Congenital colour vision deficiencies
and their occupational consequences

Colour is widely used to enhance the speed and accuracy of the transfer of information. In the workplace, the consequences of a colour vision deficiency range from simple embarrassment to the endangerment of lives.

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Colour vision deficiencies may be inherited or acquired secondary to ocular or systemic diseases, such as glaucoma and diabetes. The most common congenital deficiencies are the red–green deficiencies, which occur in about 8% of men and 0.5% of women. Acquired deficiencies are of much less concern occupationally than congenital colour vision deficiencies because they are less likely to lead to major colour vision errors, except in the more advanced stages when visual acuity is also markedly affected.

Congenital deficiencies are almost entirely red–green, but most acquired deficiencies are blue–yellow. Indeed, with age the crystalline lens yellows and everyone acquires a blue colour vision deficiency. This becomes significant occupationally only in very critical colour matching situations, such as diamond grading.

How are the congenital deficiencies classified?

Normal colour vision is based on three cone receptor types in the retina, sometimes erroneously called red, green and blue cones. For the present purpose, the terms L, M and S (for long, medium and short wavelength) cones are adopted (see the diagram of the visual spectrum in Figure 1).

The classification of congenital colour vision deficiencies is based on the cone type that is deficient, the number of types that are deficient and whether cones are absent or altered. The suffix '-anomaly' is used for an altered cone type and '-anopia' for an absent cone type. The classification and acceptable colloquial terminology is given in the Table.

The term 'colour-blind' is unacceptable in common colour vision deficiencies; even people

IN SUMMARY

- **The most common congenital colour vision deficiencies involve the discrimination of redness–greeness, and occur in about 8% of men and 0.5% of women. The degree of severity of the deficiencies varies widely.**
- **Errors in colour detection in the work place may result in minor outcomes, such as embarrassment, or major outcomes, such as fatality.**
- **Sometimes a message conveyed by colour can be augmented with other indicators, such as flashing lights or patterns, to relay the same information. However, indicators without colour may take more time to observe.**
- **Ishihara tests are often used in general practice: they are useful in detecting the presence of a colour vision deficiency and may diagnose the type of deficiency, but do not define the extent of the defect.**
- **Determining whether a patient's vision is 'defective safe' or 'defective unsafe' may be more important than defining the type and extent of colour vision deficiency.**

with an absent L or M cone can discriminate blueness and yellowness as well as those with normal colour vision. In addition, milder anomalies may be of no practical significance in many situations.

What features are typical?

The most severe, but fortunately least common, colour deficiencies are those with an absence of two or all three cone types. Clinically almost indistinguishable, people with rod monochromatic vision (all three cones missing) and those with blue cone monochromatic vision (only the S cone present) have very poor visual acuity, photophobia and nystagmus. Typically their visual acuity is 3/60 to 6/60, which is a far greater occupational problem than their lack of colour vision.

Congenital deficiencies involving the S cones are rare and seldom considered in the occupational context. The most common congenital deficiencies involve absences or alterations of the L or M cone types and the clinical characteristics of these are described below.

Protanopia (red-blind) and deuteranopia (green-blind)

Apart from the defect in their colour vision, people with a congenital colour vision deficiency have totally normal eyes and visual function, including visual acuity. Patients with protanopia and deuteranopia lack a receptor and, therefore, lack the ability to make the colour discriminations that the person with normal colour vision makes by means of that receptor. The colours they cannot distinguish can be represented as straight lines in colour space as shown in Figure 2. Along these lines these patients cannot discriminate colour; however, perpendicular to the lines, their discrimination is entirely normal.

For example, the congenitally protanopic patient cannot distinguish between blue-green and grey, but can distinguish yellow from light grey as well as any person with normal colour vision. In the red, yellow and yellow-green part of colour space, the confusions of those with deuteranopia and protanopia are very similar. Thus some assessments, such as the screening plates in an Ishihara test, are designed to identify both types of deficiency. On the other hand, if a precise diagnosis is needed then testing is best done in the blue and purple regions of the spectrum where their confusions are most different. The diagnostic plates of the Ishihara test, for example, test in these spectral regions.

In addition to the confusion of colours, there is a loss of sensitivity to red in patients with protanopia and protanomaly (protan deficiencies). Such patients see red as a relatively dark colour. Red traffic signals and brake lights appear only about 25% as bright to people with protan

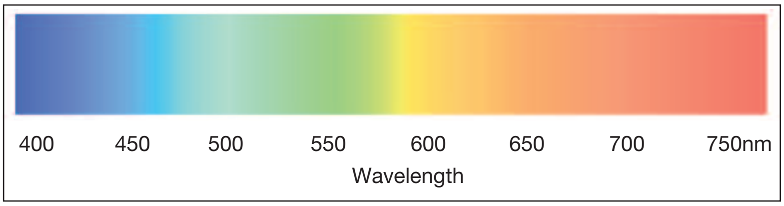

Figure 1. Wavelengths of light in the visual spectrum. Cone types are labelled L, M and S, for the corresponding wavelengths they detect. Peak sensitivities of L, M and S cone types are at 570, 540 and 450 nm, respectively.

Table. Colour vision deficiencies: classification[1] and prevalence

Classification	Prevalence
Trichromasy (subject has all three cones)	
Normal	92% of men, 99.5% of women
Anomalous (an altered cone type):	
• Protanomaly (altered L cone), colloquially called red-deficient	1% of men, 0.03% of women
• Deuteranomaly (altered M cone), colloquially called green-deficient	5% of men, 0.35% of women
• Tritanomaly (altered S cone)	0.003 to 0.007%
Dichromasy (subject has two cones)	
• Protanopia (absent L cone), colloquially called red-blind	1% of men, 0.01% of women
• Deuteranopia (absent M cone), colloquially called green-blind	1% of men, 0.01% of women
• Tritanopia (absent S cone)	0.003 to 0.007%
Monochromasy (subject has one cone)	
• π_5 (L cone only)	Estimated 0.000005%
• π_4 (M cone only)	Estimated 0.000005%
• Blue monocone (S cone only)	0.014 to 0.06% (includes blue monocones and rod monochromats)
Rod monochromat (all cones missing)	
Congenital night blind (all rods missing)	–

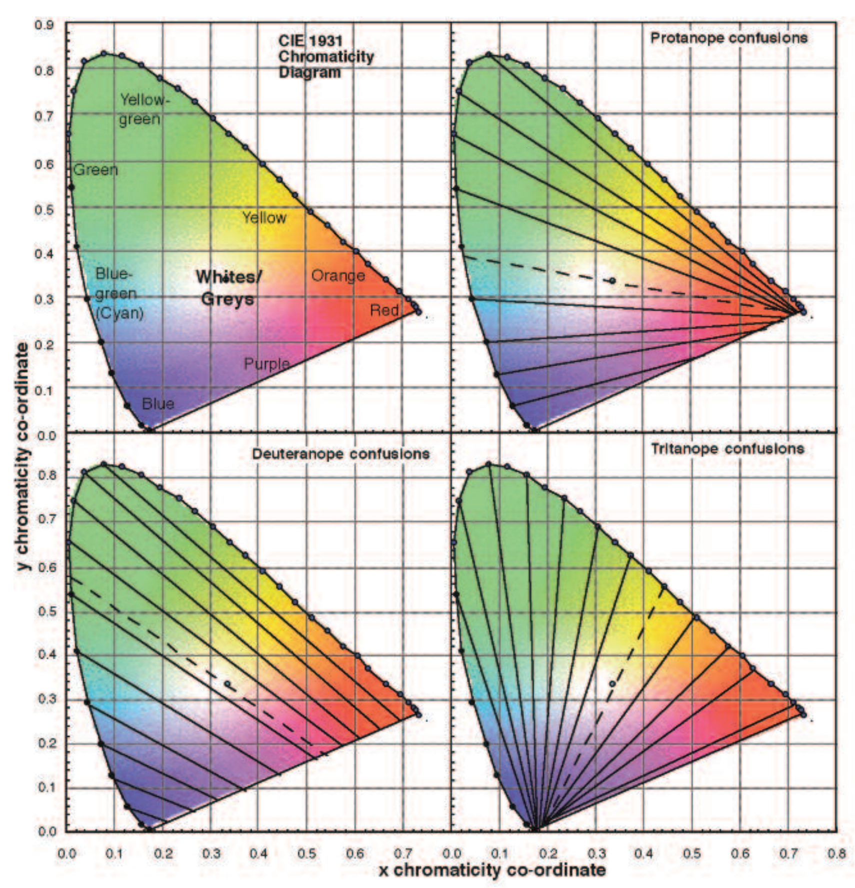

Figure 2. Diagram of the Commission Internationale de l'Éclairage (CIE). People with an absent cone type cannot distinguish pairs of colours lying on or parallel to confusion lines. Those with an altered cone type make errors in the same directions but to a lesser extent.

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Figure 3. Pipes and ducts colour coding and their meanings based on the Australian Standard 1345C. Printed with permission from Standards Australia.

deficiencies as to those with normal colour vision, and light emitting diode types of high mounted brake lights, appear only about 10% as bright. Thus those with protanopia detect red lights at only about one-third of the distance compared with people with normal colour vision and do so more slowly. Given the use of red signals in safety, the occupational consequences of this are clear.

There is a smaller loss of sensitivity to red in people with deuteranopia. These people also have a loss in green sensitivity, but this has far less dire consequences occupationally.

Protanomaly (red-deficient) and deuteranomaly (green-deficient)

People with an altered cone type make colour confusion errors in the same direction as those with that cone type absent, but to a lesser extent. For example, those with an altered cone will not confuse a pure yellow-green with pure red, as a patient with an absent cone will, but may confuse a greenish-yellow with a reddish-yellow. Those with an absent cone have only two receptors; those with an altered cone have three receptors but act as if they have two and a bit.

There are varying degrees of anomaly. They seem to form a continuum from normal colour vision to vision equal to that resulting from an absent cone, but nine distinct genetic types of cone alteration (anomaly) have been identified.

What are the occupational consequences?

Detection, recognition, differentiation and interpretation of colours may all be adversely affected by colour vision deficiencies. For example, people with protanopic or protanomalous vision, having a lowered sensitivity to red, have been shown to be over-represented in red light accidents. The consequence of an error in the workplace may range from a simple embarrassment to a fatality.

There may be other information

available conveying the same meaning as the colour, such as the red traffic light signal being always on top, but exceptions exist; red signals are not on top of railways signals. Also, this additional information may take more time to interpret. Colour adds to the speed and accuracy of a response and is used in many circumstances to aid detection and add meaning.

Often, colour is used to aid detection and recognition of warning signals and of objects for avoidance, such as high visibility garments and road barriers. In some industries standard colour coding is used, such as the Australian Standards for pipeline identification (Figure 3)[2]. The ability to clearly discriminate colour would be essential for an interior decorator, but it is also important for a caterer to establish the ripeness of fruit (Figure 4) or a doctor to recognise cyanosis. More examples of the use of colour in the occupational setting are given in the box on this page.

How are deficiencies assessed?

Lighting conditions for testing

An important consideration in the examination of colour vision is the lighting. Tests are constructed using carefully designated colours, which appear different under different lighting, and the wrong lighting tends to blur the borderline between normal and abnormal.

Generally, daylight is specified. Special (but expensive) light systems are available, but daylight fluorescent tubes and, when facing south, light from a cloudy sky (but neither direct sunlight nor light from a blue sky) are probably acceptable. Usually, hospital lighting is too yellow unless very close to the blue limit of the permitted sources[3].

The quantity of light is important also. Too little light tends to make people with normal colour vision fail the test, whereas too much light tends to allow colour vision deficient people to pass. About 200 to 250 lux (measure of luminous power per unit surface area) is considered adequate. This is on the low side of what should be in a consulting room for more general purposes.

Detecting a colour vision deficiency

Many pseudoisochromatic plate tests can be used to detect a colour vision deficiency – most notably, but not solely,

Figure 4. The colour of a ripening tomato is not clearly evident to the significantly red–green colour deficient

Examples of colour in the workplace

Occupational uses of colour

- Coloured signal lights, e.g. maritime, aviation, railway and driving industries
- Coloured warning lights, e.g. lights on industrial control panels
- Colouring of flags, e.g. maritime and railway industries
- Colour-coding of ducts, pipes, wires, liquids, resistors and capacitors
- Colour-coded diagrams, e.g. railway lines (Figure A), computer screen displays
- Colouring of objects for avoidance or recognition, such as high visibility garments and road barriers

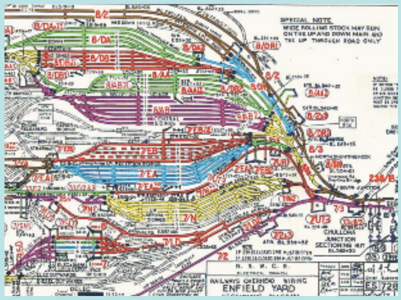

Figure A. Railway track map showing colour coding of overhead wires that are also number coded; the colour coding is much more obvious.

Colour recognition in the healthcare industry

- Detecting clinical signs, such as cyanosis
- Discriminating between lesions, such as ocular fundus colours and features, e.g. choroidal naevi
- Identifying coding of pharmaceutical products and diagnostic agents, such as dipstick urinalysis (Figure B)
- Matching fillings and crowns in the dental industry
- Co-ordinating lens tints and frames in the ophthalmic industries

Figure B. Dipstick urinalysis test, an example of colour-coded diagnostic agents.

Colour recognition in other industries

- Identification and description, e.g. providing evidence in the police services involves describing eye, skin, hair and vehicle colour
- Determining the ripeness of fruit and colouring cake decoration in the catering industry
- Identifying tickets and tokens, e.g. travel industry
- Colour matching, e.g. decorating, painting and building industries
- Checking colour consistency in a product, especially when assembled from multiple parts
- Identifying indicators, flame tests and container colour-coding in the chemical industry
- Interpreting oil and mineral colours
- Recognising sporting team colours

Ishihara's test, found in most general medical practices and in all optometrical and ophthalmological practices, is used. There is always an overlap between normal and abnormal performance, and for most practical purposes, tests such as Ishihara are sufficient in detecting an abnormality but rarely give information on the extent of the deficiency.

The definitive diagnostic instrument is an anomaloscope, which involves the subject mixing two coloured lights to match a third colour. It is an expensive and slow test, but the diagnosis is unequivocal.

Determining the deficiency type

As with determining the presence of a colour vision abnormality, determining the type of deficiency is made with an anomaloscope.

Since people with protanopic or protanomalous vision (red-blind or -deficient) present the greatest safety risk, they are explicitly excluded from some occupations, including commercial driving. The Medmont C-100 flicker-matching test distinguishes people with these red colour vision defects from everyone else. Each State and Territory's road traffic authority maintains a list of optometrical and ophthalmological practices that have this test for the purposes of assessing commercial drivers.

The Ishihara test has diagnostic plates that are relatively reliable in distinguishing between predominantly red colour deficiencies and green ones, but those mildly affected may see both coloured digits. In these cases, a diagnosis may still be obtained by asking which of the two digits is the clearer, but this is less accurate than other tests.

Assessing extent of the deficiency

No single test is considered adequate for establishing the extent of the colour vision deficiency. Estimation of the extent of the deficiency is done mainly with several tests of varying difficulty. Farnsworth-Munsell D-15, Lanthony Desaturated D-15, Adams Desaturated D-15, Farnsworth-Munsell H-16 are all tests in which the person has to arrange colours in a sequence and they vary in difficulty.

The Farnsworth-Munsell D-15 test is often used in some optometrical and ophthalmological practices to distinguish the occupationally less significant deficiencies from those of greater concern. It has, however, no immediately practical relevance.

The City University test is also quite widely used. In this test the patient identifies the closest match from four different colours and the pass or fail level is equivalent to that of the Farnsworth-Munsell D-15 test.

It is important to determine the extent of the deficiency so that those people who are mildly colour vision deficient are not unfairly discriminated against. This issue is often neglected.

Assessing practical relevance

Determining whether a patient's vision should be classified as 'defective safe' or 'defective unsafe' may be more important than making a definitive diagnosis of type and extent of the defect. Widely used, lantern tests entail the subject naming colours presented under conditions comparable to the real-life task. The International Civil Aviation Organisation and the Federal Police, for example, nominate the Farnsworth lantern test. About 15% of people with only one abnormal cone type (but all three present) can pass this test. The Australian Maritime Services Board nominates the Holmes-Wright lantern test; almost all people with a colour vision deficiency will fail this test. A few people with normal vision may fail it too.

Ad hoc tests requiring matching or naming of wire colours are often used in the electrical and electronics industry. In other occupations practical tests may be used in which the person under assessment is observed carrying out the tasks, but there are several problems with this procedure. The influence of adverse conditions may not be appropriately replicated, and difficulty in maintaining the same test conditions for all applicants may introduce equity issues and facilitate challenges to the procedure. Importantly, where the likelihood of error is small but the consequence is great, the relatively short test may not identify the problem.

How can they be treated?

Congenital colour vision deficiencies arise either from an absent gene, which would have given rise to the third receptor type, or a hybrid gene that has given rise to an anomalous receptor by substituting a few different amino acids in a protein. Red–green colour vision deficiency follows an X-linked recessive mode of inheritance. The cure, therefore, lies in genetic engineering.

Coloured lenses

Several coloured lenses are marketed that claim to 'cure'. They are probably used mainly to pass an Ishihara test to enter an occupation and then, later discarded. Certain lenses can help the wearer to distinguish colours, but are less useful in assisting colour recognition and will impede the detection of some colours. Selected with care after a full colour vision diagnosis, they have been shown to be useful in very specific occupational activities.

Coloured lenses introduce other hazards that may be more undesirable occupationally than the colour vision deficiency itself. Subsequent problems include errors in judging the distance of moving objects (a problem when driving) and reduction of light available to see objects by (like driving at night with sunglasses on). In contact lens form, they may be virtually undetectable on a brown iris, but as spectacles, they are clearly coloured, usually red-purple.

Other solutions

It may be possible to provide engineering solutions in which other clues augment or are substituted for colour coding. Rather than just having a red light, the light could be larger, brighter, a different shape, flashing or enhanced by an audible warning. In Figure 5, the casino chips are distinctively coloured but also have pattern differences that will aid the colour deficient person.

In simple colour codes, it is possible to substitute colours that will not be confused. In traffic signals, for example, Australian Standards restrict the green used to shades that are not confused with red (Figure 6). The green may, however, be confused with white.

Figure 5. Colour and pattern coding of casino chips. Even without colour, the values are evident; however, colour usually adds speed and accuracy to identification.

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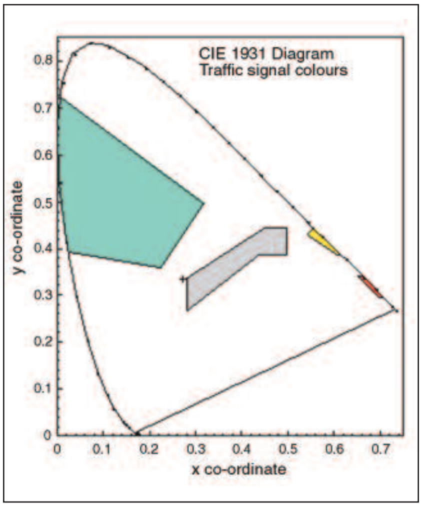

Figure 6. The specification of traffic signal colour in CIE Publication 48-1980.[4] The shades of green (yellow-greens) confused with reds are not included in the permissible greens, which are green and blue-green.

Advice to patients

Occupations with explicit entry requirements

If a patient has failed a colour vision test, the next step is to establish if the intended occupation has colour vision requirements and, if so, what they are. Failure of the Ishihara test is not usually an automatic disqualifier but, more likely, an indication for further testing. The colour vision requirements and locations where further testing may be undertaken will be known by the employer.

Occupations without explicit entry requirements

The difficulties experienced by people with colour vision deficiencies vary with the extent of the deficiency and the nature of the job, such as which colours are used and whether other clues are available. Advising a patient, therefore, requires knowledge of colour vision deficiencies, the specific diagnosis (type and extent) and the colour vision demands of the job. It is highly unlikely that any one person has adequate grounding in all these issues, so the decision will be based on information from a number of sources.

Acceptance of a person with a colour vision deficiency into a job with colour based decisions may be argued to carry some risk. The amount of risk will depend on the type and extent of the deficiency and the colour based demands of the job. The decision then becomes a matter of acceptable risk. The risk acceptor (the employer) should take this decision on the best advice available. The acceptability of the risk is also affected by the consequences of error. The more dire the consequences, the more conservative will be the standard set.

Conclusion

The most common congenital colour vision deficiencies affect discrimination of redness–greeness and occur in about 8% of men and 0.5% of women. In the workplace colour is widely used to aid and hasten recognition of information, and, therefore, assessment of colour vision is a prerequisite for entry into some occupations.

The Ishihara screening and diagnostic plates can be used by GPs, primarily to detect the presence of a colour vision deficiency. The diagnostic plates may elicit the type of deficiency, but will not define the extent of the defect. A patient who fails an Ishihara test should be referred for further assessment, the exact tests of which may be indicated by the type of work the patient plans to do. It is important to identify the magnitude of the deficiency not only to exclude those who will perform poorly in a certain job, but also to prevent unjust discrimination against those with minimally affected colour vision. However, often the differentiation between 'defective safe' and 'defective unsafe' is more valuable than the definition of type and extent of the deficiency. MT

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Further reading

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