Expert Review  Examination of Colour Vision

Sahar Parvizi and Peggy Frith

Abstract  Congenital colour vision anomalies are common, with red/green anomaly affecting 8-10% of males. Acquired loss of colour perception can be a sensitive indicator of macular and optic nerve disease. It is vital to understand how colour vision tests can be used effectively to diagnose the type of colour anomaly. This article reviews the different tests available and the protocols for their appropriate use, with an emphasis on standardised examination techniques.  Word Count: 2207 words.

Key words: Colour vision, anomaly, Ishihara, Farnsworth D15, City University

Address for correspondence: sahar.parvizi@green.ox.ac.uk

Author affiliations: Sahar Parvizi, Medical Student, University of Oxford. Dr Peggy Frith, Consultant Ophthalmologist, Oxford Eye Hospital, John Radcliffe Hospital, Oxford; Deputy Director of Clinical Studies, University of Oxford Medical School.

Introduction

John Dalton (1766-1844), an English scientist, gave the first description of “colour blindness” in 1794; it was his own. In common with his brother, he confused scarlet with green, and pink with blue. Dalton supposed that this was due to his vitreous humour being tinted. In fact, DNA analysis on preserved eye tissue showed Dalton to be a deuteranope, lacking the middle-wavelength (green) photopigment of the retina [1].

Background

Normal colour vision requires three types of cone photoreceptor with photopigments sensitive to short-wavelength (S: blue, tritan), middle-wavelength (M: green, deutran) and long-wavelength (L: red, protan) light. Colour anomaly occurs where there is a reduced ability to distinguish between different wavelengths due to defects in these photopigments.

Types of Colour Anomaly

In order to be able to interpret results of a colour vision assessment, the different forms of deficit should be known. They can be either congenital or acquired. Vischeck® is a web-based testing program that can be used to visualise some colour vision defects and simulate different images and web-pages as someone with a deficiency would perceive them [2].

Congenital Colour Vision Defects

Those with normal colour vision are known as trichromats. Defects in the photopigments lead to three main types of colour anomaly: anomalous trichromacy, dichromacy, and monochromacy detailed in Table 1.

The most common hereditary colour vision defect is X-linked failure of red-green discrimination, leading to such difficulties as distinguishing between ripe and unripe tomatoes and strawberries, for example. It can be in the form of anomalous trichromacy, dichromacy, and monochromacy detailed in Table 1.

Acquired Colour Vision Defects

Blue-yellow discriminatory failure is more common in acquired “colour blindness” and sexes are equally affected [4]. These tritan defects, affecting the S-cones, impinge on the ability to discriminate colours in the blue and green regions of the spectrum. They are different to the autosomal dominant congenital form of tritan defects in that they are usually progressive.
The suffixes –*anomaly* (meaning abnormality) and –*anopia* (Greek for absence of sight) are used to convey the degree of the defect.

**Anomalous trichromacy** One of the three cone pigments is altered in its spectral sensitivity, but trichromatic colour vision is not fully impaired. Everyday activities are not usually affected, and the defect may only be detected on colour vision testing. This accounts for about three quarters of congenital “colour blindness”; 1% of the population are protanomalous, and 4.9% are deuteranomalous.

**Protanomaly**: reduced saturation and brightness of red, leading to a shift in hue towards green. E.g. red traffic lights may be mistaken for amber.

**Deuteranomaly**: saturation of green is reduced, but the brightness is not affected. Hues appear shifted towards red. May not realise colour vision different to normal.

**Dichromacy** - one of the cone pigments is absent and colour is reduced to two dimensions. This accounts for one quarter of “colour blindness”. 1% are protanopes, and 1.1% are deuteranopes. Loss of the tritan pigment is very rare.

**Protanopia**: aware of colour vision defect. Saturation and brightness of red, orange and yellow is much reduced. E.g. red traffic lights may be thought to be turned off; pink flowers appear blue.

**Deuteranopia**: saturation of colours reduced such that there is no difference between red, orange, yellow, and green.

**Monochromacy** - two or all three of the cone pigments are absent or non-functional, and colour vision is reduced to one dimension only. This is very rare (only 0.003% of men are affected) and it is often accompanied by other serious eye problems.

**Diagnosis of Colour Vision Anomaly**

Colour vision anomaly is diagnosed through clinical testing. In more severe cases, it may be brought to the attention of healthcare professionals by families remarking on the choice of colour schemes by the affected child, but in many it is only realised on screening. Colour vision anomaly does not generally interfere with normal life though it is a problem in occupations relying on and requiring good colour vision (for example those using colour coded wiring such as electricians, some jobs in fashion or industry involving colour choosing or matching, scientists using fluorescent markers for labelling cells, train crew, fire services, Civil Aviation Authority and the Royal Navy). However, it is always of relevance in acquired cases, and colour vision can be used to detect or monitor progression of the condition.

Patients with sight threatening diabetic retinopathy were shown to exhibit changes in the tritan colour thresholds before showing any evidence of visual loss. Colour contrast sensitivity testing has also been used in monitoring the severity of age-related maculopathy and colour discrimination tests can be used in detecting macular oedema in patients with type I diabetes. Colour vision testing is thus being used as an effective and clinically viable technique to identify such cases early, before irreversible changes occur. Table 2 highlights some other aspects of clinical usefulness of colour vision testing.

<table>
<thead>
<tr>
<th>Table 1 Colour Vision Defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquired colour vision defects can be due to macular degeneration, choroidal, retinal, and neural disorders (including cortical trauma, cerebral infarction and multiple sclerosis). Different pathologies present in different ways, and Köllner’s rule can be used as a general guide to the underlying cause of the acquired loss. It is often stated as “patients with retinal disease develop blue-yellow discrimination loss, whereas optic nerve disease causes red-green discrimination loss”. However, this rule has exceptions where some optic nerve diseases, notably glaucoma, are primarily associated with blue-yellow defects, and some retinal disorders, such as central cone degeneration, may result in red-green defects.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2 Some Examples of Clinical Usefulness of Assessing Colour Vision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retinal disease involving central cones.</td>
</tr>
<tr>
<td>Plotting the clinical course of optic neuropathies, including spontaneous improvement found typically in optic neuritis.</td>
</tr>
<tr>
<td>Screening for toxic drug effects, specifically ethambutol (3 monthly intervals while on treatment).</td>
</tr>
</tbody>
</table>
Colour Vision Testing
The simplest test that can be used is to compare
the impression of colour in each eye using common
objects in a room. In acquired defects, brightness of
colours will be less in the affected eye, and said to
be ‘washed out’ or ‘greyed’ in appearance
compared to the normal eye. This should be
enquired about directly as the information may not
be volunteered [6]. Optic neuritis is the commonest
cause of such acquired defects [8], but damage
anywhere from photoreceptors to the optic nerve to
the lateral geniculate nucleus of the thalamus can
impair colour vision [10].

Many clinical tests are available, and it is necessary
to know the details and sensitivity of each test,
since there can be many variations in the results,
depending on whether the pathology is congenital
or acquired [11].

Some of the available tests are listed in Table 3.
The five more commonly used tests will be
described here. Table 4 outlines the procedure
universal to all these tests.

Table 3 Colour Vision Tests

<table>
<thead>
<tr>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ishihara Test</td>
</tr>
<tr>
<td>Farnsworth D15 Colour Vision Test</td>
</tr>
<tr>
<td>City University Test</td>
</tr>
<tr>
<td>Farnsworth-Munsell 100-Hue Test</td>
</tr>
<tr>
<td>Nagel Anomaloscope</td>
</tr>
<tr>
<td>American Optical / Hardy, Rand, and Ritter test</td>
</tr>
<tr>
<td>Titmus II Vision Tester</td>
</tr>
</tbody>
</table>

Table 4 Colour vision testing outline

Different versions of the Ishihara test plates are
available: the full version containing 38 plates for a
detailed investigation, the abbreviated version with
24 plates for quick screening and the concise
version containing 14 plates.

Each plate has a particular role in the process of
diagnosis. Table 5 shows the function of each plate
and expected results for people with normal colour
vision or with some defect in colour vision in the 24-
plate edition. Figure 1 shows four sample Ishihara
plates. There are 17 plates with numbers for adults.

The Ishihara Pseudoisochromatic Plates Test does
not show the severity of deficiency in protanopes or
deuteranopes although more errors are seen in
more severe conditions. Mild cases cannot easily be
identified. It also does not distinguish tritanopic
deficiency, although it does reveal acquired red-
green dyschromatopsia. The acquired blue-yellow
deficiency is frequently missed [7,16].

The design of the Ishihara numerals can cause
misreading by some colour normal individuals [19].
Partial loops may be filled in due to the font style,
creating different numbers e.g. 5 being read as 6, or
3 as 8. If such mistakes are made on the vanishing
plates, these are not counted as ‘errors’ and so
should not be interpreted as a failure. On the
transformation plates such filling in of loops can be potentially confusing, although clear errors on other plates minimise any uncertainty about whether this is due to a colour vision defect.

The Ishihara test should be carried out as described in Table 6. For subjects who may be unable to read numbers, the full version contains plates (plates 26-38) with winding lines connecting two Xs on the plate. The subject should tell the examiner the colour of the line, or can be asked to trace it with a brush. This takes too long for the design to be effective however, and so the use of these plates is not generally recommended [16]. Paediatric plates also exist, making use of symbols – circles, stars, crosses and squares – for testing colour vision in children.

In order to make testing more rapid and feasible in a clinical setting, it is possible to perform the Ishihara test using a minimum of six of the most efficient screening plates. A recommended combination is: four transformation plates (2, 3, 5, and 9) and two vanishing plates (plates 12 and 16), including an introductory and a classification plate [16]. It has also been suggested that the Ishihara test plates can be loaded onto handheld computers in order to guarantee reliability and quick testing [18].

The test should be conducted under normal daylight conditions or a daylight-balanced artificial light source. Direct sunlight can change the appearance of the colours on the test plates.

Hold the plates at a distance of about 75cm from the subject. In presbyopic patients, they should be held at a suitable distance for their reading correction.

Hold the plate up for a few seconds (about 3-5 seconds) for the subject to see the number.

Test each eye separately.

Read out the “instructions to the subject”. See below.

The score sheet is filled in as the test is being carried out. The scoring system allows for distinctions to be made between individuals who can complete the test easily, and those who may see partial patterns or are considered to have been hesitant.

Instructions to the subject
Tell the subject what you are going to do. Show them the introductory plate (number 1). If the number cannot be seen the test is abandoned.

Inform the subject that they should say out loud the number they see as soon as they see it. Also reassure them that some plates do not have any numbers, and to let you know if they are having any difficulty reading the numbers.

Table 6 Ishihara Test Protocol (modified from V. de Alwis et al [17])

Farnsworth D-15 Colour Vision Test
This is a modification of the Farnsworth-Munsell 100-Hue Test (see below), giving limited information on protan, deutan and tritan systems [19]. It is mainly used as a screening tool for colour vision, particularly in occupation selection such as in the military, rather than for the analysis of the defect as with the more elaborate version. Both moderate and severe colour vision deficiencies can be identified.

Each set contains 15 differently coloured samples which must be moved and placed in order in a tray (Figure 2), in relation to a reference or ‘pilot’ cap. A neutral is also included in the set, but is not used in the test. The test procedure is outlined in Table 7.
The pilot cap is placed in the tray at one end. The other caps, colour-showing side facing upwards, are placed in the tray in a random order. The neutral is kept to one side.

The subject is asked to select the cap that is the closest match in colour to the pilot, and place it next to it.

All the caps are thus placed in the tray in succession. The subject can change the order of the caps at any point during the test.

The task should be completed in two minutes.

Place the lid on the tray and turn it over.

The numbers on the undersides of the caps are seen. The sequence should be noted.

If they are in order from 1 to 15, no further action needs to be taken. A single transposition of adjacent colours is allowed, but should be recorded.

An error of two or more colour steps is a fail.

Results are marked on the score sheet. The circular diagram can serve as a visual representation of the test results.

The severity can be determined by the number of lines crossing the circle.

Table 7 Farnsworth D-15 Colour Vision Test

The Adams and Lanthony tests are desaturated versions of the D15 test for evaluation of acquired colour deficiencies [16].

City University Test
The first and second editions of the City University tests are derived from the D15 test [16]. The test displays protan, deutan, and tritan colours and thus can be used to test for all types of colour anomaly. Although the colours used are similar to that in the D15 test, the visual task is different. More protans fail the D15 test and more deutos fail the City University test.

It comprises ten plates; these plates should not be touched. On each plate, a central spot is surrounded by four peripheral colours (Figure 3). Three of these colours provide possible protan, deutan and tritan confusions, with the fourth colour being the adjacent colour in the D15 sequence. As such, subjects with normal colour vision are expected to choose this as the one most closely resembling the central colour.

The booklet should be held at 35cm from the subject. The demonstration page is shown and the instructions are given: “Here are four coloured spots surrounding one in the centre. Tell me which spot looks most near in colour to the one in the centre. Use the words top, bottom, right or left. Please do not touch the pages.” Each test plate is shown for a few seconds and the responses marked on the score sheet.

The City University test identifies those with moderate to severe deficiency in colour vision;
those with a slight deficiency pass the test. The second edition has been modified by including six of the original test plates and introducing four containing desaturated Munsell colours aiding in detecting acquired colour vision defects.

**Farnsworth-Munsell 100-Hue Test**

The Farnsworth-Munsell 100-Hue test (Figure 4) is a comprehensive and time consuming test - it can take over 30 minutes to complete. Eighty-five coloured caps must be ordered by their hue and results plotted on a dedicated chart. It gives detailed information on protan/deutan/tritan defects. It is used as a final arbiter for colour vision, and must be carried out by a professional [19].

![Figure 4 Farnsworth-Munsell 100-Hue test](image)

**Nagel Anomaloscope**

The Nagel anomaloscope (Figure 5) is the most specific test for an accurate evaluation and classification of subtle defects in colour vision. However this test is rarely available now due to no longer being manufactured [19].

![Figure 5 Neitz Nagel anomaloscope](image)

**Implications of Colour Anomaly**

There is no cure for colour vision anomaly. There are techniques that can be used to help discriminate between colours, for example: different materials, hand held filters, tinted spectacles and monocular contact lenses. However, the use of these is limited and contentious. A review of research on whether tinted lenses or filters improve visual performance in low vision concluded they actually worsen colour vision [20]. It should be emphasised that improving test scores on specialized colour vision tests is not the same thing as curing colour anomaly.

**The Future for Colour Vision Testing**

The main points to bear in mind when performing any test for colour vision are summarised in Table 8. It is important to recognise the significance of standardising the protocols in order to maintain high quality and consistency. For example, the importance of standard illumination has led to the development of ‘viewing booths’, which provide a controlled external environment in which the tests can be performed. A series of results can thus be obtained and used in patient monitoring to assess and follow up the severity and rate of loss of colour vision. Overall, it is important to appreciate the spectrum of tests available and to choose the most appropriate one.

**Table 8 Important points**

<table>
<thead>
<tr>
<th>Standard illumination [19]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard protocol</td>
</tr>
<tr>
<td>Clear instructions</td>
</tr>
<tr>
<td>Pupillary miosis and high lens density should be noted [21]</td>
</tr>
</tbody>
</table>

**Acknowledgments**

Thank you to staff in the Optometry and Photographic Suite in the Oxford Eye Hospital for their help and time in obtaining the images.

**Conflict of Interests**

None declared

**References**


<table>
<thead>
<tr>
<th>Plate number</th>
<th>Plate Function</th>
<th>Trichromatic Colour Vision</th>
<th>Colour Vision Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introductory – if not seen indicates poor visual acuity, functional loss, and/or poor understanding of task</td>
<td>Correctly read</td>
<td>Monochromats unable to read plate as the dots are isoluminant</td>
</tr>
<tr>
<td>2-7</td>
<td>Transformation/Confusion</td>
<td>Correctly read</td>
<td>Number seen different to trichromats (due to different appreciation of shades) or not seen at all. Positive evidence of colour vision deficiency.</td>
</tr>
<tr>
<td>8-13</td>
<td>Vanishing</td>
<td>Correctly read</td>
<td>No numbers seen in red-green deficiency.</td>
</tr>
<tr>
<td>14-15</td>
<td>Hidden digit</td>
<td>No number seen</td>
<td>Number seen</td>
</tr>
<tr>
<td>16-17</td>
<td>Classification (distinction between protans and deutans)</td>
<td>* Classification plates are used when the screening plates (2-15) have identified a colour deficiency</td>
<td>Protans see the number on the right; deutans see the number on the left. If both can be seen, less clear number assumed to be the defect. Severe red-green deficient people cannot see either number.</td>
</tr>
</tbody>
</table>

Table 5 Ishihara Plate Functions (modified from Doshi et al\textsuperscript{[15]})