Colour vision deficiency in the medical profession

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SUMMARY
Colour is often used as a sign in medicine, yet there have been few studies into the effects of a colour vision deficiency (CVD) on doctors' medical skills. Using a literature search, the results indicate the prevalence of CVD in the medical profession and its effects on medical skills. For the congenital form among male doctors in the United Kingdom, the prevalence is shown to be probably about the same as for the population at large; i.e. 8%. However, the data is insufficient for any estimate to be made of the small number of female doctors and for the acquired forms of CVD. The effect on skills is also shown. Because of certain features of their work, general practitioners may have special problems. Thus, it is concluded that medical students and doctors should be screened for the deficiency and advised about it, and that there should be more study of the effects of CVD on decision-making in general practice and some specialties.

Keywords: congenital and acquired colour vision deficiency; prevalence; screening.

Introduction
Colour is often used as a sign in medicine. It gives information about surface and below surface phenomena. Many descriptive and diagnostic terms in common use indicate its value when used in this way: jaundice, cyanosis, erythema, melaena, and rubella are examples. It is also used in histology, biochemistry, and coding for many new technologies. Yet there have been few enquiries into the effects of a colour vision deficiency (CVD) on doctors' medical skills.

Awareness of the implications of CVD is often limited among those who suffer from it, and even more so among those who do not. But doctors have given accounts in published articles about the difficulties it causes in medicine, and a few research articles have been published on this subject. Conclusions drawn from personal accounts inevitably have a subjective element, but recent studies have provided better evidence on the types of difficulty encountered and the effects on performance.

Congenital CVD has a prevalence in the general population of 8% for men and 0.4% for women; therefore, its prevalence in the medical profession is likely to be high if there is no widespread self-selection out of the profession as a result of it. More people will have suffered from the acquired forms, but the prevalence is not known.

Prevacational screening for the deficiency and further testing for severity are practised for a number of occupations where certain standards of colour vision are required, but, as far as is known, medical students are screened at only one university in the United Kingdom (UK) and only at a few in the rest of the world — screening for CVD is practised by all medical schools in Taiwan (personal communication: Hwei-Zu Wang, Kaohsiung Medical College, 1995).

This article gives background information on CVD, and then reviews the literature on the prevalence of the deficiencies in the medical profession and the effect on medical skills. A study of general practitioners (GPs), which is not widely known, gives evidence of problems particular to the profession. The implications are discussed.

Method
Studies to be reviewed were identified from three sources. First, MEDLINE and BIDS ISI, from 1996 to August 1997; secondly, from reference lists of the articles so identified; thirdly, from personal recommendations. Studies, with two exceptions, were in English.

Studies for prevalence data were rejected if they used inadequate screening methods or did not give the male to female ratio.

Results
Background information
Many doctors may be unfamiliar with some of the modern concepts of colour vision; however, excellent reviews are to be found. Salient features are that normal vision is trichromatic, meaning that all spectral hues can be matched by additive mixtures of three primary hues taken from the red, green, and blue parts of the spectrum. The three primary hues are detected by three types of cone cells containing pigments with photosensitivities that overlap but peak in the green (long-wavelength), yellow-green (middle-wavelength), and violet (short-wavelength) parts of the spectrum. By comparing the rates of absorption of photons, the visual system is able to discriminate colours. It is varieties of hue, saturation (the similarity of a colour to white), and brightness that lead to an estimate that the human eye is able to distinguish, at equal luminance, 17,000 perceptible differences in colour. Context, for example, adjoining colours (colour contrast and colour constancy), expectation, and memory are among factors that influence the colour actually perceived.

Widespread interest in CVD followed John Dalton’s description (1798) of his own deutan (middle-wave) deficiency, but, for the preceding centuries, the deficiency has been described as ‘an immensely well-kept secret’.

The deficiency, its nature, terminology, inheritance, and prevalence
Congenital CVD is the result of an abnormality or absence of one or other of the three forms of photopigment in the retinal cones. The three types of deficiency are protan (‘red’ or long-wave), deutan (‘green’ or middle-wave), and tritan (‘blue’ or short-wave). (These words derive from the Greek proto meaning first, deuteros meaning second, and tritos meaning third.) The terms ‘red’, ‘green’, and ‘blue’ are widely used but lead to a misunderstanding because the failure to discriminate colour is of a much wider range in each case. Classifying by severity of the ‘red-green’ forms is much more useful for predicting the effect on performance. When tested in this way, approximately equal numbers grade as mild, moderate, or severe.

The acquired deficiencies are caused by ocular and intracranial
pathologies, and also by many drugs. Diabetic retinopathy, hypertension, glaucoma, macular degeneration, and yellowing of the lens owing to ageing are common causes. Tritan deficiencies are the most common. The prevalence of acquired deficiencies are not known but are probably greater than the congenital forms, particularly in older people.

Inheritance for the ‘red-green’ forms is X-chromosome linked, recessive, and are the result of deleted or tandem genes. The tritan form is autosomal dominant.

Testing and screening

There are screening, classifying, and vocational tests for CVD. The Ishihara test, but there is now a trend away from routine universal screening towards selective checks (personal communication: JC Read, Department of Health, 1996).

The deficiency as a disability

The identification of a bush that has holly berries on it, the observation by a pilot of the patterns of coloured lights at an airport, and learning about a person’s health by their complexion are all tasks in which a person with CVD may fail. The tasks involved have been traditionally classified into the discrimination, naming, and matching of colours. A more useful classification for many common activities derives from the study of the advantages of normal trichromat vision in the life of humans and animals. These advantages are in object detection, object or pattern recognition, and in determining the significance of the colour of an object. The three tasks mentioned above each illustrate one of these.

Reds, oranges, yellows, browns, greens, purples, and violets are the colours that those with the most common ‘red-green’ deficiencies can fail to discriminate. Protans see reds as dark and tend to have more difficulties in practice than deutos. Failures are greater with dark and light colours. Dichromats fail to distinguish even some bright colours. Dalton, for example, wrote that stockings spotted with blood or with dirt would scarcely be distinguished. Circumstances can also cause failures; for example, the absence of cues, poor illumination, working at speed, and viewing objects that subtend a narrow angle at the eye.

There is an impressive body of evidence to show that some of those with CVD perform less well than others in some occupations. Occupations have been classified according to the standards of colour vision required, and these have been applied, notably in the transport and electrical industries and the armed forces, but not always effectively. For many occupations, little consensus exists about the standards to apply. Difficulties in everyday life have been reported; for example, dress, home decorating, cooking, and sport. In one study, 75% of 102 people with a deficiency reported some types of difficulty, and there was a correlation (P<0.01) between the percentage reporting difficulties and the severity of their deficiency.

There are, however, some advantages to having a CVD. Colour can rival other visual perceptions, and this explains advantages in detecting camouflage and textures. An advantage also seems to be given by the greater care that a person with CVD takes with certain tasks, and because deutos see dark/light differences at twilight better than others.

Awareness

People with a colour deficiency often lack awareness of its extent and effect. A few react by denial. In the study by Cole and Steward, 5% of dichromats and 25% of anomalous trichromats were not aware of their deficiency. Students at art school can be unaware of it even when severe. In one study, lack of awareness of the acquired form was shown by all 34 diabetics with retinopathy; and, of eight people who made more than two-step errors on home testing of urine, none were aware of any difficulty. The tritan deficiency that occurs with ageing tends to go unnoticed owing to adaptive processes occurring slowly over time.

The lack of awareness must in part be because of the effective use of cues, often unconsciously, to guess the colour of the object observed. For example, brightness can be a cue to red, the texture of a lawn to green, and the shape of a banana to yellow. In addition, it has been observed that individuals with a congenital deficiency learn from childhood to keep quiet about it and so are deprived of the opportunity of fully understanding its implications. To understand these implications takes a sustained effort, and few attempt this.

The difficulty of gaining awareness that colours are not being perceived can be shown by asking individuals with normal colour vision about their colour vision at night. Many do not realise that in dim light (scotopic conditions) they see only in black, grey, and white, except when viewing direct sources of light. Experiments have shown how strong the tendency is of even those with normal colour vision to rely on assumptions about the colour of an object. They can match, for example, the image of a brown lemon as yellow; and the poorer the colour information given, the stronger this tendency is. This helps to explain how those with a CVD can make assured but incorrect judgements of colour.

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Prevalence (%)</th>
<th>Hue discrimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dichromat (two cone photopigments only)</td>
<td>Protanopes ('red' deficiency)</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Deuteranopes ('green' deficiency)</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>Trichromat (three cone photopigments, one abnormal)</td>
<td>Protanomalous ('red' deficiency)</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Deuteranomalous ('green' deficiency)</td>
<td>5</td>
<td>0.53</td>
</tr>
</tbody>
</table>

The suffix, anomalous, denotes the possession of an abnormal photopigment. Protan and deutan are terms denoting both dichromats and trichromats. Tritan ('blue') prevalence = dichromats: 1 in 10 000; trichromats: unknown. Monochromats are extremely rare.
Prevalence of CVD in the medical profession and allied occupations

Table 2 gives the results of all known studies that include prevalence figures for doctors, dentists, and medical and dental students when reliable methods of testing for CVD have been used.

Two large studies, not included in the table, give prevalence for all students, medical and non-medical, attending Queen’s University of Belfast for two periods of five years (1949–1954 and 1954–1959). CVD testing was part of the health assessment for all entrants. The prevalence of CVD was 6.9% for 1966 men and 5.5% for 2405 men. The Ishihara test was used but with ‘no special illumination’. If tungsten lighting was used, it could account, by missing some of the deutans, for the low figures.

All prevalence figures came close to, or a little above, the average 8% for men with inherited CVD in the general population, except for ophthalmologists who had a prevalence of 6.7%, which suggests some self-selecting out for this specialty and possibly for the students of Belfast University.

Doctors with CVD

Personal accounts

Five doctors with CVD have published accounts of their experiences in medical practice. Haenel, a physician, deliberately induced snowblindness by skiing in the Alps so that he could experience the effects of CVD, which are mainly those of a tritan induced snowblindness by skiing in the Alps so that he could experience the effects of CVD, which are mainly those of a tritan (23 doctors); charts, slides, prints, and codes (24 doctors); test-strips for blood and urine (22 doctors); ophthalmoscopy (18 doctors); blood or bile in urine, faeces, sputum, or vomit (18 doctors); and otoscopy (14 doctors).

To overcome their difficulties, 17 doctors reported close observation, seven asked for the help of others, and four reported paying more attention to the history of the patient. Difficulties in microscopy, chemistry, clinical examination, and teaching methods as medical students were reported by 23 of the doctors. Seventeen doctors reported no or very few difficulties: this percentage corresponds fairly closely with that of Cole and Steward for subjects with difficulties in everyday life. It is notable that five of those who reported no or very few difficulties had severe deficiencies, and this suggests that these doctors were unaware of their observational failures.

Doctors with mild deficiencies reported fewer difficulties compared with the combined results of those with moderate or severe deficiencies (P<0.03, n = 40). No significant difference was found between protans and deutos in the numbers of difficulties experienced.

The following comment, made by a GP (moderate deutan) of his experience as a medical student, is one of many:

My loss of confidence might have been more sympathetically handled had they [my teachers] been on the lookout for this problem.

Studies of specialists and medical students with CVD

Tocantins identified, with Ishihara plates, nine junior medical students with CVD in a class of 70, and studied their skills in chemistry and microscopy. These nine made many incorrect matches compared with normal controls, who made a few, when tested for matching phenolphthalein solutions, identifying Gram-negative and acid-fast bacteria, and eosinophils.

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Voke studied endoscopists attending a conference. Colour was considered a major factor by all endoscopists. Using Ishihara plates, five were found to have a CVD and three admitted that it was a handicap. Testing skill, using a model stomach and circular coloured targets, showed some errors compared with two controls with normal vision.

Koningsberger found 15 endoscopists with CVD out of 139 attending a meeting. Skill was assessed by use of a video excerpt of endoscopies of a variety of conditions. No effect of CVD was shown by these studies, but the F2 test was used, which is only for screening, therefore, severity was not established, which reduces the value of this study.

Poole studied the skills of 132 histopathologists (15 with CVD) and 138 medical laboratory scientific officers (13 with CVD) by testing them with 20 projected transparencies of histopathology slides with various staining techniques. The colour vision tests used were Ishihara, City University, and Farnsworth-Munsell 100-line. Both groups with CVD were sig-

The doctors reported a wide range of difficulties. The most common were:

- the widespread body colour changes of pallor, cyanosis, jaundice, and cherry red (25 doctors);
- rashes and erythema of skin (25 doctors);
- charts, slides, prints, and codes (24 doctors);
- test-strips for blood and urine (22 doctors);
- ophthalmoscopy (18 doctors);
- blood or bile in urine, faeces, sputum, or vomit (18 doctors);
- and otoscopy (14 doctors).

A study of general practitioners with CVD

In a study of 40 (38 men and two women) doctors with congenital CVD, of whom 37 were GPs, who had responded to letters in medical journals, Spalding used a questionnaire and a battery of colour vision tests to determine their range of difficulties in medical practice, and to relate these to the type and severity of their deficiency. A difficulty was defined as a problem, whether or not it was overcome.
Table 2. Summary of studies giving evidence of prevalence of congenital CVD in the medical and dental professions.

<table>
<thead>
<tr>
<th>Authors, date and country of study</th>
<th>Occupation of subjects</th>
<th>Method of selection</th>
<th>Colour vision test</th>
<th>Total number of male subjects</th>
<th>Percentage (number) with CCVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tocantins et al41 1933 (USA)</td>
<td>Junior medical students</td>
<td>Not known</td>
<td>Ishihara</td>
<td>70</td>
<td>12.8 (9)</td>
</tr>
<tr>
<td>Olson42 1971 (UK)</td>
<td>Histology students</td>
<td>All students</td>
<td>Ishihara</td>
<td>320</td>
<td>8.7 (26) (1 not R/G)</td>
</tr>
<tr>
<td>Rigby et al43 1991 (UK)</td>
<td>Histopathologists: 28</td>
<td>Volunteers</td>
<td>Farnsworth-Munsell 100-line</td>
<td>23</td>
<td>10.3 (3)</td>
</tr>
<tr>
<td>Koninsberger et al44 1994 (Holland)</td>
<td>Gastroenterologists</td>
<td>All male consultant and resident pathologists and physicians of internal medicine with at least one year's experience in gastroenterology and colonoscopy visiting a conference</td>
<td>Modified F2</td>
<td>139</td>
<td>11.0 (15)</td>
</tr>
<tr>
<td>Arden et al45 1995 (UK)</td>
<td>Ophthalmologists</td>
<td>96.1% of all UK ophthalmologists</td>
<td>Computer graphic</td>
<td>810</td>
<td>6.7 (54) (1 tritan)</td>
</tr>
<tr>
<td>Poole et al46 1997 (UK)</td>
<td>Histopathologists and medical laboratory scientific officers</td>
<td>Volunteers from 45 hospitals who had spent more than one year in histopathology</td>
<td>1. Ishihara</td>
<td>132</td>
<td>13.0 (15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. City University</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>3. Farnsworth-Munsell 100-hue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McMaugh47 1977 (Australia)</td>
<td>Dentists, dental students, and ceramic technicians</td>
<td>Students: 86 Dentists: 20 Technicians: 88 (Sample of 88 tested for CVD)</td>
<td>Ishihara</td>
<td>88</td>
<td>7.9 (7)</td>
</tr>
<tr>
<td>Barna et al48 1981 (USA)</td>
<td>Dentists</td>
<td>Not given</td>
<td>American optical company charts</td>
<td>50</td>
<td>14.0 (7)</td>
</tr>
<tr>
<td>Moser et al49 1983 (USA)</td>
<td>Dentists</td>
<td>Participants in a health assessment programme</td>
<td>1. Dvorine</td>
<td>630</td>
<td>10.0 (66)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Ishihara</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Davison et al50 1990 (USA)</td>
<td>Dental students/faculty and staff of university</td>
<td>Not given</td>
<td>SPP-C-Part one</td>
<td>635</td>
<td>7.8 (18)</td>
</tr>
<tr>
<td>Wasson et al51 1992 (USA)</td>
<td>Dental students, dentists, dental hygienists, dental assistants, and university staff</td>
<td>'Recruited'</td>
<td>SPP-C-Part one</td>
<td>75</td>
<td>9.3 (7)</td>
</tr>
</tbody>
</table>

Total number of female participants = 599. Number of females with CVD = 1.
significantly poorer at identifying slides than normal sighted people. When subjects with CVD were categorized as severe, moderate, or mild, there was a significant trend towards those with severe deficiency making more mistakes ($P < 0.001$).

**Doctors’ awareness of their CVD**

In their study of 30 histopathologists, Rigby et al reported that two of the three found to have a CVD were unaware of this. Spalding reported that, of 40 doctors known to have CVD, in 24 it was severe but 19 of these did not know this. Three of the 40 doctors specified that it was mild, three did not know of the deficiency until after qualification, and one of these, a moderate deutan, did not know until six years after qualification, and later he reported many difficulties as a physician.

**Colorimetric tests for urine and blood**

There have been many studies showing that diabetics with retinopathy or congenital CVD make errors in reading certain colorimetric tests. For diabetics with retinopathy, the tests were Diastix, Clinistix, Clinitest, Haemoglotest (Bayer Diagnostics), and BM Glycemia (Boehringer Mannheim). For diabetics with congenital CVD, the tests were Glucostix, Diahex, and Clinitest (Bayer Diagnostics). Greater than one-step errors were reported for both groups. One study used colorimetric methods to show that the chromaticity of the charts used in these tests was in the range that would be expected to cause errors for quantitative testing for glucose but not for detection of its presence. Only one study out of 11 did not show more errors by diabetics with retinopathy than those without it.

There has been one study of laboratory technicians with congenital CVD using a variety of colorimetric tests, but Spalding, in his study of 40 doctors with inherited CVD, found that 22 reported difficulties with these tests. Only one reported the use of a reflectance meter.

**Rectal bleeding and haematemesis**

A proctologist reported one case of a patient with CVD who had failed to recognize rectal bleeding, which evoked subsequent correspondence in the *American Journal of Ophthalmology*. Surgeons also reported three other cases where treatment had been delayed for the same reason. No mention was made of the possibility that doctors might have the same difficulty with the stools of their patients, but one deutan GP reported, ‘I once diagnosed a haematemesis as bile. The patient was lucky to survive.’

Eighteen of the 40 doctors (37 GPs) in this study reported difficulties with detecting blood or bile in urine, faeces, spumut, or vomit.

**Discussion**

The evidence presented here suggests that the prevalence of congenital CVD in the UK medical profession is about the same as for the population at large. It follows that, in the year 1994, there were likely to have been approximately 5800 doctors in general practice in the UK with this deficiency, and more would have had an acquired deficiency. The evidence also suggests that many of these doctors will not know of its severity in their own case and a few will not know that they have any deficiency at all.

Published studies described here have shown that, in some common medical procedures, individuals with CVD, particularly if it is moderate or severe, perform less well than those with normal colour vision. This has been shown for patients using colorimetric tests for glucose in urine and in blood, both with congenital deficiencies and those owing to diabetic retinopathy, and it clearly is likely also to be true for doctors with these conditions. Medical students working in laboratories have been shown to perform less well with certain colorimetric tests and in microscopy. Recently, rather strong evidence has shown that histopathologists perform less well in examining slides using a wide range of staining techniques.

In the direct observations for physical signs in patients, there have been a number of accounts by doctors with CVDs, both in their present practice and retrospectively as students. However, there have been no published studies providing objective evidence of the effect on performance for this type of observation, apart from two of endoscopy, where the results are not conclusive. It cannot be assumed that performance is not affected. The observations that are reported to cause difficulties, for example, pallor, erythema, cyanosis, and body products, comprise the range of colours that are known to cause failures of discrimination for those with CVD.

However, doctors have many leads in the diagnosis and management of patients that do not involve colour. For outpatients, the history of the patient has been shown to be the most valuable. It is likely to be this, together with the greater care that is taken by those with CVD and the uncommon occurrence of serious error, that account for the fact that doctors with CVD are generally considered by themselves and others to perform as well as other doctors with normal colour vision. However, diagnosis can be a complex process and is often, in part, intuitive, so that it can be difficult to single out the part played by one type of observation. But from what is known of colour vision and from doctors’ comments, some features of the consultation can be predicted as likely, on occasion, to cause errors by those with CVD. In some cases there is the so-called pivotal observation, a single sign that it is essential to observe for the correct course of action to be taken. There is the unexpected and the unfamiliar case presentation that can make special demands on the doctor as observer — there is the scanning of an area for the detection of small features, for example, bacilli or a rash, and there are conditions of work, for example, at speed, alone, in poor illumination when visiting, and the patient who cannot give a history. Most of these features are particularly likely to affect the GP, the underlying reason being the difficulty in controlling the conditions of observation.

There is much evidence that doctors with normal colour vision often disagree about physical signs, but what is at issue in the present case is disagreements that may be, at least in part, resolvable or avoidable. For example, in the detection of blood in body products, a sign that is missed can have serious consequences: a doctor with CVD might be helped by viewing with a coloured filter, if carefully advised on the method, and then using an adapted peroxide test to confirm its presence. In addition, a reflectance meter could be used for some colorimetric tests.

Clearly, where error is involved, risk has to be balanced against hazard. In a valuable paper, Cole points out that, in relation to non-medical occupations, in analysis of the causes of accidents it is difficult to identify risk factors because they have so many causes and are relatively infrequent. He further comments that, if we insisted on incontrollable accident data before taking action to protect society from unnecessary risk, there would be very little action taken.

The evidence for action in the medical profession, such as the screening of all medical students for CVD, derives from many sources that need different types of assessment. The finding that doctors commonly do not know the severity of their deficiency is, for example, very significant, and what can hardly be doubted is that doctors who are aware of their limitations are more likely to make corrections.
Conclusion
The evidence points to the need for screening for CVD in medical students and doctors. This would allow testing for severity, counselling, and an informed choice of career. Doctors with known CVD could seek testing for severity, and, because of the wide range of specialties, the question of non-acceptance of applicants to medical school need hardly arise. Screening has implications for the work of occupational health physicians and teachers and examiners in medicine.

There is a case for a more detailed examination of the effects of CVD on decision-making in general practice, but also in a number of specialties; for example, ophthalmology, ENT, paediatrics, gastroenterology, and pathology.

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