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COLOUR VISION TESTS AND THEIR INTERPRETATION

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Abstract

Patients with colour vision defects characteristically confuse reds and greens or blues and yellows. Exactly which pair is confused is of significant diagnostic importance and it forms the basis of the pseudoisochromatic colour vision tests and the diagnostic basis of the arrangement colour vision tests (i.e. the Farnsworth-Munsell tests).

This paper discusses the major types of colour vision tests. The application of the tests and interpretation of the results is outlined and illustrated with case studies.

Key words: *colour vision tests, pseudoisochromatic tests, Farnsworth-Munsell tests, Ishihara, Hardy Rand Rittler, Nagel anomaloscope, lantern tests.*

INTRODUCTION

Colour vision defects may be congenital or acquired. Usually congenital colour vision defects are bilateral, symmetric and non progressive. Acquired defects are unilateral or bilateral, frequently asymmetric and progressive. Hence when a congenital defect is suspected colour vision testing may be performed binocularly, whereas the eyes should be tested individually in cases of acquired colour vision defect.

All the colours in the visual spectrum can be joined up to form a colour circle. There are four unique points on the colour circle where a colour occurs alone without a trace of another colour. (For example at one point there is a pure yellow which has no trace of red or green). The colours at these points are red, yellow, blue and green. All other colours on the circle are combinations of two or more of these four unique colours.

Patients with colour vision abnormalities usually confuse mixtures of these pairs of unique colours, i.e. they confuse reds and greens or they confuse blues and yellows. Exactly which pair is confused is of significant diagnostic importance and this forms the basis of the structure of the pseudoisochromatic colour vision tests and the diagnostic basis of arrangement colour vision tests.

This paper discusses the major types of colour vision tests.

PSEUDOISOCHROMATIC TESTS

This group of tests includes the Ishihara, Guy's Children's Colour Vision Test, Matsubara Children's Colour Vision Test, the Standard Pseudoisochromatic Plates and the Hardy Rand Rittler Test (HRR).

Each test consists of a book containing a number of 'plates'. Each plate shows a series of coloured dots forming a figure embedded in a coloured background. The colour of the dots in the figures and those in the background are selected to confuse red-green colour defective

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patients while allowing normals to see the figures clearly. Those with congenital red-green colour vision defects cannot see any figure on all the plate hence the name; pseudo means falsely or seemingly, iso means one and chromatic means colour. To the colour defective patients the plates are seemingly one colour.

The main advantage of such tests is that they are very quick and simple to perform for both patients and examiner. Also the results are easily interpreted, however their application is limited.

All of the pseudoisochromatic tests are designed to detect *CONGENITAL RED-GREEN* colour vision defects. Patients with such colour vision anomalies show characteristic patterns of colour vision abnormality so the tests consist of colours which exploit these characteristic abnormalities.

None of the pseudoisochromatic tests (with the exception of the HRR) can detect blue-yellow defects. Pseudoisochromatic tests are usually not used (or designed) to detect acquired red-green defects.

Ishihara colour vision test

As the Ishihara is a typical pseudoisochromatic test it will be discussed. The other test to be discussed is the HRR.

The Ishihara test consists of 36 plates. When doing the test the test plates must be well illuminated with daylight or a daylight globe (i.e. a Macbeth Easel light which transmits wavelengths of light that simulate daylight or a globe that gives a colour temperature of 6740° Kelvin).

Plate number 1 is the only plate in which the colour difference and contrast between the number and the background is so great that even the totally colour blind observer can see the number 12, hence this plate is used to screen for malingering patients. If a patient claims to see no figure on this plate then there is no point in continuing with the test.

Plates 2 to 9 are designed so that the red-green defective patient sees numbers but interprets them incorrectly. In plates 10 to 17 the red-green defective patients see no numbers at all. This is in contrast to plates 18 to 21 where the normal sees *NO* numbers but the red-green defective patients do see numbers.

Number of Plate	Normal Person	Person with Red-Green Deficiencies				Person with Total Colour Blindness and Weakness
1	12	12				12
2	8	3				×
3	6	5				×
4	29	70				×
5	57	35				×
6	5	2				×
7	3	5				×
8	15	17				×
9	74	21				×
10	2	×				×
11	6	×				×
12	97	×				×
13	45	×				×
14	5	×				×
15	7	×				×
16	16	×				×
17	73	×				×
18	×	5				×
19	×	2				×
20	×	45				×
21	×	73				×
		Protan		Deutan		
		Strong	Mild	Strong	Mild	
22	26	6	(2)6	2	2(6)	
23	42	2	(4)2	4	4(2)	
24	35	5	(3)5	3	3(5)	
25	96	6	(9)6	9	9(6)	

Figure 1: Ishihara test score sheet (reproduced from instruction booklet).

Plates 22 to 25 are the 'diagnostic' plates. Only those patients who have failed (i.e. shown red-green deficiencies) on the first 21 plates should be shown the diagnostic plates. These four plates classify the red-green defective patient into protanomaly (red cone anomaly) and deuteranomaly (green cone anomaly). See Figure 1.

The remaining plates (25 to 38) are designed for the illiterate observer. They are asked to trace a line between the two 'x's.

The patients response to each plate is recorded. Errors are determined by comparing the patients response to the answers which are printed on the score sheet (see Figure 1). Where there are more than six errors between plates 2 and 21 (giving incorrect responses as shown on the score sheet) there is a congenital colour vision defect.[1] The

severity of the defect found on the Ishihara is measured in terms of a number of errors made.

The major shortcoming of the pseudoisochromatic tests is that patients with poor visual acuity may fail the test. In such a case the result may be misinterpreted as a red-green defect.

Another problem with the pseudoisochromatic tests is that many clinicians are unaware that patients with acquired colour vision abnormality are able to pass the test. Hence on the basis of the pseudoisochromatic tests some patients with acquired red-green colour vision defects are pronounced normal.

Hardy Rand Rittler (HRR) colour vision test

The HRR test is the only pseudoisochromatic test which screens for both red-green and blue-yellow defects. The test consists of six screening plates, 14 diagnostic plates and a control plate. As in the Ishihara test the figures on the control plate can be seen by colour blind subjects. All the plates in the test consist of coloured dots which form a symbol such as 'O' or 'X'.

If the patient passes the six screening plates then they have normal colour vision and no more testing is necessary. If errors are made on plates 1 and 2 the patient has a blue-yellow defect. The examiner then proceeds to the diagnostic plates. These plates classify the tritan (blue-yellow) defect as mild or severe. Alternatively if the patient makes errors on plates 3 to 6 the patient has a red-green defect. The examiner then proceeds to the diagnostic plates. These plates classify the severity of the red-green defect.

Like the Ishihara test the patients response is recorded on the score sheet and diagnosis of the type and severity of the defect is apparent.

The HRR test has particular advantages because it screens for blue-yellow defects as well as red-green defects and the symbols make it easy for both the illiterate observer and the child. The major disadvantage is that patients with poor visual acuity may fail the test and incorrectly be labelled colour blind.

ARRANGEMENT COLOUR VISION TESTS

This group of tests includes the Farnsworth-Munsell (FM) 100 Hue and FM Panel D-15. The tests consist of a series of colour samples called 'chips'. The patient is required to organise the chips into a specific order forming a hue circle. The tests are performed monocularly when the suspected defect is acquired and binocularly if the defect is congenital. Contrary to the manual there should be no time limit for either test.[2] FM tests are performed under a daylight light.

Arrangement tests are designed to detect any type of abnormality in colour vision perception from minor errors made by the normal observer to total achromatopsia (total colour blindness), and test for both congenital and acquired defects, red-green and blue-yellow defects.

FM Panel D-15 colour vision test

This test is designed to select patients with moderate to severe chromatic discrimination loss. The test consists of 15 loose chips and one chip fixed in the box (i.e. the reference chip). The colour (or hue) on each chip has been chosen so that adjacent chips have approximately equal hue differences.

The patient is instructed to arrange the chips in order according to colour in the box starting next to the reference chip.

Once completed, the box is shut and inverted then re-opened. A number is then seen underneath each chip. The order in which the patient has arranged the chips is recorded and plotted on the score sheet (see Figure 2). Starting from the reference cap (point 'P' on the circular diagram) the points are connected according to the order given by the patient. Figure 3a shows the result for a normal subject.

The hue differences between adjacent chips are equal but of large degree thus errors can be made across the hue circle (for example green could be placed next to purple). Thus colour deficient observers make characteristic errors across the colour circle when performing this test. A typical pattern is seen in Figure 3b for a deuteranomoly (green deficiency), Figure 3d for protanomaly (red deficiency) and Figure 3c for tritanomaly (blue deficiency) with lines being drawn across the circle.

Subjects with normal colour vision sometimes make one or two minor errors (e.g. reversing

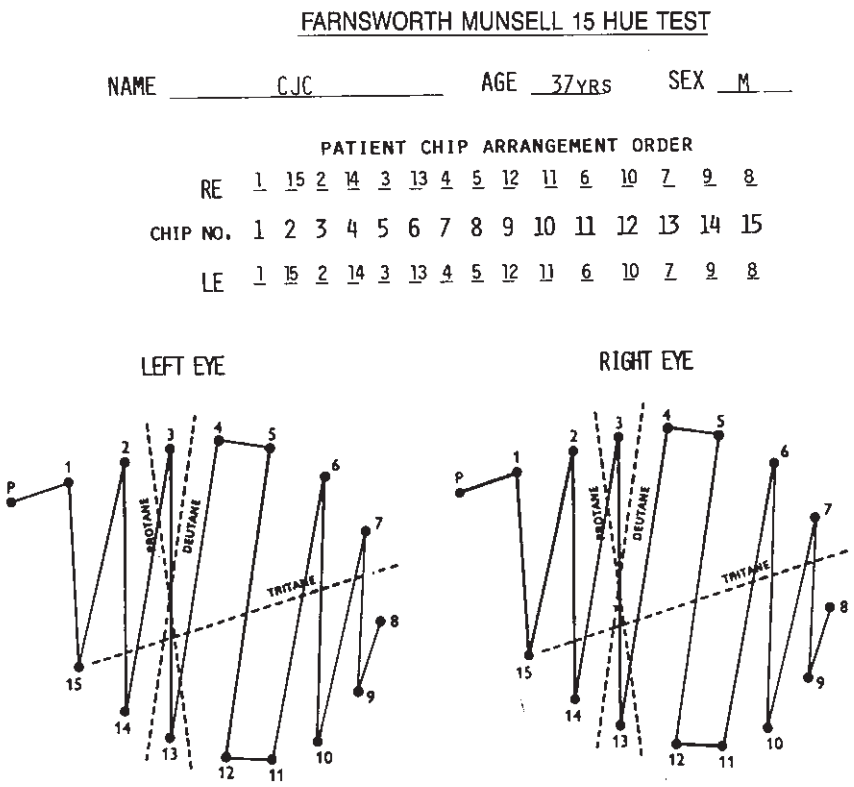

Figure 2: Score sheet for a FM Panel D-15 colour vision test.

chips 2 and 3). However, in our experience any more than two minor errors should not be considered normal. The patient may have a mild colour vision deficit which is not being detected on the FM 15-D hence they should be tested on the FM 100 Hue. Figure 4 is an example of a subject who 'passed' the 15-D test and showed marked colour vision abnormality on the 100 Hue. We have had six such subjects over a period of eight months in our department.

The FM 15-D test is once again very quick and easy to perform, score and interpret. However, the clinician should be aware that some colour defective patients can 'slip through' this test.

FM 100 Hue colour vision test

Of the tests mentioned so far, the FM 100 Hue is the test that is most likely to detect colour vision abnormalities, even in their mildest forms. The test consists of 85 chips of perceptually equal steps of hue. When put in correct order, the 85 chips form a hue circle.

The subject is asked to arrange the chips in the appropriate colour order between the two chips fixed at either end of each of the box. The colour differences between adjacent chips is so small that correct arrangement of the chips requires both normal colour vision and a good ability to discriminate between shades of the same colour. As the chips are divided into four boxes of 21 or 22 chips, any errors that occur are between adjacent chips, *NOT* across the hue circle (as seen in the FM D-15 test).

In a similar manner to that described for the FM 15-D test the subjects chip order is recorded, however, scoring and interpreting the FM 100 Hue test is more complicated.[3] The score for each individual chip is calculated by summing the absolute difference between adjacent chips. For example if the patient chip order was 9, 6, 3, 8,

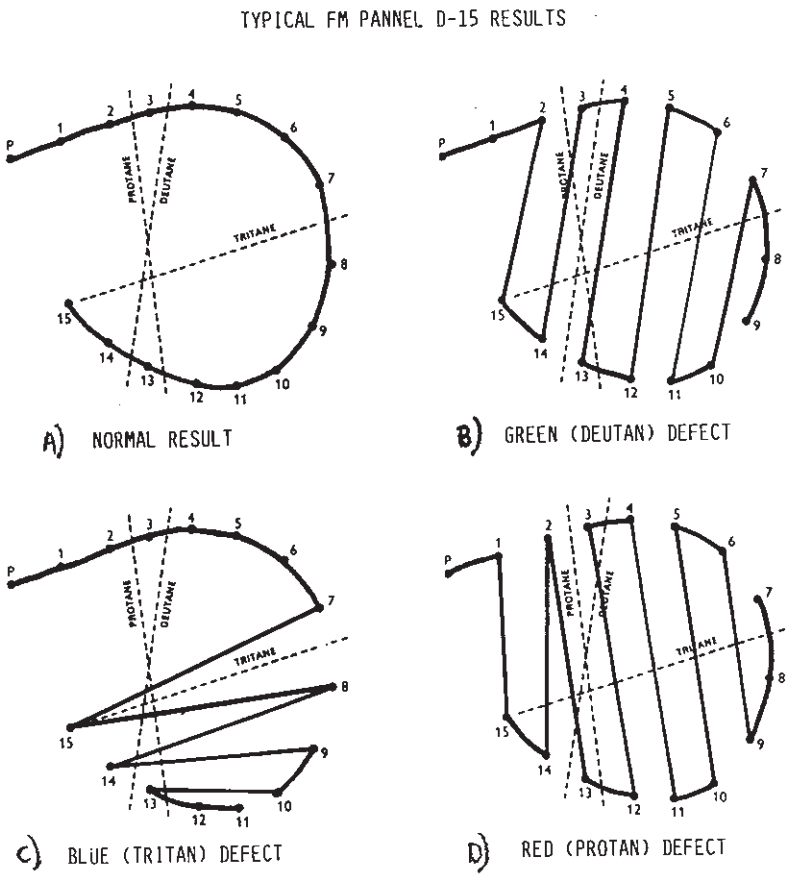

Figure 3: FM Panel D-15 test results. 3a Normal, 3b Deutan, 3c Tritan and 3d Protan.

4, etc., the score for chip '3' would be as follows:

The absolute difference between the preceding chip ('6') and chip '3' is 3. The absolute difference between chip '3' and the following chip (i.e. chip '8') is 5. The sum of the absolute differences is $3 + 5 = 8$, hence the score for chip '3' is 8.

This score is then plotted on the hue circle (see Figure 5).

With this scoring method, the minimum score for each chip is 2. For example if the patient order was 5, 6, 7, 8, 9, ... the absolute difference between each adjacent chip is 1. The sum of the absolute difference is $1 + 1 = 2$, hence the minimum score for each individual chip is 2.

After the score for each individual chip has been calculated this score is plotted on a circular hue graph. The inner circle of the graph gives the chip number and the vertical axis at 12 o'clock gives the score (see Figure 5).

The scores for each individual chip are then added together giving a total score. As there are 85 chips (each with a minimum individual score of 2) the 'perfect' score is 170 (i.e. 85×2). Of the more than 1000 FM 100 hue tests scored in our department, not one has had a perfect score of 170. This is so because the hue differences between adjacent chips is so small that normal observers (with 6/5, N5 vision) cannot tell the difference between all adjacent chips. In our department a score of 240 is considered normal (see Figure 6a).

An abnormal score (more than 240) tells the clinician that there is a colour vision abnormality

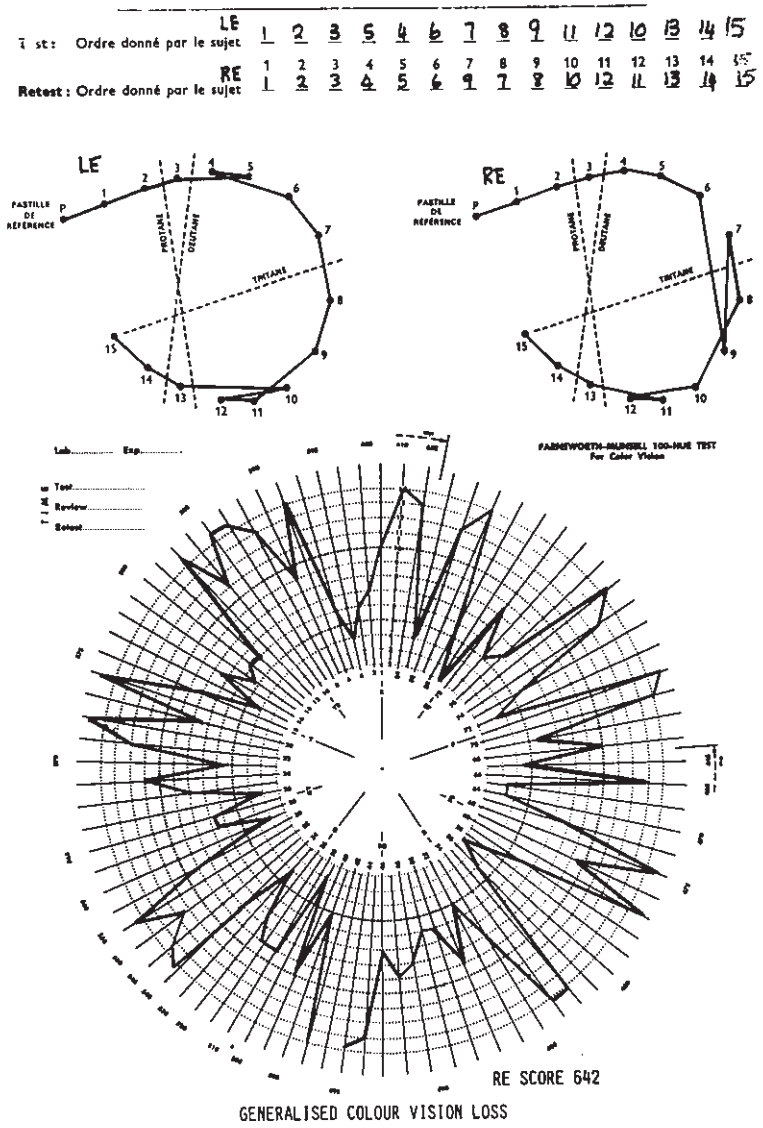

Figure 4: FM Panel D-15 and FM 100 Hue test results from the one patient. The patient passed the D-15 test and showed a severe colour vision defect on the 100 Hue test.

but; the score alone does not tell the clinician anything about the nature of the defect hence the reason for graphing the individual scores for each chip on the circular graph. Patients with congenital colour vision defects always show concentrations of errors in two well defined areas called poles. The poles occur in characteristic areas which depend on the type of deviation present.

The most common colour vision defect is the congenital defect, anomalous trichromatism. Patients with this condition have a normal population of cones all of which contain one of the three cone pigments (i.e. red, green or blue). However, there is a slight abnormality in one cone pigment. As a result the cone pigments maximally absorb slightly shorter or slightly longer wavelength light than normal cones.[3] This

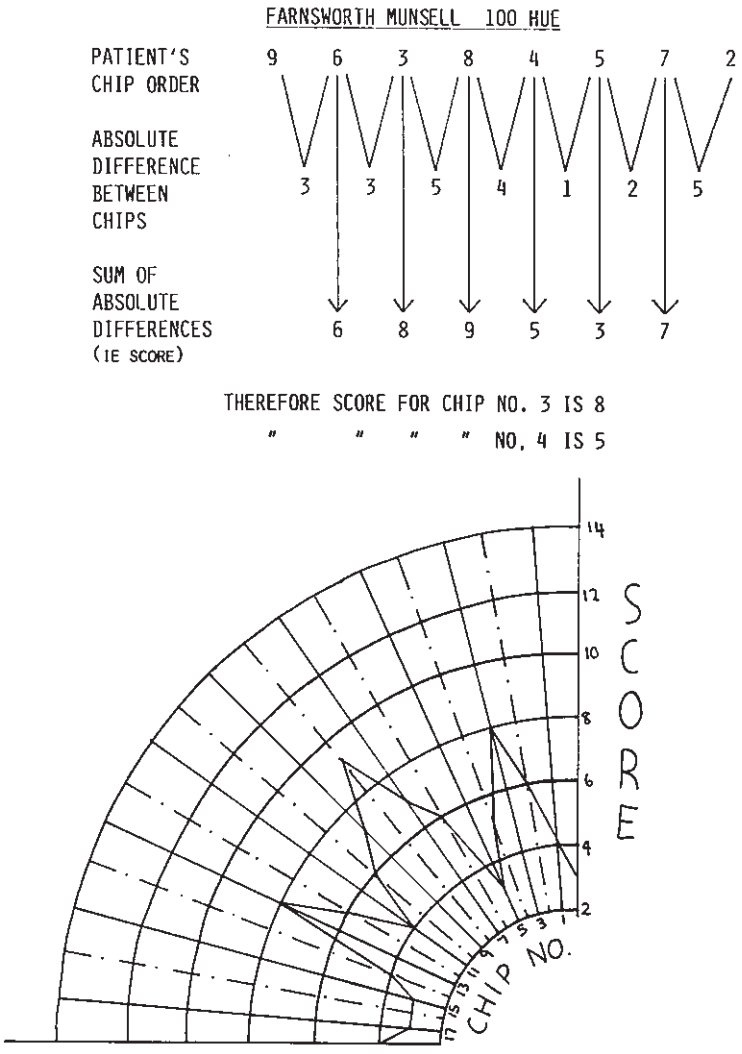

Figure 5: Scoring the FM 100 Hue colour vision test.

defect is divided into three subgroups

(1) deuteranomaly (red-green defect with abnormal green cone pigment).
(2) protanomaly (red-green deficit with abnormal red cone pigment)
(3) tritanomaly (blue-yellow deficit with abnormal blue cone pigment).

(the prefix deut means green, prot means red and trit means blue. The suffix -anomaly means abnormality).

Under normal colour vision testing conditions of bright light the red-green deficiency patients have no trouble differentiating pure reds and pure greens. Rather, they have problems with colours that fall between red and green on the colour circle, i.e. blues and yellows. This is clearly demonstrated on a FM 100 hue (see Figure 6b and 6c).

Deuteranomalous subjects score almost perfectly on the red and green areas of the colour circle and have most problems with colours lying in the areas between red and green, namely

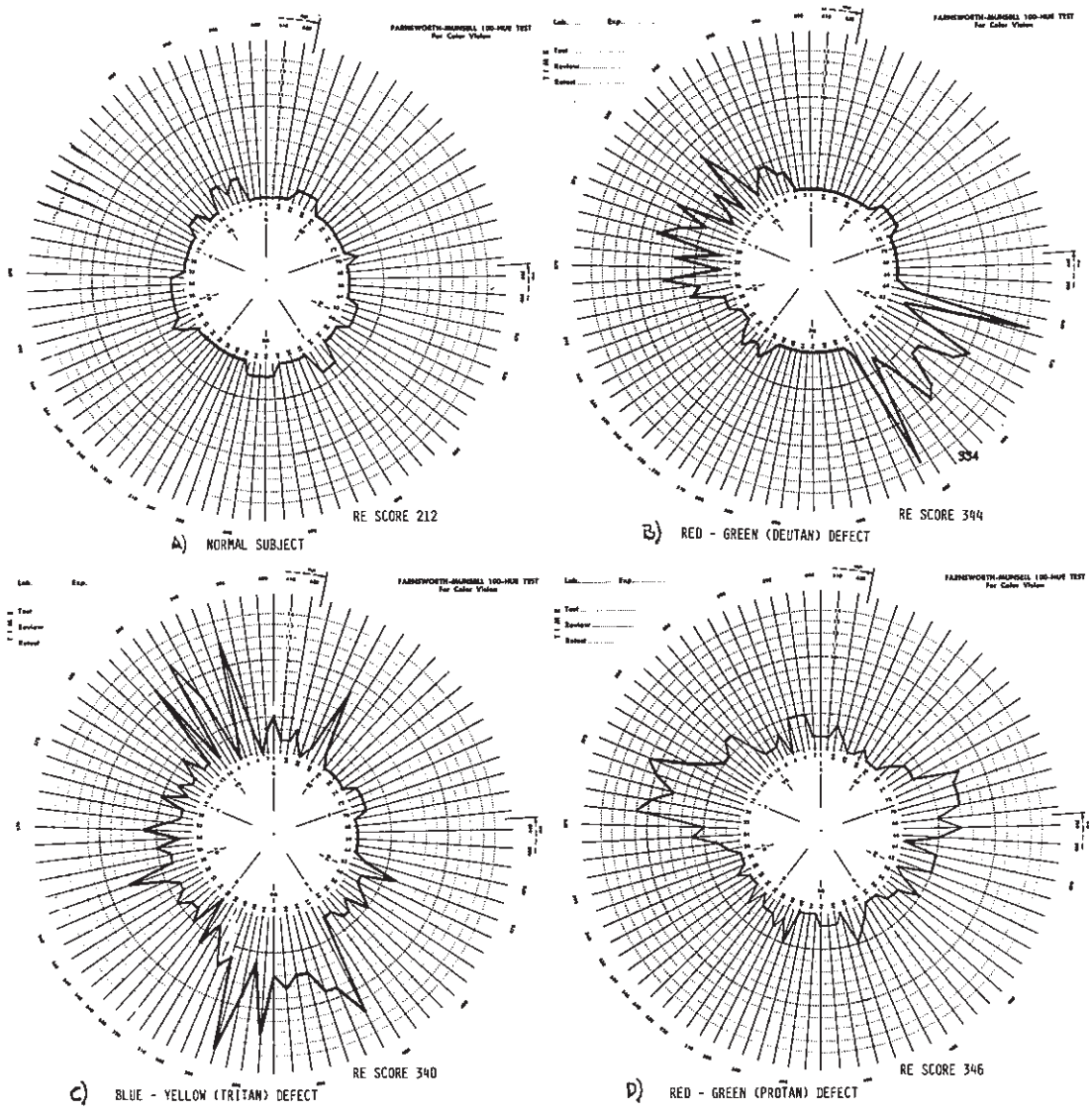

Figure 6: Typical results obtained on the 100 Hue test. 6a Normal, 6b Deuteranomalous, 6c Tritanomalous and 6d Protanomalous.

purple and blue and fewer problems with orange and yellow. Protanmalous subjects also score perfectly on the red and green axes. They have most problems with purples and some problems with yellows hence their typical response is more horizontal in appearance than that of the deuteranope.

The typical result on the FM 100 Hue test for a tritanopic subject (blue-yellow defective) is different. They score perfectly on the yellow and blue axes of the colour circle. Errors occur in the areas that lie between blue and yellow, namely green and orangy red (see Figure 6d).

Generalized loss of colour discrimination ability shows errors right around the circular graph (see Figure 4).

Another type of colour vision abnormality is dichromatic colour vision. This condition is

thought to be due to either an absence of one cone pigment (hence the patient must colour match using only two of the three cone pigments) or, the abnormality may be due to a post receptoral defect.[4,5] Dichromatic abnormalities are deuteranopia, green cone anomaly (the suffix -anopia meaning absence of), protanopia, red cone anomaly and tritanopia, blue cone anomaly. Dichromatic observers show an abnormality only in one particular area on the FM 100 hue graph if the abnormality is the result of an absence of one pigment.

COLOUR MATCHING TESTS

To date all the tests mentioned have the *CONFUSION* tests, that is they are based on the fact that patients with colour vision defects characteristically confuse certain colours. The next group of tests to be discussed are sensitivity tests. They test the patients ability to match various defects. The tests include the anomaloscope and the lantern tests.

Nagel Anomaloscope

When seated looking into the eyepiece of the anomaloscope the patient views a bipartite circular field. One half of the field is covered with a yellow hue of variable luminance. The other half consists of a variable red-green mixture of fixed luminance. The patient is asked to match the yellow seen in the bottom half of the field using a mixture of reds and greens in the top half of the field.

Deuteranomalous patients (green abnormality) would add a lot more green to complete the colour match in an anomaloscope. Protanomalous patients (red abnormality) would add more red to colour match.

Tritan defects (blue abnormalities) cannot be detected using the Nagel anomaloscope.

The Lantern tests

These tests are used for screening for colour vision defects without diagnosing the type or degree of colour vision defect.

The patient is presented with single (Edridge Green lantern) or a paired (Sloan) coloured signal and is asked to name the colours which are presented. Colours are presented at different luminance levels and different visual angles. Patients with anomalous trichromatic colour vision have most trouble detecting pure colours at low luminance levels.

The tests are used for screening prospective employees in areas such as the navy, airforce and train drivers; that is occupations where recognition of signals in poor light conditions is vital. Altering the luminance level simulates conditions such as rain or mist.

DISCUSSION

Features in the clinical examination which should alert the clinician to the possibility of a colour vision abnormality include:

(1) History: the patient or parent may volunteer a history of poor colour vision.
(2) Bilaterally reduced visual acuity, especially for near, in the presence of straight eyes. (Bilaterally reduced vision may be indicative of cone dysfunction especially if there is an associated loss of colour vision).
(3) Nystagmus: colour vision should be assessed in all cases of congenital nystagmus. Once again the nystagmus may be indicative of cone dysfunction.
(4) Recurrent amblyopia, especially if near vision is reduced; progressive cone dysfunction may be the underlying abnormality in some cases of apparent amblyopia. Loss of colour vision may alert the clinician to the fact that the problem may be more than just amblyopia.

Colour vision defects, even the non progressive ones such as anomalous trichromatic colour vision (a condition in which the patient has otherwise normal vision) are important to detect as the patient must be aware that certain career opportunities will not be available to them.

CONCLUSIONS

The colour vision tests which are most commonly used (such as the Ishihara) are those which are quick and easy to perform, score and interpret. Although these tests are the most practical to use, clinic clinicians must be aware of their limitations. If results obtained on the pseudo-isochromatic tests or the FM D-15 test are not

perfectly normal, yet do not fit into any pattern of abnormality, a FM 100 hue test should be performed. Conversely, a patient complaining of diminished colour perception should not be considered to have normal colour vision when they have only passed the Ishihara test for congenital red-green colour blindness.

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