the place of both red and green for some totally different reason—either because the nerv^e fibres which conduct the retinal excitation are not of the normal constitution, or because some still other constituent which is usually found already prepared in the retina is now absent. In this fashion it will be seen that the so called red-blind lack all the indirect effect of the light of the spectrum upon the yellow-blue substance, while that indirect effect still persists for the green-blind." (1) Ladd-Franklin regards this explanation as complicated and far-fetched.

Right lead line

5.

Ladd - Franklin Theory

Stalk

(The Molecular Dissociation Theory)

This theory assumes that the colour sense in the earliest stage of its existence was ~~that of grey~~ only, which includes the whole range of colourless sensations. The sensation of grey is produced by the decomposition of a grey molecule. The decomposition of the molecule sets free a chemical substance which acts upon the retinal nerve endings and so a sensation is experienced. The molecule consists of a firm inner core to which is loosely attached an outer range of atoms. These atoms are "torn off" in decomposition and the sensation ensues. The cause of the "tearing off" of the atoms is the ether vibrations which are in the visible spectrum. The middle part of the spectrum has a more powerful effect on the atoms as is shown by the sensations of the totally colour-blind.

(restricted to

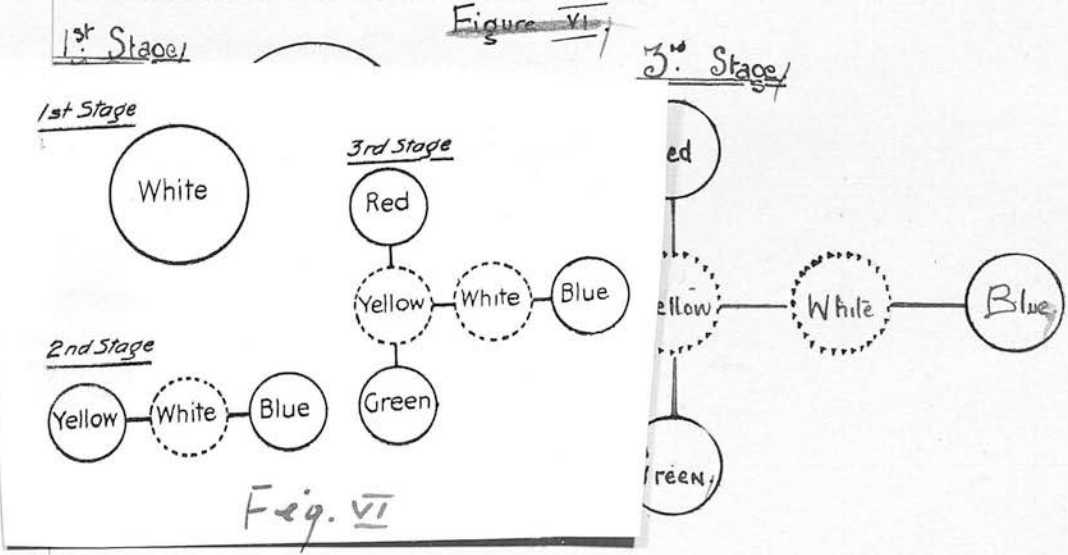
This grey substance exists both in the rods and in the cones. In the rods it still exists in an undifferentiated condition so that "it goes to pieces all at once under the influence of light of any kind." (2) In the cones a differentiation has taken place and decomposition takes place in different stages. But the complete decomposition of the molecules in both rods and cones excites sensations of white or grey. "For black, the theory supposes that, in the interest of a continuous field of view, objects which reflect no light at all upon the retina have correlated with them a definite non-light sensation—that of black." (3)

The colour molecule appears at the second stage of development. The outer range of atoms in the cones segregate into two groups having different vibration rates; "one fitted to be shaken to pieces by light from the warm end of the spectrum, and the other by light from the cold end of the spectrum." (4)

- (1) Psychological Review, Vol. 6, Article by C. Ladd-Franklin.
- (2) Psychological Review, Vol. 3. (3) ~~Ibid. Vol. 6.~~
- (3) Quoted from Woodworth, Psychology: A Study of Mental Life, p. 223.
- (4) Psychological Review, Vol. 6.



and the two sensations of yellow and blue are experienced: "in a third stage of development, the yellow producing constituent is in its turn broken up into two parts of such different internal vibrative periods that they respond respectively to the red light and green light of the spectrum." (1) The red and green colours are not complementary. If the red and green atoms are decomposed together, we find they do not blend, but revert ~~back~~ to the more primitive yellow reponse. Similarly when the yellow and blue atoms are decomposed together, they revert ~~back~~ to the more primitive white or grey sensation. When all three, yellow, red and green are stimulated, complete decomposition takes place, and the original grey sensation results. These reversions must take place below the level of consciousness for yellow does not appear to be composed of red and green nor white of yellow and blue. The combination will take place probably within the retina and be of the nature of a chemical union of some kind.



This theory assumes three fundamental colours, red, green and blue out of which all others arise by combination; it also recognizes the four primal colours red, green, blue, yellow, each unlike the other three. A compound colour such as blue-green is formed in the following way. The blue rays "tear off" from the molecules the atoms corresponding to the vibrations of the blue rays, and the green rays "tear" from the molecules the atoms whose vibration rates are coincident with the green rays and the resultant sensation is blue-green.

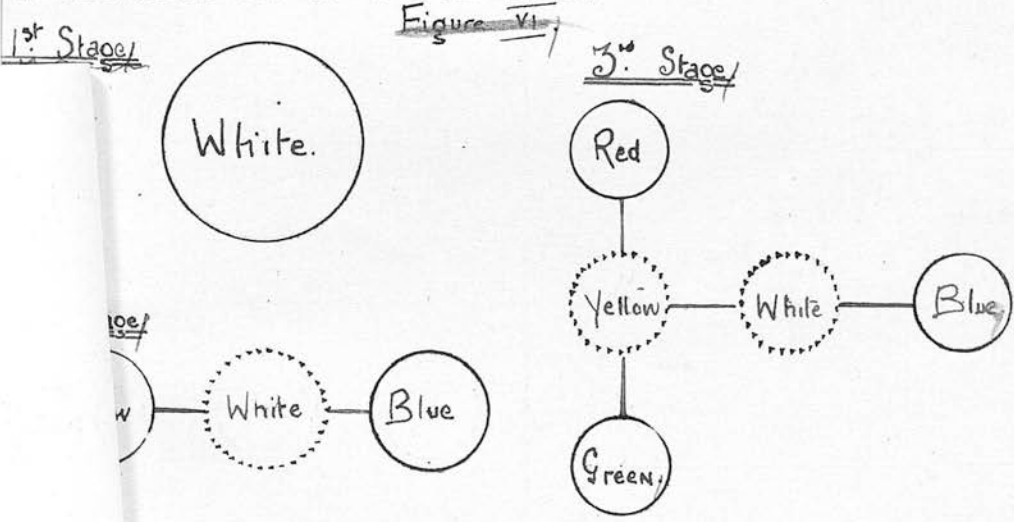
The first stage corresponds to the sensation experienced in the peripheral zone of the normal eye; the second stage corresponds to the middle yellow-blue zone; the third stage to complete vision such as in the fovea.

The grey substance in the rods can be decomposed by a single colour stimulus - but the grey substance in the cones requires a compound colour stimulus before the sensation of grey can be experienced. As we have already seen, stimulation of the cones by a single colour only causes partial decomposition and

(1) Ibid., Vol. 6



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(1) Ibid., Vol. 6



a colour sensation is produced.

The rod-pigment or visual purple which is "not the substance whose chemical decomposition affects the optical nerve-ends" (1) is a secondary means for securing adaptation to a faint light, and not directly a vision-producing substance at all. It acts by absorbing (for the purpose of re-inforcing faint light vision) a large amount of the light which usually passes entirely through the transparent rods and cones to be lost in the choroid coat, it is adapted to aiding vision in the gloomy depths of forests because green light is the light which it absorbs, and fishes which alone, of all vertebrates, have a rod pigment of a distinctly different colour, are exactly fitted for utilising the last rays of the light which penetrate deep into the waters of the sea. (2)

Colour-Blindness.

Dr. Ladd-Franklin regards colour-blindness as an atavistic condition. In total colour-blindness the grey molecule has remained undifferentiated and grey is the sole sensation, of which the retina is capable. In red-green blindness the second stage of development is permanent. The grey molecule has become differentiated into yellow and blue but no further differentiation has taken place. Yellow and blue therefore are the only two colours which are visible to the red-green colour-blind. "It is as if red-vision had fallen out and green vision had been turned into yellow-vision for the one sort; and for the other sort it is as if green-vision had fallen out and yellow-vision had taken the place of red-vision." (3)

Right headline
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6. Schenck's Theory (Hals)

Schenck's theory seems to be along somewhat similar lines. He is an advocate of the Young-Helmholtz theory which Ladd-Franklin does not claim to be. He recognises five simple sensations red, green, yellow, blue and white, but only three of these are fundamental, red, green and blue, which correspond to three "visual substances". He explains the development of the colour sense as starting from a sensation of white which belongs to the cones only and which corresponds very closely to a similar substance in the scotopic, ^{visual} substance of the rods. The white substance becomes differentiated into two substances which ^{give} sensations of yellow and blue, ^{respectively} which when simultaneously excited, revert to the primitive sensation of white. Ultimately the yellow substance becomes differentiated into red and green which when equally and simultaneously stimulated ~~reverts to~~ yellow. White and yellow accordingly have no simple

physiologically
is conditioned by
a visual substance
which

determine a
reversion
cause the
sensation of

physiological
counterparts.

Schenck assumes that each of the three visual

- (1) Ibid., Vol. ~~5~~ 5
- (2) Ibid., Vol. ~~4~~ 6
- (3) Ibid., Vol. ~~4~~ 6
- (4) Arch. f. d. ges. Physiol., ¹¹⁸ ~~CVIII~~, 129, 1907.

substances has two parts (1). One part acts as a receiver for the stimulus (a stimulus-receptor or as has been suggested, a kind of optical resonator) ^{and this} which determines the luminosity of the sensation; a second part which is set into activity by the receptor ^{and this} which determines the ultimate hue of the sensation is the sensation-stimulator (Empfindungserreger), and according

↳ by Richarz
determines a nature and intensity of the sensation

↳ (Reizempfänger)
called to its excitation which is dependent on the amount of energy set free by the stimulus receptor, the luminosity of the resultant sensation is determined.

The red substance has a special stimulus receptor and sensation stimulator and so have the green and blue; the red for long waves, the green for medium waves and the blue for short waves. The amount of energy set free by the green receptor for example, goes directly to the green stimulator and no energy is diverted along any other channels. ↳ with which it is associated physiologically,

Colour-Blindness
In red-green colour-blindness however, a difference occurs. The Blue receptor acts as before for the short-waved stimulus; the red and green ~~are~~ are not differentiated, and objective light acts on the red or green receptor or both, but they in turn are connected indiscriminately with the two corresponding receptors; the resultant sensation is always that of yellow. Schenck regards red-green colour-blindness as a case of arrested development in which the final differentiation of yellow into red and green has not taken place. In deuteranopia the three receptors and stimulators seem to be present, but the association between them has not become established in the case of the red and green visual substance. In protanopia on the other hand the receptor of the red visual substance is absent- although the stimulator is present. This means that long-waved light would cause no sensation at all in the case of red blindness but medium-waved light would stimulate the receptor of the green visual substance, which would distribute its energy indiscriminately between the red and the green stimulators causing a sensation of yellow.

therefore

Right heading

7. Edridge-Green Theory (Hals)

Professor Edridge-Green's theory assumes that visual purple is the sole visual substance. Visual purple is to be found in the rods only and the rods are concerned merely with the formation of visual purple and take no part in visual sensations. (This is contrary to the ^{strong} ~~conclusive~~ evidence of ^{his} ~~this~~ duplicity theory of von Kries and others who hold that the rods are the visual organs for scotopic vision.) (2)
Light rays impinge on the retina setting free the

↳ adduced in favour ↳ also by

- (1) See Parsons, An Introduction to the study of Colour Vision, p.286.
- (2) The experiment, carried out by Ladd-Franklin and Ebbinhaus, reported in Nature, Vol. 48, p.517) seems further conclusive evidence against this view.

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visual purple from the rods and a photograph and or
optogram is formed in the retina. The decomposition
of the visual purple or rhodopsin stimulates the ends
of the cones setting up a visual impulse which is
transmitted to the brain via the optic nerve. "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, 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 centre, only 6, 5, 4, 3 or 2. In the degrees
of colour-blindness just preceding total, only the
colours at the extremes of the spectrum are recognis-
ed as different, the remainder of the spectrum
appearing grey." (1)

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In the fovea there are cones only and no rods
therefore there is an absence of visual purple in
the fovea. Edridge-Green claims however, from direct
observation and ^{on} entoptic grounds, that there are four
canals or depressions leading into the fovea which
conduct the visual purple from the rods into the
centre of acutest vision. He and Devereux Marshall
examined the retinas of two monkeys which had been
kept in a dark room for forty-eight hours beforehand,
and they claimed that the visual purple could be seen
between the cones in the fovea. (2) Their observa-
tions, however, have not been confirmed, - in fact have
been contradicted by Kühne and Nettleship. Entoptically
~~It~~ can be seen, on waking in the morning, as a rose-
red star projected against a dull white surface, such
as the ceiling. This observation of Edridge-Green con-
firms that previously made by Tait and Boll. on

"It is difficult to say at present exactly
how the visual purple acts as a stimulus transformer,
but this^{is} because so many plausible hypotheses immedi-
ately occur to us. It is very probable that light
acting upon the visual purple is, according to its
wave-length, absorbed by particular atoms or molecules,
the amplitude of their vibrations being increased.
These vibrations may cause corresponding vibrations
in certain discs of the outer segments of the cones,
which seem especially constructed to take up vibrat-
ions. We know that when light falls on the retina

- the visual purple
in the canals*
- (1) Hunterian Lecture on Colour Vision and
Colour Blindness, p. 10, ~~1869~~.
 - (2) Transactions of the Ophthalmological Society,
1902, p. 300.
 - (3) Proceedings of the Royal Society of Edinburgh, ⁷/₄₄ 605, 1869.
- ✓

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it causes an electric current. We know how the telephone is able through electricity to convey waves of sound, and something similar may be present in the eye, the apparatus being especially constructed for vibrations of small wave-length. The current of electricity set up by light may cause the sensation of light, and the vibrations of the atoms or molecules the sensations of colour." (1)

He further points out that two processes are continually going on in the visual purple as in all vital processes; a katabolic or breaking down process of the visual purple by light and an anabolic or building up process by the pigment cells and rods.

"The retina, therefore, corresponds to a layer of photo-chemical liquid in which there are innumerable wires each connected with a galvanometer. When light falls upon a portion of this fluid the needle of the galvanometer corresponding to the nearest wire is deflected. The wires correspond to the separate fibres of the optic nerve, and the (2) galvanometers to the visual centres of the brain." (2)

Colour-Blindness

theory of the
Edridge-Green bases his evolution of the colour sense on his theory of psycho-physical units. A psycho-physical series is a physical series as it appears to the mind. In colour the physical series is represented by the solar spectrum, but the psycho-physical series differs greatly with individuals. The majority of individuals are able to distinguish six different colours in the spectrum, red, orange, yellow, green, blue and violet, and they are said to have six psycho-physical units. The colour sense has gradually evolved by increasing the number of psycho-physical units.

At first no colour is seen- the spectrum appears as different shades of grey. The first differentiation of colour will be that of the two physical stimuli which are most unlike. The spectrum then will appear all grey but with a tinge of red at one end and a tinge of violet at the other end. As the colour sense improves, the red and violet will gradually invade the grey band of the spectrum, until they may meet in the centre. "It is obvious that all the colours of the normal sighted which are included in the coloured portion of the spectrum will be seen alike and may be represented by that colour of the normal sighted which corresponds to the centre of this coloured portion. What are the two colours seen when the ^{whole} of the grey has disappeared? The colour will be represented by that colour which in the normal sighted corresponds to the centre of each of the two colours. According to the theory, these centre points ought to correspond to the centres of the two halves of the physical series. The two (1) Hunterian Lectures, p. 21, (2) Ibid, p. 23.

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colours should be complementary to each other. It is evident that these complementaries must be those which are closest to each other as far as the spectrum is concerned. The complementaries which are adjacent to each other are yellow and blue."(1) Such cases are called "dichromics."

In the next stage of evolution, a third colour appears between the other two, namely green. These are "trichromics" and can see accordingly red, green and violet. They do not see yellow and blue and are continually in difficulty with them. Yellow is the next colour to appear between the red and the green and those who can see four colours in the spectrum (red, yellow, green, violet) are termed "tetrachromics". In the next stage of evolution the colours seen are red, yellow, green, blue, violet - these are the "pentachromics". Orange is the sixth colour to be recognised and thus we get the "hexachromics" or normal group to which the majority of individuals belong. The highest development yet reached is that of the "heptachromic" who can distinguish seven colours in the spectrum - the additional colour being indigo. "This order is not in agreement with careful observations on thresholds of colour-visibility by Abney and Festing and by Abney and Watson."(2)

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Colour-blindness is atavistic and ~~is~~ all stages are represented ^{among} ~~in~~ ~~diagnosing~~ colour-blinds. The "dichromics" correspond to the class usually termed "dichromates". The Anomalous Trichromates include the three, four and five unit class of Edridge-Green.

Colour-blindness can be divided into two classes. In the first class there is a defect of light perception as well as a colour loss; in the second class there is a defect in the perception of colour only. Edridge-Green explains both by an analogy to sound. The first class represents those who are unable to hear very high or very low notes; the second class represents those who have what may be called a defective musical ear. Both defects may appear in the same individual. The defect in light perception results in a shortened spectrum either at the red or the violet end - the defect in colour perception causes a less number of colours to be seen than in normal vision.

In this theory colour-blindness is not due to a loss of colour but is caused by the inability of the individuals to detect differences between colours.

- (1) Colour-Blindness and Colour Perception, pp.34-5.
(2) Sherrington, Physiological Abstracts Vol. 7, p.161.
- 5)

Print

EXPERIMENTS.

The tests on the colour-blinds were carried out unbiassed by any preconceived theory and no rigid classification of results was attempted during the experiments themselves. Several different tests were employed and the facts obtained seemed gradually to centre round many of the characteristics peculiar to the colour-blind.

Subjects:-

The subjects were ten in all, eight of them were students attending the graduating course in Experimental Psychology, the other two were Science students. All therefore, were accustomed to experimental procedure and may be regarded as reliable subjects. I should like here to express my gratitude to them for the many hours which they placed at my disposal and for their very helpful co-operation.

The experiments were carried out at different hours in the Combe Psychological Laboratory. The periods of testing lasted for one hour at a time, and as far as possible fatigue was avoided. The subjects are all cases of congenital dichromasy and belong to the most common form of this defect - an inability to distinguish red and green.

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Chapter III
Description of Tests and Discussion of Results

Small caps

TESTS.

1. Stilling's Pseudo-Isochromatic Tables

Mals

Left headline

Tests and Results

The 12th. edition of the Tables was used. This was generally the first test employed as it was the first test by means of which the colour-blinds were detected. In conducting experiments with colour with a large body of students it was found that certain students experienced considerable difficulty in carrying out the required experiments owing to a decided inability to detect certain colours. These students were examined in the course of the ordinary Laboratory period by means of Stilling's Tables, and some of them failed completely to pass the tests. This led to a more thorough investigation of such cases.

The Tables consist of coloured ^{numbers} ~~letters~~ on a coloured background and there are fourteen ^{numbers} in all. Table 1. for example, consists of red ^{numbers} ~~letters~~ on a green ground which are easily distinguishable to the normal eye but which present great difficulty to certain colour-blinds because there is no contrast effect between the ^{numbers} ~~letters~~ and the background. The Tables are based on the fact that if two colours of equal brightness lie on the same side of the neutral band of the spectrum of the dichromat^e, they cannot be ~~deciphered~~ distinguished.

The Tables test both red-green blindness and blue-yellow blindness and further differentiate between shortened and unshortened spectrum. Red-green blinds with normal length of spectrum are unable to read Tables 1 and 2, but can read Tables 3 and 12; Red-green blinds with shortened spectrum read Tables 1 and 2, then 11 and 12, but no others. They have special difficulty with Table 3. Tables 5, 6, 11 and 12, test blue-yellow blindness in the same way. Tables 13 and 14 are to detect simulation and every colour-blind is able to see the figures thereon. The subjects were tested with all fourteen Tables.

The following are the results obtained: #

+ indicates complete pass of the table.
- " " failure
1/2 " " partial success.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A.	+	+	-	-	-	-	1/2	-	1/2	-	1/2	+	+	+
B.	-	-	+	-	-	-	1/2	-	+	-	1/2	+	+	+
C.	1/2	1/2	+	1/2	1/2	1/2	1/2	1/2	+	-	1/2	+	+	+
D.	1/2	1/2	+	1/2	1/2	1/2	1/2	1/2	-	1/2	-	1/2	+	+
E.	-	-	+	-	-	-	1/2	-	1/2	-	+	+	+	+
F.	-	-	-	-	-	-	-	-	-	-	1/2	1/2	+	+
G.	-	-	+	-	-	-	1/2	-	1/2	-	1/2	+	+	+
H.	+	+	-	-	-	-	1/2	-	1/2	-	1/2	+	+	+
I.	+	+	-	-	-	-	1/2	-	-	-	+	+	+	+
J.	-	-	-	-	-	-	1/2	-	-	-	1/2	1/2	+	+

Right headline
Stilling's Tables

NEW FIGHT-NAME
FACE HERE

Tab
no rules

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The Stilling Tables divide the subjects into two fairly-well marked groups. Five subjects are totally unable to read Tables 1 and 2; two attempt to decipher the figures with varied success, making many mistakes but managing a figure here and there. The other three subjects read the Tables with ease. With Table three the position is reversed. Those unable to read the first two Tables are delighted to be able to read the third Table without any difficulty, whereas those who can read easily the first two Tables, find the deciphering of the numbers in the third Table to be impossible. On a first finding then all subjects are red-green colour-blind. Five of them have a spectrum shortened at the red end and five of them have a normal length of spectrum. The two subjects who partially pass the Tables show conflicting results in some of the later tests.

One of the subjects discovered that he could read Tables 1 and 2 which before were undecipherable to him, with the aid of a red glass. The red appeared whitish and the green very dark - the contrast between the figures and the background standing out clearly. The subject ~~was~~ remarked that he was now convinced that the figures did actually exist, ~~as~~ of which he had been sceptical before. Others of the tables he could read by means of a green glass. In all cases it was merely ~~the case of~~ obtaining a good contrast effect - the red and green glasses absorbed part of the rays of light and neutralized the colours. Red and green glasses have been tried frequently to see if they would cause any palliation of the defect, but they do not seem to have met with much success.

necessary to

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right headlines

2. Holmgren's Wool Test, (Hals)

The wool test is based on comparison of different colours. It was originally suggested by Seebeck and later used by Wilson ~~is~~ of course in a more or less primitive form. Both investigators recognized that merely testing a colour-blind by naming colours alone, was a very inefficient ~~method~~. Seebeck used about 200 pieces of coloured paper and asked his colour-blinds to sort them. Wilson used skeins of wools in a similar fashion. Holmgren however, was the first to systematize the test and put it on a scientific basis. He was a staunch adherent of the Young-Helmholtz theory, and in fact devised his test in support of the theory.

The wool test has been generally recommended because it has many advantages such as portability, absence of need for names of colours, and because the wools reflect the light equally in every direction.

The 'confusion' skeins which number over 100 are spread out in irregular order before the subject. They include all varieties of colours and many shades and tints. The examinee is asked to pick out all the

method.

✓

skeins the same colour as a given test skein, irrespective of shade. He is told that no two specimens are alike, and that resemblance of colour only is all that is desired.

Holmgren advocates the use of three such test skeins, and those he chose are in agreement with the theory he favoured: A a very pale green, a light purple or pink and a full red. The first skein determines the presence of the defect, the second decides if the defect be one of red-blindness or green-blindness, judged by the confusion skeins chosen, the third skein acts as a confirmatory skein.

The tests employed as test skeins in these experiments were not those advocated by Holmgren, but were more or less experimental in character. In all, nine skeins were employed as tests.

1. Vivid green.
2. Vivid red.
3. Brown.
4. Magenta.
5. Green - of medium saturation.
6. Pink - of medium saturation.
7. Very pale green.
8. Very pale pink.
9. Pale blue.

The vivid red, medium pink and pale pink formed a series in intensity which was found to give rather interesting results; the vivid green, medium green and light green formed a corresponding series in green. These different degrees of intensity of colour were added as the experiment was proceeded with. The magenta was suggested from a reading of Sanford (1), and the brown suggested from a reading of Abney (2). The pale blue was added because of a tendency noted to confuse blue and pink, and to ascertain whether the confusion was habitual or merely accidental, and whether it was characteristic of all subjects.

It will be found that the results obtained from testing with the wools seem to point to varying degrees of colour defect.

It is interesting further to note the method employed by the colour-blinds. Their general attitude to the test is important, and the fact as to whether they select their colours with ease or with a great deal of hesitancy. The colour-blinds are very particular with their matches and select the skeins with extreme care. The skeins which they reject are as illuminative of their defect as those they accept and the numbers of both were noted.

We are accustomed to speak of red-green colour-blindness and to mean that the individual cannot distinguish reds or it may be greens or both. If he can see red or green then he is no longer colour-blind but is referred to as colour-weak or as belonging to the class of 'anomalous trichromates.' We have

- (1) Experimental Psychology.
- (2) Researches in Colour Vision.

finding
~~Result~~

seen that Professor Hayes challenges that, and states that individuals in whose colour system red and green are totally invisible, and blue and yellow the only two colours recognisable, belong to the extreme or limiting class, and that in the typical cases of colour-blindness some kind of red or green is seen by the individual but not to an extent which would justify his inclusion in the class of anomalous trichromates.

The ten cases examined can not be classified as cases of colour-weakness, ~~in that they show~~ slight deviation from normality. They all seem to be cases of colour-blindness, but they range from extreme cases in which neither red nor green can be distinguished to cases in which red and green can be distinguished with varying degrees of accuracy, if of sufficient intensity. This result is well indicated ~~in~~ Holmgren's wool and later in the other tests. Fewer mistakes occur with the vivid red and the vivid green than with the pale pink and the pale green - but the number of mistakes varies of course, according to the extent of the defect.

Showing

with

Results of Wool Test

The results of each skein are separated in order to show the gradual increase in the ~~greater~~ number of the confusion colours as the defect increases in degree. The subjects are named from A to J approximately in the order of their deficiency - no rigid series of gradation is intended.

21
spt

1. Vivid Green

Selects h
" h
" h
" h
" h
" h
" h
" h
" h
" h

- A. h greens and brownish greens.
- B. h " " " "
- C. h " " " "
- D. h adds yellowish greens.
- E. h greens of all shades and one brown.
- F. h greens of all shades and yellow orange, drab.
- G. h greens and pale brown.
- H. h greens.
- I. h adds in addition to greens and browns, fawns, creams, and yellow, orange and salmon.
- J. h greens, blue-greens, salmon, orange fawns, reds and crimsons, pinks, magenta and drabs.

Rejects.

- h olive and green.
- h olive and brown.
- h orange, pale blue and brown.
- h salmon, pink and olive
- h " " " "
- h fawn.
- h pale green.
- h 2 red greens. 2 drabs.

h rejects
" "
" "
" "
" "
" "
" "
" "
" "
" "

Subjects A to D match the test skein correctly, which seems to indicate an ability to select the proper colours. H also gave correct matches - but he called the test skein orange and selected his matches more for their brightness than hue. F, G, I and J show confusion - particularly subject J who may be regarded as a limiting case of dichromasy. This subject found it difficult to imagine what skeins would be like several tones lighter. It is characteristic of him that he matches each skein with practically all

✓

the confusion skeins -in this case he had 46 matches.

2. Vivid Red

Rejects.

8) rejects

selects
 " "
 " "
 " "
 " "
 " "
 " "
 " "
 " "

- A. L reds and crimsons.
- B. L reds.
- C. L reds, crimsons, pink, cinnamons.
- D. L do. and d. mauve.
- E. L do. and L bluish red.
- F. L I v. vivid red, I v. dark green
- G. L reds, crimsons, pinks, blues, purples, drabs and grey.
- H. L v.d. red, greens, p. brown.
- I. L I red, different shades of green, brown, blue.
- J. L crimsons, reds, salmon, brown, yellows, straws, all shades of green including blue-greens, one pale blue, v.d. violet, d. slate, drabs.

- L —
- L a brownish red.
- L crimson, brown
- L pink (too green)
- L bluish pink (because violet)
- L —
- L p. green myrtle terracotta.
- L —
- L v.d. green and v.d. crimson.
- L —

- L "
- L "
- L "
- L "
- L "
- L "
- L "
- L "
- L "
- L "

A and B select correct matches which seem to indicate an ability to distinguish red. The others show the confusion gradually increasing until subject J is reached, and it will be noticed he includes a large assortment of all kinds numbering 52 in all. It seems clear even from these two examples that the defect differs in degree with subjects A and J.

3. Medium Green

Rejects.

8)

selects
 " "
 " "
 " "
 " "
 " "
 " "
 " "

- A. L greens and brownish yellow.
(N.b. confusion beginning.)
- B. L greens, yellows, orange, brownish yellows and fawns.
- C. L do. do.
- D. L greens, yellowish greens, and brownish greens.
- E. L Yellowish and olive greens, fawn, creams, straws, cinnamon, terracotta, salmon.
- F. L an emerald and a yellowish green, orange, canary, yellow.
- G. L greens (all shades) yellow, orange, browns and greys, a dark blue and a dark violet.
- H. L same as B and C.
- I. L greens, cream, yellow, brown.
- J. L all shades of green, including blue-greens and brownish greens, browns, reds, v. dark slate - almost black, one light orange.

- L 1. orange, canary.
- L salmon, brown, greenish yellow.
- L terracotta and a green.
- L —
- L —
- L pale green (because too red), & olive green.
- L —
- L —
- L —
- L 1 blue pink.
- L 1 pink.
- L 1 dark mauve.

- L rejects
- L "
- L "
- L "
- L "
- L "
- L "
- L "
- L "
- L "
- L "

There is a suggestion of the confusion



beginning with subject A. She rejects a light orange and a canary. In other words she considered these likely to be matched to a green. B likewise rejects a salmon pink but he selects as correct yellow and orange skeins. The others show the same confusion as before in increasing measure.

4. Medium Pink

Rejects.

5) *off*
 ✓ selects
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "

- A. ✓ pinks, bluish pinks and bluish reds. ✓ bluish pink.
- B. ✓ do. do. do. ✓ —
- C. ✓ adds to above pale greens ✓ blue pink and a cream.
- D. ✓ pinks, bluish pinks and bluish reds ✓ yellowish fawn.
- E. ✓ bluish pinks, yellows, straws, creams, ✓ —
- F. ✓ pinks, bluish pinks, violet, pale blues one greenish blue, one greenish grey.
- G. ✓ pinks, greens, reds, and violets. ✓ a yellowish fawn.
- H. ✓ no pinks, but pale greens, bluish greens, yellowish greens and a dark violet. ✓ a bluish pink and an emerald green.
- I. ✓ bluish pinks, blues and greys ✓ —
- J. ✓ pinks, one bluish pink, terracottas, reds and crimsons. ✓ —
 Greens (all shades) greenish greys, greys, drabs, straws, browns, blues (one v.d. slate blue two royal blues, one pale blue) one dull heliotrope.

87
 ✓ rejects
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "

No confusion seems to be existent in cases A. B. D. but is much in evidence in the other cases. The confusion between pink and green begins with subject C. onwards. With the vivid red it did not appear until subject F. was reached. Subject J. had sixty-seven matches.

5. Pale Green

Rejects.

✓ selects
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "

- A. ✓ yellows, creams and salmon pink.

(N.B. first confusion of pink & green)

- B. ✓ do. and pink and orange. ✓ greenish yellow.
- C. ✓ cream, canary and yellow. ✓ salmon.
- D. ✓ do. do. do. ✓ —
- E. ✓ different shades of green, yellows, creams, straws, pinks, salmons, pale blues. ✓ —
- F. ✓ same as C. ✓ —
- G. ✓ greens, browns, pinks, greys, drab, blue and violet. ✓ —
- H. ✓ same as C. ✓ —
- I. ✓ yellows, pinks, greens, creams and orange. ✓ —
- J. ✓ emerald green, cream, canary, yellow, orange, fawn. ✓ —

87
 ✓ rejects
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "
 ✓ "

6. Pale Pink

Rejects.

87

selects
/ "
/ "
/ "
/ "
/ "
/ "
/ "
/ "

- A. / bluish pink, yellow-greens, pale blues and violets. / bluish pink.
- B. / yellows, pinks, creams,, yellow-greens and greens. / red.
- C. / pinks, bluish pink and green. / pale pink and drab.
- D. / no match. / —
- E. / pinks, bluish pinks, greys, straws, yellow-greens, pale blue / —
- F. / bluish pinks, blues, pale green and greys. / pink, green, blue
- G. / no match. (skein = dirty white.) / bluish pink & emerald green.
- H. / bluish pinks, pale greens, blue and green and blues. / pale pink because too blue.
- I. / bluish pinks, vivid blues reds and greys. / —
- J. / pinks, one blue pink, terracotta, reds and crimsons, greens, (all shades) greenish greys, greys, drabs, straws, browns, blue and dull heliotrope. / —

rejects
/ "
/ "
/ "
/ "
/ "
/ "
/ "
/ "
/ "
/ "

With E,F,G,H,I,J, the confusion between red and green is present from the beginning; with A, red is not confused with green until the very palest skein is to be matched, then the pale green is confused with pink, and the usual confusion with yellow. With subject B. the confusion is noticeable in the medium green though not to any great extent and the confusion increases throughout with more or less regularity. This seems to indicate different degrees of colour defect, which seems to be verified in the later experiments.

7. The Magenta Skein gave some rather curious results

Rejects.

87

selects
/ "
/ "
/ "
/ "
/ "
/ "
/ "
/ "
/ "
/ "

- A. / reds, bluish pinks, rose pinks, pale pinks. / pink.
- B. / blues and violets of all shades, one bluish red (but not confident about it). / ~~pink~~ / vivid blue violet and pink
- C. / reds and bluish pinks. / lavender grey violet.
- D. / crimsons and reds, bluish pinks dark mauve. / —
- E. / bluish pinks, rose pinks, violets, blues. / —
- F. / one bluish red, one bluish pink, pinks, v.d.purples, violets & blues. / —
- G. / crimsons, reds, pinks, bluish reds and mauve. / green, pink, pale blue.
- H. / d.mauve, d.violet, dark blue and violet. / —
- I. / bluish pink, salmon pink, d.purple, violets, blues. / —
- J. / magenta reds and medium pinks, bluish pinks, violets, blues, blue greens. / —

rejects
/ "
/ "
/ "
/ "
/ "
/ "
/ "
/ "
/ "
/ "

B. and H. matched the test skein with blues and violets of all shades and B. added one bluish red evidently chosen for its bluish element only, although he evinced considerable hesitation before finally accepting it. When asked the colour of the skein, both confidently declared it to be blue. The majority of the others also matched it with blue and violet but added some reds as well. I and J. also thought the skein was blue but their matches showed considerable confusion. J. rejected six skeins, then accepted them, to reject them later. All were of bluish or purple shades.

(9)
 22

8. The Brown Skein seemed to cause considerable difficulty.
- A. Calling the skein dark green matched it carefully with one skein of a very dark olive-green and rejected a green and a brown.
 - B. Matched it with dark greens and brownish greens but rejected all pure browns.
 - C. Matched it carefully with two skeins, a very dark crimson and an emerald green.
 - D. Matched it with brown though limited to three in number.
 - E. Matched it with brown and greens.
 - F. Experienced great difficulty in getting any match and finally accepted one reddish brown.
 - G. and I. both thought they had been given skein No. 2. again in mistake, (the vivid red) and expostulated that they had matched the brown skein before! They therefore gave similar matches as with the former skein, brown, brownish greens, reds and crimsons.
 - H. Matched it with greens of all kinds and a few browns.
 - J. As before showed the greatest confusion of all. Crimson, reds, salmon, cinnamon, pure brown, canary, yellow, straws, yellow-greens, greens all shades, blue-green, one pale blue, drabs, v.d. violet, dark slate.

It will be noticed that all show confusion, though the confusion seems to increase with the various subjects. Subject J. included in his match a pale blue. He thought the skein was a grey and the pale blue a lighter shade of grey. This would seem to indicate a blindness to blue as well, but the subject in some of the tests was found to recognise blue quite easily; he seems, however, from the evidence to have a weakened sensitivity to blue as well as complete blindness to green and red.

✓

that a dark brown skein be substituted. A dark brown skein does appear to give a better result and all the subjects found it a difficult colour to match, for brown is one of their most puzzling colours. It does not follow however from the results obtained that the subjects can be divided into two groups according to the confusion colours chosen. Abney states that the red-blind will match not only dark green, but also light green with it; the green blinds will pick out the browns and the reds. On such a basis subject C. would be difficult to place as he matched it with a very dark crimson and an emerald green! G.I.J. likewise.

The same criticism applies to the other two test skeins as recommended by Holmgren.

The pale-green test is most satisfactory for it seems to show up the defect immediately. For this reason too, the pale-pink is most useful. The weaker cases of colour-blindness, as we have seen, are able to pass the test when the colours are more highly saturated. It is the pale colours they have greater difficulty with. Edridge-Green objects to such a green being used as a test skein and declares it to be the worst possible colour to choose, for the colour-blinds can easily pass through such a test without detection. The results of these experiments do not seem to justify such a conclusion, for all subjects substantially failed in their matches with the pale-green. The medium pinks and greens and the full reds and greens are useful in giving an approximate insight into the extent of the defect, but as tests alone are unreliable.

The magenta skein is also a useful one. All but one subject thought it was blue, or violet as some called it, and it was astounding to have all shades of blues and violets picked out as good matches. This too, by subject B. who acquitted himself so well in matching the vivid red skein. It would seem that the blue had been much more powerful than the red to him, and that the red sensation in consequence had suffered. Subject A. on the other hand gave a good match although she thought the skein was a purple one. The results, therefore, in her case might be misleading. She has a general confusion of blue and pink and it would seem that the result she did obtain was due largely to chance. This does ^{not} alter the fact however, that red is visible to her under certain circumstances; where she confuses blue and pink, or in this case magenta and purple, the blue element must be the stronger one, so strong in fact that it seems almost to blot out the red sensation.

With the blue skein A. made no confusion with blues and pinks in the actual choice she made, but it is noteworthy that she examined one or two pinks and then rejected them; the confusion was certainly present.

Confusion of blue with pink is said to be characteristic of a shortened spectrum. If the pink is made up of a mixture of red and violet, the red element is invisible and the violet remains which is seen as blue. Subject G. however, who has no short-

-ening of the spectrum- if Stilling's Tables are trustworthy- also shows a similar confusion.

In conducting this wool test, Holmgren advocates that the examiner, in cases where a reliable explanation fails, should resort to actually showing the individual how the selection should be done, and he argues that no one with a defective chromatic sense finds the correct skeins in the pile the more easily from the fact of having a moment before seen others looking for and arranging them. From practical experience in testing colour-blinds, this method must be strongly deprecated. A shrewd colour-blind, once he obtains a clue to the colours required, will make a wonderful show of accuracy. Further Holmgren's second instruction, that in testing large numbers, the candidate should be instructed "to attentively observe the examination of those preceding them" seems to be defeating the purpose of the test.

The great advantage of Holmgren's test is that it is based on comparing colours, not on naming colours, ~~naming colours being unsatisfactory~~. Certainly, when Holmgren devised his test, it was a step in the right direction, for the testing of colour-blinds by naming alone is most unsatisfactory. But in conducting the wool test just described the subject was always asked what colour he thought the test skein was, and his ^{answers} were most illuminating, and increased the value of the test tenfold. ~~It has been discovered since~~ that Edridge-Green in his classification test, which is a modified wool test employing different test skeins, advocates the same procedure. In fact the candidate is asked to name each colour as he selects it. It was found most instructive too, to ask the names of the rejected colours, and why they were rejected, and the reasons throw considerable light upon the colour defect. The combined method therefore of comparing and naming seems to yield the best results.

The author has since

In conclusion, the most outstanding result of this series of tests is the confirmation of Professor Hayes' results, that there are varying degrees of red-green colour-blindness. The graded series of reds and greens brought this result clearly out, and it will be found that later experiments ~~strengthen it~~ point strongly in the same direction.

Right header

3. Colour Naming

(Hall)

hostile criticism

Tests involving colour naming have come in for a large share of ~~approbrium~~, and were considered as unsatisfactory by the Committee appointed to report on Colour Vision, in 1892. "Tests which involve the naming of colours should be avoided in deciding the question of colour-blindness." (2) The colour-blinds judge of colours by difference in shade, and a difference in shade to them often means a difference in colour. They hear a colour called red which to them ^{may} appear as a very dark yellow and they associate the name and

(1) Jeffries: Colour Blindness: Its Dangers and its Detection p. 211. Translation from Holmgren
(2) Proc. Roy. Soc. London, Vol. 51
(Proceedings of R. Royal Society of London, Vol. 51.)

the shade together. In some cases their skill in using correct colour names is remarkable and renders the detection of their defect more difficult.

Dr. Pole, himself, remained ignorant of his defect for thirty years. Dalton, too, in speaking of some of his pupils, remarked, "They, like all the rest of us colour-blinds, were not aware of their actually seeing colours different from other people, but imagined there was great perplexity in the names ascribed to particular colours."

It was for this reason that Holmgren devised his test, which obviates the need for colour names. 'To judge correctly of colour-blindness, and the various practical questions connected with it, it is of the highest importance to distinctly observe the difference between the manner in which the colour-blind sees, and the manner in which he names, colours. The sensation is based upon the nature of the sense of colours in the organization of the optic nerve from birth. The name, on the contrary, is learned. It is conventional; it depends upon exercise and habit. The names of colours are naturally the objective expression of subjective sensations; but, on the other hand, they are regulated by the system of normal sight, and cannot consequently agree with that of the colour-blind." (1)

The objection which Holmgren had against testing by naming colours seems to have arisen from the fact that such a test used to be applied to detect colour-blinds in a most haphazard manner, and no other test was added. Colour naming is a useful test, but it must be of a supplementary nature. Alone, it is most unreliable, particularly if names of familiar objects are asked for.

Dr. Jeffries, to test this point, conducted an interesting questionnaire with blind children; children blind from birth, to form as well as to colour. He asked them the colours of familiar objects such as the sky, an apple, banana, strawberry, grass, leaves, water etc., and ~~gained~~ curious answers. For example, to banana, he received the following replies, 'Don't know: No idea: Yellow; Don't know: Don't know: Green-uncertain?' These were children ranging in age from ten to nineteen. Unfortunately the experiment could not be continued for colours became the topic of conversation throughout the institution after that. The colours of grass and cherry, however, were fairly well known. "Through the ear alone these answers were learned, and retained by memory. The attachment of the name of a colour to an object is an attribute not learned by the eye alone. A wholly uneducated person who handles bricks if he hears them called black, will so call them when questioned as to their colour." (2) This is a similar condition to that found in the colour-blind. He

received

(1) Quoted from Jeffries, Colour Blindness: Its Dangers and its Detection, p. 94.

(2) ibid., p. 100.

learns by the ear the names of familiar objects, and in addition in some cases he associates them with an eye sensation, not the same as ours, but probably some fine discrimination of shade which comes to mean for him a new colour.

Edridge-Green, however, adopts an entirely different attitude, and is a strong advocate in favour of testing nomenclature, particularly for practical purposes. He introduces colour naming into his classification test and into his lantern test. The latter test in its relation to colour naming, we shall consider later. As long as the objects to be named are carefully chosen, colour naming gives a considerable insight into the colour-blind's defect. It will be found that in many cases the colour-blind does not guess the names of colours; he has a regular system of his own which he firmly adheres to.

To test the validity of colour naming two methods were tried:

1. The naming of the dots in Stilling's Tables.
2. The naming of Holmgren's Wools.

Some of the subjects were tested after the lapse of a year and their colour nomenclature was found to remain constant. This confirms the fact that guessing is not the rule, but that the colour-blinds are guided by definite colour sensations which give them a regular colour system.

Results.

(a) Stilling's Tables

	Table 1, (Light and Medium)	(Light and Medium)
	Red. figures	on Green back ground.
A.	red.	green.
B.	red.	green.
C.	dark green and brown.	yellow and brown.
D.	red.	dark green.
E.	violet.	grey.
F.	red?	yellow and green.
G.	red.	green.
H.	brown.	yellow and orange.
I.	green and red.	green or yellow and green.
J.	All shades	of grey.

The colour names employed are characteristic of the defect and it must be admitted they reveal how great that defect is. Subject B. though recognising the colours could not decipher the figures. Subject C. could partially read the figures although it will be noticed that his nomenclature shows considerable confusion. This is characteristic of him throughout all the tests. Being questioned, he declared he had no interest in colours at all, and had not thought whether he confused them or not. Finally he admitted that crimsons and the finer shades were difficult for him but the question of colour in general seemed to have caused him no concern. J. as

(11)

8/4-

(24)



before shows the defect to be much graver than the others and sees all colours as shades of grey.

(12)

e/c

spl

Table 2/

	(Light and Medium)	(Light and Dark)
	<u>Green.</u> figures on <u>Red.</u>	back ground
A.	green.	red.
B.	orange red and red.	red.
C.	<u>Yellow</u> and dark green	light green & dark red.
D.	dark green.	light and dark brown.
E.	bright green.	greyish green & grey.
F.	yellow and ?	green and red.
G.	yellow and green.	red and green.
H.	yellow and orange.	dark brown and black.
I.	green.	red and black.
J.	different shades	of grey.

How does this compare with the first table? A's results are similar to first table- she recognises red and green. B. however shows confusion this time. Yellow is evidently confused with pale-green in the cases of subjects C, F and H- a common confusion. J. remains constant and sees all as shades of grey. One other point of interest worth noting is in the case of subject H.- the medium green which resembles somewhat a grass green, he calls orange. This is characteristic of him and tested a year later the same naming held good. This is verified in the other tests. Note also that he calls the red black - this at once indicates a shortened spectrum.

those in the

(13)

spl

Table 3/

	Bright Red	figures on Mole and Black background.
A.	red	green
B.	red	green and black
C.	red	green
D.	dark red	brown.
E.	red	green
F.	light red	darker shades of red.
G.	red	green and dark green
H.	brown	grey and black
I.	grey	shades of grey
J.	black	shades of grey

The red used in this table is a very bright red and was recognised as such by subjects A to G. This particular shade of red which seems similar to that used in the Nagel cards gave similar results there. It will be noticed that the background contains a difficult colour for them, one of these indefinite colours which is always a puzzle for them and which rarely fails to detect them. The majority have called it green. J. as before sees all the colours as grey - red is seen as black which denotes a shortened spectrum. Subject H. sees this shade of red as brown - that is, a dark shade of red is black, a medium shade is brown.



Table 4

Red figures on Fawn and Mole background.		
A.	red	green and black
B.	red	green
C.	red	dark green
D.	red	dark brown
E.	red	dark green and grey
F. r	red	green
G.	red	green
H.	grey and black	grey and brown
I.	grey	brown and black
J.	black	shades of grey

Red again is recognised by subjects A to G. It is the same particular brightness of Table 3. H. and J. confirm the shortened ^{spectrum} The background contains confusion colours ~~and~~ are not recognised.

which/

Table 5

Fawn and Red figures on Grey and Mole background.		
A.	green and red	green
B.	shades of green	green
C.	green	green
D.	shades of brown	dark brown
E.	grey and red	grey
F.	light red	red
G.	green	green
H.	grey and brown	grey
I.	grey	brown and green
J.	different shades of	grey

The red in this table is a dull red - what might be called a 'blae' colour, and few subjects could identify it. This is a striking difference from the last table. It seems to point to the fact that the colour must be somewhat resembling what may be designated as a 'pure red' in order that it may be identified. It must be reds like these which are confused with greens. The background as before shows grey mistaken for green. Note subject J. again - he truly seems a limiting case of dichromasy.

Table 6

Fawn and Red figures on Grey and Mole background, (dots however larger in size).		
A.	red	green
B.	crimson	green
C.	green or brown	green
D.	shades of brown	dark grey
E.	all different shades	of grey
F.	light red	dark red
G.	red and green	green
H.	grey and brown	grey and light brown
I.	dark grey	green
J.	different shades of	grey

A. and B. this time recognise the red, but otherwise the naming remains much similar to the preceding table except E. who sees the colours as shades of grey.

✓

Table 7

Crimson figures on Brown and Brownish-green background

A. red	green
B. crimson	green
C. brown	brown
D. red	grey
E. dark brown	brown and dark green
F. red	?
G. red	brown
H. brown and black	two shades of brown
I. dark brown and black	dark grey
J. different shades of	grey

^{certain} This confirms the previous tables, that red under circumstances can be recognised. The background shows confusion of green and brown. Subject I now shows signs of a shortened spectrum because of confusion of red and black. That is from colour naming alone H, I, and J have been found to have shortened spectrum which verifies the results obtained from the reading of the tables.

Table 8

Bright Red and Crimson figures on Brown and ^{Greenish-brown} ~~Green~~ background

A. red	green
B. crimson	red and brown
C. brown	light brown
D. dark red	brown
E. red	dark green
F. red	brown
G. red	green
H. brown	brown and grey
I. dark grey or black	shades of brown
J. different shades of	grey.

The red here is fairly well recognised because it is of this bright variety. Subject C however calls it brown. His nomenclature is not good throughout, and shows considerable confusion. This is curious when we remember that he can partially pass the Stilling Tables so far as deciphering the numbers is concerned.

Table 9

Pink figures on Brown and d. brown background

A. red	green and red
B. greenish red	brown and black
C. green	brown
D. dark brown	grey
E. medium grey	brown
F. light red	?
G. green	green
H. black	grey and black
I. green and brown	brown or red
J. figures decidedly lighter;	all however shades of grey

This table gives interesting results - all show confusion. Note the description given by B of the figures, greenish red. This term is characteristic of the mild forms of colour-blindness and of cases too where red seems sometimes to be recognised.



No two call ^{both} ~~the~~ colours the same in both cases. J. still maintains his different shades of grey. Evidently he has not learned to associate a shade with the name of a colour. Subject E. has more than once called a colour a grey, and it was he who called the blue skein in the Holmgren's wools a grey. Does this suggest a lowered sensitivity to colours in general? Subject F. is very often completely at a loss as to the name of a colour and finds it impossible to make even a guess at it. (It will also be noticed that green is more often mentioned than red, which shows, tentatively suggest^{at}, that, when in doubt, green is the accepted solution.

25

we may

Table 10

	Red figures on Fawn & Brown background.
A. red.	green and red.
B. red.	green and reddish brown.
C. red.	green and brown.
D. all dark red.	shades of grey.
E. red.	light green.
F. red.	may be brown.
G. red and green.	nondescript and green.
H. brown.	grey and brown.
I. brown.	green.
J. different shades of grey.	

20

Brown and red are often mistaken for one another; further, as we have already noticed, green and fawn are liable to be confused. The red is more correctly and more frequently distinguished than the green and does not seem ~~open~~ to the same amount of confusion. Often the back-ground which contains two shades of the same colour is described as red and green - a difference in shade means a difference in colour.

liable/

Table 11.

	Crimson figures on Orange & brown background.
A. red	green and red
B. crimson	orange and green
C. red	yellow
D. red	red and grey
E. red	light brown
F. red	yellowish tinge
G. red	yellow and red
H. black	orange and brown
I. dark grey	light brown or green and dark brown
J. figures are black against the background	

21

The red figures are well recognised again except for the last three subjects, who are well-marked cases of shortened spectrum, and who in consequence see the red as black. The orange and brown both proved difficult colours. ~~Subject A notes,~~ confuses brown and red, therefore red can not always be a clear sensation for her.

Note that subject A/

✓

Table 12

(22)

	<u>Yellow-green(l. & d.) figures on Blue(l. & d.) background</u>
A.	yellow-green and green blue
B.	shades of green different shades of blue
C.	green and brown green and blue
D.	shades of green slate colour
F.	colours vary(no idea) red and d. blue
G.	green blue
H.	shades of grey grey and blue
I.	green and brown pink and blue
J.	white med. grey and blue (hesitation)

Two things are of interest here.

1). The light shade of blue is often seen as pale grey. This confirms the results obtained in matching the wools, and seems to be characteristic of some colour-blinds. J was doubtful about the blue and finally described it as being the colour of ink.

2). The light shade of blue is confused with pink. This is a further sign of a shortened spectrum. F and I who show this confusion have a shortened spectrum, for they can not decipher the figures in Table 3.

Table 13

(23)

	<u>Crimson figures on Fawn and Mole background</u>
A.	red two different greens
B.	crimson two different greens
C.	brown green
D.	dark red two greys
E.	dark red light grey
F.	darker shade shades of brown
G.	red brown green
H.	black grey and brown
I.	black or d. grey green and brown
J.	black shades of grey

tr. / The three last again show signs of shortened spectrum; the others show a discrimination of red. Fawn and mole as before are confused with green. Note F's indefinite phraseology.

Table 14

(24)

	<u>Crimson(l. and d.) figures on Brown and Mole background</u>
A.	red green
B.	crimson red reddish green
C.	brown l. brown
D.	l. grey and d. grey v. l. grey and brown
E.	d. brown green
F.	may be d. red darker shades
G.	brown and ? green
H.	black all brown
I.	dark grey or brown light brown
J.	black fairly d. grey.

tr. / This particular red is not so well recognised. The three last as before call it black. Subject B employs his former terminology and designates the

background as reddish green. C and D who partially pass the Stilling's tests so far as reading the numbers are concerned, are bad at colour naming. This table shows clearly the confusions they make. Further the background as before shows how greatly green is confused with brown. The puzzling colours seem more liable to be called green than to be called red.

From the results of colour naming, various facts may be deduced.

- 1) There are different grades of colour-blindness ranging from extreme cases in which no red and green can be perceived to cases in which red and green can be perceived under certain circumstances. Subject J is the extreme case.
- 2) Red, if of sufficient brightness, can be distinguished by some colour-blinds. *Vide* subjects A and B
- 3) Red is seen as black by those with shortened spectrum.
- 4) Red is confused with blue in certain case of shortened spectrum.
- 5) Brown is a common confusion colour of green.
- 6) Greenish red is a ~~term~~ employed by colour-blinds *colour name /*
- 7) Pale blue in some cases of red-green blindness is seen as pale grey.
- 8) Partial passing of the Tables does not coincide with good nomenclature.
- 9) Finally, and this is perhaps the most important result obtained, the colour-blinds do not guess names of colours, but have a regular colour system which determines the names they employ.

It will be seen, therefore, that a large amount of information has been gathered from merely asking the examinees to name colours and that an insight into their respective defects has been obtained.

Red appears 13 times in the Tables.

A.	recognised it	13	times.
B.	.. "	11	.. "
C.	.. "	4	.. "
D.	.. "	8	.. "
E.	.. "	7	.. "
F.	.. "	9	.. "
G.	.. "	7	.. "
H.	.. "	0	.. "
I.	.. "	0	.. "
J.	.. "	0	.. "

(25)

sp

The above table speaks for itself and shows the great variety of the ten colour-blinds examined. The case of C is a curious one and all through his results are conflicting. The recognition of red only 4 times would seem to place him much nearer the extreme case, and some experiments would verify this, but others again would make his defect appear less grave. Note H, I and J failed completely to identify red.

among /

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(b) The Naming of Holmeran's Wools

All the skeins were named by each colour-blind. Below are a few samples of the names given. The full list is appended.

(26)
 Green
 Spl-
 set oblong

Colour of Skein	A	B.	C	D	E	F	G	H	I	J.
1. vivid green	green	green	Red or Yellow green	green	green	yellow	Green	orange	green	l. grey
2. vivid red.	red.	red	red.	red.	red.	red.	red	brown	brown	nearly black
3. brown.	d. green	green	v.d. green	brown	d. brown	brownish tawny	green	brown	brown	d. grey
4. magenta	purple	blue	blue + red.	v.d. red.	violet	reddish blue.	pink	blue	blue or purple	d. blue
5. med. green.	yellow	green	green	green	l. brown	+ red. red + white	+ green	yellow	green	med. grey
6. med. pink	pink	pink	l. green	v.p. grey	white	some other colour.	pink	grey	p. blue	l. grey
7. light green	yellow or pink	green	green	green	l. brown	red.	green	yellow	l. green	yellow
8. light pink	pink	pink	l. green	d. grey	flesh	night red.	dirty white	greyish white	white	l. grey
9. pale blue.	p. green	blue	+ blue green	l. green	grey	blue	pink	blue	white blue	l. grey
10. straw	pink	p. yellow	brown + yellow	cream	cream	white	green	pink	green	l. grey
11. drab.	green	grey	green	brown	grey	red.	red	d. blue	green	med. grey
12. very d. violet	violet	greenish brown	green	slate	slate	some pale red	slate	slate	pinkish greenish brownish	med. grey
13. rose.	pink	pink	green + red about it	pink	pink	red.	pink	blue	blue.	? blue.

(26)

These few examples give characteristic results. Very pale greys, drabs and creams are usually thought to be pale pinks or pale greens. Subjects A. B. D. E. only confused the pale shades and subject A. volunteered the information that she could distinguish bright shades without difficulty - it was just the pale shades of colours which she knew she confused. Subject C's nomenclature is very bad - in fact is misleading. In colour mixing he could distinguish differences between colours to a very fine degree, although he would call a pink, green and a green red. He is very fond of using the terms greenish red or reddish green - a pink is, in ~~the~~ of a colour term, composed of green and red; similarly lavender is composed of blue and green; a bluish red, a bluish pink and a pale green are all composed of red and green. This verifies the results obtained from the naming of Stilling's Tables.

lack/

is described as

Subject I's nomenclature is perhaps worse but it coincides with his colour matches. Pinks of all shades he calls blues, reds are called browns, and greens, yellow. Orange cannot be distinguished from yellow nor purple or violet from blue - reds and greens change names promiscuously. He was very proud of one colour - a very dark green which he claimed twice over with evident satisfaction to be crimson lake.

A summary of his results runs as follows:- Dark crimson and red he calls brown; pink is blue, sometimes green, orange is yellow; yellow is yellow or green, but the yellow element can always be

✓

distinguished in compound colours such as a yellowish green; yellow green is yellow; dark olive green is brown, but twice called crimson lake; emerald green is dark yellow; pale green is grey or pink; blue green is called brown, but if very pale is described as a dirty white; blue is sometimes called blue, sometimes called purple; pale blue is pink; violet usually blue sometimes pink; brown is called brown, green or red; all greys, drabs or straws are called greens or pinks.

The other subjects show somewhat similar results with variations here and there.

Subject J. however sees the colours as a monotonous series of shades of grey. A glance down the column in which his results are recorded shows that yellow and blue are the sole colour names of his vocabulary. Four times he calls dark green brown and once he ventures the name purple and once the name orange; but apart from these instances, yellow and blue are his only colours.

The wools give a more varied result than the Stilling's Tables simply because there is a larger variety of hues.

We see subject F's indefinite phraseology continued, "some red in it," "red and something else," "might be red," and so on, which characterised his naming in the Tables. We find the same confusion of green, and yellow, and brown, and grey; of pink and blue; of red and brown, and red and black; of violet and blue. Further we find the phrase reddishgreen used with fair frequency.

The results from colour naming, therefore, are not to be despised, for they yield a large return.

6pt Table follows

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Holmgren's Woolly

Where no colours are given colours were named correctly, L.=light, P.=pale d.=dark, v.=very, med.=medium

6/11
along
on page

	A	B	C	D	E	F	G	H	I	J
1. Straw.	pink	p. yellow	br. yellow brown and yellow	-	-	white	green	pink	green	l. grey
2. Greenish grey	-	d. grey	green	-	-	green	green	-	green	med. grey
3. Rose pink.	-	-	go with red about it.	-	-	red	-	blue	blue	? blue
4. Emerald green	-	-	-	-	grey	-	-	grey	-	med. grey
5. L. orange.	-	yellow.	yellow.	-	Yellow	yellow	-	-	yellow	d. yellow
6. P. green.	grey.	-	-	-	l. grey	-	-	grey	-	med. grey
7. P. pink.	-	-	L. green	L. grey	-	-	p. green	blue	blue	l. green
8. P. green.	-	-	-	-	yellow and brown yellowish	grey white	-	yellowish y ^l sh white	-	v. d. grey
9. Canary.	-	-	-	brown.	-	-	-	-	-	-
10. P. brown.	green.	-	-	-	-	d. brown	greenish green	brown	-	-
11. V. d. purple.	blue.	blue.	d. blue.	-	blue	blue	-	-	-	d. blue
12. Blue.	-	-	-	-	brown	red	-	grey	-	med. grey
13. Cream.	pink	-	Green and yellow	-	-	white	p. red	-	-	v. l. yellow
14. Emerald green	-	yellow	L. brown	-	-	yellow	-	orange	d. yellow	d. yellow
15. V. d. red brown	-	-	-	brown	red	brown	-	d. brown	brown	v. d. grey
16. Salmon pink.	pink	p. yellow	-	-	v. l. brown	green watered	-	orange	green	l. grey
17. V. p. green.	green	p. blue	-	yellow	l. grey	greyish white	-	grey	-	l. grey
18. Vivid pink.	-	-	-	-	-	reddish blue	-	-	blue	? blue
19. P. yellowish green.	brown	p. yellow	blue and green	-	brown	yellowish brown	-	orange	-	brown
20. Yellowish green	yellow	yellow	yellow	-	-	yellow	yellow	yellow	yellow	-
21. Cinnamon.	-	-	-	-	-	-	salmon	-	greenish brown	-
22. Drab.	green	-	green	brown	-	red	red	d. blue	green	-
23. Fawnish yellow	pink	-	-	brown	-	-	salmon	-	pink	-
24. V. d. crimson. br.	-	-	-	d. green	d. brown	brown	-	brown	d. brown	black
25. Yellowish fawn.	-	-	fawn green and brown	-	-	-	-	-	green	fairly
26. Red.	-	-	red	-	-	-	-	-	blue	l. grey
27. Fawn	-	-	-	-	-	-	green	green	green	d. grey
28. Bottle green.	-	-	-	-	-	red with brown init.	-	grey	-	med. grey
29. Orange.	darker yellow	d. yellow	yellow	brown	-	yellow	-	-	yellow	d. yellow
30. Bluish pink.	-	-	red and green and	red	red	blue	-	blue	blue	purple?
31. Pale cream.	pink	l. green almost yellow	-	brown	yellowish brown	white	pale and red	green	green	l. yellow
32. Pea green.	-	-	-	blue	-	red and white	-	grey	yellow y ^l w or green	med. grey
33. Yellow.	-	-	yellow	-	-	-	-	-	-	-
34. P. violet.	pink	blue	l. blue	blue	pink	blue	red	blue	blue	l. blue
35. P. green.	pink	p. yellow	-	blue or green	l. brown	white	p. red	pinkish	green	l. grey
36. Pinkish yellow.	pink	p. yellow	v. l. green	brown	l. brown	-	-	grey	-	l. grey
37. Geranium pink	-	-	-	-	-	-	-	-	-	med. grey
38. Dark blue.	-	-	-	-	-	-	-	-	purple	-
39. D. green.	-	-	-	-	-	green ?	-	d. green	brown	d. grey
40. D. slate blue.	green	d. grey	green	-	-	some red in it	d. green	-	d. grey	d. grey
41. V. d. violet.	-	greenish brown	-	-	-	some red in it	slate	-	pinkish greenish brown	med. grey
42. Jade green	grey	-	grey	-	l. grey	-	-	grey	greenish - brownish	med. grey
43. D. olive green	-	-	-	-	-	orange	-	grey	yellowish yellowish brown	d. grey
44. Dull helio.	-	blue with something else	-	-	-	red	blue green	grey blue	d. pink	bluey grey
45. V. d. blue.	-	-	-	-	d. blue d. grey	-	-	-	-	d. blue
46. P. crimson,	pink	-	pink	-	brown	-	-	brown	brown with pink in it	med. grey
47. Brownish green	-	l. brown	-	-	brown	d. brown	-	d. orange	golden brown	d. grey

Direction of prints: Colours names in full.

	A	B	C	D	E	F	G	H	I	J
48. Blue pink.	-	ce- grn&blue	green	grey	red in it	blue	-	l.blue	blue	med.grey
49. Grey (nat.)	-	in it	l.green	-	-	red	red	pink	pink	l.grey
50. P.bluish pink.	-	-	l.green	grey	flesh	red	-	white	greenish	l.grey
51. P.green.	-	p.yellow	-	-	-	-	-	l.brown	brown	l.grey
52. Blue green.	-	-	blue & green	-	grey	red	-	grey	brn wth pk in it	med.grey
53. Pink.	-	-	grn&red	-	-	-	-	blue	blue	l.grey
54. Crimson.	-	-	-	-	-	-	-	d.brown	brown	v.d.grey
55. Brownish green	-	reddish yellow	l.brown green & brown	-	l.brown	orange	-	orange	golden brown	orange fairly d.grey
56. Olive green.	brown	brown	red & green	-	-	brown some	-	brown	-	-
57. P. green.	-	-	greenish brownish	-	-	red ?	-	-	d.pink	l.grey
58. Emerald green	-	yellow	yellow	-	brownish green	yellow	-	orange	yellow	d.orange
59. Grey.	greenish	blue dark	l.green	-	-	l.red	l.green	pink	pink	l.grey
60. V.d.blue green	-	blue	-	-	d.steel grey	red ?	blue	almost grey	crimson lake	v.d.grey
61. P.blue green	blue	blue	blue	blue	grn wth pink in it	l.grey	blue	white	dirty white	l.grey
62. Pink.	-	-	-	-	-	-	-	-	blue or pink	med.grey
63. Slate blue.	-	greenish	green	grey	-	red	p.green	brown	greenish bluish	l.grey
64. Royal.	-	-	-	-	-	-	-	-	-	l.blue
65. V.d.olive green	-	d.brown	brown	-	brown	d.brown	-	-	brown	d.grey
66. Sea green.	-	-	-	-	l.blue	red & ?	p.green	pink	dirty white	l.grey
67. Green.	-	grey	-	-	grey wth green in it	-	-	pink	brown wth pink in it	fairly d.grey
68. Lavender.	blue	blue	blue & green	blue	blue	blue	-	d.grey	blue	med.blue
69. Blue.	-	-	greenish blue	-	blue ?	-	-	-	-	-
70. D.olive green	-	brown	brown	brown	-	brown	-	brown	brown	d.grey
71. Green	-	-	-	-	blue grey	red	blue	-	brown	med.grey touch of
72. Bluish pink.	blue	p.blue	red & green	-	red	blue	-	l.blue	blue	blue
73. Greenish blue.	-	-	-	-	blue gry	-	-	-	jade green	l.blue
74. Grey.	green	greenish brown	green	-	-	red & brown	green	-	bluish greenish-brownish	med.grey
75. P.terra-cotta.	-	-	-	fawn	brown	green	pink	l.brown	brownish	fairly d.grey
76. Blue.	-	-	-	green	-	-	-	-	-	-
77. Violet.	-	blue	blue	blue	-	-	blue	blue	-	d.blue
78. Emerald green	-	brown	l.brown	-	-	orange	-	orange	golden brown	med.grey
79. Myrtle green.	d.green	Almost black d.brown	green	-	d.grey	? brown	d.green	grey	d.grey	d.grey
80. D.mauve.	-	blue	blue	-	blue	blue	-	blue	-	d.blue
81. V.d.green	-	-	-	-	d.grey	? brown	blue	d.grey	crimson lake	black
82. Brownish green	-	-	brown	-	brown	brown	-	brown	brown	d.grey
83. Blue green.	-	-	-	-	-	red blue	-	-	-	med.blue
84. Bluish red.	-	pink	red & green	-	-	blue	-	-	purple	d.grey
85. P.violet.	blue	blue	blue	blue	blue	blue	blue	-	-	med.blue
86. Brownish green	-	l.brown	brown	-	brown	brown	brown	brown	brown	brown
87. Grey.	pink	-	-	yellow	-	red	green	-	pink	-

Directions & prints - Colours names in full

	A	B	C	D	E	F	G	H	I	J
88. L. olive green Almost blue	-	l.brown	l.brown red & green	-	green ^{and} brown	orange some	-	orange	yellow & brown dirty	l.grey
89. P. green	-	-	green & brown	-	green ?	red	p.green	pink	white	l.grey
90. Brown	green	greenish brownish	green & brown	d.grey	-	-	green	blue	purple	d.grey
91. Blue.	-	-	-	-	-	-	-	-	-	-
92. D. violet.	-	blue	blue	-	blue	blue	blue	-	-	p. blue
93. D. greenish brown	brown	brown	brown	-	brown	brown	-	-	brown	brown
94. Sea blue.	-	-	blu grn	-	-	-	-	-	pink	-
95. Emerald green	-	-	-	-	-	brown	-	-	brown	d.grey
96. P. blue.	p.green	bluish pink	blue & green	brown	-	red	pink	-	pink	l.grey
97. Grey green	-	d.grey	d.green green & greenish	-	d.grey l.blue	red	-	-	pink brown red white	brown
98. P. blue.	p. green	blue	blue	l.green	grey	-	pink	-	or blue	l.grey
99. Terra-cotta.	-	-	-	crimson	brown	brown	red	-	brown	d.grey
100. P. blue.	-	-	-	-	-	-	-	-	-	-
101. P. brown	-	brown	bluish green	-	blu- blue grey	green	green	-	-	d.grey
102. Blue.	-	-	-	green	d.grey	red brown	-	-	-	-
103. D. green.	-	-	-	-	-	-	-	grey	brown red blue or purple	d.grey
104. L. violet.	-	blue	blue	blue	l.blue	blue	blue	-	-	l.blue
105. Violet.	-	-	-	-	-	-	-	-	-	l.blue
106. Violet.	blue	blue	blue	Blue-green	blue	blue	-	blue	-	l.blue
107. Olive green.	brown	l.brown	-	-	l.brown	brown	-	brown	-	med.grey
108. P. blue.	p.green	-	green	-	-	-	-	-	pinkish	l.grey
109. D. blue.	-	-	-	-	grey blue	reddish blue	-	-	-	-
110. Olive green.	-	l.brown	-	-	-	brown	-	brown	-	brown

TEST SKEINS

1. Vivid green.	-	-	red-yellow-brown rd. yl. br	-
2. Vivid red.	-	-	red	-
3. Brown.	d.green	green	v.d.green blue & red	v.d. red
4. Magenta.	purple	blue	green	-
5. Med. green.	yellow	-	l.grey yellowish green	v.p.grey
6. Med. pink.	-	-	l.green	d.grey
7. V.p.green.	yellow or pink	-	-	-
8. V.p. pink.	-	-	-	-

TEST SKEINS

green	yellow	-	orange	-	l.grey
red	red brown	-	brown	brown	black fairly
d.brown	tinge reddish	green	brown	brown	d.grey
violet	blue yellow	pink fawn ^{and} green	blue	blue or purple	fairly d.blue
l.brown nearly white	or red red ^{and} ? white	-	yellow	-	med.grey yl. tinge
l.brown	red	-	grey	p.blue yellow	l.grey
flesh	? red	dirty white	yellow grey white	blue-green white or p.blue	yellow l.grey

Sheet to printer - Colour name in full.

Chapter IV
Small Copy Tests and Results, (Continued) (Hald)

4. Colour Equations, (Hald)

Colour mixings, to detect colour defect, seem to have originated with Professor Clerk Maxwell who devised his Colour Top. Since then this method has gained considerable favour in the diagnosis of abnormalities of colour vision.

In the series of experiments conducted, the Bradley colour papers were employed. These ~~are~~ all pure spectral colours. The discs were rotated in the usual way on an electric colour wheel. ~~Two sizes of discs were used and both were rotated on the one colour wheel.~~ As far as possible the intensity of light ~~was~~ kept constant. An equation for green was tried first of all. 360° green was rotated on the wheel and in front of it two smaller interlocked discs of black and white respectively were simultaneously ~~not~~ rotated, ~~and~~ an endeavour ~~was~~ made to get the outer and the inner discs to match. The black and white discs were adjusted according to the wish of the examinee until he was perfectly satisfied with the match. The proportions were then measured by means of a circular protractor. The colour-blind are very careful in matching colours and express intense dissatisfaction if the slightest difference is visible. Ten colour equations were tried in all, and each subject was tested with the complete set.

- | | | |
|-------------------------|---|----------------|
| 1. Green | = | black + white. |
| 2. Red. | = | black + white |
| 3. Red | = | green |
| 4. Red | = | yellow + black |
| 5. Green + red (+ blue) | = | black + white |
| 6. Blue + yellow | = | black + white |
| 7. *Green | = | yellow + black |
| 8. Violet | = | blue + black |
| 9. Orange | = | yellow + black |
| 10. Orange | = | green |

Below are the exact ^{Bradley} colours employed.

- Red = red tint 1.
 Green = blue-green
 Yellow = yellow tint 1.
 Violet = violet shade 2
 Orange = orange
 Blue = blue
 * Green = green

(1) Green = Black + White

Space	<u>Green + White</u>	=	<u>Black + White</u>
A.	360	=	216 + 144
B.	360	=	249 + 111
C.	—		—
D.	15 + 305	=	20 + 320
E.	122 + 238	=	135 + 225
F.	86 + 274	=	34 + 326
G.	360	=	241 + 119
H.	360	=	193 + 167
I.	197 + 163	=	110 + 250
J.	360	=	249 + 111

54
 Test & Results continued
 Colour Equations

profess to be
 Insert A here
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27

87

(27A)

(28)

insert-

A,

A circular piece of stout paper with a small aperture in the centre is fixed on the colour-wheel. In front of this, a large uncut disc is placed, or two large discs with edges cut along one radius, as the case may be. If there are two discs they are interlocked so that their proportions can be easily adjusted. In front of these large discs, and on the same wheel, smaller discs of paper are fixed. When the wheel is rotated, the colours of the larger discs are thrown so rapidly in succession on the retina that they mix and form one colour. Similarly, the smaller discs appear of one hue. The object of the experiment is to make the colour obtained from the inner discs identical in hue and brightness with the colour obtained from the outer discs when in rotation.

Such a method reveals the great difference which exists between the normal and the colour-defective eye. Matches are made by the colour-blind which appear absurd to the normal ^{to them} eye; and reds and greens in many cases, appearing colourless ^{to them} can be matched with greys. Consequently, equations are obtained which reveal the defect of the colour-blind. As far as possible...

W. S. P. 1881

In this case five of the subjects were able to obtain a perfect match - others required the green to be diluted with white before seeing it as a grey. The results of these five show a curious correspondence - in fact the equations of B and J, the two extremes as we may call them, are identical. This would denote for these particular subjects a complete blindness to green or rather blue-green. Later it was found that the blue-green in the spectrum formed ~~their~~^a neutral band. For a considerable time H. saw pink in the black-white disc where no pink was visible to examiner, whereas the final match, which to H. seemed perfect, appeared pinkish to examiner. The other subjects required the green to be diluted with white before it could be matched with a grey. In all cases however except in that of subject D, the green was clearly visible to examiner. The equations of C. and D. were excellent and perfectly normal - C's was not recorded but it was very similar to that of D. This is curious when their nomenclature is remembered - but it agrees with the fact that they did better than the other subjects in the Stilling Test.

for them

(2) Red = Black + White

	<u>Red + White</u>			=	<u>Black + White</u>		
A.	85	+	275	=	89	+	271
B.	82	+	278	=	68	+	292
C.							
D.	22.5	+	337.5	=	11	+	349
E.	49	+	311	=	64	+	296
F.	102	+	258	=	115	+	245
G.	143	+	217	=	33	+	327
H.	253	+	107	=	229	+	131
I.	195	+	165	=	278	+	82
J.	360	+		=	342	+	18

This series of equations clearly shows a difference in blindness to red. Only the extreme case J is able to match 360° with grey or rather black. H saw the 360° red as dark brown which he afterwards matched with a darkened yellow. This red which might be called a medium red he matches with grey. The others require differing amounts of red, ~~showing~~ blindness to red, but suggesting that the blindness to red is not of so grave a nature as the blindness to green. This would confirm the results obtained from colour naming, that red as a colour was more often recognised than green. The results of Subjects C and D again however point to a lesser defect. Subject I, although he called red black, could not get an equation with the full red disc. Both discs when rotated appeared grey to him but the one was more of a drab colour than the other. Subject F saw both the outer and inner rings red long before he could get them equated. The equations of A and B are very similar.

which shows

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(3) Red = Green

Red + White = Green + Black

A.						
B.						
C.						
D.						
E.						
F.						
G.	112	+	248	=	140	+ 220
H.	232	+	128	=	288	+ 72 (2greys)
I.	222	+	138	=	66	+ 124 + 170 white
J.	360			=	196	+ 164

This table gives striking results. Subjects A and F could not get an equation - surely this means that red and green are visible to them in some measure. Only the four last cases were able to obtain a match. In their final equations the red discs to the normal eye appeared a vivid red and the green discs a vivid green. G. had to get white into the green to lighten it and black in, not to make it darker, but to make it "heavier." Note the results of J. which differs from the others in that the red disc did not require dilution. A further equation was obtained with 360° green. In other words the colour equation could be obtained from him in any proportion. This was not so with the others. This seems to prove *once again* that there are varying degrees of colour-blindness - even G. and H. differ from one another. The variations occur too, apart from any individual idiosyncrasy - it seems to be a variation solely of degree.

(4) Red = Yellow + Black

Red = Yellow + Black

A.						
B.						
C.						
D.						
E.						
F.						
G.						
H.	360	=		25	+ 335	(2 browns)
I.						
J.	360	=		36	+ 324	

This confirms the results of equation 3. as regards severity of defect. H. sees red as dark brown and these two equations of H. and J. place them at once in the Scoterythrous Class as described by Professor Myers in his Experimental Psychology, where he gives the equation, 360° R = 18° + 342° Black. Helmholtz in the second edition of his Physiological Optics gives a similar equation. Dark red therefore appears as a very much darkened yellow, in the case of these two subjects, almost a black. Subject F. almost obtained an equation. The outer ring (the red

(1) At least red and green are influencing their sensations to some extent.
 (2) 360° sealing wax red = 35° yellow + 325° black.

28

(30)

split

(31)

split

87

✓

ring) was red; the inner ring was red and brown. The brownish tinge could not be obliterated. The other subjects failed completely to match the two discs.

(5) Green + Red = Black + White

Green + Red + Blue = Black + White

Space →

Normal	194	+	113	+	53	=	255	+	105
A.	162	+	108.5	+	53.5	=	276.5	+	83.5
B.	302.5	+	28	+	29.5	=	240.5	+	119.5
C.	198	+	110	+	52	=	269	+	91
D.	204.5	+	118.5	+	86.437	=	264	+	96
E.	230	+	130			=	237	+	123
F.	155	+	131	+	74	=	275	+	85
G.	277	+	83			=	261	+	99
H.	192	+	168			=	187	+	173
I.	231.5	+	68	+	60.5	=	271	+	89
J.	162	+	198			=	279	+	81

N.B. J. can employ any proportion of red and green and get an equation for he sees both as grey.

A green and red disc alone cannot be equated by the normal eye for there appears, on adjusting, either too much red or too much green. If the green and the red are eliminated, the result is yellow. A third colour therefore is necessary before a satisfactory equation can be obtained. This experiment was carried out on 22 normal subjects and the average of their results gives a fair indication of the normal equation. The equations obtained from the colour-blind subjects show marked deviations in some cases. Six of them required the addition of the blue before they evinced satisfaction, although in 4 cases their final equations appeared defective to the normal eye; the other 4 were able to obtain a match from the mixture of the red and the green alone.

C and D as before gave excellent results. C's match was almost identical with the normal equation.

A, B, F and I show deviations from the normal. All four cases declared the match to be perfect. In the cases of B and I the outer ring appeared very green to the experimenter and the inner ring decidedly pink by contrast. Both show an excessive proportion of green.

Normal 194°
B 302°
I 231°

and a correspondingly small section of red, seeming to point to the fact that the subjects are more blind to green than to red, (this result we have obtained before). B could not get a match with red and green alone for the outer ring appeared too green and the inner too pink; yet when blue was added he immediately expressed complete satisfaction, although to the experimenter's eye the green was still in evidence. Subject A also was dissatisfied with red and green alone, but immediately the blue was added, an instant change of judgment was given and the discs were claimed to be identical. Subject F shows an abnormal

this &



proportion of blue.

The other four subjects were able to obtain good matches without the addition of a third colour, and all expressed satisfaction with their equations. Subject J could obtain perfect equations with any proportions of red and green. How is it that this is so, and that other subjects suffering from the same defect are unable to do so? The other three show a larger proportion of green than red.

These results show considerable divergence and point to different degrees of colour-blindness ranging round red and green. The first few subjects gave clear evidence of seeing and recognising red and green.

thus

It might perhaps be added that an anomalous trichromate, who was tested and who could pass Stilling's Tables, gave the following ^{equation} $50^\circ \text{green} + 208^\circ \text{red} + 53^\circ \text{blue} = 280^\circ \text{black} + 80^\circ \text{white}$ which showed her to be red-anomalous.

(6) Blue + Yellow = Black + White

Similar results were obtained with blue and yellow discs, the yellow containing a green tinge. The normal eye requires to add a third disc of red before a satisfactory match can be obtained.

Blue + Yellow + Red = Black + White

Space
(34)
g/h

	Normal	Blue	Yellow	Red	=	Black	+ White
	165	+	147	+	48	=	213 + 147
A	237	+	101	+	22	=	197.5 + 162.5
B	172	+	188	—		=	165 + 195
C	175	+	155	+	30	=	195 + 165
D	192	+	147	+	21	=	236 + 124
E	204	+	156	—		=	240 + 120
F	171	+	189	—		=	238 + 122
G	170	+	190	—		=	240 + 120
H	202	+	158	—		=	236 + 124
I	183	+	177	—		=	219 + 141
J	169	+	191	—		=	199 + 161

Only three subjects required the third disc of blue. C's and D's equations show great similarity to the normal as before. A in her equation shows more blue and much less red than the normal. The other subjects were able to obtain a ~~satisfactory~~ equation without the addition of the third disc. Their results show a considerable similarity. The green contained in the yellow evidently was not detected by the examinees and the consequence was a set of equations which appear entirely faulty when viewed by the normal eye. B's results are not what might be expected from the previous results obtained, but he expressed great satisfaction with the match. He is a most reliable subject and always takes great pains with all his equations, not allowing the smallest difference to pass unobserved. To subject E. the final equation appeared as grey, although the discs appeared respectively pink and green to the examiner. Subject I called the two discs blue in his equation, although as before pink and green were clearly visible.

satisfactory

arrangement

the final result represented by



(7) Green = Yellow + Black

The green in this equation was a grass green.

Space

	<u>Green</u>	=	<u>Yellow</u>	+	<u>Black</u>
A.	360	=	278	+	82
B.	360	=	223	+	137
C.					
D.					
E.	cannot get rid of brown tint in yellow.				
F.	360	=	111	+	249
G.	outer circle green: inner red.				
H.	360	=	240	+	220
I.	360	=	186	+	174
J.	360	=	194	+	166

This is a characteristic equation of colour-blinds. Green is seen as a darkened yellow and most of the subjects obtained this equation. C. and D. as before stand apart. The green was not tried diluted or perhaps an equation with E and G might have been successful. Evidently this particular shade of green or perhaps of yellow did not suit their colour scheme.

(8) Violet = Blue + Black

	<u>Violet</u>	=	<u>Blue</u>	+	<u>Black</u>
A.	360	=	202	+	158
B.					
C.					
D.					
E.	360	=	131	+	229
F.	360	=	255	+	105
G.	360	=	246	+	114
H.	360	=	216	+	144
I.	360	=	202	+	158
J.	360	=	335	+	25

These were

This again is a typical colour-blind equation. Blue and violet are constantly being confused. The fact that C and D could not obtain an equation calls for little remark. C. however always showed considerable confusion in naming colours when matching them. Violet and blue were both called shades of blue. Then when rotated simultaneously and after a considerable amount of adjusting had been done, he declared he saw too much green! on the outer disc (evidently the red in the violet). He finally declared the inner disc to be a purer blue and although still convinced that the two discs represented two shades of blue, he was unable to get them matched.

D likewise called both discs shades of blue, the violet being the darker. Immediately the discs were rotated on the colour wheel, he called the violet disc no longer blue, but purple.

The fact that B is unable to obtain the equation is a curious one. He confuses blue and violet if presented separately, but when rotated he can immediately detect the purple element. The equations show a fair similarity except in the case of J, whose

they are ✓

in respect of

equation is totally different from any of the others ~~is~~ the small proportion of black employed. Does this indicate a blindness to blue or a defect in shade? The blue disc must have differed in brightness from the violet disc, being considerably lighter if we take the other subjects' equations as valid. The results from the Bradley test show that there does exist a deficiency in shade perception. To the subjects who obtained the equation violet appears as a darkened blue; the violet appears as a fairly bright blue. On the other hand other tests suggest the other explanation - a weakened sensitivity to blue.

L Paper

(9) Orange = Yellow + Black

Orange = Yellow + Black

A.				
B.				
C.				
D.				
E.				
F.	360	=	117	+ 243
G.				
H.	360	=	92	+ 268
I.	360	=	89	+ 271
J.	360	=	90	+ 270

8/11

The last three equations are very similar; that of subject F shows more yellow. Orange therefore appears as a darkened yellow, much darker than green appears to be, if we compare the results obtained from equation 7. This seems correct, for if the spectrum left of the neutral band is seen as shades of yellow, the orange will appear a darker shade of yellow than the green.

inf to the

Take H's results for example:

- 360 red = 25 yellow + 335 black
- 360 orange = 92 yellow + 268 black
- 360 green = 240 yellow + 220 black

The yellow disc employed in all three equations was the same; more yellow is required as we pass from red to green.

(10) Orange = Green

Orange + White = Green + White

A.	45.5	+	314.5	=	93	+	267
B.	114	+	236	=	134	+	226
C.	156	+	204	=	148	+	212
D.							
E.	37	+	323	=	76	+	284
F.							
G.							
H.	256	+	104	=	360		
I.	257	+	103	=	360		
J.	360	+		=	317	+	43 black..

In the equations of subjects A and E, the orange was so diluted that it appeared as a very ,

✓

very pale pink, the other disc as a very pale green. The colours in B's discs were more pronounced. C. this time obtained an equation, a stronger one than B. even. In both cases however the final discs resembled pale pink and pale green. Subject E. could not procure an equation, although he called the outer orange ring green, and the inner ring which was green red. With subject G. the outer ring was orange, the inner a grey and therefore no match could be obtained. It will be noted that the equations of H and I are very similar, although H called his orange, while I. named his green. In both cases the full green disc was matched with a diluted orange. Subject J. as before has an equation of his own, which totally differs from all others. ~~The full orange disc is~~ The full orange disc is matched with a darkened green; both appeared as a dark grey.

as regards colour

result

The equation of magenta and violet was tried, but unsuccessfully. To subject I for example the two discs appeared to him as two shades of blue, the former much darker than the latter but although both were blues it was impossible to equate them, not because they were of different colours but because the violet appeared a "cheerful" blue, whereas the magenta was of a "washed-out drab" appearance. With subject H. an equation of magenta and crimson was tried, but when rotated together they could not be matched for the blue appeared in the magenta. But when the magenta was matched with a blue or with a violet, it lost its blueness and became a grey, evidently an application of Weber's Law.

example of the operation

30

Colour-mixings are valuable for giving the precise colours which appear similar to a colour-blind, and seem to be a most useful test. The one disadvantage- at least, if used for practical purposes- is the time they require, but for theoretical requirements they are indispensable. Besides giving valuable insight into the individual cases examined, they yield general results in addition.

(1) Each case has been studied by means of the same ten colour mixings; the same objective tests have been applied, but the subjective results have varied considerably. The outstanding result which appeared with the Hering's wools and in nomenclature was that the colour defect could be graded. This same result appears decisively here. The subjects at the beginning of the list could not obtain equations which could be procured from those at the other end. The extreme cases had no difficulty in matching all the discs whereas those of the milder type could not possibly accept some of those equations. Without labouring the point, there is assuredly a clear difference in the degree of defect of all ten subjects. The weaker cases are without doubt influenced by red and green sensations.

(2) Each case is different from every other case. While making allowances for grade of defect,

✓

There still exists an individuality which marks off each particular case. A and B who are very similar in defect, do not always agree in their matches, and the one often fails to equate two colours which have been successfully equated by the other. Subject J. seems to have an individuality all his own, which was clearly shown on more than one occasion.

(3) The colour mixings show that in extreme cases, yellow and blue are the two colours from which every other colour is derived. To quote subject H's results :-

Red	=	25 yellow	+	335 black
Orange	=	92 yellow	+	268 black
Yellow	=			
Green	=	240 yellow	+	120 black
Blue-green	=	167 white	+	193 black
Blue	=			
Violet	=	216 Blue	+	144 Black

The above may be taken as the colours of the spectrum. Red, orange, yellow, and green are seen as shades of yellow, the blue-green forms the neutral band; the rest of the spectrum is seen as shades of blue.

Subject J.

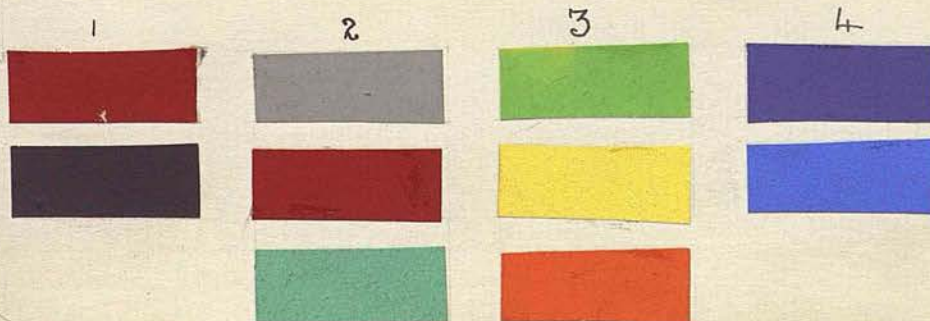
Red	=	36 yellow	+	300 black
Orange	=	90 yellow	+	270 black
Yellow	=			
Green	=	194 yellow	+	166 black
Blue-green	=	111 white	+	249 black
Blue.	=			
Violet	=	335 blue	+	25 black

This result is similar to that of H. In addition however this subject matches the same red with 18° white + 342° black. In both cases the red is seen as black. With H. the red had to be diluted a little before it was matched with a dark grey.

(4) The following colours are those which may be confused by a red-green colour-blind.

Red with grey, or with black in the case of a shortened spectrum; ^{blue -} green with grey, and red with green; yellow with orange, and green; also blue with violet.

Below are samples of J's matches, making small allowances for difference in shade.



Do be inserted if possible.

Omit

(39)

(40)

Omit

(5) The defect seems greater as regards green than as regards red. Otherwise how does one account for 360° green being matched with a grey in the case of A and B for example, whereas the red had to be diluted practically to that ~~of~~ normal vision before it could be matched with a grey. This agrees with the results from Stilling's Tables, that the red is more often recognised than the green.

required by /

(6) Colour Blinds accept as correct equations which can be obtained by the normal eye.

Right header

5. Rayleigh Equation (1) *(Hals)*

This is a particular form of colour equation so called after Lord Rayleigh (1881) who by this means was enabled to detect two special forms of variation from the normal, known now as 'anomalous trichromates.' In matching red and green= yellow, the majority tested centre round a common equation; there are some however who show marked deviation from the normal. The 'green anomalous' require a considerably large proportion of green before a match can be obtained, the 'red anomalous' require a similarly large proportion of red. The dichromate accepts the normal Rayleigh equation and also marked deviation from the normal.

All subjects were tested with the equation except subject I from whom unfortunately further data could not be obtained.

The results were as follows, and some of them compare quite favourably with the normal:

(41)

	<u>Red</u>	+	<u>Green</u>	=	<u>Yellow</u>	+	<u>White</u>	+	<u>Black</u>
Normal.	197	+	163	=	48	+	48.5	+	263.5
A.	184	+	176	=	47	+	52.5	+	260.5
B.	181	+	179	=	46	+	48.5	+	265.5
C.	186	+	174	=	36	+	65	+	259
D.	200	+	160	=	38	+	57	+	265
E.	248	+	112	=	27	+	62	+	271
F.	187	+	173	=	57	+	47	+	256
G.	158	+	202	=	38	+	74	+	248
H.	224	+	136	=	32	+	30	+	298
J.	338	+	22	=	35	+		+	325
J.	15	+	345	=	191	+	26	+	143

Anomalous Trichromate.

208	+	152	=	44	+	50	+	266
-----	---	-----	---	----	---	----	---	-----

The large extremes which are allowed by subject J. are remarkable. Unfortunately the limits in the other matches were not specially noted, but they showed less variation than that of J. D. for example, allowed a variation of about 40 degrees, after which the red was clearly distinguished.

those /

(1) Nature, 1881.

expressed in the words of

A and B. and D. would permit very little alteration in the proportions. The conclusion we would draw may be aptly ~~fit~~ Professor Hayes:- "All the subjects objected to wider extremes of red and green by correctly naming red or green when either one was increased beyond the limits finally decided upon; they insisted that the mixture was different in quality from the dirty yellow with which it was being matched, no matter how the yellow mixture was varied. Now, since dichromates are supposed to see red and green as yellows it is difficult to imagine how they were able to detect the reds and greens under the conditions, unless we grant the possibility that they may have some sense of red and green as a colour quality distinct from yellow." (1)

All subjects except H. and J. recognised the red and green in the two discs, which bears out Professor Hayes' conclusions, and confirms the results previously established.

Right heading

(Hals)

6. Analysis of Spectrum

In the absence of a spectrometer, which was not available for the experiment, ~~resort had to be made~~ to testing the subjects with a coloured plate - that in Parson's 'Introduction to Colour Vision'. A piece of firm paper sufficient to cover the spectrum in its entirety and containing a small vertical aperture was employed. This allowed only a very small part of the spectrum to be seen at one time and the subject was asked to name the colour visible. This test, without doubt, is open to most serious objections and as a test is not in the least reliable. It is wonderful therefore that the results obtained from this primitive spectral exploration ~~verified~~ the results obtained from more exact methods.

we had to resort

agreed with

The following points of the spectrum were taken - they are expressed in Angstrom Units (2)

The wave-lengths are indicated by the presence of Fraunhofer lines, which being constant in position, give a series of fixed points in the spectrum. The colours centre more or less around these points, ~~therefore their~~ wave length is to a certain degree arbitrary.

the selection of

but / 8

(12)

8/8

Colours	A. U.
Black	
Dark Red	A. - 7606
Red	B. - 6869
Orange	C. - 6564
Yellow	D. - 5897
Yellow-green	
Green	E. - 5271
Blue-green	F. - 4862
Blue	G. - 4308
Violet	H. - 3696
Black	

(1) American Journal of Psychology, 1911.

(2) Angstrom unit = 1 mm.

(43)

delay
of
rules

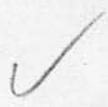
	Black	d.Red.	Red.	Orange	Yellow	Y-Green.	Green	B-Green.	Blue	Violet	Black.
A.	Black	d.Red.	Red	Orange	Yellow	Y-Green	Green	Greenish Grey.	Blue	Violet	Black
B.	Black	d.Red	Red	Orange	Yellow	Y-Green	Green	Greenish Grey.	Blue	Purple	Black
C.	Black	Brown	R-Yellow	Orange	Yellow	Orange	Orange	Green	Blue	d.Grey	Black
D.	v.d. ^{Blue} ack	d.Brown	Red	Yellow	Brown	l. Yellow	l. Green	Green	Blue or Green	Purple	Black
E.	Black	Reddish Grey	Red	Orange	Yellow	l. Green	Grey	Greenish Grey	l. Blue	Grey	Black
F.	d.Red.	d.Red.	Brown	Yellowish Brown	Yellow	Brownish Yellow	l.Red.	l.Red.	l.Rad.	Red	d.Red.
G.	Black	d.Red	Red	Red	Yellow	Orange	Grey	Grey	Blue	Greenish Blue	Black
H.	Black	d.Grey	d.Brown	Green	Yellow	Orange	Grey	Grey	Blue	d.Grey	Black
I.	Black	d.Red or Black	d.Red or Black	Reddish Yellow.	Yellow	Reddish Yellow	Greenish Red	Pinkish Green	Blue	d.Blue	Blue.
J.	Black	Black.	Black	medium Grey.	Yellow	Pinkish Brown Grey	medium Grey	d.Grey	Blue.	Black	Black.

This rough spectral diagnosis is instructive. A glance at J's spectrum reveals the fact that his defect is very grave. He has the spectrum considerably shortened at the red end, for no colour is seen until the sodium or D line is reached; even the orange is seen as a medium grey. A large neutral band is revealed in the centre including the yellow-green, the green and the blue-green; this is larger than is usual, for the yellow-green too is merely seen as a brightness. The spectrum at the violet end seems to be shortened leaving only a narrow band of blue. It is interesting to note that Dr. Edward Raehlmann in Halle, when testing for colour-blindness, noticed that when the red end of the spectrum was shortened the violet end was also reduced. This does not seem to have been generally acknowledged. This subject thus has only two narrow bands of colour in the spectrum - a narrow band of yellow, and one of blue, ~~this~~ account for the regular which would / unfailling series of greys which all colours appear to him to be. It may further account for the fact that blue is often seen as a grey.

The spectrum of subject I. is somewhat different ~~and~~ from his ~~extreme~~ nomenclature it is difficult to ~~conclude as to~~ what spectral colours are visible to him. At the time of being tested his colour vision had become the centre of interest at home, and he had been instructed in the colours of the spectrum just before he was tested, which was unfortunate for the test. It is evident however that he has the red end of the spectrum shortened but not to such an extent as J. Sensations of colour begin for him about the band of orange. He probably has an extended neutral band, but this would require a more thorough investigation before a definite decision could be reached. Yellow-green he calls reddish yellow or pinkish brown, green he calls greenish red, and blue-green he designates as pinkish green. This shows an entire lack of recognition of

but/
determine

confused/



the colours. His blue, however, is more extended and reaches well out to the violet end.

Subject H. is a third case of a shortened spectrum. His colour sensations begin in the red. He has a large neutral band over the green and blue-green, and he seems to have - as in the case of J. - the spectrum shortened at the violet end.

Subject E. has not generally been regarded as having a shortened spectrum, for he passed Stilling's Table 3., and in the matches with wools and in nomenclature, he did not give any evidence which might give rise to the belief that a shortened spectrum ~~did~~ existed. He was one of the subjects however who more than once called a blue a grey, and it would seem here that the violet end of the spectrum is shortened, leaving a narrower band of blue than usual. It will be noticed further that he names the dark red a reddish-grey. He has a neutral band which embraces green and blue-green.

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Subject C. is the only other one who calls the violet, grey; he also calls the dark red a brown, but his nomenclature is so bad that it is an unreliable criterion.

Subject G. with a normal length of spectrum has a large neutral band extending over the green and the blue-green. A. and B. with shortened and unshortened spectrums respectively - if Stilling's Tables are correct - have a grey band in the blue-green. This spectral examination reveals no shortened spectrum in the case of A. as one might expect, for she was totally unable to read Table 3. of the Pseudo-isochromatic Tables of Stilling.

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These results amplify the conclusions already reached regarding the difference in degree of the defect. Those cases in which the spectrum is shortened appear to suffer from a greater abnormality of vision than those whose spectrum is of normal length. Also they raise the problem as to whether a spectrum shortened at the red end indicates a shortening at the violet end as well. Further, the neutral band varies its position; sometimes it is in the blue-green, at other times in the green; while it occasionally includes both. In more extreme cases it may extend to the yellow-green.

The results also /

light headedness

(7) Bradley Papers Test

Hals

This test was kindly suggested by Dr Drever. It was originally devised as a possible means of explaining the term reddish green which is used by some colour-blinds, but it was found also to give a fairly reliable spectral analysis. The Bradley colours with shades and tints were arranged in a specific order on a large rectangular ^{oblong} of white cardboard. The colours in each case measured two inches by one inch. These were arranged at equal distances apart eighteen in a row, five rows in all. The centre rows (called ϕ) contained the pure spectral and extra-spectral colours

as we have seen,

87

and C respectively /

two /
on each sheet

beginning with violet-red, red, orange-red, red-orange orange, and passing with as many gradations through yellow, green, blue and violet until red-violet was reached. The two rows above that contained Shades 1 and 2 of these colours (shade 1 called B; shade 2-called A). The two rows below that contained two tints of these colours (tint 1 called D; tint 2 called E). Looking from left to right were the spectral colours, five rows in all, A, B, C, D, E; looking from top to bottom were eighteen vertical rows containing variations of tint and shade of ONE colour. The total number of colours equalled 90. A ~~second~~ smaller card contained the ten Bradley shades of black, white and grey.

band ka and kd and ke and

(Substitute)
Looking from left to right, with the two sheets contiguous, there were eighteen vertical columns, each containing five colours comprising tints and shades of a single hue.

third /
of each

In addition 100 oblongs of colour (including shades of grey) were affixed to visiting cards and their position relative to the larger card indicated on the back.

The method of procedure might be divided into three parts. 1) The large placard containing the colours was spread out in a good light before the examinee. The experimenter picked out at random one of the smaller cards containing a colour or a grey and asked the subjects to match it exactly from the larger assortment before him, with colour and brightness identical. To the normal eye this is simplicity itself, but it was amazing that to the colour-blinds this often proved a task of stupendous difficulty, even although the arrangement of colours in a regular order would seem to offer a little guidance.

(The arrangement of the colourless series on a separate card did not seem to suggest a difference in sensations either, as the greys, the black and the white were often matched with colours. 2) The subjects were asked to name the colours in the different rows. This gave a good indication of the spectrum as it appeared to them and considerable insight into their defect. 3) An attempt was made to analyse the colour sensation known as 'reddish green'.

- { 1) / The Naming of the Colours /
- { 2) / Matching Colours /

The second part of the test acted as a confirmatory test to the last one. A larger variety of spectral hues was available which accordingly gave more accurate results. Although the results are rather lengthy, it will be advisable to record them in full.

On the next page is the table with the colours as they appear to the normal eye.

a	b	c	d	e
1 Red-Violet	Violet	Violet-Red	pale Violet	pale Violet
2 v. d. Red	Violet-Red-Violet	Red	Red	Pink
3 Red-Violet	dull R-Orange	Red	pale Pink	pale Pink
4 Bright Red	dull Br-Red	Red	pale Pink	pale Pink
5 . . .	Orange	Orange	pale ORANGE	pale Pink
6 Red-Orange	l. ORANGE	Orange	pale Y-Pink	Y-Pink
7 dull Yellow	l. Br-Orange	Yellow	pale Br-Yellow	pale BROWN
8 dull Green	Y-GREEN	pale Yellow	Yellow	Cream
9 Green	Green	Y-GREEN	Y-GREEN	very p. GREEN
A.	B.	C.	D.	E.
1 Green	Y-GREEN	Y-GREEN	pale Y-GREEN	Cream
2 Green	grass-GREEN	Green	pale GREEN	pale GREEN
3 Blue-GREEN	Blue-GREEN	Blue-GREEN	pale B-GREEN	pale B-GREEN
4 Blue	Blue	Blue	pale Blue	pale B-GREEN
5 Blue	Blue	Blue	Blue	pale Blue
6 Violet	Violet	royal-Blue	pale V-Blue	paleViolet
7 Violet	Purple	Purple	pale V-Blue	paleViolet
8 d. Purple	d. Purple	Violet	pale Violet	paleViolet
9 v. d. -Violet	v. d. -Violet	Red-Violet	pale B-Pink	paleViolet

~~All colours~~

1. Black
2. White
- 3-10. Shades of Grey ✓

Below are the results of the different subjects. The first two parts of the experiment will be discussed together.

Subject A:

a	b	c	d	e
1 d. Violet	Violet	Violet	Violet	pale Violet
2 d. Red	d. Red	d. Red	Red	Red
3 Red	Red	Red	Red	Pink
4 Red	Red	Red	Red	Pink
5 Red	Red	Orange	Red	Pink
6 Brown	Orange	Orange	Reddish-Yellow	Pink with Yellow
7 Green	Greenish-Yellow	Yellow	Yellow	Yellow
8 Green	Greenish-Yellow	Yellow	Yellow	Yellow
9 Green	Green	Y-GREEN	Yellow	Yellow
A.	B.	C.	D.	E.
1 Green	Green	Green	Yellow	Yellow
2 Green	Green	Green	Green	pale GREEN
3 Green	Green	Green	Green	Blue
4 Blue	Blue	Blue	Blue	Blue
5 Blue	Blue	Blue	Blue	Blue
6 Blue	Purplish	Blue	Blue	Blue
7 Blue	Purplish	Blue	Blue	Blue
8 Blue	Purplish	Violet	Blue-t	Blue
9 d. Grey	Violet	Violet	Violet	Blue

1. Black ✓
2. White ✓
3. Grey ✓
4. Green ✓
5. Greenish Grey
6. Shades of Greenish
7. Grey ✓
8.
9.
10.

(44)

8/1-

7 (45)

8/1-

✓

in the naming is

The most striking fact about this table is that the shades of grey are taken to be shades of greenish grey, a clear confusion of green with grey. This confirms all the other experiments that the blindness is more one of green than red, the only exception, curiously enough, being the Rayleigh equation where less green than red was employed to match the yellow. A neutral band in the spectrum does not make its appearance but later the grey cards are invariably matched with the blue-green thus indicating a weakened sensitivity in this region. The green in yellow-green is not always recognised but is frequently called yellow. There is also a confusion of blues and violets and purples. One of the red-violets is called a dark grey. This colour is an extra-spectral colour and is the complementary of the blue-green which forms the neutral band. This forms a second neutral band beyond the spectrum... There seems to be no sign of a shortened spectrum.

the colour

In matching colours, A made many mistakes particularly with the blue-greens. The most interesting results were obtained by asking the subject to match the grey cards. These she invariably matched with the blue-greens. The white card too was thought to be green and was matched with C3, D3 and E3, blue-green and its two tints. A darker shade of grey she matched with B3 (a shade of blue-green) and when asked to match B3, she looked carefully over all the greys. The darkest shade of grey was matched with the darkest shade of blue-green. This proves conclusively the presence of a blue-green neutral band.

33

Other matches show a confusion of blues with violets. D8 (a violet) was matched with C4 (a blue).

The perception of shade seems to be good, although mistakes occur here and there. For example, d2 is matched with d2, d4, b3 and b4; ~~not~~ these are all thought to be identical in colour and shade.

Subject B/

(4b)

a	b	c	d	e
1 Greenish Crimson	Greenish Purple	Purple Crimson	Blue-Pink red	Pink
2 v.d.Crim	Crimson	Crimson	Red	Red
3 Brown	d. Red	Red	pale Red	Pink
4 l.Brown	d. Red	Red	pale Red	Pink
5 l.Brown	Red	Orange	pale Red	Yellowish Pink
6 Green	Greenish	Orange	Yellow	Yellowish Pink
7 Green	Greenish	Red	Yellow	Yellow
8 Green	Greenish	Red	Yellow	Yellow
9 Green	Green	Greenish	Yellow	Yellow
A	B	C	D	E
1 d.Green	Green	grass Green	Greenish	Yellow
2 d.Green	Green	Green	Green	Greenish White
3 v.d.Green	Grey	Blue-Green	Blue-Green	Greenish Blue
4 Blue	Purple	Blue	Blue	Blue
5 Blue	Blue	Blue	Blue	pale Blue
6 Blue	d.Blue	Blue	Blue	pale Blue
7 Blue	Purple	Violet	Blue	pale Blue
8 l.Blue	Purple	Purple	Blue	Blue with Red
9 l. Blue	d.Purp	Purple	Reddish Blue	Blue with Red

SP

Blue-Green and Red

✓

- 1. Black/
- 2. White/
- 3-10. Different Shades of Green/

Here again the shades of grey are seen as different shades of green, and there is a suggestion of a neutral band in the blue-green. The extra-spectral colours give interesting results. They are evidently puzzling colours. We find they are described as greenish crimson, dark greenish purple, and blue-green. The green in the greenish crimson (a dark shade of violet-red) is said to be similar to that of the same shade of the blue-green, which seems a striking coincidence.

This subject seems to have a greater confusion of colours than subject A; he does not always clearly distinguish between yellows and greens, nor can he always discriminate the reds.

In matching colours, he shows a better perception of shade than A. His confusion is similar to hers in that greys and blue-greens are constantly mixed. He also matches one of the extra-spectral colours with C3, the blue-green.

Subject C/

a	b	c	d	e
1 Green or Grey	Green or Grey	Green or Grey	Green or Grey	Green or Grey
2 Brown	Brown	Brown	Brown	Reddish Green
3 Brown	Brown	Brown	Greenish Red	Reddish Green
4 Brown	Brown	Crimson	Greenish Red	Yellow Green
5 Brown	Brown	1. Brown	Yellow 1. Brown	Y. & Green
6 Brown	1. Brown	1. Brown	1. Brown	Y. & Green
7 1. Brown	1. Brown	Yellow	1. Brown	Y. & Green
8 L. Brown	1. Brown	Yellow	Yellow	Y. & Green
9 1. Brown	Greenish Brown	Greenish Yellow	1. Brown	Y. & White
A				
1 Greenish Brown	Greenish Brown	Greenish Brown	1. Brown	Y. & White
2 Green	Greenish Brown	d. Green	Greenish Brown	Green White
3 d. Green	Green	1. Greenish Grey	Grey	1. Green
4 Blue	Blue	Blue	Blue	1. Green
5 Blue	Blue	Blue	Blue	1. Blue
6 Blue	Blue	Blue	Blue	Blue
7 Blue	Blue	Blue	Blue	Blue
8 Blue	Blue	Blue	Blue	Blue
9 d. Green or Grey	Green	Blue	Blue	Blue

- 1. Black
- 2. White
- 3-10. Grey or Green/

This table emphasises the serious features of C's defects. We have already seen how his nomenclature is at variance with his colour equations. This is a further proof of the curiously contradictory results which the diagnosis of his case reveals.

There evidently exists a blue-green neutral band, with the complementary purple also seen as grey. All the hues of violet-red and some of those of red-violet he calls grey or green and compares them with

the grey cards as being of a similar nature. He has a well-marked confusion of blue and violet; he only mentions red once (crimson) except when he uses the term in the compound phrase, reddish green. This would seem to indicate either a deficiency in red, or an extremely bad nomenclature. The term orange, too, is never mentioned; brown takes the place of it and red.

In colour matching he shows great confusion in shade as well as in colour. A dark Grey which he thought was a green was matched with d1, a pale violet; e1, a similar colour, was matched with a grey. These two colours belong to the extra-spectral neutral band of grey. A8, a dark purple, was matched with B1, a yellow-green, and also with a6, a8, a9, orange and greens. B8, of the same hue, was matched with a lighter shade of yellow-green. For d5, an orange colour, no match could be found, and the subject could not even remember the name of the colour. He later described it when going over the colours as composed of yellow and light brown. He is rarely content with giving one match to a colour but frequently gives three or four showing a defect in shade.

was/
gave/

- e.g. A8 = a6, a8, a9, B1.
 B8 = B4, B8, b8, C8,
 b7 = b7, b8, c5, c6,

It is difficult to reconcile these results with the results obtained from him in his colour equations but they do correspond with the other tests we have considered.

(48)

Subject D/

a	b	c	d	e
1 Purple	Purple	Purple	Purple	Purple
2 Brown	d.Brown	d.Grey	d.Brown	d.Brown
3 Brown	Brown	l.Red	Red	Brown
4 Brown	Brown	Red	Red	Brown
5 Brown	Yellow	Brown	l.Yellow	Brown
6 Yellow	Brown	Yellow	Brown	Brown
7 Brown	Brown	Brown	Yellow	Brown
8 Green	Green or Yellow	Yellow	Yellow	Yellow
9 Green	Green	Green	Br-Y or Gr ^{cc} _λ	Yellow
A.	B.	C.	D.	E.
1 Green	Green	Green	Green	v.l.Gr ^{cc} _λ
2 Green	Green	d.Green	Green	v.l.Gr ^{cc} _λ
3 Green	Gr ^{cc} _λ or Blue	paleBlue	v.l.Gr ^{cc} _λ	Blue
4 Blue	Blue	l.Blue	Blue	Blue
5 Blue	Blue	Blue	Blue	Blue
6 Purple	Blue	Blue	Purple	Blue
7 Purple	Purple	Purple	Purple	Blue
8 Purple	Purple	d.Purple	Purple	Purple
9 Brown	Purple	Purple	Purple	Purple

Brownish-Yellow/

1. Black/
2. White/
- 3-10. Shades of Grey/

This table calls for little comment. It seems to suggest a neutral band of red, for red is seen as a dark grey. Further, orange is not recognised through-out. It shows a confusion of red ~~and~~ brown and of yellow with green. It also reveals difficulty with the purples, and some doubt in naming them. In the pale tints in Row e, he sees no pink at all, but names them brown. d8, a yellow, is described as a brown, or yellow, or green. He would appear to be better classed as an Anomalous Trichromate and not as a colour-blind had not the acceptance of the Rayleigh equation proved otherwise. He is certainly a 'dangerous' colour-blind so far as practical occupations go.

with/

In matching colours he shows a slight defect in shade and at times is unable to obtain a match to satisfy him. For example, in matching c9, he states that c9 is too dark and d9 too light - the exact match lies between these two. [a6 is matched with a5, a4, b4, b3.

One match which tends to suggest a neutral band in the extra-spectral purple is the match used with c1. c1 is technically known as a violet red, but it was matched with c9, a yellow green. This is the same colour which he could not describe and about which he could only state that it was not a purple. This may indicate the existence of a small band of the spectrum in which green is not visible, and further it may suggest that the yellow spreads out into the yellow-green, for it is always about that region that mistakes occur. It is an interesting case which would repay further study by more exact methods.

Subject E:

a	b	c	d	e	
1 v.d. Grey	d. Blue	a1- Blue	a ₂ Red	d. Pink	Pink
	almost Black	almost Black			
2 v.d. Red	d. Red	d. Red	Red	1. Red	
	almost Black				
3 d. Red	Red	Red	1. Red	Flesh	
4 d. Red	Red	Red	1. Red	1. Red	
5 Bght Red	Brighter Red	Orange	Red	Red	Red
6 Brown	1. Brown	Orange	Red & Yellow	Red & Yellow	
7 Bright Green	1. Brown	Yellow	Bght. Yellow	1. Yellow	
8 Green	1. Brown	Yellow	Yellow	Yellow	
9 Green	Green	Bght. Gr ^{cc}	Green	Yellow & Gr ^{cc}	
A.	B.	C.	D.	E.	
1 Green	Green	Green	Green	almost White	
2 Grey	Gr ^{cc} Gr ^{cc}	d. Green	Green	Gr ^{cc} Gr ^{cc}	
3 d. Grey	Grey	Grey	Grey	1. Grey	
4 Blue	Blue	Blue	Blue	Blue	
5 Blue	Blue	Blue	Blue	Blue	
6 Blue	Blue	Blue	Blue	Blue	
7 Blue	Blue	Blue	Blue	Blue	
8 Blue	Blue	Blue	Blue	Blue	
9 Blue	Black	Blue	Blue	Blue	

- 1. Black,
- 2. White!
- 3-9 Shades of Grey
- 10 Grey Green

X

Handwritten scribble

✓

This table clearly reveals a neutral band in the green and the blue-green which confirms the diagnosis of the previous test. The two shades of red-violet and violet-red appear as almost black, revealing a second neutral band there. The violets themselves are not recognised, but all ^{are} considered as shades of blue. Red, orange and yellow are discriminated as colours although occasionally they overlap and the change of colour as seen by the normal eye, is delayed in his case. It is only in the centre ~~column~~ that he recognises orange - to the tints and shades the term is not applied although he twice uses the expression red and yellow. a7, seen by the normal eye as a dull yellow, the subject describes as a bright green. While the greys appear as such, the darkest shade is thought to be a green.

row/

In matching colours, considerable confusion is revealed with the greys. Shades 3, 5, 7, and 8 are all matched with C3, the blue-green. This occurred with most of the subjects. Shade 6 is matched with B3, a blue-green. Shade 9 is matched with c2, a3, b3, a5; that is, with red and shades of red. This shows a confusion of red and grey - a conclusion we have previously reached. Shade 10, which is to him a dark green, is matched with A3 and B3, two shades of blue-green.

A3, a blue-green, which he considers to be a grey containing red, is matched correctly but only after all the reds have been carefully examined. A4, a blue to the normal eye, (though technically a tint of green-blue) is matched with a4, a5, b3, b4, shades of red and orange. A9, a very dark violet, is matched with A9, B9, b1, and A1; b1 is the other extra-spectral colour and A1 a green, which all appear as grey. This explains why purples, greens and greys are considered as correct matches. It may also explain why some violets or purples were seen as grey in some of the previous experiments.

Subject P,

a	b	c	d	e
1 Red	Red	Reddish Blue	Reddish Blue	1. Red
2 Red	Red	Red	Red	Red
3 Red	Red	Red	Reddish Green	Green
4 Red	Red	Red	Green	Green
5 Red	Reddish Brown	Reddish Brown	Yellowish Brown	? Gr ^{ae} in it
6 Reddish Brown	Reddish Brown	Yellow	Yellow	Yellow
7 Yellowish Brown	Yellow	Yellow	Yellow	Yellow
8 Yellowish Brown	Yellow	Yellow	Yellow	Yellow
9 Yellowish Brown	Yellow	Yellow	Yellow	Yellow
A	B	C	D	E
1 Reddish Brown	Reddish Brown	Yellow	Yellow	Yellow
2 Reddish Brown	Reddish Brown	Yellowish h. Brown	Yellowish Gr ^{ae} n	Gray
3 Red	Red	Greenish Grey	Reddish Gr ^{ae} n	1. Green ?
4 Reddish Blue	Reddish Blue	Blue	Blue	Reddish Blue
5 Blue	Blue	Blue	Blue	Blue
6 Blue	Blue	Blue	Blue	Blue
7 Blue	Blue	Blue	Blue	Blue
8 Blue	Blue	Blue	Blue	Blue
9 Blue	Red	Blue	Blue	Blue

34

(50)

8/1

✓

- 1. Black.
- 2. White.
- 3. Reddish Green
- 4. Reddish Green
- 5. Red
- 6. Red.
- 7. Grey.
- 8. Reddish Green.
- 9. Grey.
- 10. Green.

Much confusion is exhibited between the red and green in this table. The green sensation is weakened in the green and the blue-green; whether there is a complete neutral band here is doubtful-but there is a possibility that such is the case. Certainly, the green is not a clearly defined sensation for him. It is curious, too, how often a green sensation is named red by the subject. Usually a green is confused with yellow, but in this instance there is a direct confusion with red. In columns a and b, green is never mentioned, but its place is taken by a yellowish and a reddish brown. e3 and e4, two pale greens, are both termed pinks; e5 however, another green, is recognised as such but in association with some other colour. The darker tint of the same green is described as a reddish green.

Violet is seen as blue throughout. The shades of grey appear as greys, reds, greens and reddish greens. (reds and greens) The complete confusion of with each other, and with grey, seems to be indicated in this instance.

Matching colours reveal^s a good perception of shade. The white card was matched with E3, a very pale blue-green, and grey was matched with C3, also a blue-green. e1, an extra-spectral purple was matched with E4, another pale blue-green. This seems to be a characteristic of colour-blinds. E8, a pale violet, was matched with e1 and d4, a purple and a pale pink. This is the typical confusion of blue with pink. a7, a dull yellow, and C2, a green, were judged to be identical.

It is worthy of note that the violet-reds are described as reddish blues, but ~~these lose value~~ when we find that green-blues are similarly described.

the significance of this fact becomes clear

relatively correct description

(51)

Subject G				
a	b	c	d	e
1?d.crim	d.Grey	Violet	Grey	Grey or Green
2Crimson	Crimson	Crimson	Red	Red
3Red	Red	Red	Red	very p.Red
4Red	Red	Red	Red	Green
5Red	Red	Red	Red & Yellow	Green
6Green	Green	Green	Red & more Yellow	Green
7Green	Green	Yellow	Yellowish Green	Grnsh, Yellow
8Green	Green	Yellow	Yellow	Yellowish Green
9Green	Green	Green	Green	Yellowish Green
A	B	C	D	E
1Green	Green	Green	Green	Cream
2Green	Green	Green	Grey	Grey
3Grey	Grey	Grey	Grey	Bluish Grey
4Blue	Blue	Blue	Blue	Bluish Grey
5Blue	Blue	Blue	Blue	Blue
6not so Blue	Blue	Blue	Blue	Blue
7Blue	Blue	Blue	Blue	Blue
8Blue	Blue	Red & Blue	Blue	Blue
9Grey	Grey	Blue	Blue	Blue

✓

- 1. Black
- 2. White
- 3-10. Green

As in previous cases the neutral band in the blue-green is strongly marked, but it extends into the green as well. The purples present great difficulty and are sometimes called grey, sometimes green. Orange is not recognised, but is replaced by green; e4 and e5, pale pinks, are described as greens. To the right of the neutral band the spectrum is seen as shades of blue. The shades of grey are not discriminated from shades of green.

In matching, the white card is confused with E3, a very pale blue-green, the greys likewise. c9, a yellow-green is not differentiated from C4, a green-blue. There is, too, frequent confusion between yellows and yellow-greens.

Subject H

(52)

Brown/
Brown/
Brown/
Brown/

a	b	c	d	e
1 Black	Blue	d.Blue	Blue	l.Blue
2 d.Br ^{very black}	Brown	d.Br ^{very black}	Med.Brown	Med.Brown
3 d.Brown	Brown	d.Brown	Grey	Grey
4 l.Brown	Brown	l.Brown	Grey	Grey
5 l.Brown	Brown	l.Brown	Grey	Grey
6 very l.Br	l.Brown	very l.Br	h.Grey	Dirty Yellow
7 very l.Br	Orange	Orange	Yellow	Dirty Yellow
8 very l.Br	d.Orange	l.Orange	Yellow	l.Yellow
9 very l.Br	d.Orange	d.Orange	d.Yellow	l.Yellow
A	B	C	D	E
1 Brown	l.Brown	Orange	l.Yellow	White
2 Med.Brown	l.Brown	Med.Brown	Grey	Dirty White
3 Grey	very d.Grey	d.Grey	Grey	l.Grey
4 d.Blue	d.Blue	d.Blue	Blue	d.Grey
5 d.Blue	Vivid Blue	d.Blue	Blue	Blue
6 v.d.Blue	Blue	v.d.Blue	Blue	Blue
7 d.Blue	Blue	v.d.Grey	Blue	Blue
8 d.Blue	Blue	v.d.Grey	Blue	l.Blue
9 Black.	Blue	Blue	Blue	l.Blue

- 1.Black
- 2. White
- 3-10. Shades of Grey

This table is an interesting one for it plainly shows the effect of a shortened spectrum. The neutral band embraces the green and the blue-green, and is present in the unsaturated green-blues. This will account for the fact that certain blues in the wool test were considered greys. Very pale tints of this colour or very dark shades will be so confused.

The complementary colour of the blue-greens is seen as blue or black; the shades as black, the tints as blue. The tint which appears as a bluish pink to the normal eye is composed of red and violet. As the subject is blind to red, the red sensation is completely absent, and the violet sensation remains, which is seen as blue.

Red is seen as black or very dark brown, and if we consider Row C this colour name serves to describe

✓

All the red and the orange sensations. No colour is recognised until the orange-yellow(c7) is reached. This is called orange by the examinee, and the same name includes pure yellow, green-yellow, and yellow-green. 'Orange' is constantly applied to a green containing yellow.

The tints show markedly the absence of a red sensation, for d1, d2, d3, and d4 yield only greys.

One other interesting feature is worthy of note. C7 and C8, a blue violet and a violet respectively, are colourless, which points to a shortening of the violet end of the spectrum. This coincides with the finding of the last experiment.

In matching, many points of interest came to light. The black card was matched with red, the white with a very pale blue-green. Certain shades of grey were confused with e2, e3 and c3, reds and pinks; others were thought to be identical with the blue-greens. The general mistakes made with the colours were blues erroneously judged to be violets, and yellows, greens.

A defect in shade, though not a serious one, occurs frequently.

- e.g. B7 and c8
- D1 d9
- A4 A6
- E9 E7
- b4 d5

In these cases the colour is correct, but the shade is defective.

Subject J!

a	b	c	d	e
1 Grey	Grey	Blue tinge	Blue tinge	Grey
2 Black	Black	Black	Black	Grey
3 Grey	Grey	Grey	Grey	Grey
4 Grey	Grey	Grey	Grey	Grey
5 Grey	Grey	Grey	Grey	Grey
6 Grey	Grey	Orange	Grey	Grey
7 Grey	Grey	Yellow	Orange	Yellow
8 Grey	Grey	Yellow	Yellow	Yellow
9 Grey	Grey	Yellow	Yellow	1.Yellow
A	B	C	D	E
1 Grey	Grey	Grey	Yellow	White
2 Grey	Grey	Grey	Grey	Grey
3 Grey	Grey	Grey	Grey	Faint Blue
4 Blue	Blue	Blue	Blue	Blue
5 Blue	Blue	Blue	Blue	Blue
6 Blue	Blue	Blue	Blue	Blue
7 Blue	Blue	Blue	Blue	Blue
8 Blue	Blue	Blue	Blue	Blue
9 Black	Black	Blue	Blue	Blue

- 1. Black
- 2. White
- 3-10. Grey

This was a most difficult test for this subject and caused him intense fatigue, for he had to rest his eyes frequently.

This table presents different features from any of the others, for it reveals an amazing lack of

35

9 (53)

81

77

colour sensation. The spectrum is shortened and no colour is seen before the yellow-orange. (c6) With the last subject, the colours beyond that were named brown but with this subject they are merely brightnesses. The yellow band in the two shades is non-existent, and only grey is seen until the blue begins to make an impression, which indicates a weakened sensitivity to yellow. The neutral band is large, extending over the yellow-green, the green, and the blue-green. His spectrum accordingly, is as follows:- A shortened spectrum at the red end; a large grey band; larger than ordinary; and then a region of blue which seems here to extend to the violet. The last diagnosis pointed to shortening at the violet end.

In matching colours marked confusion was revealed, which was to be expected, considering the large number of colours which the subject sees as grey. This part of the experiment was lengthy because J. had to search all the cards each time.

Black was matched with a2, a3, b2, c2, d2, all reds, which is a typical feature of his case. White was matched with e8, B3, B4, a cream colour and two very pale blue-greens. No. 4. a shade of grey was confused with b4, c4, e2, orange red, red and pink and with A2, and B3, green and blue-green. No. 7. a different shade of grey was matched with a9, b5, B1, C3, c4, d3, e2, all of which were claimed to be identical with the test card. They include green, orange, yellow-green, red, blue-green, pink. No. 9. a dark shade of grey was not differentiated from e2, b3, d3, b4, c4, B3, pinks, reddish-orange, red and blue-green.

It will be noticed from these few examples that there exists a decided defect in shade perception, which seems to be caused by the shortening of the spectrum.

In matching colours the same confusion exists, and all are characterised by the large selection made.

d1, a tint of red violet, was found to be a most difficult test, for it did not appear as a pure blue. It was finally matched with d1, c1, C9 ~~and~~ B4, as well as with / a blue. c6, an orange, was matched with the following large variety, c6, c5, b6, b7, a7, a8, a9, B1, B2, A2. shades of orange, yellow and green. C5, a blue, yielded an interesting assortment of colours. It was matched correctly and with different shades of the same colour, but placed with it were greens and pinks, giving a total of eight in all. This includes the typical confusion of blues and pinks. Very often the extra-spectral colours are matched with blue, and then inevitable confusion of blue with violet constantly occurs.

This experiment confirmed some of the facts previously noted in the other tests.

1) It has shown clearly the difference in degree of the colour-blindness of the ten subjects, and suggested the reason why. In the case of J, it was seen that the yellow and blue bands of the spectrum were very small in extent compared with the other subjects. His neutral band in the centre was broader, comprising yellow-green, green and blue-green. H's neutral band

✓

extended over the green and blue-green only, likewise Subject E. In the milder cases, the blue-green was the sole region affected. The extent of the neutral band must therefore be a factor determining the degree of defect. If the blue-green alone is affected, then the green appears to be seen either as yellow or as green.

2) A neutral band at the red end of the spectrum as H and J have, seems to ~~cause the defect to assume~~ a graver character.

be associated with a defect of

3) The most abnormal cases recorded are those with shortened spectrum except in the case of A who according to Stilling's Tables has a shortened spectrum but who shows little evidence of it apart from confusing blues and pinks.

4) It appears that a shortened spectrum ~~causes~~ a defect in perception of shade. This is evident with H and J.

is associated with

5) A second neutral band occurs beyond the spectrum in the purples.

6) Although a colour may be recognised by a colour-blind, it may when mixed with white or black, undergo a change in hue imperceptible to the normal eye but which will cause it to be placed in a different category by the colour-blind.

36

3. The Colour Sensation of Reddish Green

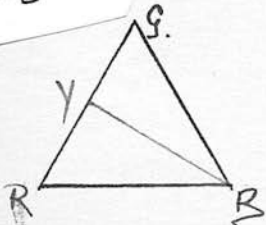
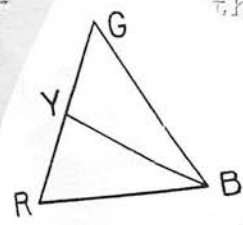
Reddish green is a term much employed by colour-blinds, but it does not seem to be characteristic of all cases. H and J do not use the term at all. This may mean that it is not common in severe cases of colour-blindness, but is only employed where the defect is milder. Edridge-Green explains it ~~along the lines that~~ the term belongs to the three unit class, those who can see red, green and violet. Reddish green is the term applied to the colour seen at the junction of their ^{red} and their green. It is not a pure red nor is it a pure green, and the best description of it seems to be in terms of both colours. This is quite a sound explanation and meets the facts, if the theory of Edridge-Green is accepted. If we, for a moment, place subject B among the three-unit class, and admit that he can distinguish three colours in the spectrum, then the explanation seems quite feasible. But one characteristic of the three-unit class is that red and green are never confused. This does not apply to B for he often mistakes the one colour for the other. This fact necessarily excludes him from the three-unit class, and the explanation no longer applies.

from the point of view

Dr Peddie, in his recent book on Colour seems to attribute this term to special cases of chromatic vision. He is an ~~upholder~~ of the Helmholtz theory and accepts the three fundamental colours, Red, Green and Blue as forming the three ~~apices~~ of the colour triangle. There may exist a case ~~case~~ in which the red and the blue remain unaltered, while the green becomes the yellow

adherent / apices /

complementary to the blue. In other words



extended over the green and blue-green only, likewise Subject E. In the milder cases, the blue-green was the sole region affected. The extent of the neutral band must therefore be a factor determining the degree of defect. If the blue-green alone is affected, then the green appears to be seen either as yellow or as green.

2) A neutral band at the red end of the spectrum as H and J have, seems to ~~cause the defect to assume~~ a graver character.

be associated with a defect of

3) The most abnormal cases recorded are those with shortened spectrum except in the case of A who according to Stilling's Tables has a shortened spectrum but who shows little evidence of it apart from confusing blues and pinks.

4) It appears that a shortened spectrum ~~causes~~ a defect in perception of shade. This is evident with H and J.

is associated with

5) A second neutral band occurs beyond the spectrum in the purples.

6) Although a colour may be recognised by a colour-blind, it may when mixed with white or black, undergo a change in hue imperceptible to the normal eye but which will cause it to be placed in a different category by the colour-blind.

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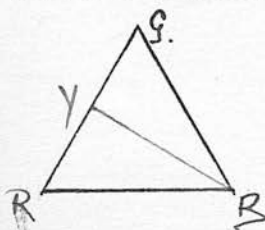
3. The Colour Sensation of Reddish Green

Reddish green is a term much employed by colour-blinds, but it does not seem to be characteristic of all cases. H and J do not use the term at all. This may mean that it is not common in severe cases of colour-blindness, but is only employed where the defect is milder. Edridge-Green explains it ~~along~~ the lines that the term belongs to the three unit class, those who can see red, green and violet. Reddish green is the term applied to the colour seen at the junction of their ^{red} and their green. It is not a pure red nor is it a pure green, and the best description of it seems to be in terms of both colours. This is quite a sound explanation and meets the facts, if the theory of Edridge-Green is accepted. If we, for a moment, place subject B among the three-unit class, and admit that he can distinguish three colours in the spectrum, then the explanation seems quite feasible. But one characteristic of the three-unit class is that red and green are never confused. This does not apply to B for he often mistakes the one colour for the other. This fact necessarily excludes him from the three-unit class, and the explanation no longer applies.

from the point of view

Dr Peddie, in his recent book on Colour Vision seems to attribute this term to special cases of trichromatic vision. He is an ~~upholder~~ of the Young-Helmholtz theory and accepts the three fundamental colours, Red, Green and Blue as forming the three ~~apices~~ of the colour triangle.

*adherent/
apices/*



There may exist a case ~~case~~ in which the red and the blue remain unaltered, while the green becomes the yellow

complementary to the blue. In other words

R

the lower half of the absolute triangle becomes the colour triangle. Two of the fundamental colours are still "simple" colours, " the third has become a "fused" colour - yellow, which is nevertheless by training called green, and is stimulated by the wave lengths which normally stimulate green. So the identical stimulations, which normally extend over the spectrum range red to yellow, now extend from red to green; and the double colour characteristics of the intermediate yellow-reds or red-yellows now extend from red to green. The compulsory change in nomenclature is therefore found by replacing "yellow" by "green". Thus arise the "red-greens" of some trichromatic eyes. (1)

Let us now consider what colours have been called ^{reddish} green by the colour blind.

It is noteworthy that the term was never employed by certain of the subjects and these subjects are not confined to one extreme. They are A, D, G, H and J. The two extreme cases A and J do not use this term to describe any colour. B, C, E, F and I have all at one time or another made use of this phrase.

Subject B.

In Stilling's Tables he twice used this phrase, once to describe a mole colour which he called a reddish green, and once to describe a pink which he called a greenish red. In the Bradley Papers test, he used this expression too. b6, b7, and b8 which are Shades I of yellow-orange, orange-yellow, and yellow respectively and which appear to the normal eye as ^{cinnamon} brown, ^{brownish} ~~yellow~~ ^{orange} and ~~green~~, were called greenish reds. In Row C, ^{yellowish olive-green} however, there were no greenish reds, but the corresponding colours were termed orange, yellow and yellow. The name was reserved therefore for the shades. The orange-yellow ^{etc.} could be explained along Peddie's line.

a1, b1 and A9, the extra-spectral purples are called greenish crimson, dark greenish purple and blue-green and red, respectively. The green in a1 is said to be similar to the green in A3 which is tint 2 of the blue-green which forms the neutral band of this subject. This seems ^{to} tentatively suggest, a connection of the neutral band with this phrase. Part of the colour circle outside the spectrum forms a neutral band, as we have seen, complementary to the blue-green. It seems to be that the grey of the neutral band is being called green and the violet element mixed with red appears as an impure blue which cannot be called a pure blue, for it does not correspond with the subject's customary sensation of that colour, and in consequence is termed a red, producing the compound colour, red-green. This may occur therefore at the junction of the neutral band and the adjoining colours. These same colours were thought to be grey or green by a number of those examined. If B can distinguish some colour element which J, for example, can not distinguish, and if he designates as green the part which J sees, then he uses the double term to express this compound sensation which he is experiencing. He described A9, as

There!

(one might say)

the!

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composed of blue, red and green, but B9, a lighter shade of A9 appeared a dark purple, and he refused to admit the presence of a green in it. To the subject therefore A9 contained something which B9 did not contain, although to the normal eye there is no indication of any colour change. ~~It~~ must be some definite sensation which is giving rise to the ~~addition~~ addition of green.

on These /
A by the subject
B/

With the Edridge-Green Lantern ~~we~~ saw the pure green glass as a reddish green. On being asked to match the glass with a skein of wool, he chose a pinkish yellow. This skein appeared green to him but contained some other colour as well, probably a red and so the colour as a whole was described as reddish green.

With this subject two different colours have been described as greenish red,)

- (1) The region between the yellow-orange and the yellow.
- (2) The purples.

Subject C

(54)

This subject called a number of the Holmgren Wools reddish green, or at least red and green.	
rose pink	green with red about it.
pink	green and red
pale crimson	reddish green
bluish pink	red and green
bluish pink	red and green
bluish red	red and green
pale green	green and red
pale green-blue	red and green

In the case of the bluish pinks it may be due to nomenclature. The blue is named red, the pink, green, and the combined result is a red-green. But that does not explain the pinks nor the greens. With the Bradley Papers he placed the reddish greens in the region of the orange, which would seem to agree with Peddie's and Edridge-Green's results. d3, and d4, tints of orange-red and red-orange, were both termed greenish reds, and e4 was described as a lighter shade of greenish red. e2, a pink, was also designated a reddish green.

Subject B and C do not always use the phrase to describe the same objective colour stimulus. B employs the term seemingly ~~to~~ dark colours (shades), and C ~~to~~ light colours (tints).

for /
for /

Subject I

Subject I was not tested with the Bradley Papers; but with Holmgren's wools, he described a very dark purple as pinkish, greenish, brownish; and a grey likewise. This again seems to connect the neutral band with the term. In the spectrum he called green, greenish red, and blue-green, pinkish green, which once more is a description of the neutral band in terms of the compound phrase.

Subject E

ask

He only once used this phrase to describe a pale blue ~~green~~ green with pink in it!

Subject F

In the Bradley Papers, d3 a tint of orange was said to be a reddish green; D3, a tint of blue-green, likewise. Some of the greys which later were

L

matched with the blue-greens were described as reddish greens.

the results given by k'

From these different subjects there seem to be three specific kinds of colour experience which are called reddish-greens; the neutral band of the spectrum, the neutral band beyond the spectrum, and somewhere in the vicinity of the orange region. The phrase is not used by all the subjects, but only by those whom we have constantly maintained are not limiting cases of dichromasy. If our postulate is correct, that colour-blinds can see red and green in certain circumstances then the orange is explained along the two cited lines of explanation, namely, that of Peddie and Edridge-Green. The subjects are not to be classed, however, as abnormal trichromates nor as belonging to the three-unit class. They do not see red as normals do, nor green as normals do, but are blind to both colours; on certain occasions they may recognise one or the other and the intermediate sensation becomes a reddish green.

right head line

8. Contrast Experiments, (Hals)

Since Stilling suggested ^{that} contrast colours might be used as a suitable test of colour-blindness, various devices have been adopted. Three contrast tests were utilised here.

To produce coloured shadows

(a) Coloured Shadows

~~This was arranged so that~~ a lantern was focussed on a white screen. Coloured glasses of red, green, blue, and yellow, respectively, were introduced in turn, and thrown on to the screen. A second source of light was provided by an electric lamp suitably placed. If a pencil is interposed between the ~~source of light~~ and the coloured screen, the rays are cut off and the area of the pencil is illuminated solely by the white light from the lamp, and assumes the complementary colour of its surroundings. The colour-blind is asked to identify the colour of the ~~interposed~~ pencil. (The natural light from both sources contained a great number of yellow rays).

the coloured light

lantern /

Shadow of the

ed /

Stiff paper discs are employed

(b) Rings Contrast

Each disc is divided into three parts, an inner area of colour and an outer area of the same colour. Interposed between them is a narrower ring of black and white which when rotated yields a sensation of grey. The grey ring assumes, on the colour mixer, the complementary colour of its surrounding areas.

(c) Negative After Images

The colours red, green, yellow, blue, orange, violet, were cut 'W' shape out of Bradley paper. A small pencil mark in the centre of the stimulus colour served

✓

as a point of fixation, and was placed over a corresponding pencil mark made on the paper beneath. The time of stimulation varied slightly with different subjects. At a given signal the subject fixated the mark and after 20 to 30 seconds had elapsed, the stimulus was removed by the experimenter and the after image appeared on the white paper beneath.

(a) Coloured Shadows

The coloured glasses used were blue, yellow, red and green. They were presented in irregular order in a series of twelve. The results are shown collected together for each subject. The colour of the shadow appears within the bracket, and it was this colour the subject was asked to name.

	<u>Red</u> (Green)	<u>Green</u> (Red)	<u>Blue</u> (Yellow)	<u>Yellow</u> (Blue)
A.	Red	Red	Green	Pinkish-Red.
B.	Blue-Green	Purple	Greenish* Greenish-Yellowish- Brown	Blue.
C.	Grey.	Grey.	l.Brown	Blue
D.	Green	Yellow	Yellow	Blue
E.	Green	Red	l.Brown	Blue
F.	Red	Red	Yellowish Brown	d.Red
G.	Blue	Blue	Green	Blue
H.	Grey	d.Grey or Black	Orange	d.Blue
J.	Grey	Grey	Grey	Blue

The subjects have responded to the test in different ways. The green shadow was only recognised as such by B, D, and E. A failed to recognise the green and confused it with red; C, H, and J failed to discern any colour, a grey shadow being all that was visible to them. G called it blue: -- the red is seen as a grey, but the blue rays in the shadow - caused by the yellow rays from the source of light - remain. This also explains the blue-green of B.

(this may be because

The response to the red shadow shows slightly different results. A and B both recognise the colour, and B discriminates as before the blue element, which makes him describe the sensation as purple. A always seems to recognise red better than she does green. The red is identified too, by E and F. D calls it yellow and G blue. The latter can not be explained as a confusion of red and blue, for that is not characteristic of G's case. It is more probable that the same explanation holds as in the response to green, that the red element is not visible in the shadow, only the strong blue rays remain. The double shadow, which can be seen simultaneously if the pencil approached the screen and which appeared red and green respectively, was both seen as blue by this subject. C, H, and J. see nothing but grey. This test reveals C's weakness, for he does much ~~worse~~ in it than he did in the wool test. To H. the red appears almost black; his

hand can/ s/

worse/

38

(55)

s/ are/

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shortened spectrum accounts for this.

Yellow is clearly visible to most subjects, although A, B, and G, call it green. This as we have previously shown is a very common confusion. The shadow is seen as brown by E, and yellowish-brown by F, which is a favourite colour name of the latter. H describes it in terms of his favourite name, orange. J. is the only one of the subjects who fails to experience a colour sensation; and this fact - that the yellow appears grey - indicates once more a weakened sensitivity.

The blue ~~sensation~~ is more clearly seen by all, although two subjects mistake it for red.

shadow/

This experiment showed the characteristic defects of the examinees and proved quite satisfactory. It points to a better discrimination of red than green in the case of some of the subjects. J. as before must be regarded as an extreme case, with H. a close second coming next, - although H. has a decidedly better colour system than J. The other subjects, excepting C and G, in this case, are affected by the stimulation of red and green lights, and their results seem to show some cognizance of these two colours.

(b) Rings Contrast

The contrast colour is bracketed as before. It was this colour the subjects were asked to name.

(56)

	Red/ (Green)	Green/ (Pink)	Blue/ (Yellow)
A.	Grey	Red	Brownish
B.	Bluish- Green	Purple	Green
C.	Grey	Grey	Green
D.	Grey	Grey	Grey
E.	Greenish- Grey	Grey	Brownish- Grey
F.	Red	Red	Reddish- Brown
G.	Grey	Grey	Grey
H.	dark grey	Blue	dark Grey
J.	light grey	light Blue	medium- Grey

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The stimuli as in the shadow experiment gave varied results. A. once more failed to perceive the green although the red was clearly visible. B. as before termed the green and red, bluish-green and purple respectively. He is the only subject who can distinguish the two colours. C. sees both red and green as grey; D, usually able to distinguish colours, is not successful this time for both appear colourless to him. With E, the green only is recognised; with F, the red only. G, H, and J, fail to see both colours. It is curious that H and J both thought the red colour to be blue.

The yellow was not too distinct a colour and resembled a brown more than a yellow. Some subjects have called it brown, some green, one red, and four grey, including the last three subjects.

5

(c) After-Images

The colour of the stimuli is given along the top of the columns, - the after-image in brackets.

	Yellow	Blue	Red	Green	Orange	Violet
	(Blue)	(Yellow)	(Green)	(Red)	(Blue-Green)	(Yellow)
A.	Blue	Yellow	White	Pink	p.Blue	Yellow
B.	Blue	Yellow	almost* White* v.p.Green	? Pink v.pale	Blue- Green	Yellow
C.	Blue	Yellow	Grey	Red	Blue	Yellow
D.	Blue	Yellow	Green	Grey	Blue	Yellow
E.	l.Blue	Yellow	Grey	Grey	l.Blue	Yellow
F.	Blue* or Red	Yellow	White	Blue	Blue	l.Brown
G.	p.Blue	Yellow	White	White	p.Blue	Yellow
H.	Blue	Yellow	Grey	Grey	Blue	Yellow
J.	l.Blue	Yellow	l.Grey* almost* White.	medium- Grey	v.l.Blue	Yellow

The blue and yellow after-images are clearly seen by all the subjects, if we overlook the fact that F calls the blue image, blue or red. The after images of the orange and the violet appear distinctly also, even to Subject J. It is instructive to note that B is the only one who calls the after image blue-green.

When we consider the red and green after-images, a different result makes its appearance. Subject B alone sees the colours correctly, and he is very doubtful of what his sensations are, for they are very pale, approaching white. In the case of Subject A the red stimulus can not give her an after-image of green, but the green makes sufficient impression to give her an after-image of red. This confirms the previous conclusions that the blindness to green is greater than that to red. To C no green after-sensation appears, although the red one is visible; for D the reverse holds, although we would expect him to describe both images correctly. E, F, G, H and J fail to perceive any sensation.

This test is instructive when supplementary. Alone it is unreliable, for there is no objective control.

Chapter V

Small Tests and Results (Concluded)

9. The Nagel Cards Test

*Left Testboard Results concluded
Right The Nagel Card Test*

There are two sets of cards; 16 marked A, 4 marked B. The procedure differs slightly in the two cases.

In section A the 16 cards are spread out in good daylight illumination. The subject stands upright before the table on which lie the cards; he is not allowed to pick them up nor examine the cards at close range, but is asked to indicate his answers by pointing to the cards he selects. Each card contains a circle of variously coloured dots.

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Four questions are asked.

- 1) On which cards are there red or reddish spots?
(This does not exclude other colours being present also).
- 2) On which cards are there red spots only?
- 3) On which cards are there green spots only?
- 4) On which cards are there grey spots only?

In question I, for example, most colour-blinds select cards 6 or 11 or 12, as containing red spots; they mistake the yellowish-green and the brown which these contain for red. ~~These errors~~. These errors, Nagel states, are almost complete evidence of colour-blindness. The Anomalous Trichromates, on the other hand, are usually able to pass this test successfully as well as number 2, but they come to grief in questions 3 and 4.

In Section B, the colour-blind is asked to designate each colour he sees on the cards. This is not intended as a test of fine discrimination but is merely to ascertain if red can be distinguished from green, or if ~~they~~ are confused with some other colour. A mistake in BI only is no criterion of colour-blindness, although it may indicate colour anomaly of some kind; the other cards must also show deficiency, *before we diagnose colour-blindness.*

these

1. Red or Reddish Spots

Correct	1	2	3	7	8	10	14	15	16						
A		2	3	4	7	8		12	15	16					
B		1	2	3		8		11	15	16					
C								11							
D		1							15	16					
E		1	2	3	7	8	10	11	12	14	15	16			
F		1	2	3	4	6	7	9	10	11	12	13	14	15	16
G					7						15				
H		None													
J.					6						12				

(58)

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Section A was found to be a most satisfactory test for all the subjects.

The results divide the subjects into two groups: (1) those who are able to select a number of cards and (2) those who find few or no cards containing the colours they are looking for. These two groups divide the subjects almost equally according to the order in which they are progressively arranged; C is the only exception.

It will be more satisfactory instead of treating the results separately as before, to discuss them in two groups, the first group containing subjects A, B, D, E, F; the second group, C, G, H, and J.

Of the first group, A is the only one who omits card 1. The four dots on this card are very pale and undecided, just the kind of pink which the subject is apt to confuse with green. 2, 3, 7, 8, 15 and 16 are practically selected by all, the reds on these cards ~~are~~ either numerous or very bright. 10 and 14 seem not to be so easily recognised. The dots on 10 are mixed with blue or black and are impure. They may

being

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be mistaken for black by those of shortened spectrum, or be confused with the adjacent mole colour. 14 contains two contiguous fairly bright reds, a shade darker than those of card 1 but they were undiscriminated by A, B and D.

The cards wrongly inserted were 4, 6, 9, 12, 13 and particularly 11. Card 4 consists of green and grey dots only. ~~This~~ is the mistake of A and F. The latter was the only one to insert 6; it consists of grey and green as before with yellowish-brown in addition. Card 11 has grey, sea-green and yellowish-brown dots; 12 contains two very dark purples which are generally ~~thought to be red~~. 13 chosen by F ~~verified~~ his former choice of 4 and 6, for it is composed of greens and greys only. ~~Thereas~~ 9 is a card of grey dots only.

The wrong insertion of card 6

mistaken for 8

confirmed / which he includes

These subjects all show confusion of reds, greens and greys. The test has many advantages, for it requires little apparatus and involves little time. It could be extended by asking the examinee to point to the red dots, and valuable information would be obtained as to the nature of the existing defect.

which clearly points /

D was the only subject who made no mistakes, but then he only selected three cards out of a possible 9, ~~pointing~~ to defect of some kind. If results were based on this part alone of Nagel's test, he is the only one who would require further testing.)

[It is evident, however, that some reds can be distinguished, for the cards can not all be selected by chance.

correct

60

The second group of subjects show entire failure to recognise the red cards, and those which they have selected are faulty, except in the case of G. H could find no suitable cards, for he saw all the pinks on the cards as blues.

(59)

2. Red Spots only

Correct	3		
A	3	8	
B	3		15
C			
D			
E	3		15
F	3	9	15
G			
H			
J			

No subject answered this part correctly. Those who selected the proper card, added a second erroneous card. Card 8 selected by A contained bright greens and moles; 9 was all grey, and 15 had some greens. It is curious that F should chose ~~as red only~~ the card which contains nothing but grey spots.

Second question /

as containing red spots only



3. Green only

<u>Correct</u>	<u>5</u>
A	
B	
C	3 5 7 8 9 10 15
D	4 5 9
E	5 12
F	
G	1 2 3 4 5 6 9 10 11 12 13 14 15 16
H	
J	7

This test again is valuable for picking out the colour-blinds. Subject G's result is remarkable: he chooses 14 cards out of the 16 possible. There is here evidently a very big confusion of red and green, for the majority of the cards selected, have vivid red spots on them. Number 15 was previously considered correct in question 1. Subject C, too, chose quite a few cards. It is noteworthy that A and B failed in this part of the test; D fared badly also.

Answer to

4. Grey only

<u>Correct</u>	<u>9</u>
A	1
B	
C	
D	3
E	7 9
F	
G	
H	3 9
J	All 16 cards.

(61)

J's result is noteworthy, but very characteristic. All 16 cards appear to him as shades of grey. This agrees with all our previous findings. A omitted card 1 when selecting cards containing red spots; it is now ~~accepted~~, showing confusion of red with grey. Card 3 has red spots only.

selected/

This part of Nagel's test is most satisfactory, and detects all the ~~candidates~~.

Subjects/

Section B

In this section the subjects are asked to name the colours on four different cards containing variously coloured dots. This part does not seem of such intrinsic value as the first portion, and appears unnecessary.



(62)

B. 1

Correct.	Dark Purple	Green	Chocolate-Brown
A.	Red	Brown	Brown
B.	Red	Green	Green
C.	dark Green	Brown	Brown
D.	Brown	Green	dark Grey
E.	dark Red	Greenish Brown	Brown
F.	Red	Orange	Orange
G.	Green	Green	v.d. Green
H.	d. Brown	d. Brown	light Brown
J.	Black	med. Grey	med. Grey

[Handwritten signature]

These show typical results for all the subjects, such as have been obtained from previous tests. C shows confusion of the purple with green and does not recognise the green. D. does not discern the purple; G. sees all the dots as green.

B. 2

(63)

Correct	Bright Red	Chocolate-Brown	Dark Brown
A.	Red	Reddish	Brown
B.	Red	Green	Green
C.	Red	Green	dark Green
D.	Red	Brown	dark Grey
E.	Red	dark Red	Brown
F.	Brown	Red	Red
G.	Red	Red	Red
H.	dark Brown	light Brown	Brown
J.	light Grey	light Grey	dark Grey

[Handwritten signature]

This card contains the bright reds which some of the subjects can identify. The browns are confused with reds and greens. Subject G. saw all the spots as red and J. all of them as grey.

B. 3

(64)

Correct	Dark Green	Medium Green	Grey
A.	Green	Green	Green
B.	Green	Green	Green
C.	Green	Green	Green
D.	Green	Green	Green
E.	Green	light Green	Grey
F.	Grey or light Red	Brown	Red
G.	Green	Green	Green
H.	Grey	Brown	Grey
J.	Medium Grey	Medium Grey	light Grey

[Handwritten signature]

The ~~answers~~ ^{results for} to this card are very similar, and show the general confusion of green and grey.

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B. 4

Correct	Dark Brown	Chocolate Brown	Bright Red
A.	Red	Red	Red
B.	Green or Brown	Green	Red
C.	Green	light Brown	Red
D.	Brown	Brown	Red
E.	Brown	Brown	Red
F.	Brown	Green	Red
G.	Red	Green	Red
H.	Brown	Grey	Brown
J.	Majority Black; some light Greys.		

The bright red spots are recognised by subjects A. to G. This particular red always seems to be correctly identified. A, however, sees all the dots as red. Brown is a difficult colour and is confused either with red or green.

This part of the test is not so satisfactory as part A. It does ^{not} yield ~~such~~ data, except to show the prevalent confusion. Part A. is much more instructive and valuable, and reveals immediately the presence of any colour anomaly. Undoubtedly it is most reliable as a test for colour-blinds, and its use is to be commended.

additional / to any extent

light bodies

10. The Edridge-Green Lantern

(Hals)

This lantern ~~is~~ devised to detect all dangerous colour-blinds and is the result of much research and practical experience. "The lantern contains five discs; three carrying seven coloured glasses, one carrying seven different sized apertures and one obturator and one carrying seven modifying glasses. Each disc has a clear aperture. The other mechanical details are:- an electric lamp holder in a parabolic reflector, handles for moving the discs, and the indicating ring showing the colour, aperture or modifier in use. The discs are numbered 1-5 on side plates under handles" ⁽¹⁾

was

Disc No. I contains the different sized apertures, the largest of which was used throughout the experiment. The size of the aperture correspond to the distance of the examinee from a 5 1/2 inch railway signal lamp, or from a 7 inch ship's lamp. Seated 20 feet from the largest aperture (0.75 inch) is equivalent to a distance of 50 yards from a railway signal, 40 feet away is equivalent to a distance of 100 yards, 80 feet away, ⁽¹⁾ a distance of 200 yards, and so on. As such distances may not be available for ordinary purposes the aperture may be reduced instead;- one foot away from the smallest aperture equals a distance of

*is intended to
The distance of!*

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(1) Official description supplied with Lantern.

50 yards from the signal, 2 feet away, 100 yards etc. The lantern therefore is useful for detecting those cases in which red and green can be distinguished near at hand, but not at a distance. Such cases are certainly dangerous and should be rejected for practical purposes.

The distance from the lantern during the tests was about 3 feet instead of 20 - the reason being that the tests were not being applied for practical purposes, but merely to aid in an investigation.

of colour defect

The second, third and fourth discs contain the coloured glasses. In order they are as follows:-

(1) Clear (2) Red A (3) Red B (4) Yellow (5) Green (6) Signal Green (7) Blue (8) Purple. The three discs are similar in every respect. The colours are brought into view by moving one or more of the handles to position

until they correspond with the scale at the top of the lantern. Edridge-Green has given a spectroscopic analysis of the light transmitted through each glass (Colour-Blindness and Colour Perception). Red A is the signal red which presents little difficulty to the colour-blind, but which is useful in combinations. Red B, a very decided red to the normal eye, is often mistaken for green by them. Yellow is a most useful colour and is frequently misnamed. The pure green is troublesome, as is the Signal-green also. The Blue appears of a lavender shade, but if desired a purer blue is available by combining it with signal-green. The purple glass offers special features and aids in diagnosis.

Vide

Disc NO.5 contains the following modifying glasses:- (1) Clear (2) Ground Glass (3) Ribbed Glass (4) Neutral 1 (5) Neutral 2 (6) Neutral 3 (7) Neutral 4 (8) Neutral 5.

The colour-blind can distinguish a difference between standard red and standard green close at hand in the same way that a normal person may be able to distinguish between a green and a blue-green. But if only one were shown, and particularly at a distance, the power of recognition would be ~~less~~. In testing therefore, it is necessary that the intensity of the light should be changed without the subject's knowledge, and this is achieved by means of the neutral glasses which modify the light so that it appears as if it were under atmospheric conditions. The neutral glasses represent fog, the ground glass mist, and the ribbed glass rain. The normal-visioned can still distinguish

of these its/

or with poor illumination impossible/

Certain

the colours except with the thickest neutral, but the colour-blind find the task a very difficult one.

The ground and ribbed glasses do not alter the colour of the light but scatter it, and they diminish the luminosity of the whole of the spectrum. "The neutral glasses make the red appear like the green of the colour-blind, and the green like the red".

- No. 1 neutral diminishes the intensity of light
- No. 2 neutral imparts a faintly greenish light.
- No. 3 neutral imparts an orange tinge.
- No. 4 neutral imparts a reddish tinge.
- No. 5 imparts a redder tinge.

✓

The test is based on four principles.

1) The colour-blind match colours according to their psycho-physical units. They actually judge by colour and their judgments remain constant. The glasses employed in the lantern are those particularly liable to be confused by the colour-blind.

2) The colour-blind name colours in accordance with their psycho-physical units and thus show to what class they belong. Guessing is improbable.

3) Colours may be changed to the colour-blind while remaining unaltered to the normal eye.

4) Simultaneous contrast is more marked in the colour-blind than in the normal eye. A yellow contrasted with red appears green, and a yellow contrasted with green appears red - this is particularly characteristic of the 3 unit.

It will be noticed that in this test the candidate is asked to name the colours; this is a striking feature of all Edridge-Green's tests. He believes, and rightly too, that if an examinee sees a red light but says to himself "That's green" then he is a source of danger to the community. By this test the colour-ignorant is excluded as well as the colour-blind; the former can be re-examined at some later date if he so desires.

The candidate is to be rejected

- (1) If he calls the red, green, or the green, red, in any circumstances.
- (2) If he calls the white light red, or green, or vice versa, in any circumstances.
- (3) If he calls the red, green, or the white light, black, in any circumstances.

Any of these mistakes is sufficient evidence of defective vision; if other mistakes are made the candidate requires a more thorough examination.

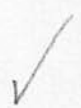
About twenty glasses in all are shown to each candidate so that the test involves little time. It is advisable that it be conducted in a darkened room.

In the experiments conducted with the colour-blinds, seventy-six differently coloured lights and combinations of light were tried with each subject which gave a reliable estimate of the validity of the test. The light of the lantern was switched off after the subject had identified the colour, the handle readjusted, and then the light switched on again. It is important when two lights are being combined that the examinee does not see a green for example, before it is altered by means of a modifying glass. This danger is removed when the handles are adjusted with the lantern's light extinguished. The experiment was conducted in a darkened room.

Below is given the glasses in the order in which they were shown. The subject was asked to name the colour visible to him.

colour

42



- 1. Red A
- 2. Neutral 2
- 3. Blue
- 4. Purple+N.4
- 5. Pure Green
- 6. Neutral 3
- 7. Blue+Signal Green
- 8. Clear
- 9. Yellow+Blue
- 10. Red B
- 11. Ribbed Glass+Red B
- 12. Ground Glass
- 13. Red a+Signal Green
- 14. Yellow
- 15. Red B+^{Yellow}Signal Green.
- 16. Ribbed Glass+Clear
- 17. Red A+Purple
- 18. Purple
- 19. Green+N.4
- 20. Red A+N.4
- 21. Neutral 4
- 22. N.1+Red B
- 23. Signal Green
- 24. Yellow+Pure Green
- 25. ^{Yellow}Y+Pure Green+Purple.
- 26. Neutral 5
- 27. Neutral 1
- 28. Yellow
- 29. Red a
- 30. Yellow
- 31. Green
- 32. Yellow
- 33. Red A+N.4
- 34. Red A
- 35. Red A+N.4
- 36. Yellow+Ground Glass
- 37. Red B+Pure Green
- 38. Signal Green+N.5
- 39. Yellow+Ribbed Glass
- 40. Blue + N.4
- 41. Red A+^{Signal}Green+N.3
- 42. Yellow + N.4
- 43. Red B+Pure Green+N.1
- 44. Purple+Yellow
- 45. Red B+^{Yellow}Pure Green
- 46. Red B+Pure Green+N.2
- 47. Red B+Signal Green+Purple
- 48. ^{Yellow}Y+Pure Green+N.4
- 49. Green+Ground Glass
- 50. Blue + N.3
- 51. Pure Green + N.5
- 52. Blue
- 53. Signal Green+Blue
- 54. Blue
- 55. Purple
- 56. Pure Green
- 57. Yellow
- 58. Pure Green
- 59. Yellow
- 60. Red B
- 61. Yellow
- 62. Green
- 63. Red A
- 64. Clear
- 65. Red B
- 66. Yellow
- 67. Yellow + Yellow
- 68. Green
- 69. Green + Green
- 70. Green
- 71. Red B
- 72. Yellow
- 73. Signal Green
- 74. Purple
- 75. Blue
- 76. Purple + N.4

Red: To make the results more comparable, the replies to red have been collected (including Red A and Red B and combinations giving Red) . Red was shown twenty-seven times in all.

	Recognized Red	Confused	
A.	20 times	Or.2 G.4	Colourless 1
B.	16 ..	Or.4 G.3 Y.3 W.1	Orange/Green/Yellow/White/
C.	7 ..	G.7 Gy.3 Br.10	Colourless 1 Green/Grey/Brown/
D.	24 ..	Y.1 Dk.1 X.1	Yellow/Black/White
E.	20 ..	Or.2 Gy.1 Br.3 Y.1	Orange/Grey/Brown/White/
F.	9 ..	Br.6 G.2 Y.2 Gy.1 W.1	Colourless 2 Brown/Green/Yellow/Grey/White
G.	15 ..	Y.1 Yellowish-Red 4	
H.	0 ..	Green 1.12	
I.	0 ..	Or.12 A.14 Dk.1 Gy.9 W.1	Orange/Yellow/Black/Grey/White/
J.	0 ..	Br.1 W.1 Dk.5 Gy.20	Colourless 1 Brown/White/Black/Grey/

This table shows the number of times red was recognised by each subject and the number of confusions made with some other colour. H and J show complete failure in discriminating red, but the colours they mistake it

for are not alike in each case. H saw it mainly as orange yellow; J, however, could perceive no colour, and all the glasses appeared as greys. There exists a common confusion of Red with Green, which is particularly noticeable in the case of G. This test gives good results with this subject; he customarily tries to minimise his disability as much as possible, but the changes in the intensity of the light with the insertion of modifying glasses, defeat his purpose.

far/

If we analyse the responses further, we shall see more lucidly the effects of the various modifying glasses.

clearly

Presented alone, Red A was distinguished by A, B, D, E and G. C thought it was yellow or green, F yellow, H dark yellow, and J a dark grey. Combined with neutral 4 the colour became changed for C and G. Alone, G called it red; shown with N.4 which modifies the light ~~as~~ it appears ^{as} in a thick fog, his judgment was changed to green.

so that/

Red B alone was recognised by A, B, C, D, E and G. Combined with Neutral I, it remained unchanged for A, D, E and G, but altered in colour for the others. For B it caused a change from Red to Yellow, for C, a change to light brown, and for E, a change to orange. H and J as before, saw the colours as orange and medium grey respectively, and they remained unaffected when combined with the modifier. Neutral I merely diminishes the intensity of light, but this was sufficient to cause a change of hue in the case of three of the subjects.

and for F a change from yellowish-brown to yellowish-red.

Edridge-Green recommends showing a colour with modifying glass, withdrawing the modifier, thus presenting the colour alone, and then replacing it. This was done with Red A and Neutral 4. The results were as follows.

(68)

	Red A + N.4;	Red A /	Red A + N.4 //
A	Red	Red	Red
B	Red	Red or orange	Red
C	Green	l. Brown	Green
D	Red	Red	Red
E	Red	l. Red	d. Red
F	Yellowish Red	Yellowish Red	Red
G	Green	Red	Green
H	d.d. Grey	d. Yellow	d.d. Grey
J	Black	d. Grey	d. Grey

8/

The effect of the neutral glass on Subject G is clearly marked, for it completely changes the character of the light for him. It is interesting to note that the neutral glass causes a difference, too, in the case of Subject H.

GREEN: m

The number of times Green was correctly named was compiled in the same way. The numbers given include pure green, signal green and combinations giving green. They will be analysed later. In all, green was presented 16 times.



	Recognized Green	Confused
A.	9 times	R.1 Y.6
B.	8 ..	O.3 Y.2 Y-G.1 R-G.1 Bk.1
C.	2 ..	R.1 Y.2 V.1 B.1 Br.3 W.1 Gy.5 just sees disc 1.
D.	12 ..	R.2 Y-G.1 Bk.1
E.	10 ..	Br.2 Gray 4
F.	0 ..	R.5 Y.2 Y-R.1 Bk.1 just sees disc 7
G.	13 ..	R.1 Y-R.2
H.	0 ..	O.9 Y.2 W.1 Grey 3 Bk.1
J.	0 ...	O.1 Grey 13 Bk.2

Direction to printer: - Colours
names in full R = Red
Br = Brown
Bk = Black
B = Blue
G = Green
Gy = Grey
W. = White
Y = Yellow

About half the number of greens shown was recognised by the better subjects. F, H and J failed completely to recognise the colour. The green was more apt to be confused with orange and yellow than with red except in the case of F. It was surprising the number of times it was identified with a grey.

The results of pure and signal green differed with the varying subjects; they also differed when combined with neutral glasses.

	Green	Signal Green	Green+N.4	Sig.Green+N.5
A.	Green	Almost White	Green	Green
B.	Yellow	Green	Green	Green
C.	?	White	Blue	Grey
D.	v.l.Green	v.l.Green	d.Green	Nothing
E.	Bright Green	l.Green	Grey brown	Grey
F.	Yellow	pale Red	d.Red	Nothing.
G.	Green	Blue-Green	v.d.Green	v.d.Green
H.	Yellow	White	d.Grey	d.Grey
J.	v.l.Grey	v.l.Grey	v.d.Grey	Black.

The responses to the first two columns show differences for the same subject. A, for example, did not recognise signal green, although discriminating pure green, and saw it as almost white. This would at once cause rejection if tested for practical purposes. The lantern seems to detect the less severe cases of colour blindness as well as the extreme cases. C, also, saw this ~~color~~ colour as white; F showed confusion of it with red. B, although recognising signal green failed to discriminate the pure green from yellow.

(She was lying)

The neutral glasses with these colours did not trouble Subject G as they did with the red, but that is no criterion of reliability for if in doubt he invariably ventured green.

The pure green disc was shown alone then combined with the second green disc which was afterwards withdrawn.

	Green	Green+Green	Green
A.	Yellow	Green	Yellow
B.	Green	Green	Yellow
C.	Grey	Grey	Yellow or Grey
D.	d.Green	Blue or Green	Green
E.	Green	d.Green	l.Green
F.	Yellowish Brown	Yellowish Red	Yellowish Brown
G.	Green	Green	Green
H.	l.Orange	d.Orange	l.Orange
J.	Med.Grey	Med.Grey	l.Grey



(69)

8/1-

(70)

8/1-

8/1

43

(71)

8/1

With some, this change in intensity caused the colour to assume a deeper shade; with others it effected a complete change of hue. A was unable to identify the green alone, but combined with a second disc, the colour became recognisable. B was unaffected by the double disc, but by contrast the following single disc was changed in colour. The two discs in the case of F were sufficient to alter the judgment from a yellowish brown to a yellowish red.

Red A combined with Signal Green appears a foggy red to the normal eye. This yielded interesting results. To A it appeared colourless; to B a green. C, D, E and H could see nothing; and all that F and J could discern were grey and black respectively. G, curiously enough, was the only one who named the colour correctly. This is a most searching combination of discs and laid bare each subject's defect.

combination of

Red B combined with pure Green produces a yellow inclining to Red. F saw it as a light red, and D as a yellowish white. To the other subjects it appeared green except to J who perceived it as a grey.

YELLOW: A'

The yellow disc, of a deep orange colour, is a very useful one, and can be used alone or in combinations. It was presented 18 times.

(72)

	Recognized	Confused
	Yellow	
A.	10 times	0.3 R.2 G.2 Y-G.1
B.	3	0.7 R.5 G.1 W.2
C.	4	R.1 G.4 Br.9
D.	12	W.1 Br.3 Y-r.1 W-R.1
E.	0	0.5 R.2 G.2 W.2 Br.7
F.	6	R.2 W.2 Br.8
G.	1	0.1 R.13 G.13
H.	5	0.12
J.	0	0.4 W.1 Grey 13

*Direction to printer:-
Colour name in full
See p. 94.*

The yellow was not always recognised as such; although its frequent identification with orange may be considered permissible. Its constant confusion with red and green is more serious. Subject G thought it to be red 13 times, and green 13 times and only recognised it correctly twice. C. called it brown 9 times, E. 7, and F. 8 times, which again is not a grave defect. J. gave his usual characteristic result for practically it appeared every time to him as grey. This confirms our previous findings of a reduced sensitivity to yellow.

*87
tot*

If we take the results separately- for the above table by collating results passes over many interesting facts- we find varied responses. The yellow disc alone was mistaken by B and G for red. Combined with N.4 (which changed the colour to red for the normal eye) it remained unchanged for B, but appeared green to G. The modifying glasses, as we have pointed out above, markedly affect colours for this subject. A, E and F called the yellow orange; combined with the neutral glass it became green for A

✓

remaining unchanged for the others. C, D and F named it brown; with the modifying glass C saw it as a grey, D as Red (correct) and F as Green.

Showing the disc alone and then combining it with a second disc of yellow, left the colour unchanged for all the examinees except E who called the double disc red in distinction to his previous designation of the single disc as orange.

Simultaneous and successive contrast is more marked in the colour-blind than in the normal-visioned. This is clearly shown by using a yellow, a red, and a green disc. To the normal eye, the yellow alters little when contrasted with the red or the green. To the color-blind, however, the yellow may appear green when contrasted with a red, and red when contrasted with a green. This can be demonstrated with the Edridge-Green Lantern, and is one of the principles on which the lantern is based. Discs were shown in the order, yellow, red A, yellow, green, yellow. The only contrast effect was that of G, who called the yellow disc appearing after the red one, green.

(as already noted

with this sequence

A second set with the discs presented as follows, pure green, yellow, pure green, yellow, red B, yellow, green, gave better results.

(Red A

(73)

	G	Y	G	Y	Red B	Y	G	Red A
A.	G	Y	Y	Y	O	Y	Y	R
B.	O	R	R-G	O	not R but R orange	R-O	G	O
C.	G	l.Br	l.Br	l.Br	l.Br	l.Br	l.Br	R
D.	G-Y	Y	G	Y	d.R	Y	l.G	R
E.	l.Br	O	G	O	R	Br	G	R
F.	Y-Br	Y-Br	Y-Br	Y-Br	Y-Br	Y-Br	Y-Br	Y-R
G.	Y-R	R	G	O	R	R	G	R
H.	O	d.O	d.O	v.d.O	v.d.O	v.d.O	l.O	vd.O
J.	l.Gy	O	md.Gy	O	d.Gy	m.Gy	m.Gy	d.Gy

Direction to present
Spec Colour names in full
See p. 94.

effect of

The contrast is clear in certain cases; the yellow is called green or it is seen as red. Occasionally the yellow affects the green or the red following. Very often the green appears yellow when it has been preceded by that colour. Note that B describes yellow as red, and the green which follows it, he designates as reddish green. Subject G as before has heightened contrast and his yellows are changed according to the previous colours. With H and J it is interesting to observe that the contrast effect takes the form of a difference in shade.

Yellow and pure green combined appear a yellowish green to the normal eye. This was seen as green by A, B, D and E; yellow by C, yellowish brown by F, orange by H and J, and Red by G.

BLUE: A

The blue disc was presented twice only. It is not a pure blue but appears of a lavender shade. All subjects identified it with blue, however, except A who once called it violet, and D who described it as Blue+Red. A pure blue is obtained by combining the blue disc with signal green. The subjects experienced no difficulty in recognising the pure colour,



although D was doubtful as to whether it was a green or blue. This indicates that blue is a clear sensation to them, and is one of their ^{best} colours. The "three unit" of Edridge-Green who see Green, Red and Violet have difficulty with blues, which seems peculiar, for repeatedly the colour-blinds are able to recognise this colour better than any other. They certainly can not distinguish blue from violet or purple, but this confusion stands in a totally different category from the mistakes made with reds and greens.

Blue combined with N.3 or N.4 produces a rose colour. This was correctly indicated by five of the subjects. C named it red with N.3, but grey with N.4; G both times identified it with green; H and J saw both as greys.

PURPLE: 4

This disc was shown alone three times and to most subjects it appeared a blue. B always qualified his answer and stated it was a different blue from the others. This shows he was able to detect some difference between it and the blue or violet disc. H and J discerned it quite readily as blue which is so different from J's usual series of greys. E described it once as blue and red, once as purple and red, and once as red with a purple edge. He never seemed to see the disc all one colour. D named it dark green, blue and red, and dark red respectively.

Purple combined with N.4 yields a sensation of red. It was correctly named by A, B, D and G. C saw it as brown; E recognised it one time but the second time he described it as 'dark with orange in it'. F with difficulty could just discern the disc. To H and J it appeared Grey.

NEUTRALS: 4

The neutrals were shown alone as single glasses. There are five in all:- the colours they gave to the flame is shown in brackets.

The flame itself was seen as a greenish yellow by A and a green by C. The other subjects all saw it as a white light.

light /
light /

	N.1 (Yellow)	N.2 (Yellow)	N.3 (Orange)	N.4 (Red)	N.5 (Red)
A.	Yellow	almost Y.	Green	Green	Green
B.	p.Yellow	Yellow	Yellow	Yellow	Orange
C.	Yellow	Green	Crimson	Green	l.Brown
D.	Y-White	Red	White-Y-R	Red	Red
E.	l.Brown	Red	Brown	R with Y	Red
F.	Yellow	p.Yellow	Reddish Y	Green	Green
G.	Red	Red	Red	Red	Green
H.	d.Yellow	l.Yellow	d.Yellow	Orange	d.Orange
J.	med.Grey	l.Grey	d.Grey	med.Grey	v.d.Grey

pellant
manus

These columns show the difference that a modifier makes to the flame of the lantern. N.3, N.4 and N.5 change the light from red to green for A. With B the light remains unaltered and the red effect which is very plain to normal vision has no existence for him. C manifests great confusion of green with red and the neutrals effectively change the light in a most erratic

light /

✓ ✓

manner. E exhibits confusion with Neutrals I and 3. N.4 and N.5 trouble Subject F and change the light from red to green. G has difficulty with N.1 and N.2, and N.5 causes a complete change of judgment. The effect on H is to darken the ~~flame~~ - J as before remains impervious to all colours.

light/

These results speak well for the validity of the neutral glasses and uphold Edridge-Green's dictum that they 'make red appear like the green of the colour-blind and the green like the red.' They make a very effective test, and show how greatly atmospheric conditions alter the light to the colour-blind. They seem to pick out the weak points immediately. They have clearly manifested the fact that all the subjects are 'dangerous' colour-blinds. They form part of an excellent practical test and are thoroughly to be relied upon.

colour of a

GROUND GLASS: A

With the ground glass the ~~flame~~ appeared white to most of the subjects. A, however, described it as 'Red, with more yellow in it'. For C it changed the light to a green, and to G a faint yellow-green was visible.

light/

G found the ground glass troublesome, and it took him always a considerable time to decide on the colours when so modified. It did not affect the other subjects so much. In front of the yellow glass, it changed the colour for G to red. In front of the green glass, it altered the colour to a yellow-red, which he found most difficult to distinguish. The only other result was to transform the green glass to an orange in B's case.

The ground glass does not appear to be effective with all colour-blinds, but in some cases it may completely alter the colour of the light.

RIBBED GLASS: A

The ribbed glass in front of the ~~flame~~ produced no change in colour except with subjects C and G. In both cases it altered the ~~flame~~ to green. In front of Red B, it had no effect on any of the subjects, the red merely appearing to them as it did without the modifying glass. Combined with the yellow ~~flame~~, it resulted in no change of judgment. G called the colour red, but he described the ~~flame~~ alone as red so that the ribbed ^{glass} effected no difference. This glass apparently, does not seem to be of much utility, at least if these results are ~~conclusive~~.

light/

light/

light/

light/

reliable/

It is very useful in testing to combine colours. Certain discs presented together, produce black which is ~~helpful~~ in cases of shortened spectrum.

useful/

- Red A + Signal Green + N.3
- Red B + Pure Green + Purple
- Yellow + Pure Green + Purple

These three combinations were included in the test at irregular intervals. They were all described as black by the subjects.

Yellow + Pure Green + N.4 is also a valuable combination. It appears as a whitish grey. Some colour-

if a black were never shown, a colour blind would hesitate to call any combination of discs black.

✓✓

blinds call it green, others red, and some are just able to see the disc.

Edridge-Green advocates in any examination the presentation of a red made from Red A and Purple. This gave informative results.

Red A + Purple (Red) r

- A. Red
- B. Red
- C. Green
- D. Red
- E. d.Red
- F. See light only
- G. d.Green
- H. d.Grey
- J. Black

This is a very advantageous red to show. It may be confused with green or in cases of a shortened spectrum it may appear a black. This is the reason why it is ~~beneficial~~ to combine colours such as we described above, to produce sensations of black.

suitable

advisable

Yellow in conjunction with Purple forms another red which is useful for diagnostic purposes. In this test it was discriminated by Subjects A-F. G described it as green, however, and H and J a very dark grey.

Three other combinations are worthy of mention for the results they yield.

- Red B + Yellow + Signal Green =Red (1)
- Red B + Yellow + Pure Green =Red (2)
- Red B + Pure Green + N.3 =Green (3)

	(1) (1) Red	(2) Red	(3) Green
A.	Red	Red	Green
B.	Green	Green	Black
C.	Brown or Green	Grey	Grey
D.	Dirty Red	l.Yellow	Red
E.	Grey Brown	Grey Brown	Steel Grey
F.	Red	Red	Red
G.	Green	d.Green	Green
H.	d.Grey	d.Grey	Black
J.	Black	v.d.Grey	-----

It will be seen from the table above that these three combinations are highly instructive. A is the only subject who names the colours correctly. The others reveal confusion from B downwards, even D showing complete inability to discriminate the colours. This is an example of the many combinations of discs which can be produced by this Lantern, and which aid in making it so satisfactory a test.

APERTURE 3: A

The above experiments were all carried out using the large aperture. Only one or two of the subjects were tried with Aperture 3.

For C it changed Red A to Yellow and made all the other colours appear white; even Blue was reduced to a grey.

E merely saw the colours (Red A, Red B, Yellow, Green, Signal Green) as a spot of light. He

✓✓

45
12 (75)

(76)

recognised the Blue and saw the Purple as a darker shade.

To F Red A remained unaltered: Red B appeared orange: Yellow and pure Green were discriminated, the former called brown; thus retaining his former terminology. Signal Green however was seen as a dark grey, which is a serious mistake.

he retained

The Lantern Test as a whole is most comprehensive, and proved very reliable. The subjects tested by it are all diagnosed as 'dangerous' colour-blinds. It has the advantage that the results obtained from one lantern ~~is~~ constant and therefore comparable. The colours used are precisely those which are most confused by the colour-blinds. It is easy to work, and so many combinations can be made and the order of testing can be changed so frequently, that no coaching will enable a colour-blind to elude detection. This ~~disarms~~ the criticism applied to so many otherwise excellent tests. For practical purposes it has the great advantage that the effect of atmospheric conditions on colours is tested, and we have seen how misleading that effect can be when it is a question of colour-blindness.

are with one another

The lantern

avoids / urged against

Undoubtedly, this test is one of the best which has yet been evolved. It is based on the actual sensations which the colour-blind experience, and the recognition of colours, ~~which serve so important a purpose of the test,~~ is in itself, of supreme importance. The test combines the advantages of showing 'confusion' colours with the naming of colours, and ~~lacks~~ all the elements which usually make tests involving nomenclature so unreliable and untrustworthy. It is a test to be highly commended.

which is to so great an extent the basis of the method of testing

avoids

defects

light lead lines

11, Painting Test, (Hals)

(a) Coloured Diagrams.

For this test I am indebted to Professor Roaf of Cardiff, ~~who is keenly interested in colour-blind tests, and~~ who has kindly allowed me to make use of this test here. He is working out ~~the~~ test on a new principle, and subjects the paintings to a spectral analysis. The paintings consist of squares divided geometrically into 25 parts each differently coloured, with the colours in some cases repeated twice.

87

a/

A special box of paints containing 15 pigments is used throughout - no mixing of paints is necessary and the examinee is allowed to try the paints on a spare piece of paper first. (1)

Professor Roaf's scheme is not so much to test for colour-blindness ~~but~~ is a new attempt to analyse cases, to find out by a simple method what part of the spectrum is at fault.

defective

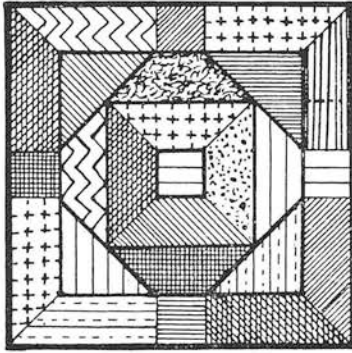
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of the sp. Therpigments being impure reflect a fairly

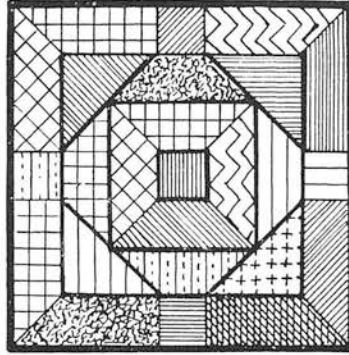
(1) See Journal of Physiology, Vol. LVII.

and Quarterly Experimental Journal of Physiology, Nos 1 and 2, 1924. Article by Professor Roaf.

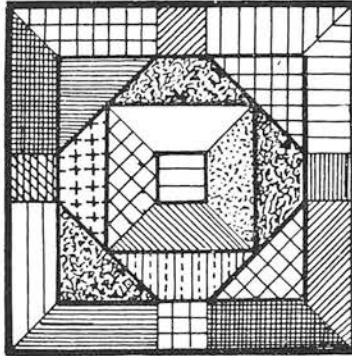
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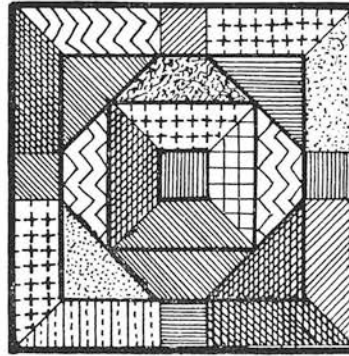
SUBJECT A



SUBJECT F.



SUBJECT J.



Royal Blue	Magenta	Pale Pink	Purple	Brown
Grass Green	Jade Green	Burnt Sienna	Pale Violet	Yellow
Orange	Lilac	Grey	Pale Green	Red
Pale Blue	Pawn			

Fig VII

wide region of the spectrum. If an individual fails to appreciate one part of the spectrum as different from another part he may do ^{three} things. He may match them correctly either by accident, or by shade, or some other means. He may add the colour which he does not recognise or he may subtract that colour. If he fails to recognise red he may add red to green thus putting a yellow, grey, or some such colour to match green. He may subtract red from grey or yellow putting green as a match for the neutral colours, or match blue and purple. If the mistakes all occur in one region of the spectrum, ~~they~~ they can be matched by examining them in light deficient in the rays in which the colour-blind differs from the normal.

One of

the colour-blind's copy and the original

The paintings are examined through colour screens and in the recombined spectrum after certain parts of the spectrum have been cut out. Colour screens are used and different regions of the spectrum are cut out, until the abnormal painting matches the original. This is possible, exclusive of slight differences of shade. When the minimum amount of reduction possible to give an absolute match is made, the region of the spectrum defective for that individual can be ascertained.

The paintings determine, therefore, the wave length of light that the individual colour-blind person fails to recognise as different ~~from the part~~ of the spectrum.

in a particular region

The paintings done by ^{three} eight of the subjects tested are appended. (1) ~~The coloured diagram supplied to the subjects is shown first followed by their attempts to imitate.~~

They are not given in their original colours, but have been redrawn in black and white. They lose considerably in the transference, and the results of all the subjects have not been included. A description, however, of the paintings of all the subjects tested, throw light upon the diagram from a psychological point of view.

Apart from the spectral analysis which the paintings reveal, they are interesting also for themselves alone, and the errors committed by the colour-blind are illuminative of their defect.

A. Started with blues, then yellows. The painting exhibits the customary confusion of blues with violets; the pale lavender is mistaken for pale blue. The pale green is painted pale lavender at one time, but pale blue takes its place another time. The red is correctly matched as is also the magenta, but much hesitation is displayed in the greens. The jade-green appears a grey, which the subject thought was a blue-green. (This is the subject's neutral band.) The two browns cause trouble; they are both represented by vivid green. The orange is not distinguished from light brown.

B. Started, as in the case above, with blues and yellows. His efforts show confusion of blues and purples. He found the test difficult but matched the colours with wonderful accuracy; and produced a fair copy of the original. For pale green, he tried dark green, magenta, pale green, then gave it up, but ultimately returned to pale green. The pale pink is represented by grey on both occasions. The green is correctly matched but the grey is represented by a vivid green. The red and magenta are correctly matched.

(1) These are ^{from} copies, the originals of which are in the possession of Professor Roaf.

46

(See figure VII)

✓

C. Found the test very difficult. His reproduction of the pigments is remarkable for the pale shades he used. Probably the pale colours are a sign of additional confusion, and Professor Roaf concurs in this opinion. This effort displays poor colour perception, for yellow is practically the only colour properly matched. The blue and Purple on the outside of the diagram are correct, but in the centre the purple (dark and pale) is mistaken for blue. The reds are not recognised, but are matched with orange, probably thought to be brown. This is the form of confusion which red generally takes with this subject. On the magenta triangle, he tried pink first of all, then washed it out, tried green, and finally brown. Pink is represented by grey at one time, and by very pale green at another. The greens are differently matched; the bright or grass green is replaced by pink, the pale greens by pale pink. The jade green is matched with grey and vice versa. The pale shades do not seem to have been recognised at all, and must have appeared colourless to the subject (such as the lavenders and very pale blues). The browns, too, are not discriminated from the burnt sienna. This whole painting reveals faulty matching, and points to the defect being of a grave nature. This confirms all the results obtained from this subject except those from the colour equations. l.c.

E. E began with yellows, and found most difficulty with the pale colours, grey, green and pink. The diagram is very correctly matched and only the following errors are made: - blue and violet; pale green and pale blue.

F. ~~H~~ experienced great difficulty in selecting the colours to match. This reproduction contains a large number of confusions. The yellow is the only colour which is painted correctly. The blues and violets are interchanged. The lavenders are represented by a pale blue in one case, and a pale green in the other. The reds and magentas show a curious mixture. The red is represented correctly at one time, but is matched with magenta elsewhere. The magenta, however, is not distinguished from blue. This corresponds with the confusion skeins chosen in matching the magenta skein in the Holmgren wool test. The pale pinks are mistaken for greys. The greens are variously represented. Grass green is shown by a fawn colour, jade green by magenta. Between this latter, and the red no distinction is made, but they are both painted indiscriminately the same colour; therefore they must have appeared similar in hue to the subject. The pale greens are matched with pale pinks. The browns, too, show confusion, in one place with green, in another with orange. One part of the diagram appeared unpainted to the subject.

G. This subject, as indicated before, is a difficult one to test, as he is always endeavouring to cover his defect, and employs as many artifices as he can devise. The painting test was no exception. He tried out a great number of colours to begin with on the spare paper, and decided there were not enough colours in the box. The blues were too blue or not blue enough. (N.B. the confusion between the blues and the purples - he saw no difference in the two adjoining colours on the outside of the diagram, but painted them all a uniform purple). He held the spare paper

close to the coloured diagram each time trying different colours, until he found one which gave a satisfactory match; it was not till then that he painted in the colour on the allotted space.

The greens he left to the end, simply because he could not match them - he ultimately painted them correctly but by the merest chance.

It will be noticed that his diagram is wonderfully accurate, the only confusion being lavender with green and pink with grey.

This painting is a good example of the resources of an educated subject aware of his defect.

47

H. H took $1\frac{1}{4}$ hours to paint his diagram, a much longer time than any of the others. He found the colours very difficult to match, and like G, tried a large number of them before deciding on the correct one. With pink, for example, he had no idea what colour it was, nor with what colour he was matching it, he went entirely by shade. A slight difference in shade was a big factor in the ultimate decision so that dilution of the pigment played a large part in the matches made. This is evident in the fact that the same colour is sometimes differently matched.

It will be noticed that the magentas are correctly represented. The reds, however, show confusion, and in one case red is matched with brown. The jade green is accurately painted, but the same green is used as a match for brown, showing that the former correct match was probably accidental. The grass green is mistaken for light brown.

The pale ^{colours} reveal perplexity. Pink is matched correctly in one case, but is confused in another case with grey. Lavender and pale greens are intermixed. Blues and purples are not distinguished, and the orange is not differentiated from the burnt sienna.

changed/

J. Started with yellows and blues. He matched the jade green by mere accident, for on questioning ^{the subject} after ^{the} subject had completed painting, it was found that pink also was a good match. He chose colours by their brightness value only. Red, which is in the right place, he thought was black. Magenta was the most difficult of all; he saw it as an impure black which he matched correctly by the chance device of going over all the colours in the paint-box until he found one of the same shade.

he/ considered

the subject
the

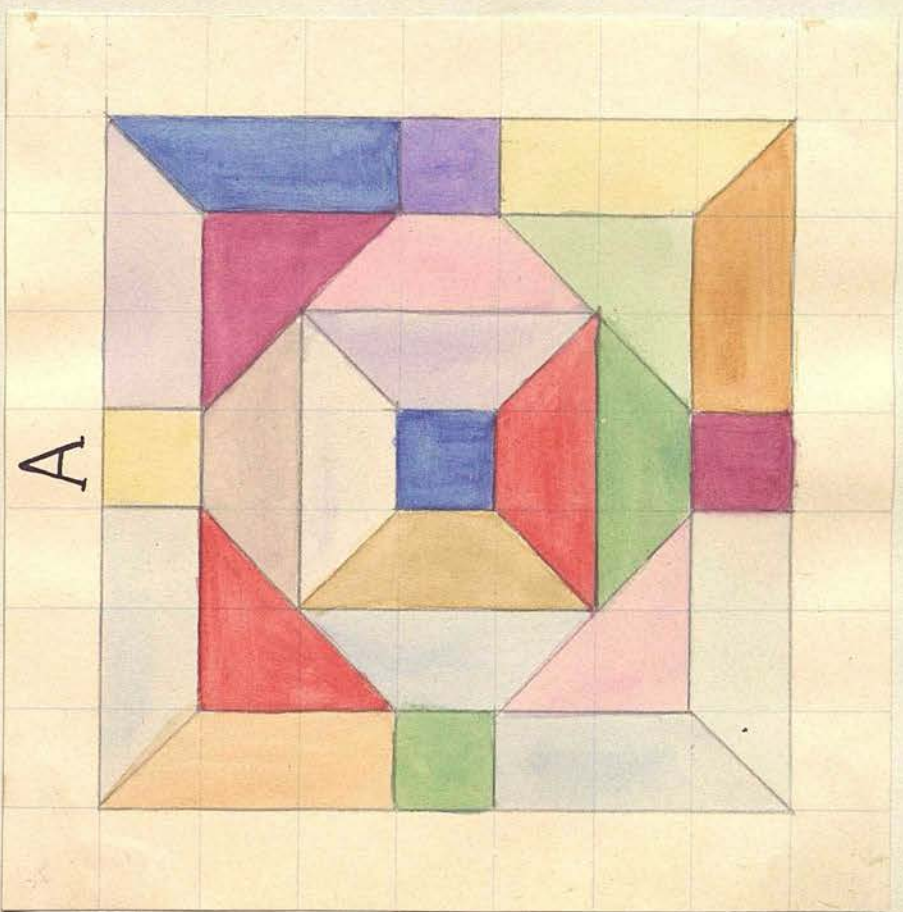
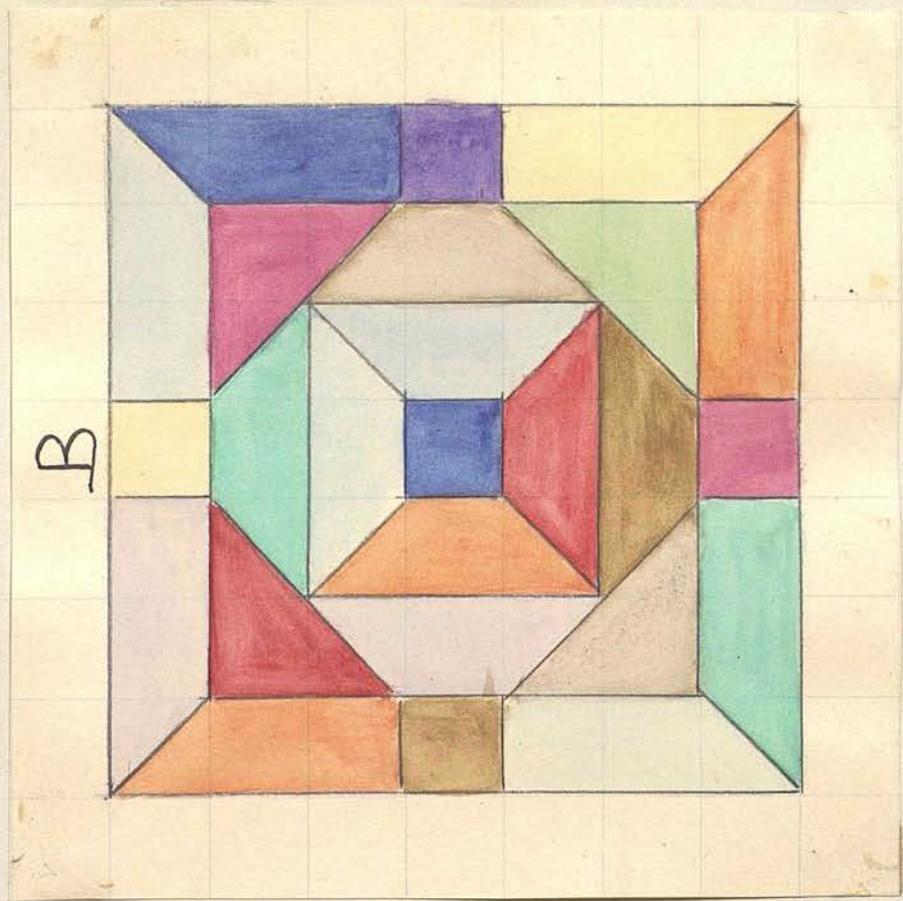
It was very noticeable with this subject that when he started to fill in part of the diagram and went back to the box for more paint, he often forgot what colour he had been using, and sometimes had to begin all over again.

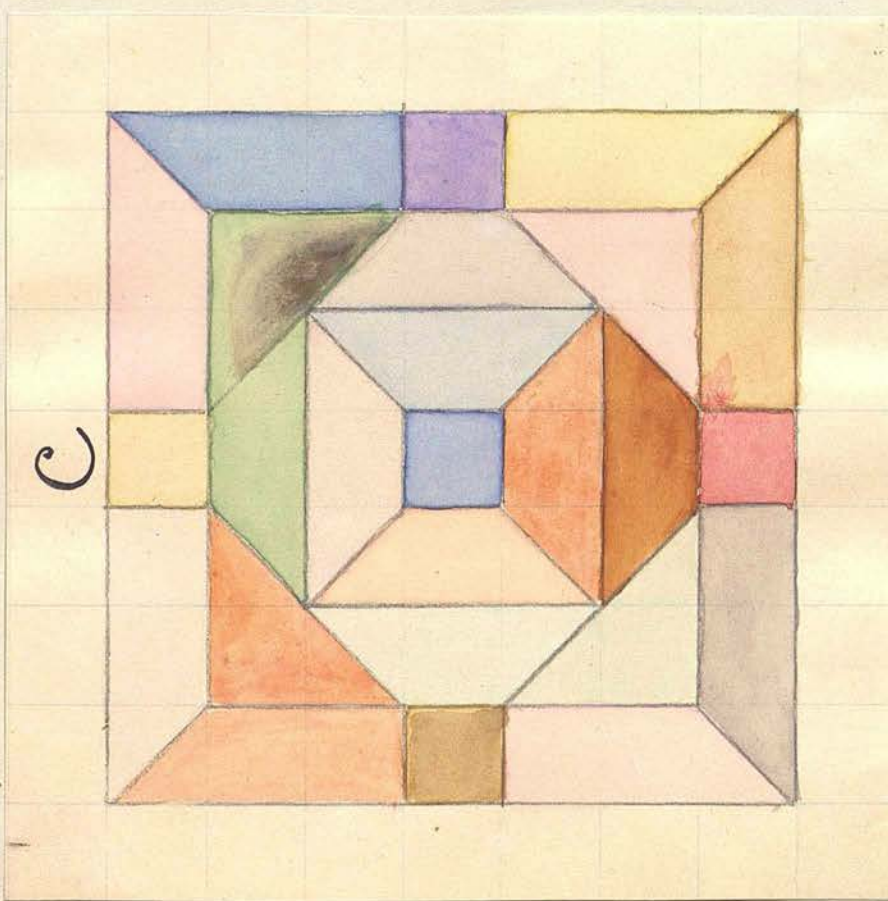
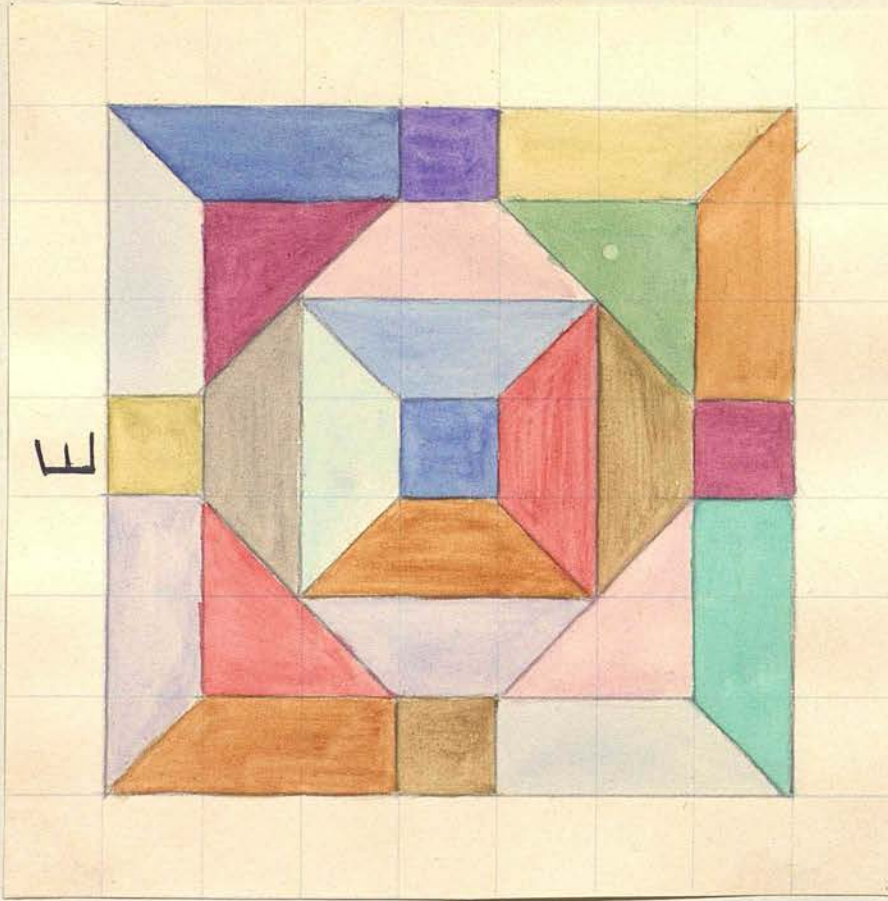
The diagram itself shows confusion of blue with purple; red with brown; pink with lavender. The grass green is matched with orange, and the jade green with a pale shade of the grass green.

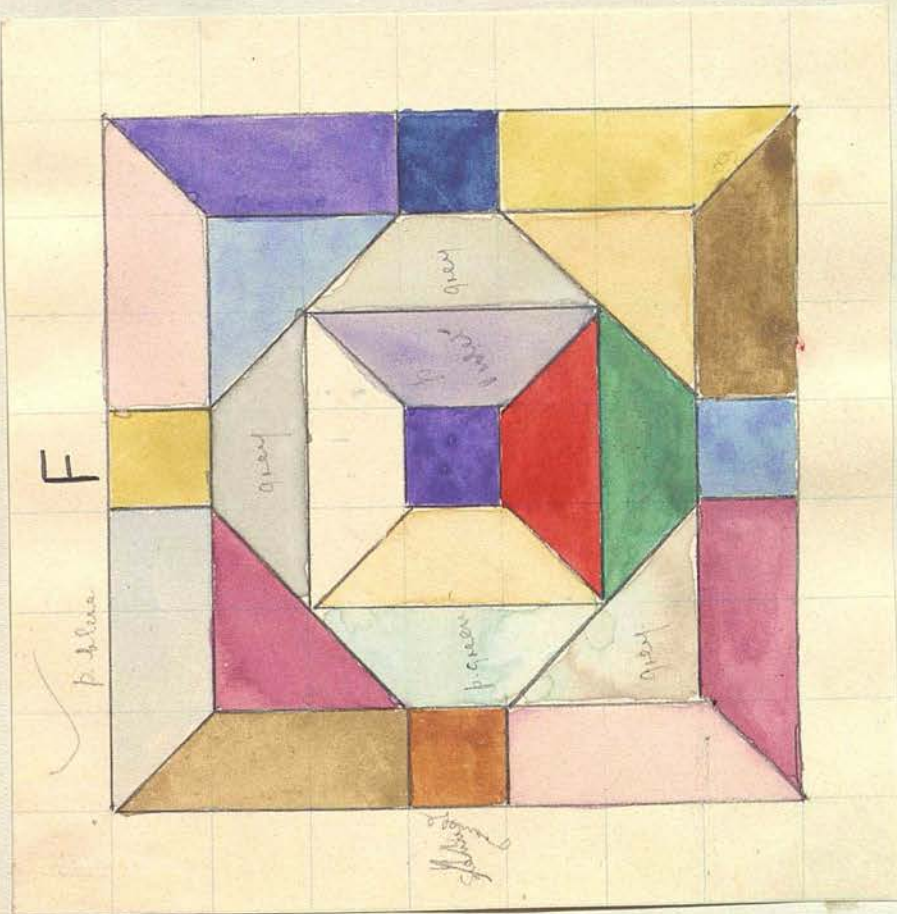
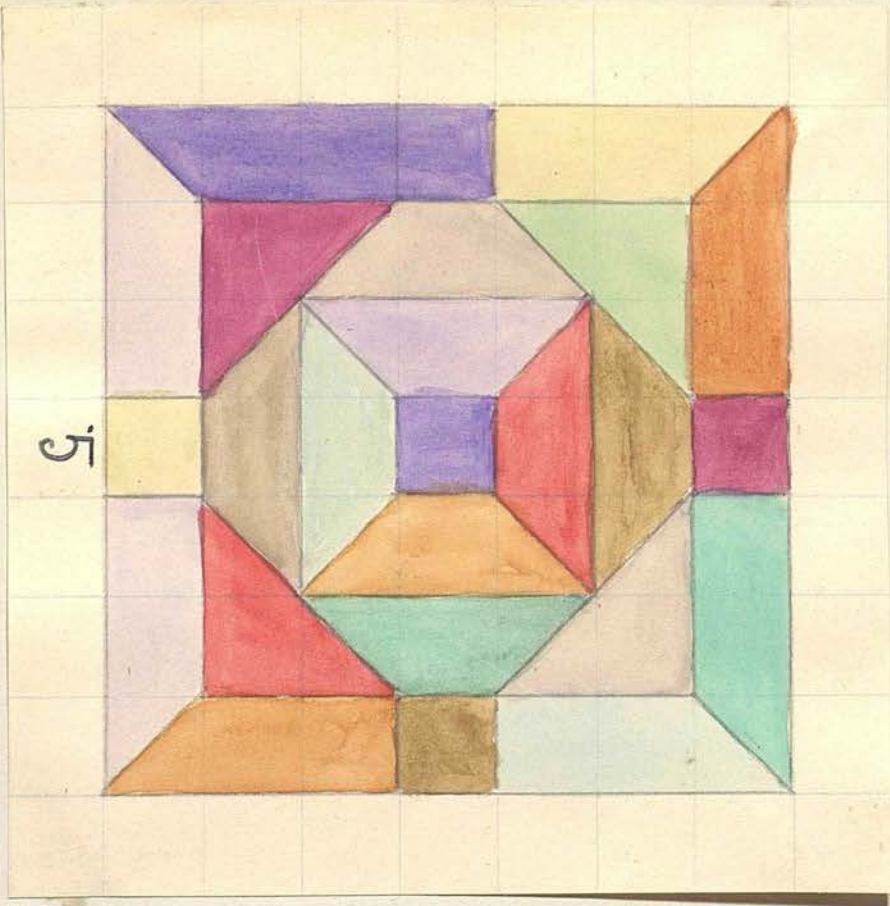
These paintings give typical results and show the confusions which exist with colour-blinds. From the observations made during the paintings, one fact stands out clearly, that shade is a potent factor. A difference in shade which means no alteration of colour for normal vision, effects a change in hue for the colour-blind. It is noteworthy, too, that yellow and blue were the first colours to be matched by the majority of the subjects.

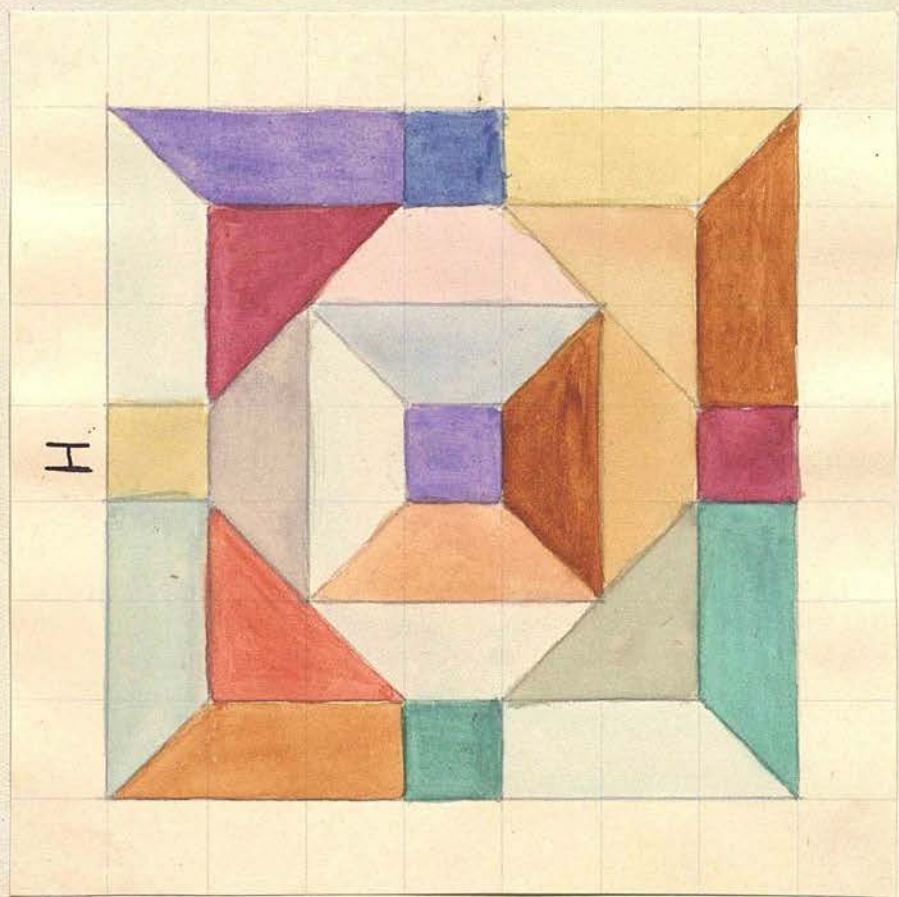
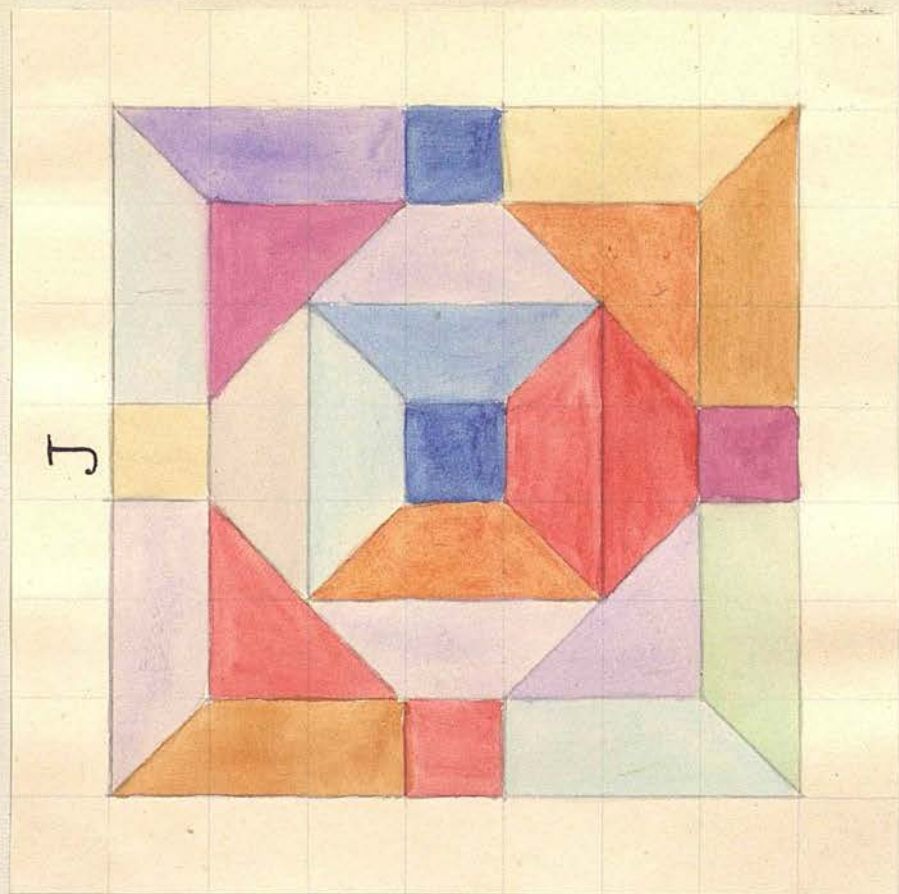
✓

✓









Mr 104510
Cancelled

Professor Roaf who submitted the original drawings to a spectral analysis very kindly sent me the results he obtained.

The results show ^{what} wave-lengths must be excluded from the spectrum of an Arc lamp in order that the copy and the original may match. There are three tables:-

- 1) of progressive cutting off of the red end of the spectrum
 - 2) of viewing the diagrams in a limited region of the spectrum.
 - 3) of cutting out a band in the spectrum.
- + means that the diagram matches the original
 - means that it does not match.
 ? means that it almost matches but that there may exist a difference in colour that would be recognised by an independent observer.
 O means that no observation was made.

The results are appended without comment.

Table 1

	6629	6552	6353	6346	6202	6128	6002	5926	5827	5625	5222	4973
A.	O	O	-	O	O	-	-	-	-	+	O	O
B.	O	O	-	O	O	-	-	?	?	?	?	+
C.	O	O	O	O	O	O	-	O	-	O	O	O
E.	-	-	+	+	+	+	O	O	O	O	O	O
F.	O	O	-	O	O	-	-	-	-	?	-	?
G.	-	-	?	+	+	+	O	O	O	O	O	O
H.	O	O	-	O	O	-	-	?	?	+	O	O
G.	O	O	-	O	O	-	-	-	-	?	+	O

Table 2

	6346-5827	6031-5625	5096-4844	4946-4733	4733-4165
A.	-	?	+	-	+
B.	+	+	+	+	+
C.	O	O	O	O	O
E.	+	+	+	+	+
F.	-	?	?	-	+
G.	+	+	+	+	+
H.	-	?	?	-	+
J.	-	-	-	-	+

Table 3

(on next page)



Table 3

	6779-5827	6779-4953	6678-6377	6678-6346	6678-6202	6678-6002	6678-5852	6678-5726	6678-5648
A.	-	--	0	0	-	-	-	-	?
B.	-	-	0	0	--	-	?	?	?
C.	-	-	0	0	-	-	-	-	-
E.	+	0	-	+	+	+	+	+	+
F.	-	-	0	0	-	-	+	-	?
G.	+	0	-	+	+	+	+	+	+
H.	-	-	0	0	-	-	?	?	?
J.	-	-	0	0	-	-	-	-	?

(continued)

	6527-4872	6527-4893	6580-6101	6402-5775	6429-5978	6377-4844
A.	-	0	0	0	0	0
B.	?	0	0	0	0	0
C.	0	0	0	0	0	0
E.	+	-	?	?	?	-
F.	-	0	0	0	0	0
G.	-	-	?	?	?	-
H.	-	0	0	0	0	0
J.	-	0	0	0	0	0

(continued)

	6353-6202	6353-5978	6353-5799	6127-5954	6328-4795
A.	0	0	0	-	-
B.	0	0	0	-	-
C.	0	0	0	0	-
E.	-	-	-	-	-
F.	0	0	0	-	-
G.	-	-	-	-	-
H.	0	0	0	-	-
J.	0	0	0	-	-

Insert B. here.

B

Professor Roaf finds that his subjects can be divided into three groups; (a) when the red end of the spectrum is cut off up to λ 6200. These show only one mistake, the confusion of blue with purple. This is explained by a shortening of the spectrum, i.e., an absolute lack of stimulation by a portion of the extreme red end of the spectrum.

The conclusion is that such subjects "seem to recognise some differential effect of the spectrum between λ 5800 and the extreme red end of the spectrum, but they do not have as great a discrimination for red as a normal person." (1)

(b) The second group matches when the spectrum is cut off as far as λ 5800. In this group other confusions are made in addition to blue and purple; for example, green and grey. The diagrams can not be matched if the least trace of the red end of the spectrum is present.

(c) The third group requires the spectrum to be cut off to about λ 4800, leaving only the violet end of the spectrum in which to view the colours. In this class the diagrams show confusion of red and green. They will not match if any of the red end of the spectrum is present, nor if any of the green region is in the recombined light. They match when the spectrum is cut off to λ 4800. They show one peculiarity not shown by the other two groups. If they are examined in light from a narrow region of the spectrum, so that a monochromatic effect is produced, they will match in light from the yellow region ~~to~~ about λ 5500 to λ 6000, depending on the width of the band used." (2)

These results have led Professor Roaf to a hypothesis which was first formulated by Schultze in 1866 (3). To quote from the same article, Roaf states that "In studying the coloured globules in the retinae of birds he (Schultze) pointed out that any light reaching the cones must be filtered through the corresponding globules, hence any light that is perceived must be that which can pass through the globules in front of the cone. In other words, the colour perception by a cone depends upon the filter placed in front of it and the photochemical processes by which the nerve impulse is produced may be the same in all cones. This colour-filter hypothesis, which is comparable to the result produced by a Lumière or Paget plate negative, can explain most if not all the phenomena of colour vision.

"This aspect of the subject is being investigated. For instance, in a preliminary examination of the retina of a hen it was found that the red globules cut off daylight to about λ 5800, whilst the yellow globules cut off the spectrum to about λ 5000." (4)

Professor Roaf concludes: "It is premature to discuss this subject in detail, but I hope to pursue the investigation and test its application to colour-vision in man." (4)

- (1) Loc. cit., p. 155,
- (2) Loc. cit., p. 156,
- (3) Arch. f. mikr. Anat., 1866, p. 255,
- (4) Loc. cit., p. 158,

(b) COLOURED PICTURE.

The copying of coloured pictures by colour-blinds forms a most instructive test. The painting (original and copy) shown in the Frontispiece is one executed by subject J., and is submitted as a point of further interest. A number of such paintings would make an intensely fascinating collection. The original painting was placed before the subject along with an outline of the object shown, and he was instructed to copy the colours of the original. Only six pigments were given, red, green, blue, yellow, pink, and brown. ~~and~~ Although the limited number of the colours may seem to suggest less confusion, and perhaps offer a little guidance to the colour-blind, such does not seem to ~~be~~ have been the result. With all the subjects tested, the characteristic confusions made themselves ~~shown~~ evident.

The reproduction in the frontispiece is a typical example of J.'s work along these lines. His paintings exhibit a general but regular confusion. Red and green are interchanged promiscuously; yellow is confused with green, and pink with blue, ~~which are the results to be expected.~~

It will be noticed (in the picture) ~~submitted as an example,~~ that the blue sky is represented by pink, and the green sea by brown. The red splash at the side is an interesting feature. The red was judged to be too dark to represent the beach- so green was substituted as it was of a lighter shade of the same colour, and in consequence gave a more satisfactory match with the original.

✓ ✓

~~P A I N T I N G S~~ . d/-

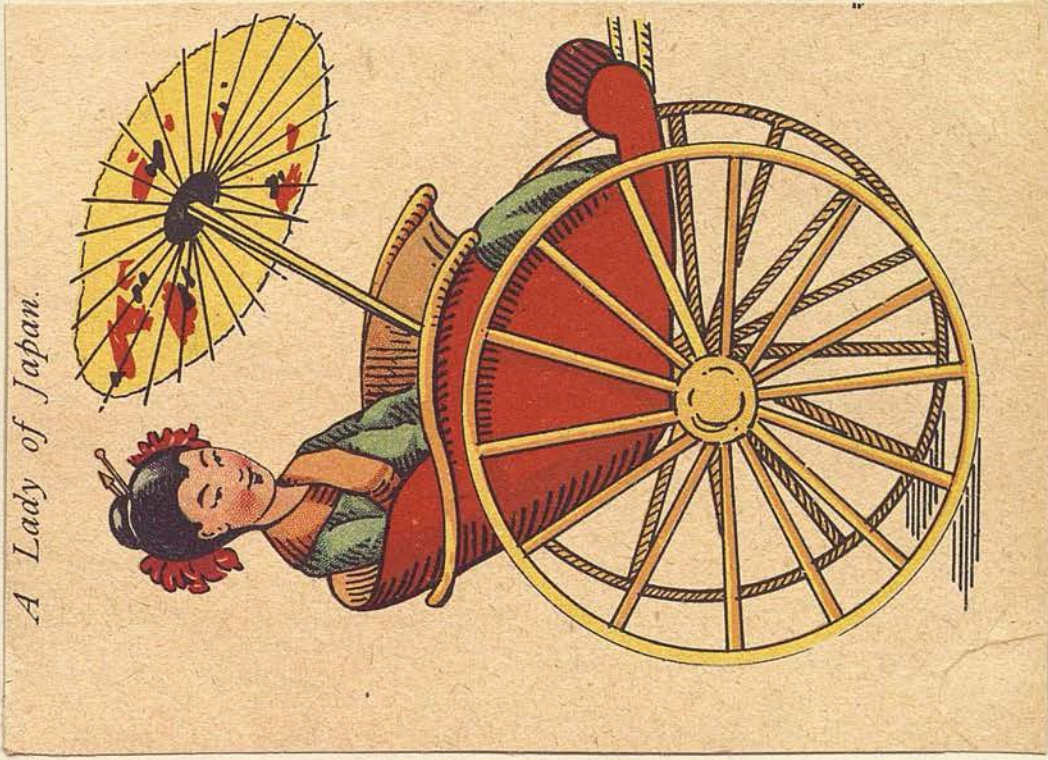
Three paintings are submitted as a point of further interest. They were painted from six colours, red, green; blue, yellow, pink and brown. The first one is the work of Subject A; the other two of Subject J. They are the original paintings.

It will be noticed that A's painting confirms the results we have previously obtained, namely that she is more blind to green than to red, and further, it shows the characteristic confusion of green with yellow.

J's paintings exhibit a general but regular confusion. Red and Green and Brown are interchanged promiscuously; yellow is confused with green, and pink with blue which are results to be expected. The same results appear in the second picture and a similar confusion is revealed. The blue sky is represented by pink, and the green sea by brown. The red splash of colour at the side of the boat and noted on the picture is rather interesting.

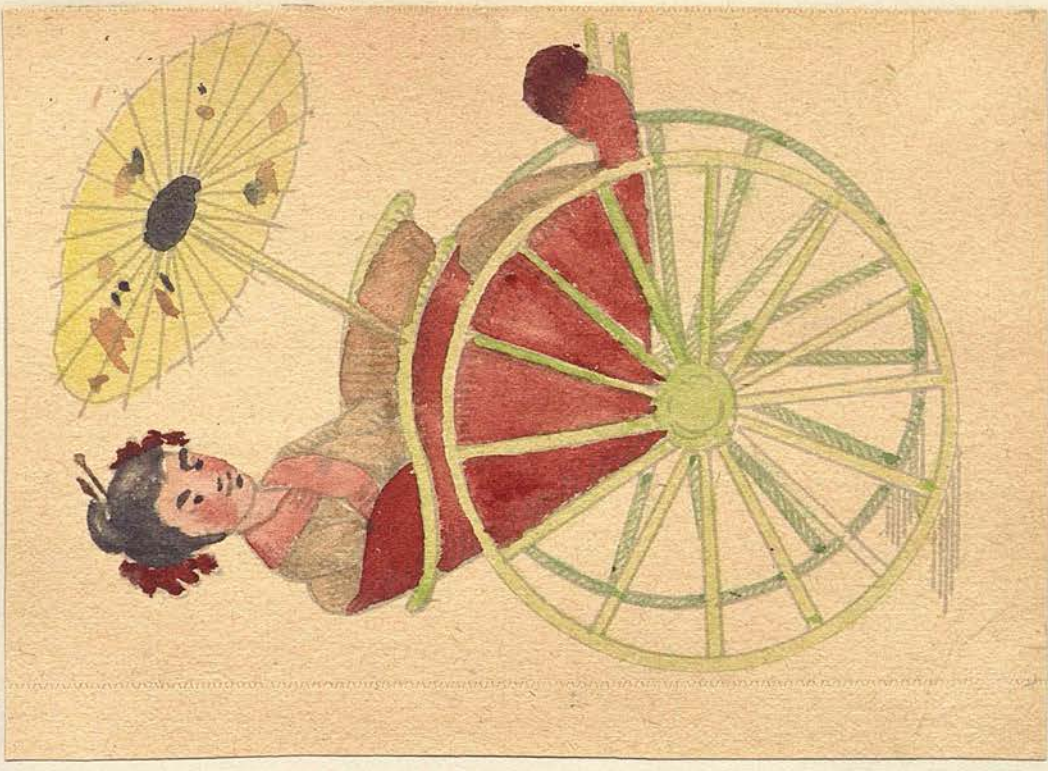
J's first picture (the engine) was shown to H who made the following observations on it:-
The green part (painted correctly by J) should have been orange. Where the red is represented by green, he would have put brown. The blue represented by pink is correct, but the pink might have been just a little darker.

Franklin
Deane

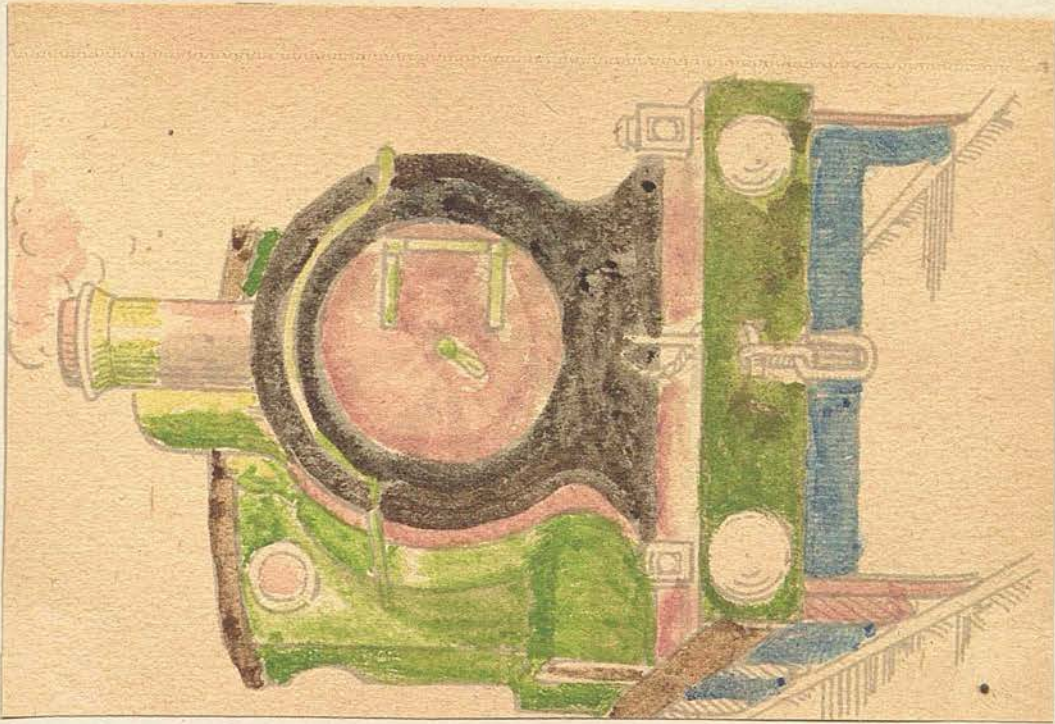


A

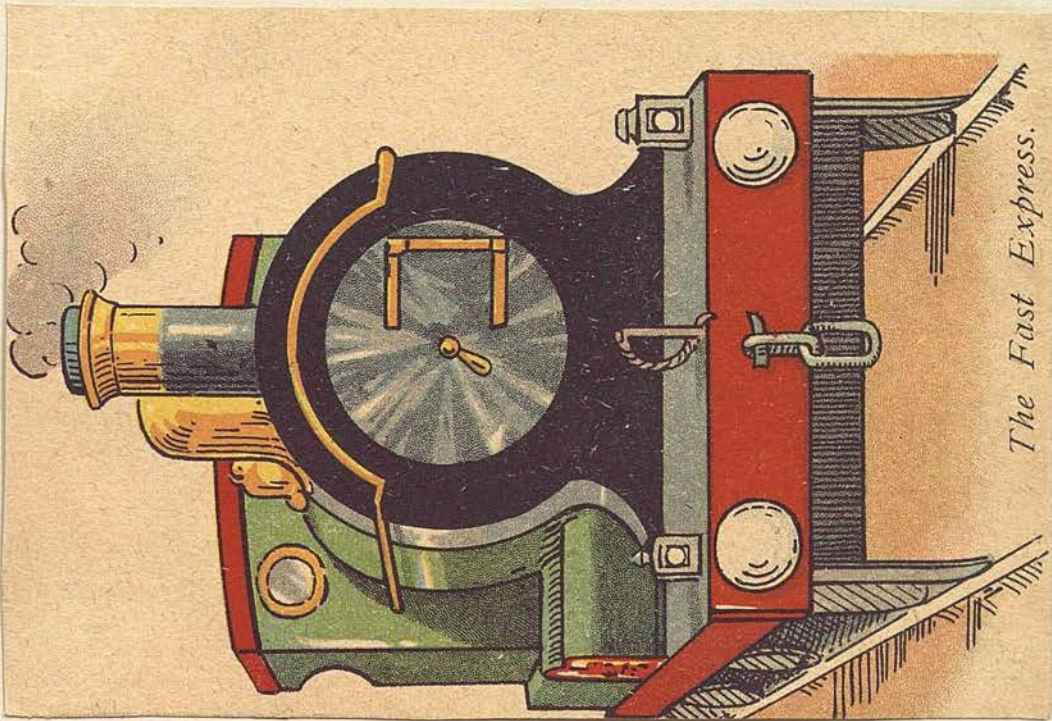
A Lady of Japan.



hote confusion of green with brown.
 " " " yellow with green.



J.

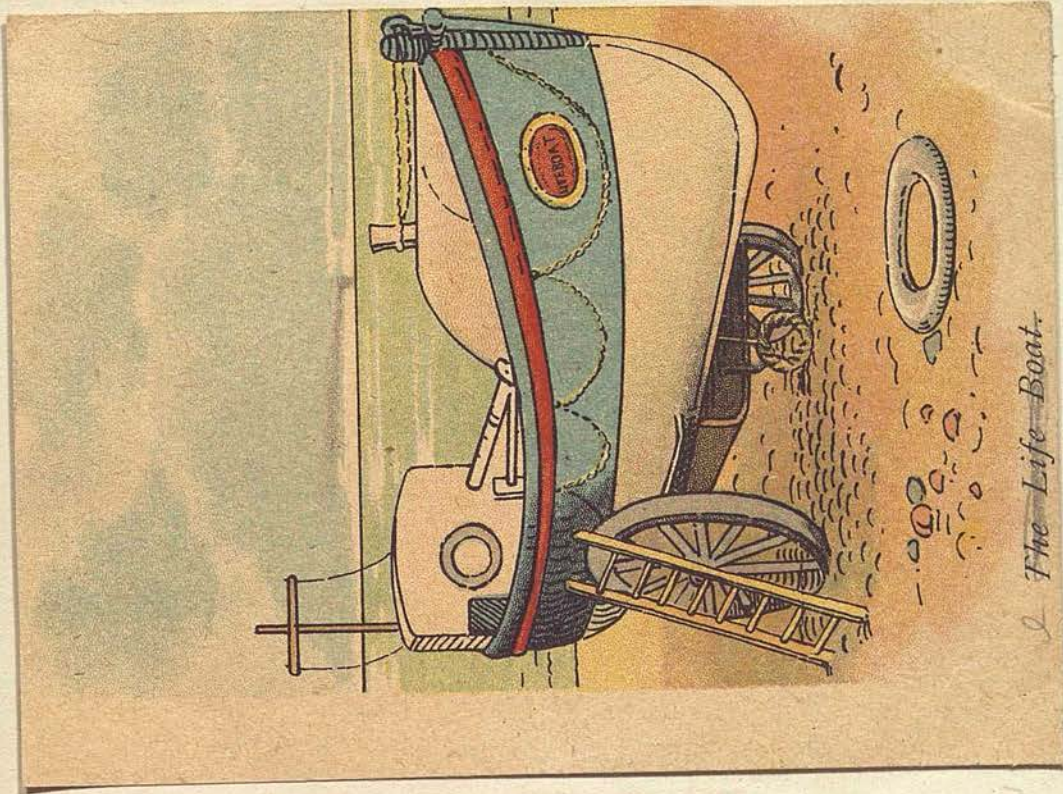


The Fast Express.

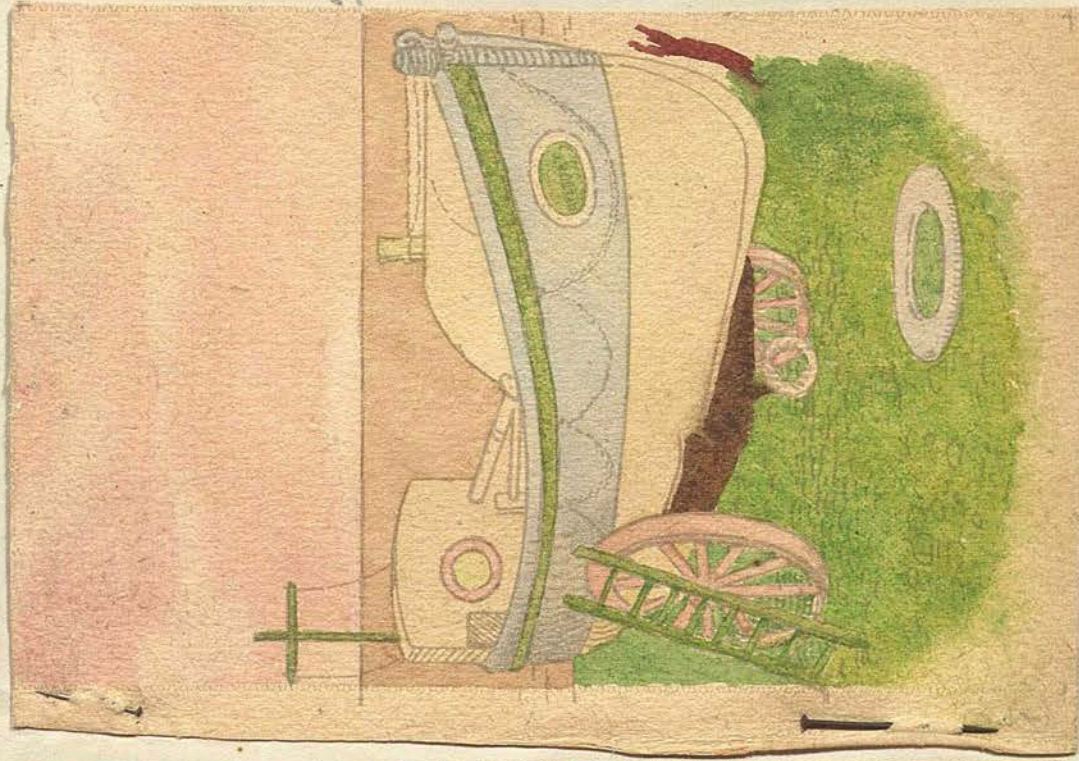
note confusion of red with brown.
 " " red with green.
 " " blue with pink.
 " " yellow with green.

1st four-color block (to make one
day (600 pages)

Front piece



The Life Boat.



Similar confusion as in preceding painting; but this time green
 also is confused with brown. The red splash at the right hand side
 was judged to be too dark to represent the beach - so green was
 substituted as it was of a lighter shade of the same colour, and in
 consequence came a more satisfactory match.

12 Colour Preference, (Hals)

A test of colour-preference was carried out by the subjects themselves by the method of paired comparison, and I was able to obtain the results for some of them. The colours were six in number, magenta, red, blue, green, yellow, and violet; and they were presented in pairs - the subject each time indicating the colour preferred. There were thirty pairs in all, which were arranged in chance order, involving thirty judgments. The experiment was so arranged that fatigue would be avoided, ten judgments only being made at one stretch; the colours arranged by the experimenter were kept hidden until a given signal by means of a cover sheet. The same area of colour was shown in each case, the two colours being slipped into a specially devised apparatus somewhat resembling a double photograph frame. The whole experiment was regulated by means of a metronome.

(76)

	Mag.	R	B	G	Y	V
A.	4	2	10	0	9	5
B.	6	4	10	3	0	7
D.	1	8	9	1	6	5
H.	2	2	13	0	8	5

B. thought the magenta was purple, and the violet blue. H. thought likewise, but he also considered the red to be brown and the green, grey.

In all four cases, green is more or less disliked and is only chosen four times out of a possible 120 - Fred also in the case of A, B and H.

Blue and Violet combined give the following results:-

(79)

A	chose them	15 times,
B	..	117
D	..	14
H	..	18

and together they form half the choice. The Violet in many cases was thought to be blue.

(80)

Blue+Violet+Yellow	{	A - 24 times out of 30	
		B - 17	..
		D - 20	..
		H - 24	..

This seems to point to the fact that the easily distinguished colours are the favourite ones and those difficult to see are generally disliked.



It will be advisable to follow Professor Hayes' plan and gather together on a single page the results of all the experiments; that is in so far as red or green was able to be distinguished. R indicates that Red was recognised with fair frequency in the test, G that Green was recognised. "con" indicates that the typical colour-blind confusions took place. It can be clearly seen from the evidence that the subjects are not all limiting cases, and that red and green can be seen by some red-green colour-blinds.

	A	B	C	D	E	F	G	H	I	J
Stilling T.	Red	R	con	R G	con	con	con	con	con	con
Holm.Wools.	con	con	con	R	con	con	con	con	con	con
Nomenclature	R G	R G	con	R G	R G	R G	R G	con	con	con
Colour-Mixing	R	R	R G	R G	R	R G	R	con	con	con
Rayleigh Eqn.	R G	R G	R	G	G	R G	R	con	---	con
Col.Shadows	R	R G	con	G	R G	R	con	con	---	con
Col.Contrast	R	R G	con	con	G	R	con	con	---	con
After-Images	R	R G	con	R G	con	con	con	con	---	con
Bradley Test	R	R	con	R G	R	con	R	con	---	con
E.G.Lantern	con	con	con	R? G	R G	con	con	con	---	con
Nagel Cards	R?	R?	con	con	con	con	con	con	---	con
Painting Test	R	G	con	---	R G	con	R?G?	con	---	con

The number of times red and green can be distinguished relative to the number of confusions, gives a fair indication of the degree of the defect. H and J failed completely in every test, and may be regarded as limiting cases.

p.c.

THE TESTS

All the tests used yielded favourable results. The most unsatisfactory are what may be termed the subjective tests, those tests over which no objective control is possible. The most marked are the after-images and the contrast experiments. In the former, it is difficult to regulate the time of perceiving the stimulus, for it was found sometimes that an after-image made its appearance with prolonged fixation where no image had been previously reported. The rings contrast too are unreliable. The coloured shadow is a better test, but varies from ~~observer to observer~~ with different experiments unless an analysis of the source of light is possible. Colour equations, though trustworthy with reliable subjects, are not altogether satisfactory, for the experimenter is entirely dependent on the subjects and has no control over the final equation.

Tests involving comparison seem preferable, in which the examinee is asked to do something himself. Holmgren's Wools in its original or in a modified form holds the field here. Although discredited from time to time, chiefly because of its implications with the Young-Helmholtz theory, it has remained the best modes of testing. The improvements have taken two forms 1). either the number of confusion colours has been reduced, or 2). the test skeins have

49
one of the simplest

been altered. The principle of the test, however, has remained unchanged. The Bradley Paper Test is based somewhat along the same lines, but in addition it has the advantage in that it gives a fairly reliable spectral analysis where more exact methods are not available.

devised /

Stilling's Tables and the Nagel Card Test also deserve commendation for they have both been found to be excellent for testing purposes. They are useful for detecting the presence of an abnormality, but for diagnosis they require supplementing. Part B of Nagel's Test does not seem to be of much service and could be dispensed with. Part A forms an admirable test.

The Edridge-Green Lantern is a test in a category by itself. It proved to be a most efficient one in every way. It has been devised after a long period spent in practical work with the colour-blinds, and is based on a thorough knowledge of their characteristics. For practical purposes it should prove of intrinsic worth. It combines the recognition of colours with the naming of them, which was found to be of great utility, throughout the experiments. The modifying glasses are well adapted for the purposes intended, and proved most satisfactory. ~~It~~ has the advantage that a short examination with it is sufficient to reveal the defect. Further, it seems impossible to coach a colour-blind to pass such a test, so many combinations of glasses are possible.

the very highest value /

The test /



Left & right headlines
Diagnoses of
Individual Cases

A BRIEF Diagnosis

SUMMARY OF THE INDIVIDUAL CASES

f.c. Stals

NEW RIGHT
PAGE

Although the cases of colour-blindness which were tested, have been discussed in connection with the tests, the discussion has been hampered by the massing of results. It will be instructive, therefore to collect the data for each colour-blind, and give a brief diagnosis of each individual as revealed by the tests.

SUBJECT A: A

A is a typical colour-blind. From different tests it has been gathered that she has a neutral band in the blue-green region of the spectrum. From Stilling's Tables it would appear that she has a shortened spectrum at the red end, for she is unable to read Table 3. This was confirmed in her confusion of blue with pink. She does not, however, mistake red for black. The subject can distinguish highly saturated greens and reds, but has always experienced great difficulty with pale colours; yellows, fawns, pale-pinks, and pale greens, are constantly confused, but the subject has always been aware of this difficulty. In the wool test, we saw that the matches to the vivid green and the vivid red were excellent; it was only when the paler colours were reached, that the confusion began to make its appearance. On being asked to divide out all the skeins into bundles, she placed together blues and violets; greens, yellows and fawns; greens, moles and greys; greens and browns; light greens and yellows; pale green and pink. She distinguished the reds, however, from the blue-reds.

by/

her/ him this respect

All through the tests, it has been confirmed again and again that certain reds are visible to her. How otherwise can we justify the result that in the Nagel Card Test, in the Edridge-Green Lantern, in the wool test, and in others, red can be distinguished? In the colour naming too, the bright red dots in Stilling's Tables are clearly recognised.

explain/

It would seem, however, that red is much better recognised than green, and that the blindness to green is the greater. The green when it inclines to a blue-green is seen as a grey, but otherwise there is a constant confusion with yellow. ~~It would seem that~~ Dr. Ladd-Franklin's description would just fit the case, namely, that red vision had 'fallen out' and green vision had been turned into yellow-vision, were it possible for the red vision not to have 'fallen out' entirely.

Apparently/

A, of course, does not always recognise red, for she sometimes calls it green as we saw with the Edridge-Green Lantern. Signal green, however, appeared to her almost white. In after-images the red stimulus gave a white after-image but the green stimulus gave a red after-image. In coloured shadows the red shadow was correctly named, but the green shadow was mistaken for red, and the yellow one was called green. In the rings contrast, the red contrast colour was seen, but the green one only appeared grey. In the coloured diagram, the reds were correctly matched, but the greens

And 8/

✓✓

30

were matched with greys, lavenders and blues, while greens were confused with browns. In the Bradley Paper Test, it was always the greens and greys that showed confusion with the blues. In colour mixing the blue-green was matched with a grey, and the green with a yellow, but the red had to be considerably diluted before it could be matched with a grey. These results cannot all be accidental, but the curious ^{fact} is, that if Stilling's Tables are correct then her sensibility to red should be weakened, as the red end of the spectrum is shortened. The only confirmation of this is the confusion of blue with pink. But the results taken as a whole would indicate that the shortening ~~must~~ *cannot* be extensive, as we failed to find any other evidence of it.

for we do not find

Our final finding is that the subject is a red-green colour-blind. She is not ~~totally~~ colour-blind, *entirely red-green* that she cannot see these colours at all. She makes the typical mistakes of the colour-blind, but under favourable circumstances, if the colour be of a certain hue, red and green can both be distinguished. The blindness to red, moreover, is less severe than the blindness to green, for the former colour is better identified.

SUBJECT B: M

This subject presents a somewhat similar case, and his chief difficulty lies with the pale colours. Since being tested, he has discovered that his brother suffers from a like defect, and makes the same kind of mistakes as the subject does.

B. is a red-green colour-blind with normal length of spectrum, and a neutral band in the blue-green. He is an extremely careful subject, and matched the skeins in the wool test with great care, and to outward appearance, with great difficulty. He confuses greens, fawns and yellows, and pale greens with pale-pinks. Very often in choosing skeins he lifts one up, lays it side by side with the test skein, and after long deliberation accepts or rejects it. He spontaneously gives his opinion of the confusion skein, saying whether lighter or darker. The magenta skein he matched with all shades of blue and violets which **clearly** showed a deficiency in red. He can frequently detect differences in colours such as violet and blue, or even magenta and crimson; for it is impossible to get these equated on a colour mixer. He is one of those who require the addition of a third disc of blue in equating Red and Green equal to Grey. In matching blue-green with grey, his final equation does not give him entire satisfaction.

He seems to be more sensitive to red than A for he recognises the red in the coloured shadow, in the rings contrast, and in the after-images; although he expresses doubt in the last case. In the Nagel Card test, however, he includes Card 2. with the reddish spots showing a confusion of red with brown and further he includes Card 15 - which only contains two red spots - in the reds only. He found this test one of great difficulty, but it is noteworthy that whenever a particular bright shade of red appeared it

was invariably identified.

The subject has greater difficulty with greens, and they are often confused with yellow. The shades of grey, however, in the Bradley Papers, were all thought to be shades of green.

This subject yields a similar diagnosis to A's., he is a red-green colour-blind with, however, a normal length of spectrum and a small neutral band in the blue-green. He is not totally blind to red and green for they can be seen if conditions are favourable.

SUBJECT C:*

This is a most curious case of colour-blindness, and it may be instructive to examine the results obtained from him with a little more detail than in the preceding cases.

In Stilling's Tables, the first table reads;

56	27	89	43
----	----	----	----

the subject read:-

86	28	89	48
----	----	----	----

Similarly in Table 2. we find:-

39	42	86	75
----	----	----	----

the subject read:-

88	48	88	75
----	----	----	----

These give evidence of colour weakness only, and at first the case was considered as showing, not blindness to colours, but a slight colour anomaly. The subject reads Table 3. correctly, but Tables 4, 5, 6, 7, 8 and 10 ~~are~~ beyond him.

In naming the colours of the spots on the tables, it was found that a curious confusion existed in the subject's mind. Red and green were constantly mistaken, and the usual confusions of the colour-blind made their appearance. For example, in the first table, which contains red figures on a green background; he described them as brown and dark green figures on a brown and a yellow background; and if we trace his results all through the Tables we find the same confusion existing.

With Holmgren's Wools, he makes many mistakes and finds the test a difficult one, for he is not at all sure of the colours of the skeins. Brown he matches with a very dark crimson, and an emerald green, and throughout he makes the characteristic mistakes of the colour-blind. Here again, too, his nomenclature is very faulty, test skein 1. he declares to be red, or yellow, or brown; brown, he calls very dark green; pink, he names green; rose-pink, he describes as green with red about it; violets and purples, he calls blue; orange is thought to be yellow; and he often employs the term reddish-green. Red and green too, are frequently confused.

Therefore it is all the more extraordinary to find that he can match colours with surprising accuracy on the colour wheel, while in the majority of cases he can obtain a normal equation. His naming of the colours while matching them shows much confusion, and yet his ultimate result is good. The equation, green and red, and blue equal grey, is almost identical with the normal equation. Attempts failed to match blue and violet, green and grey, red and grey,

green and yellow; in fact no match could be obtained which would not be accepted by the normal eye. The matches for colour mixings seem therefore to indicate perfect colour vision, whereas atrocious nomenclature and mistakes in selecting wools seem to indicate red-green colour-blindness.

The other experiments emphasise the defect and point to the subject being colour-blind. The Bradley Papers indicate weakness in the blue-green regions of the spectrum and a corresponding defect in the extra-spectral purples. The greys appear to him green. In the coloured shadows he sees both the red and green shadows as grey; in the rings contrast, grey again is seen where red and green are clearly visible to the normal eye. The after image likewise reveals a similar defect. The Nagel Card Test points to the defect being a grave one. No red dots at all are visible to him, and seven cards are said to contain green only, whereas but one of these is correct. The Edridge-Green Lantern confirms these results and shows a hopeless confusion of colours. If the subject had been the correct distance away from the lantern, ^{his} results would have been greatly ~~increased~~. In fact the *emphasized* reduction of the aperture to No. 3. reduced most of the colours to a spot of light.

The evidence of these experiments, and the fact that he accepted the normal Rayleigh equation place him among the colour-blinds.

Colour equations and Stilling's Tables are the only two tests which credit him with good colour vision. The other tests all point to the defect as one of red-green colour-blindness, with a normal length of spectrum, and a neutral band in the blue-greens. It seems possible, *therefore*, for a colour-blind to avoid detection if Stilling's Tables are used alone. (1)

SUBJECT D:4A

This subject is a 'dangerous' colour-blind. He presents a somewhat similar case to that of C. He can partially pass Stilling's Tables, but his nomenclature shows considerable confusion. Pale blue he calls brown or green; pale pink, he sees as grey *or yellow*; violet, he calls blue; ~~pale pink, is yellow~~; and in selecting the wools much confusion is exhibited, and the usual mistakes of the red-green colour-blind are perpetrated. When tested with colour mixing, however, his results show great improvement. With the complementary red and green, he requires the addition of a third colour before he is satisfied. It is impossible to get equations from him such as were obtained from the other colour-blinds. In the coloured shadows, *experiment*

made

del.

(1) Edridge-Green in discussing colour-blindness states; "Many colour-blinds match correctly, but name the principal colours wrongly."

✓ ✓

the green shadow is recognised, but the red shadow is seen as yellow. In the rings contrast, the red and green are seen as grey, but in the after-images both the red and the green images can be distinguished. In the Nagel Card Test, he can **only** pick out three cards containing red spots, out of a possible ten. He can see none containing red spots only; and makes mistakes in picking out the green and grey cards. With the Edridge-Green Lantern he mistakes the purple disc for green; a dull foggy red is invisible to him; green combined with neutral 5, which to the normal eye appears red, is seen as a green.

He is certainly colour defective, but his acceptance of the normal Rayleigh Equation prevents his inclusion in the class of 'anomalous trichromates.' He must be classed as a red-green colour-blind. His Rayleigh equation is; 200 red + 160 green = 38yellow + 74 white + 248 black. Compare with his equation of red and green = grey; 118.5red + 204.5 green + 37 blue = 264 black + 96 white. The former shows an excess of red beyond the normal; the latter, an excess of green.

[this

maybe

There is no doubt, however, that red and green ~~are~~ visible to him, (but they are not always recognised as such). He seems a mild case of colour-blindness, milder even than A. or B.

under certain conditions

SUBJECT E:A

This subject from cumulative evidence appears to have a large neutral band embracing the greens and the blue-greens. In the Stilling's test he is unable to read tables 1 and 2, but reads table 3, which suggests that he has a spectrum of normal length. From the spectral diagnosis and the Bradley Papers, it seems probable, however, that the spectrum is a little shortened at the red end, and it is interesting to note that this conclusion is confirmed by Professor Roaf's spectral diagnosis of the painting.

his

In matching the wools he does the vivid red and the vivid green correctly, although in making the latter match, he was seen to examine and reject a pink. The medium greens and pinks show the typical colour-blind confusion with yellows and browns, ~~also with greens and pinks.~~ The medium pink appears almost a white to the subject, and to obtain suitable matches is a task of extreme difficulty. The magenta skein is matched with bluish pinks, blues and violets.

with one another and

His nomenclature shows the typical confusion. For example in the first of Stilling's Tables, he describes the red figures on the green background as violet on grey. The second table, which reverses the same colours, is described as green on grey. He shows a further confusion of red with brown, and green with fawn and mole. Naming the wools gives like results; orange is mistaken for yellow; purple for blue; violet for pink; pink and green for grey. A colour is often described as a blue-grey, a green-grey, a red-grey; and the term 'flesh-colour' is often utilised.

52

The coloured shadows are rightly discrimin-

✓

ated, although the yellow is described as brown. In rings contrast the pink is not recognised; the green and the yellow are named greenish-grey and brownish-grey respectively. No after-images could be obtained from ^ared or ^agreen stimulus.

The Nagel Card Test he finds difficult and he had to trace each ring round with a pencil before making a decision. In selecting cards with red spots he chooses No. 12, which Nagel states is almost complete evidence of colour-blindness; the brown spots on this card he mistakes for red. This same card is selected later as containing green spots only. Similar mistakes in selecting grey only and red only are made.

In the colour equations he can obtain a satisfactory match with red and green, equalling grey without the addition of the blue disc. A similar equation can be obtained for blue and yellow. This latter equation - perfect to E. - appears decidedly pink and green to the normal eye. He matched blue-green with grey but not green with yellow. This can be explained if the green forms a neutral band and is seen as grey, and not as yellow. The subject cannot get rid of the brown tint in the yellow. Violet is matched with blue, but red cannot be equated with green, nor with yellow and black.

In the Edridge-Green Lantern red often appears as brown; yellow is sometimes green, ~~yellow is sometimes green~~, sometimes red, sometimes brown; violet is seen as blue. Although signal green itself is seen as green, yet when modified by neutral 4 or neutral 5, it appears as grey. Pure green + N5 is seen as grey brown, and pure green alone appears a light brown. Yellow alone may be called a light brown; but a double disc of yellow changes the colour to red. Aperture 3 changes the colours Red A, Red B, yellow, pure green, signal green, blue, violet; to red, orange, brown, green, dark grey, red-blue, red.

Yellow and blue are clearly recognised; red and green seem sometimes to be recognised. It is interesting in this subject's case to note, however, that pale blue is at times seen as a grey, and that violet is more than once described as a dark grey. There is a possibility of a shortening of the spectrum at the violet end, probably similar to the shortening at the red end.

SUBJECT F:4/

This subject cannot read the first 12 Tables in Stilling's Tests, although he occasionally reads a figure here and there. This would suggest he was blue-yellow blind as well as red-green blind, which he certainly is not. He appears to be red-green blind with slight shortening of the spectrum at the red end, and there is a suggestion of a weakened sensitivity in the green and blue-green regions.

With the Holmgren wools, he shows confusion from the beginning. The vivid green he matches with greens, yellows and drabs; the vivid red with a vivid



red skein, and a very dark green. The brown proved difficult to match; with the magenta he put pinks, violets, blues, greens and greys. The medium and pale skeins showed the usual confusion. With the pale blue he invariably matched blues and pinks- ~~which~~ extended to the darker shades of red as well. *and this confusion*

In colour naming he makes many mistakes. Red is confused with fawn and mole, drab and brown, and very often with blue. Green is often taken for yellow or pink. What is very characteristic of this subject, however, is his vague, indefinite phraseology in describing colours, which we noted in the colour-naming tests. "Some red init", "red and something else" etc.. A grey skein of wool he describes as "red and something else, perhaps brown."

The Nagel Card Test he finds difficult and he shows great confusion of green with red both in selecting the proper cards in Section A and in naming the cards in Section B. In the coloured shadow test, the red shadow is seen correctly, but the green is described as red. A similar result appears in the rings contrast. The after-image of yellow is described as blue or red, that of red as white, and that of green as blue.

In colour mixing he requires the third disc of blue in matching the complementary colours, red and green, but his final equation shows a marked deviation from the normal. He matches red and blue-green with grey, green with yellow, orange with yellow, and violet with blue.

The Edridge-Green Lantern was a severe test for him; and he took longer to test than any of the other subjects. He finds the red especially trying. Red A is thought to be yellow, and Red B a yellowish brown. Very often signal green is confused with red and when combined with neutral 5, it becomes invisible. Pure green is seen as yellow, but neutral 5 placed before it, changes it to red. Neutral 4 and neutral 5, both reddish, are seen as green by the subject. Purple and N.4, which gives a full red, he can hardly see. The reduction of the aperture to 3 causes the colours to appear as spots of light, except those of blue and violet which he recognises as blues.

This case shows a greater defect than that of A or B. It was discovered by chance in the playing of a game in which colours had to be distinguished; but the subject was quite unaware of any abnormality in his colour vision.

(53) SUBJECT G:A

G. was unaware of his defect until tested and accordingly was loath to admit its presence. He is a difficult subject to test, for he tries as much as possible to cover his failings. His spectrum is of normal length, (there may be a slight shortening at the red end) with a neutral band extending over the green and blue-green.

He fails completely to read Tables I and 2 of Stilling's Test, but reads 3 without difficulty. In naming the colour of the dots and the wools, he

...makes the typical mistakes of a red-green colour-blind. In matching the test skeins of wools, he selects his colours with great deliberation, but notwithstanding all his caution, he betrays his defect by making the characteristic confusions. With the vivid red, he places pinks, drabs, greys and blues. He can give no match to the pale pink skein, for it appears to him as a 'dirty white'. The medium green and pink are matched with a large variety of wools of different hues.

The following colour-mixings are successful:- green with grey; red with grey; violet with blue. Red is matched with green, both discs diluted, but the two colours clearly visible to a normal eye. No third disc is required in equating red and green with grey, nor blue and yellow with grey. Green can not be matched with yellow which may be explained by the presence of a neutral band there.

In the Nagel card test, he is able to find only two cards containing reddish spots, can find none with red or grey only, but selects 14 cards containing green alone, only one of which is correct. In Section B of the same test, he commits many errors.

In the coloured shadows red and green are invisible, but the yellow appears green. The green in the rings contrast is seen as d.grey, the red as blue. Red and green stimuli only result in grey after-images.

very prettily

The Edridge-Green Lantern reveals his defect ~~with great skill~~, for the modifying glasses are troublesome to him. Red A and Red B can be distinguished, but with a neutral glass in front, they become green every time. The first four neutral glasses are seen as reds, but Neutral 5 is a green. If in doubt as to a colour, green is the name preferred. Yellow is a difficult colour for him and is usually confused with red, particularly when a red precedes it. The ground glass is especially trying for G, and it is noticeable that when such a modifying glass is used, he spends a very long time coming to a decision. It seems to change the colour completely (and causes an erroneous answer to be made).

G seems to be able sometimes to distinguish red and green, but neither is a clear sensation for him, and they are both liable to be confused with one another or with some other colour.

SUBJECT H, : *MA*

This subject is a limiting case of dichromasy: his only sensations are those of blue and yellow. Red and green are totally invisible and under no circumstances can they be recognised. The spectrum shows a shortening at the red end, with a neutral band embracing the green and the blue-green. From cumulative evidence, the violet end of the spectrum appears to be cut off to a small extent. From the colour-mixings it is seen that Red, Orange, Yellow and

l.c.

Green appear as nuances of Yellow, blue and Violet as

l.c. ✓

l.e.

nuances of Blue. His nomenclature is very constant - red is called black, but if a little diluted is termed a brown. Green is seen as grey, but a bright green with a touch of yellow in it, is termed orange.

It is noteworthy that in the Nagel Card test, he fails completely in Section A; no red spots at all can be found for they all appear to him as blue. No card containing green spots only can be selected, and the ^{card} with nothing but red spots is picked out as of a uniform grey.

Red is not seen once when tested with the Lantern and signal green appears white. The modifying glass causes no change in colour but suggests a difference in shade. Grey is a frequent answer given, and orange too is employed on many occasions.

he is

The coloured shadows reveal a total lack of red and green sensations, which is confirmed in the rings contrast test and in the after-images. In all three, red and green are replaced by grey.

result

l. test

With the Bradley Paper Test, a definite defect in shade is noticeable. This seems to be characteristic of a shortened spectrum.

This subject has two brothers who have monochromatic vision.

SUBJECT I : A

This subject is noteworthy for his remarkably uniform nomenclature, and for the variety of colours which he confuses.

In the Stilling's Tables, 1 and 2 can be deciphered but with extreme difficulty. Table 3 cannot be read at all. This indicates a shortened spectrum. The colours of this table which are crimson on black and mole are seen as d. grey on shades of grey. Crimson and red, as ~~are~~ to be expected, are frequently mistaken for black or d. grey.

is/

In naming the wools, reddish-green is a term made use of on numerous occasions. He is seldom content with a single colour name, but uses such phrases as 'golden brown', and 'crimson lake', the former applied to browns, the latter to dark green. These terms are used with evident satisfaction. A threefold description is not unusual, and grey or dark violet may be termed as 'pinkish, greenish, brownish.' In matching the Holmgren wools he thought the brown skein was the vivid red one given to him again in mistake. The confusions he makes with the wools are numerous, and begin in the highly saturated skeins. Vivid green is matched with greens, pinks, and browns; vivid red with greens, browns and blues. The other skeins reveal a like confusion.

(It is difficult to get colours equated on the colour wheel, for his nomenclature is so misleading. In equating red and green with grey, a third disc is required, but the final equation contains only 68° red as compared with the normal 113°, and contains a correspondingly large sector of green. Green and red diluted are both matched with grey, 197° ~~with~~ of green compared with 195° of red, so that it is possible

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to match green directly with red. His equations are very similar to those of H., except that red can not be equated with yellow and black. Green is matched with yellow and orange, and violet with blue.

It seems evident that this case is a red-green colour-blind, with shortened spectrum at the red end and probably at the violet end (for results tend to point to that conclusion) and a neutral band in the blue-greens. His colour sensations seem to be that of yellow and blue.

SUBJECT J: A

It will have been gathered from the tests that this subject is completely blind to red and green. In the centre he has a large neutral band embracing the yellow-greens, greens and blue-greens. The two colour sensations which he does experience seem to fill only a small part of the spectrum, and from the results of different tests, it appears that there is a reduced sensitivity to these two colours. In the coloured shadows, the yellow can not be discriminated, and the shadow which appears vivid to the experimenter, is merely called grey. In other words, the yellow must be highly saturated before it is distinguished. A disc of yellow was rotated on a colour wheel and when diluted with a little white it was matched with a grey by the subject. 258° yellow + 102° white = 92° black + 268° white. The yellow was distinctly ~~seen~~ in the final equation, but seemed to make no impression on the subject.

visible /

The large number of colour skeins, all selected as of the same hue, is remarkable; and each time a skein is given, most of the wools are matched with it. In naming the dots in Stilling's Tables, he can perceive no colour, but monotonously maintains they are all 'shades of grey.' In naming the wools too, the same result is apparent. We have already described his ~~his~~ colour equations under experiment No. 4. and appended examples of his colour matches. In the I. Lantern test his answers were unfailingly 'grey', and it was a relief sometimes to hear the name 'blue', or even 'black.' Out of the 76 combinations shown, 50 of these were described as grey, 6 as black, 2 as white, while on six occasions nothing was experienced, giving a grand total of 64 colourless sensations.

In the Nagel Card Test, all sixteen cards in Section A. are seen as grey, while the cards in Section B. merely represent ~~different~~ different shades of grey and black.

In the Bradley test, a grave defect in shade is apparent, evidently typical of a shortened spectrum. The red end of the spectrum is considerably shortened, and there seems to be an accompanying shortening of the violet end as well. This might be described as a case of colour-blindness just preceding total, in which the yellow and blue regions have become restricted to narrow patches in the spectrum.

L Papers

The subject's maternal grandmother had great difficulty with colours, and his uncle on the same side can distinguish highly saturated colours only, having

L

great difficulty with pale colours. I tested his sister's vision, and found it to be perfectly normal. The subject discovered his defect while in the army, when he failed to distinguish S.O.S. signals while out on patrol.

l.c.

AN ANOMALOUS TRICHROMATE: *un*

An anomalous trichromate was tested with Stilling's Tables. She was found able to read most of them, but made a few mistakes with No. 6. and No. 10. Her colour naming was excellent both in the tables and with the wools, nor did she make any confusions in selecting suitable matches. From the Rayleigh equation she was found to be red anomalous which was again verified in matches of red and green with grey.

l.c.

RAYLEIGH EQUATION:-

208° red + 152° green. =
Compare with → 208 red + 50 green + 53 blue =

It is a strange coincidence that the sections of red in both equations are identical.

In the coloured shadows both red and green were identified, but in the rings contrast the green was called grey and the red purple.

There exists a hiatus between this case and the colour-blinds, but it seems probable that the gap could be filled by gradation cases with the defect step by step becoming more serious and the confusion increasing. The case appears the beginning of a defect in red, which one can imagine increasing in severity until a milder form of colour-blindness takes its place.

Λ

Λ Insert C here

From the analysis of the colour-blinds, one fact stands clearly out, that the sensations which they experience most distinctly are blue and yellow. Certainly, in the case of the last three subjects, these are the only colours visible to them. Dr. Pole in describing his own case of colour vision, made this quite clear, and the diagnosis of his spectrum might well be that of H. (1) "The most salient fact in dichromic vision is its remarkably simple and symmetrical character, consisting of one pair of complementary colours, with gradations of nuance perfectly symmetrically disposed." Appended below is the circular diagram for normal vision of Helmholtz, perfected by Donders in 1881, to represent the dichromic spectrum. In this the pair of visible colours are shown with their maxima diametrically opposite, and from these two points they become modified, in one direction by darkening only, in the other by darkening combined with dilution, till, at the top and bottom, the colours meet, and become lost in the neutral points. And these two neutral points, also diametrically opposite each other, correspond to the other pair of complementary colours, the purple-red

Λ (Figure VIII) drawn first by Newton and * and Pole describes it thus/

Λ Figure IX was constructed on (Figures VIII) Similar principle

(1) Transactions of the Royal Society Edinburgh, Vol. 371

of [handwritten marks]

A second subject was tested- since the above was written- who seems also well classed among the anomalous trichromates. Her sensation of colour is considerably weakened, and it is worthy of note that her father and brothers suffer from colour-blindness.

The defect of this subject first came to light in an experiment involving colour mixing. The difficulties in obtaining a match were very noticeable, and a long time was spent in the adjustment of the discs. Finally, the match given as perfect was not valid for the normal eye. A further investigation with Stilling's Tables revealed- not coloured blindness, but coloured weakness. The test with Holmgren's Wools did not indicate any serious defect- although many omissions of skeins occurred- nor did the test with the Bradley Papers reveal much colour anomaly. In the latter test, however, one fact attracted considerable attention. It was obvious that almost immediately on seeing the colours the eyes of the subject became extremely fatigued. The colours seemed to have a dazzling effect, and a rest-pause had to be instituted after every choice of colour made. This fatigue was very marked, and the subject confessed that after the colour mixing experiment in class the previous week, her eyes had been very painful.

55

the results of which are

In the colour-mixing experiments tried as part of the investigation, and comparable with the colour blinds tested, the following equations were obtained:-

h those of

127° Green + 233° White = 56° Black + 304° White.

138° Red + 222° White = 83° Black + 287° White.

360° Violet = 135° Blue + 225° Black.

From these results, it is evident that there is a slight weakness to both green and red, for in the first two equations, where both these colours are matched with greys, they were not- to the normal eye- totally eliminated by the admixture of white, but, though pale, were clearly visible. The matching of violet with blue was rather a surprise to the experimenter, who had not judged the colour defect serious enough to give this particular colour equation.

With the Edridge-Green Lantern test, one or two mistakes were made. It is worthy of note that this test apparently caused little or no fatigue. The yellow disc (which approximates to orange) was difficult to describe, and at last was recognised as a 'pure colour between grey and white'. This disc was always identified when it appeared, but no more definite name could be ascribed to it; when two yellows were shown, however, the name given was yellowish brown. Neutral 1. which imparts a yellowish tinge, could not be distinguished. What was described as yellow was Neutral 4. which resembles red more than yellow.

assigned

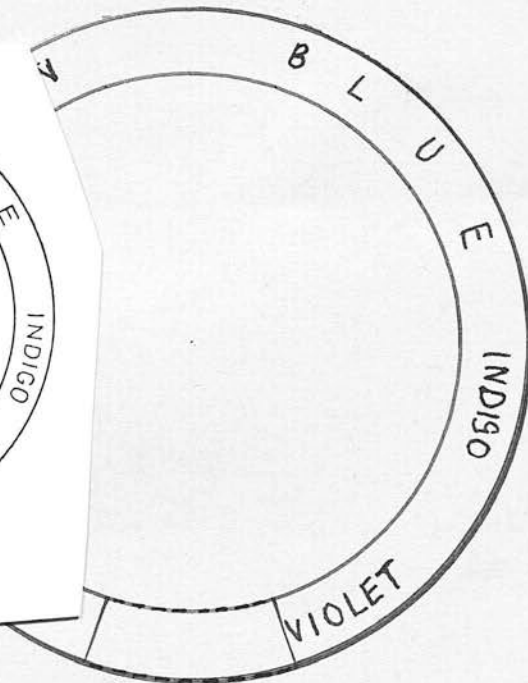
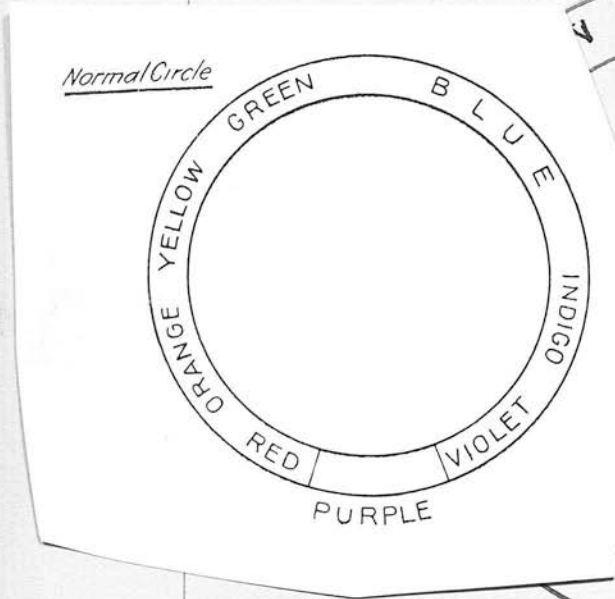
diminishes the intensity of light

✓

and blue-green, which though most prominent colours to the normal eyed, are invisible colours to the colour-blind. It will be at once seen what a remarkable symmetry this structure presents, and how greatly the regular arrangement of the dichromic series of colour impressions differs from the irregular structure of the normal series in the adjacent figure."

~~Figure VIII~~

NORMAL CIRCLE



PURPLE
Fig VIII

DICHROMIC CIRCLE

~~Figure IX~~

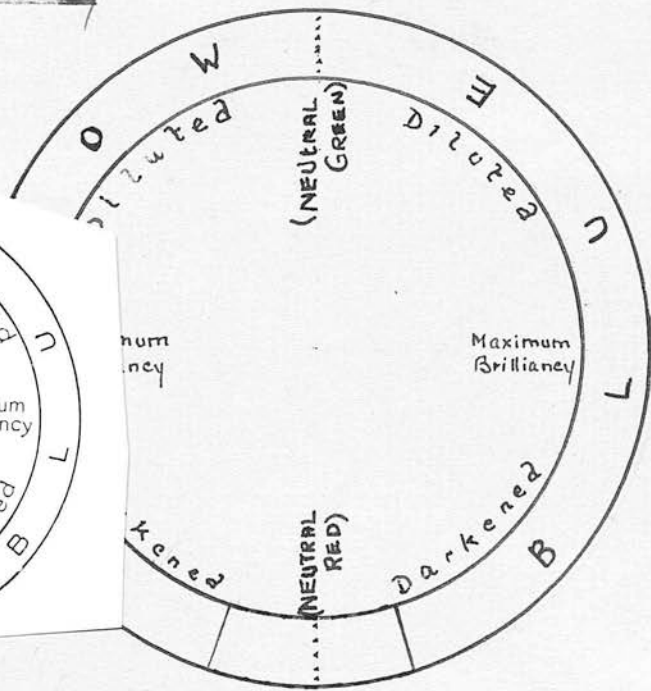
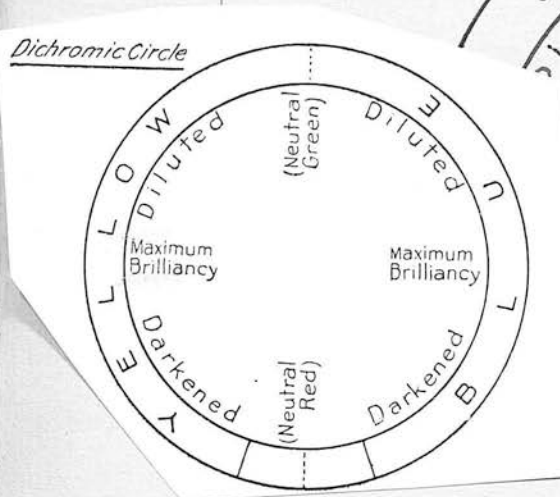
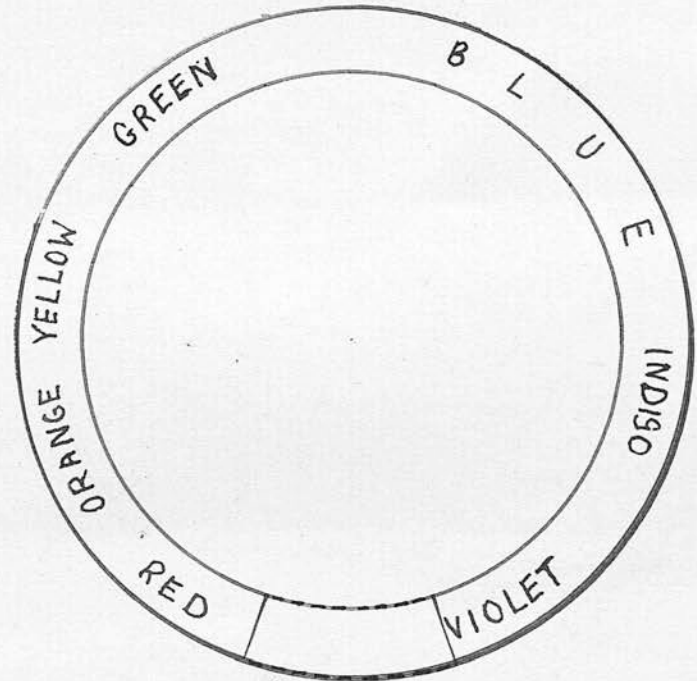


Fig IX

and blue-green, which though most prominent colours to the normal eyed, are invisible colours to the colour-blind. It will be at once seen what a remarkable symmetry this structure presents, and how greatly the regular arrangement of the dichromic series of colour impressions differs from the irregular structure of the normal series in the adjacent figure."

~~Figure VIII~~

NORMAL CIRCLE



PURPLE
Fig VIII

~~Figure IX~~

Dichromic Circle

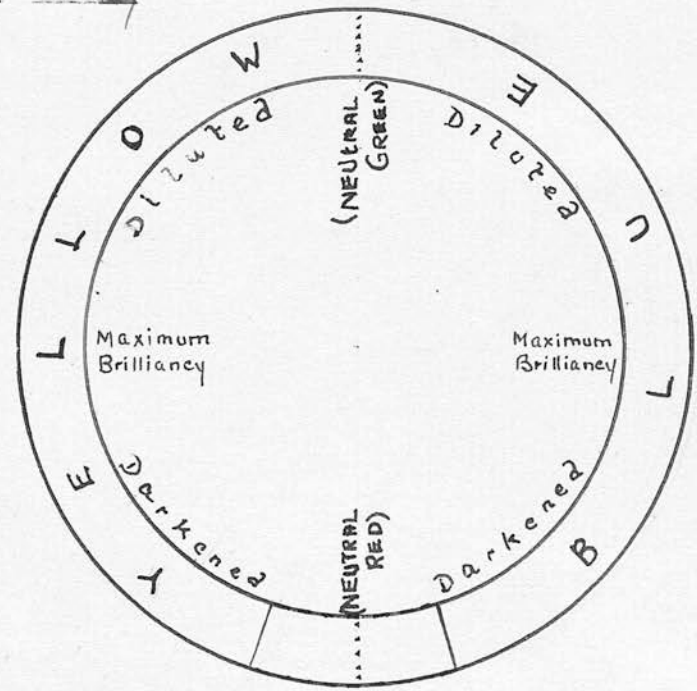


Fig IX

This diagram has been accepted by more than one investigator as being true to fact. It certainly only meets such extreme cases as those of subject H. in which the spectrum left of the neutral band appears yellow, and right of the neutral band is seen as blue. Yet even in his case the neutral ^{band} would require to be extended over the green as well as the blue-green. J. however, would require a modified diagram, for red and green with him are not replaced by yellows, but by grey. His sensations of colour have one point of resemblance with those of H, in that they are similar in hue. The one difference is, that they vary in extent, and only cover a very small portion of the spectrum. This distinctly shows the large variety which exists among colour-blinds. These two may be regarded as extreme cases and yet they present entirely different features, for the one has a much larger colour range, if we may so term it, than the other. It therefore seems unprofitable to systematise the colour sensations of the colour-blind, so many individual types exist.

See Figure X

56

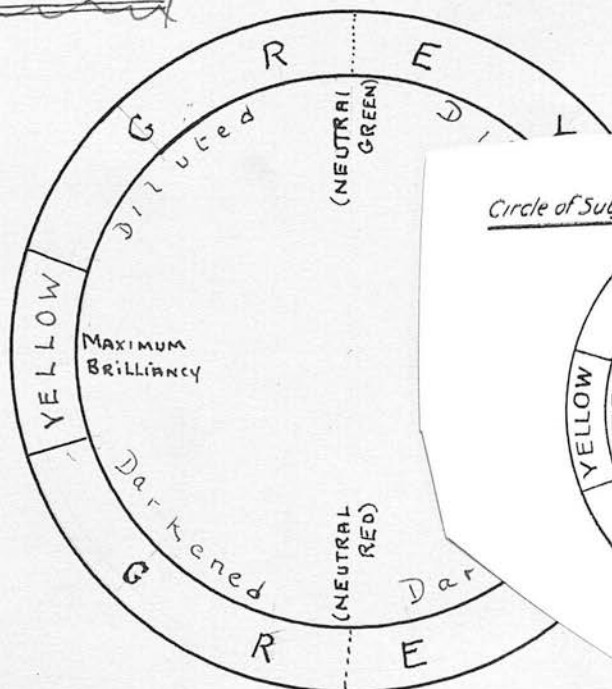
Moreover, a totally different diagram would be required for the milder cases of dichromasy, for not only are yellow and blue visible to them, but red and green too, if circumstances are favourable. They agree with the diagram, however, in so far that yellow and blue are distinct sensations to them, which are never confused with one another no matter how grave or how mild the defect; but it gives a false impression of such cases where these two sensations are not the only ones existent. Allowance must be made for these less extreme cases which we have been describing, and which appear to be more prevalent than the limiting types.

87

the diagram

~~Figure X~~

Circle of Subject J



Circle of Subject J

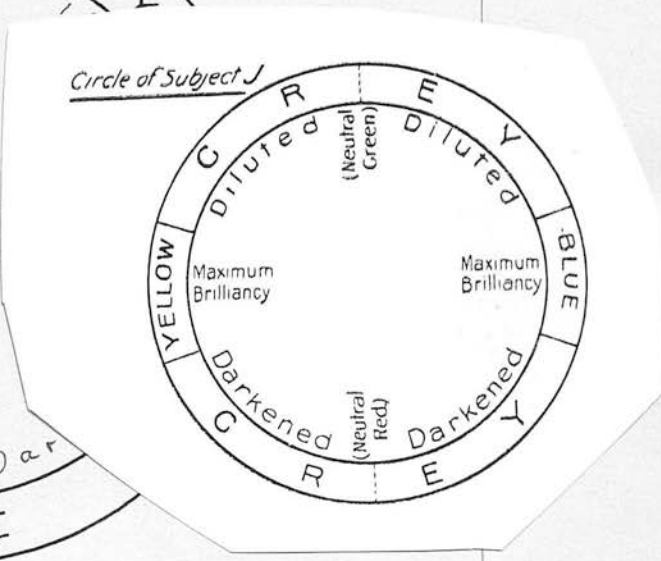


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~~Figure X~~

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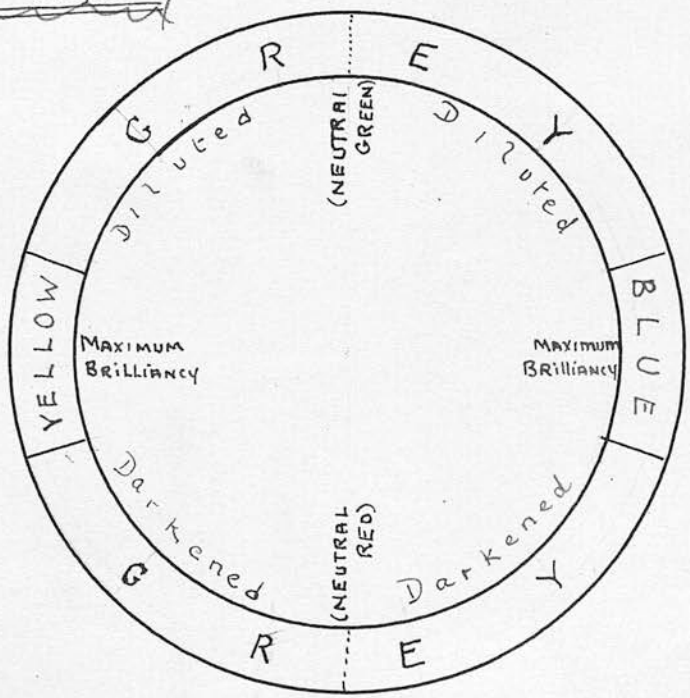


Fig X

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Conclusion

Clarendon

CONCLUDING
ADDITIONAL REMARKS

E. H. I.

1. Colours Confused by the Colour-Blind

Hals

1. Confusion of Red with Black:- This indicates shortening of the red end of the spectrum.
2. Confusion of Violet with Black:- This indicates shortening of the violet end (1). If the violet is not always so confused, or is only confused when the colour is at a distance, the shortening is not very great. (This fact issues from cases 'E. H. I. and J.)
3. Confusion of Blue with Black:- This occurred only once with subject I. It may be accidental, for it is rarely met with; it would suggest a neutral band in the blue.
4. Confusion of a Colour with Grey:- This indicates a neutral band in that respective colour. Blue-green we found was often mistaken for grey; likewise red.
5. Confusion of Blue with Pink:- This, as has already been discussed, indicates a shortened spectrum.
6. Other common confusions all characteristic of the defect are:
 - red with green.
 - red with brown.
 - green with brown.
 - green with yellow.
 - most pale colours
7. Green may be confused with purple due to a second neutral band beyond the spectrum.
8. Red may be invisible to the individual or may be replaced by yellow; likewise green.

emerges in the /

pointed out /

with one another
owing /

Constancy of Colours

2. Colours Remain Constant for the Colour-Blind

Hals

The colour-blind do not guess colours as is very generally supposed. They have a definite system of colour sensations which often prevents their detection. It has been made generally clear from the results discussed, that the examinees were regulating their answers from their own experiences. The case of H. and his use of the term 'orange' provides an excellent example.

by /

One other fact stands out clearly in this connection. With some subjects a colour name is appropriated and is used with frequency until it may become an idiosyncrasy. E's particular phrase is 'yellowish-brown', F's is 'flesh-colour', I's use of 'crimson lake' and 'golden brown' may also be submitted as striking examples.

almost

such as to /

Some

3. Characteristics of the Colour-Blind

Hals

1. They are more ~~open~~ sensitive to contrast than the normal. This was clearly indicated in the Lantern Test.
2. They show quicker fatigue to colours than

Sensitive / effects

(1) The shortening of the violet end of the spectrum may have a different explanation. It may be caused by the second neutral band extending as far as and into the violet.

the normal. The case of J. is the strongest example, for fatigue was noticeably present when tested with the Bradley Papers. B. too, in the after-image test, had to rest his eyes for quite a long period before a fresh stimulus could be presented.

↳ he was

3. In case of shortened spectrum, there may exist a defective shade perception, due to the absence of the red rays.

this end/

4. Some colour-blinds try to conceal their defect and employ every device they can think of to ~~hid~~ their disability.

5. A modification in intensity of light is for the colour-blind a change of colour.

Bearing of Results on Theories of Colour Vision

(Hall)

4. Theories.

It is not proposed in this section to assert dogmatically that the results fit in with any particular theory. It was explained in the introduction that the experiments were carried out without any preconceived theory ~~to form~~ a bias, and the question now arises, ~~do the results obtained tend to support any theory or are they antagonistic?~~

causing/

how far do the results tell for or against existing theories?

↳ we

considerable/

Although ~~have~~ an admiration for Dr. Edridge-Green's practical achievements, which have been productive of much valuable information and many useful tests, it must be admitted that his theory of colour vision is difficult to reconcile with facts. It has been found impossible to group the ten subjects into specific unit classes. H. and J. may be grouped as two-units, although ~~it is very grudgingly admitted~~ that Red and Violet are the two colours visible to them. It somewhat disarms criticism to find that they are not supposed to see these two colours, but only the centres of their two psycho-physical units which are yellow and blue. Even admitting this, subject J. raises a difficulty. He appears an extreme case of red-green colour-blindness with his yellow and blue sensations reduced in sensitivity. In fact he may be regarded as akin to, or as just preceding monochromatic vision. If so, and if Edridge-Green's theory is understood correctly, should not Red and Violet, the two extremes of the spectrum, be the colours visible to J.?

↳ we should be very loath to admit/

↳ according to Edridge-Green,

(57)

↳ Further,

if the centre colours of the units are always the colours seen, ~~this takes away any constancy from the sensations of the colour-blind,~~ ^{since} the position of their psycho-physical units ~~must vary~~. In fact a shortening of the spectrum at either end will narrow the band of colour. J. has shortened spectrum at the red end, a large neutral band, a small region of yellow, a second neutral band, a small region of blue, and the violet end shortened. There is no suggestion whatsoever that red and violet are the colours he sees, and certainly yellow does not form the centre of his red, nor blue the centre of his violet. It seems quite clear that yellow and blue are the two colours seen, and that these colours are the last seen before monochromatic vision ~~takes its place.~~

then the colour/ must vary from individual to individual,

Supervenes/

When we come to the three-units, the same difficulty arises. We find that reddish-green is a term used by the three-unit, therefore we try to place B. in the three-unit class, from that and other evidence, but without success. The three colours of the three-unit class are red, green, and violet. The three-unit never confuses red with green, but is always in difficulty with yellows and blues. This seems contrary to fact. B., or any of the other subjects examined, ~~is~~ always confusing red with green, but yellow and blue are two of ~~their~~ clearest sensations. The confusion of brown with green is a diagnostic sign of the four-unit. This class can see clearly red, yellow, green, and violet, but here again the facts point to different conclusions. The results therefore, as we have found them, are difficult to reconcile with this theory, and rather appear to give direct evidence against it.

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As a further point of explanation, it may be argued that yellow and blue are not clearly seen by the three-unit, that yellow is frequently confused with green, and blue with violet as Edridge-Green affirms. This is true, but it appears to be a begging of the question. Yellow is confused with green in ~~such~~ cases where the green element is absent, as in a compound of yellow-green, or in ~~such~~ cases of colour-blindness where green has been replaced by yellow and called green by convention, but that does not alter the statement that yellow is a distinct colour sensation. Blue likewise shows confusion with violet and with pink, but is not that because the red element is not recognised. It does not affect the validity of the statement that blue is ~~their~~ clear colour sensation, ~~of the red-green colour-blind.~~

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in these two cases

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In the Ladd-Franklin Theory, the red element 'falls out' in red-blindness, and green is replaced by yellow; in green-blindness the green element 'falls out' and yellow replaces red.

support/

In the results submitted, certain cases seem partially to support this theory; whether they wholly support it is difficult to decide. One fact, which does give it ~~allegiance~~ in the extreme cases, is that yellow and blue are the only two colours visible. In H. and J.'s cases the red and green must both have 'fallen out' and been replaced by yellow; in other words there has been a total regression to the second stage.

It seems more difficult to account for the milder forms. With some of the examinees green is replaced by yellow, which would appear to support the theory; that occurs in cases of red-blindness or in those cases in which the spectrum is shortened. But we have repeatedly shown that red is not totally invisible, nor green either. Therefore all the red cannot have 'fallen out', nor all the green been replaced by yellow.

In green-blindness, the green sensation is said to be missing, and yellow vision takes the place of the red. The same argument holds here, for the red is not always replaced by yellow nor does the green element always appear to be missing. In fact the

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division of colour-blinds into two such groups seems unnatural ~~for it is necessarily~~ artificial. There is little difference between a case of shortened spectrum and a case in which the spectrum is of normal length when milder forms of the defect are in question. For in our results there seems little difference between A. and B. although the former is credited with a shortening of the spectrum. It may be that Dr. Ladd-Franklin has modified her theory to explain such cases but so far attempts to find ~~such~~ a reference

and essentially/

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to such modification

The 'old' explanation of Helmholtz ~~is~~ completely left the field, for the newer explanation fits the facts much better. It must be admitted that few text books on the subject seem to recognise or acknowledge this second mode of explanation, and still give Helmholtz's views along the line which he himself so vigorously repudiated.

may be set aside/

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~~and spec~~ In red-blindness - that is in cases of shortened spectrum - the red substance has become equal to the green substance; but yellow and blue are the two colours visible. The yellow begins in the orange, and the blue-green forms the neutral band. In green blindness, the opposite ~~proceeds~~ occurs and the neutral band appears in the green.

condition/

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This theory while accounting for some of the facts, seems again to make an unnatural division between colour-blinds and not to make any allowance for the type of case we have been describing, or those described by Professor Hayes. Even Mc Dougall's modification seems to fail to account for these red-green colour-blind cases in which these two colours may sometimes be recognised. If colour-blindness is atavistic, and facts seem to confirm that hypothesis, these cases may be regarded as midway between normal vision and total reversion to the blue-yellow stage. The great point of superiority of Edridge-Green's theory is that he recognises such transitional cases.

Helmholtz's theory admirably fits the facts for extreme cases, those cases in which blue and yellow are the colour sensations experienced. It also gives a satisfactory reason why the neutral band should lie in the blue-green in red blindness and in the green in green blindness. Yet subjects H. and J., as far as we were able to discover, appeared to have a neutral band embracing both. They are neither red blind nor green blind but are red-green blind.

It does not seem, however, to explain the milder cases of partial colour-blindness, unless it may be possible to account for them along the lines of Peddie by the formation of some derived colour triangle which will ~~agree~~ with facts.

conform to the/

The Hering theory ~~leads~~ itself to the same objection, namely, that it explains solely the limiting cases. It has the apparent advantage that red-green blindness is treated as a whole and is not so artificially divided into the types of Helmholtz. The variations, which do undoubtedly exist in this defect, are accounted for by differences in the pigmentation of the eye, and Hering decided, on the basis of

poses/

(1) Dr. Houston's results, of which the writer has just become aware, confirms this statement. (Wide p. 136 F)

experimental results, that colour blinds could be regarded as yellow-sighted or blue-sighted. We have little evidence in favour ~~for~~ or against this view, although it is possible that the condition is

of/

One outstanding result which does support the Hering theory is that the position of the neutral bands of the colour-blind corresponds with the fundamental colours adopted in the theory. The one neutral band lies in the blue-green which is the green of the Hering theory; the other lies in the complementary of that green, in the purples, which is the red employed by Hering- a red beyond the red end of the spectrum. These facts lend strong support to the theory in the fundamental colours chosen, for if the substances for these two elementary colours are absent, then the colour sense must be deficient in red and green, leaving as clear sensations the other two fundamental colours, blue and yellow.

Finally our tentative ~~and final~~ finding is that the Hering theory, the Young-Helmholtz theory, and the Ladd-Franklin theory all fit the facts of red-green colour-blindness when the defect takes an extreme form, but they seem to fail to take account of cases which suffer from this disability in a less marked degree.

of

PERCENTAGE OF COLOUR BLINDS, (Capl)

Five schools were examined in different districts of Edinburgh, involving the testing of over 1000 children whose ages ranged from 9 years to 12 years inclusive. The children were examined in groups by means of Stilling's Tables. They were supplied with pencils and paper and were asked to write down the figures they saw.

Age	Girls	Boys
9	0	1
10	1	4
11	2	4
12	1	2

Above gives a total of 4 girls out of 575 or 7% and 11 boys out of 563 or 2%. Four schools were mixed, and the fifth was a boys' school; it yielded the largest number of cases, about one in each class of 30 pupils or slightly over 3%. The school which showed the next largest proportion was a mixed school in one of the poorest parts of the city, and it was this school which curiously enough yielded more girls' cases than boys', 3 girls out of the 88 tested. When it is recalled that the complete total for girls for all the schools was only 4, the result is more amazing, but

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probably it is merely accidental. The other schools showed no connection between the defect and social status.

It is important that tests for colour-blindness should be inaugurated in the schools, so that the children's parents may become acquainted with the defect. The detection of colour is involved in so many occupations that it is a waste of time and opportunity training a boy or girl for some particular vocation which ~~is~~ afterwards found to be unsuitable. The literature of the subject abounds with instances of difficulties and hardships which apprentices have undergone because of their failure to see certain

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necessary colours. To quote a few instances of occupations unsuitable for those suffering from this disability will make this quite apparent:- physician, chemist, artist, weaver, upholsterer, tailor, milliner, florist, the navy, the railway, the post-office, and so on. This constitutes quite a formidable and startling list and although the discrimination of colours may not be absolutely essential in some of these vocations, the lack of it may lead to serious error.

In school too, it must cause great inconvenience to the child. One of the subjects related how he remembered being dismissed from a drawing class at school by an irate master who thought he was amusing himself when mixing colours! The defect was not realised until the subject attended the secondary school, where his defect was discovered by the mathematical master in a curious manner. In geometry coloured chalks were used to differentiate between two triangles on the black-board. The master naturally spoke of the red triangle and the green triangle, but the subject became greatly confused, and found it impossible to follow the explanation. To remedy matters, the subject was brought nearer as the cause was attributed to bad eyesight, with however no better result. Sometime later it occurred to the master that there existed some defect in colour ~~initiation~~ results, and the mystery was solved.

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which was causing the difficulty/

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but instances/

This is a single isolated instance, ~~which~~ probably could be multiplied indefinitely. It is essential that teachers should be aware that such a disability exists and the form it assumes. The testing of children in schools cannot be too strongly recommended. The Stilling's Tables make a very suitable group test by means of which 'abnormals' can be detected and then examined more thoroughly to confirm the previous finding and diagnose the extent of the anomaly.

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It may be advisable to give an account of the percentage of colour-blind from some authenticated source, for comparison, and for practical purposes. The percentage given by different investigators has varied slightly, but one fact stands out clearly- the frequency with which this defect occurs in men, and the limited number of cases which have been reported among women.

The following

An interesting Table is given in an article by Thomson and Weiland (1) which shows the prevalence of the defect among males of different nationalities, and the few cases which have been reported among women.

	Males Examined	Colour Blind	per cent.	Females Examined	Colour Blind	per cent.
Holmgren.	32,165	1,019	3.16			
Jeffries.	19,183	802	4.12	14,764	11	0.073
Committee of the Ophthalmological Society of England.	14,846	617	4.16	489	2	0.4
Fontenay in Denmark.	4,000	155	3.8			
Dr. Adele Field in China.	600	19	3.16	600	1	0.17
In two Japanese regiments.	1,200	41	3.4			
Total	71,994	2,653	3.69	15,853	14	0.088

(62)
8/1
Sills

The percentage of colour blinds in the male population is about 3.5 while in the female population it is only 0.088. This list can be supplemented from Jeffries (2) who devotes an entire chapter to this question, ~~getting~~ quoting result after result of percentages from extensive examinations carried out by different investigators. Edridge-Green objects to these results because they are mainly based on examination with the Holmgren Wool test. His results, however, tally with the above percentage, for he also gives the percentage of colour-blinds as 3.5, which he considers near enough for practical purposes. ~~As for women, only about one in two thousand is found to be a colour-blind, suffer from this defect.~~

- (1) Norris and Oliver, System of Diseases of the Eye.
- (2) Colour Blindness; its Dangers and its Detection.

Thomson and Weiland

A word or two may be mentioned here of the way in which colour-blindness is inherited. Usually it is transmitted from grandfather to grandson, whilst the mother of the son remains free from the defect. Dr. Pliny Earle in 1845 (1) reported the colour-blindness of four generations of his own family. In the fourth generation, from 17 marriages, there were 32 male descendants, eighteen of whom ^{were} ~~are~~ colour-blind. Of the 29 females, only 2 were colour-blind. In the third generation no colour anomaly is reported, showing how colour-blindness may pass over one generation but reappear in the succeeding one. In the cases of the two colour-blinds in the fifth generation neither parents nor grandparents showed the defect, showing here an interval of two generations.

Horner's Law (based on the tracing of cases of transmission of the defect by Professor Horner of Zürich) seems to have been generally substantiated- at least his observations have been verified by different observers. His general conclusions are:-

- (a) That colour-blind fathers have normal-eyed sons.
- (b) That colour-blind sons have normal-eyed fathers.
- (c) That sons of daughters whose father was colour-blind are most likely to be the same, although not without exception: or colour-blindness is transmitted from grandfather to grandchild.

The hereditary nature of colour-blindness is unquestioned; usually each colour-blind can tell of a brother or some other relative who suffers from a similar defect to his own.

(1) American Journal of the American Sciences.

Dr Houston's Investigation (Case)

The results of Dr, R. A. Houston, of Glasgow University, have just been brought to our notice(1). He has adopted a new method of testing colour-blinds, described by him as a 'microscope' test. His conclusion is that he finds it impossible to separate his subjects into two classes or even to recognise two pronounced types such as advocated by Helmholtz. "The fundamental characteristic of the system of Helmholtz and Maxwell was that the colour sensations of the normal could be represented on a plane, whereas the sensations of the colour-blind required only a line or a point. All my cases require plane diagrams. Thus it follows that the colour-blind are trichromates."

We are not prepared to accept this without qualification, for our subjects H. and J. can not possibly be trichromatic. It has been proved throughout all the experiments that they are true dichromates. But the statement supports the diagnoses of our other cases, in which we have repeatedly asserted that their colour sensations are not restricted to blue and yellow, but that sometimes green, at other times red, becomes visible to them. This finding of Dr. Houston supports Professor Hayes' results, and incidentally our own conclusions.



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