Colour vision requirements of firefighters

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To perform their job safely firefighters must be able to identify colours on industrial gas cylinders, portable fire extinguishers, road traffic signals and several pieces of firefighting equipment. Although good colour vision is necessary we believe that the existing colour vision standard, which bars entry to the fire service to applicants who fail more than two plates of the Ishihara test, is unnecessarily stringent. We have identified and quantified the colour coded information encountered by firefighters. Colours were plotted on the CIE chromaticity diagram (1931) and isochromatic zones, which document the colour confusions of colour deficient observers, superimposed. This novel technique established possible colour confusions in different types of colour deficiency. Analysis of the results showed that red/green dichromats (protanopes and deuteranopes), severe deuteranomalous trichromats who fail the Farnsworth D15 test, and protanomalous trichromats are unsuitable for firefighting work. However, people with slight deuteranomalous trichromatism who pass the D15 test, are not disadvantaged and can be employed safely as firefighters. A new colour vision standard and a new testing procedure is recommended.

INTRODUCTION

Currently, only individuals with perfect colour vision are recruited to the fire service. The present standard specifies that colour vision be tested with the Ishihara plates and that people who make more than two identification errors are barred entry to the fire service. This standard replaced an earlier one that allowed individuals to enter the fire service who had failed the Ishihara test but were able to pass a vocational wool test. Although firefighters must discriminate colours because their work involves the recognition of various colour codes, it does not necessarily follow that ‘perfect’ colour vision is needed. The present standard excludes all colour deficient applicants although previous studies suggest that people with slight colour deficiency may be employed safely. The maxim of Equal Opportunities For All dictates that all vision standards must be appropriate and defensible. It is not apparent that the present colour vision standard meets these criteria.

This investigation uses a novel three stage analysis to determine suitable colour vision standards for firefighters. All the colour codes currently in use on the fireground were tabulated and numerical colour specifications obtained. These were then compared with the known colour confusions of people with different types of colour deficiency in order to determine whether mistakes, which might compromise safety, are likely to occur.

COLOUR VISION

Normal colour vision is mediated by long-wavelength (red), medium-wavelength (green) and short wavelength (blue) sensitive cone photoreceptors. The different responses of the three types of cone to light of a particular wavelength are processed in the visual pathway and this subsequently gives rise to the perception of colour. People who have normal trichromatic colour vision can discriminate an estimated 3 million separate colours if all variables of luminance, hue and saturation are allowed. Normal hue discrimination ability can be represented by a series of discrimination ellipses in the chromaticity diagram established by the Committee Internationale d'Eclairage (CIE) in 1931. The CIE colour measurement system is universally accepted as a means of specifying colours used in science and industry. Individual colours are specified numerically in terms of x, y chromaticity co-ordinates together with a luminance or reflection factor. White
Figure 1. The CIE chromacity diagram and a sample of discrimination ellipses. Any colour may be specified by referencing its \(x, y\) co-ordinates. Colours that fall within an ellipse (shown enlarged approximately 10 times) appear to be the same to people with normal colour vision.

Figure 2. Isochromatic lines of dichromats. Each line represents the longer axis of the dichromats discrimination ellipse. Colours represented by points along each line cannot be distinguished by dichromats, providing the luminance of each colour is the same. (a) Isochromatic lines of protanopes; (b) Isochromatic lines of deutanopes.

is located at the centre of the chromaticity diagram. Spectral hues are located along the curved boundary and desaturated colours are located at intermediate positions between white and the spectral locus. People with normal trichromatic colour vision cannot distinguish between colours with \(x, y\) co-ordinates inside an individual ellipse (see Figure 1).

Abnormal colour vision is caused by a variety of inherited cone photopigment anomalies. Monochromats have either no functioning cone photoreceptors or a single cone type. Visual acuity is significantly reduced. Monochromats are truly 'colour blind' and cannot discriminate wavelength differences in the environment.

Approximately 8% of men and 0.4% of women have some form of congenital colour deficiency. Defects differ in type and in severity but the number of separate hues that can be distinguished is always greatly reduced in comparison to the norm.

Dichromats have only two cone photopigments. There are three types of dichromat depending on which of the three normal photopigments is non-functioning. Protanopes lack the red sensitive photopigment, deuteranopes lack the green sensitive photopigment and tritanopes lack the blue. Anomalous trichromats have three types of cone but the spectral sensitivity of one cone photopigment is abnormal. The terms protanomalous, deuteranomalous and tritanomalous trichromatism are used to denote abnormalities of the red, green and blue sensitive photopigments respectively. Abnormalities of the blue photopigment are rare and this type of colour deficiency will not be considered further.

Protan and deutan defects are known collectively as red/green colour deficiency. The different types of deficiency do not occur with the same frequency. Protanopia, deuteranopia and protanomalous trichromatism are each found in approximately 1% of men whereas deuteranomalous trichromatism occurs in about 5% (see Table 1). A range of abnormal photopigments can occur and there are marked differences in the severity of colour deficiency within each classification of anomalous trichromatism. The hue discrimination ability of some anomalous trichromats is only slightly reduced whereas others have poor hue discrimination similar to that of the corresponding
dichromat. Dichromats confuse a wide range of colours including spectral hues; reds are confused with greens and purples are confused with blue-greens. Anomalous trichromats may only confuse desaturated, pale or dark colours. People with red/green colour deficiency always have difficulty distinguishing between reds, oranges, yellows, browns and greens. Protans have poor sensitivity at the long wave-length limit of the visible spectrum; red appears dark, and may be confused with black.

The colour confusions of protanopes and deuteranopes can each be represented by a series of isochromatic zones on the CIE chromaticity diagram (see Figures 2a and 2b). There are approximately 17 zones for protanopes and 27 for deuteranopes. Colours specified by x, y co-ordinates within isochromatic zones cannot be discriminated and will be confused by an observer of that particular type as long as no luminance contrast exists between the colours. The isochromatic zones of anomalous trichromats are similar to that of the corresponding dichromat but do not include the full range of chromaticities. Discrimination ellipses of differing size occur within isochromatic zones.

Congenital colour deficiency does not change with age. However, although colour deficiency is usually inherited it can also be acquired as a result of some diseases or as a side effect of some types of prolonged medication. Acquired defects usually affect the blue mechanism and the severity of the deficiency changes with time. Acquired red/green colour deficiency can occur in optic nerve pathology but is always accompanied by symptoms which include loss of visual acuity. Firefighters are less likely to present with acquired colour deficiency than a person in the general population because they are relatively young (the average age is 36 years) and they must have good general health.7-8

### Table 1. Prevalence of inherited colour deficiency in men and women

<table>
<thead>
<tr>
<th>Type of deficiency</th>
<th>% of men</th>
<th>% of women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protanopia</td>
<td>1%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Protanomalous trichromatism</td>
<td>1%</td>
<td>0.03%</td>
</tr>
<tr>
<td>Deuteranopia</td>
<td>1%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Deuteranomalous trichromatism</td>
<td>5%</td>
<td>0.35%</td>
</tr>
<tr>
<td>Total</td>
<td>8%</td>
<td>0.40%</td>
</tr>
</tbody>
</table>

Colour discrimination on the fireground

Firefighting is a varied, demanding and unpredictable occupation where the cost of non-performance is high. In many situations, where firefighters need to discriminate between colours, not only are errors in identification unacceptable but the time allowed for identification is restricted. Viewing conditions are often far from ideal; smoke and semi-darkness make the task of colour identification particularly difficult. In addition, colours on the fireground are often muted because of soiling caused by soot, dust and ash. Firefighters may have to interpret a number of formalized colour codes such as those used to identify industrial gas cylinders, portable fire extinguishers, traffic signal lights and pipelines. Colour is also used as a means of identification on a variety of firefighting equipment, e.g. colour coding of high and low pressure air lines used with cutting, spreading and lifting equipment. In addition, firefighters may gain useful information about the origins of a fire by the colour of smoke or flames.

Colour vision tests and visual standards

A number of colour vision tests have been developed that may be used to select personnel. Tests can be classified as being either clinical or vocational.

Vocational or trade tests, as they are sometimes known, can be used to select personnel when the colour vision task required by a job is readily identifiable and when it is conducted under repeatable lighting conditions. Generally these tests try to recreate the tasks and conditions of the work place. For example, a suitable colour vision test for a job that involves identifying electrical resistors might be to determine if a potential employee can correctly identify the coloured bars on a series of resistors. Although this trade test is simple and apparently fair it highlights some of the possible sources of error that affect vocational colour vision
tests, i.e. examiner variability, lack of standardization and the use of colour naming. As we shall show, firefighters must be able to distinguish between a plethora of different colours in a number of different conditions. It is not possible to recreate the conditions encountered on the fireground and therefore a trade test would be an inappropriate and unjustifiable means of selecting firefighter recruits.

Clinical tests have been designed to perform a variety of tasks. These include: identifying people with defective colour vision, grading the severity of the defect and/or classifying the defect as protan, deutan, or tritan. Clinical tests that use surface colours are unable to differentiate between people who are dichromatic and those who have severe anomalous trichromatism. Although some clinical tests are better than others at particular tasks, their great advantage over trade tests is that their sensitivity and specificity have been established in clinical trials, they avoid the use of colour naming and minimize the effect of examiner variability by adopting a standardized test routine.

Most clinical tests require the person being examined to identify a figure, match colours or to arrange colours in a sequence. The ‘confusion’ colours used in clinical tests are carefully chosen so that they fall within the isochromatic zones for colour deficient observers but are not encompassed within a single discrimination ellipse of the normal observer. By ensuring that the confusion colours used in the test fall within the isochromatic zones of a particular class of colour deficiency it is possible to classify the defect into either protan, deutan or tritan. Quantification of the defect may be achieved by tests which use colours that have different colour difference steps within zones.

The Ishihara pseudoisochromatic test, currently used by the fire service, is a particularly efficient screening test for red-green colour deficiency. Although protans and deutans are identified, the test is neither designed to screen for tritan defects nor is it able to grade the severity of red-green colour deficiency. If standards are to be appropriate, tests must be able to identify colour deficient people as well as to classify and grade the defect. Several clinical tests have been designed to do this. These include the Farnsworth D15 test, the City University Test, the Farnsworth-Munsell 100 hue test, the Nagel anomaloscope and the American Optical Hardy, Rand and Rittler (HRR) plates.

The D15 test was developed by Farnsworth in 1943 to distinguish between ‘safe’ and ‘unsafe’ colour deficient applicants to the electronics industry. The test is well suited to occupational colour vision assessment. The test, contained in a single box, is comprised of 15 movable, standardized Munsell colour samples and a fixed reference sample. The person being tested is simply required to arrange the colours in sequence. Approximately 5% of men fail the Farnsworth D15. The test is quick, easy to use, inexpensive and the results are readily interpreted by relatively inexperienced examiners. The x, y co-ordinates of each of the Munsell samples can be located on the CIE chromacity diagram. Failure of the test occurs when colours from opposite sides of the hue circle are placed together in the arrangement. These errors represent isochromatic colour confusions equal to the separation of the colours across the hue circle.

We concur with the views of others that clinical tests alone provide a suitable means of selecting personnel.

METHODS

To determine suitable colour vision standards for the fire service we used a novel objective technique. Briefly, this involved the identification of all colour coded information that a firefighter may reasonably expect to encounter at work. The colours were quantified by determining their CIE co-ordinates; this information was used to plot the colours on the CIE chromacity diagram. By superimposing the isochromatic zones of the different categories of colour deficiency it was possible to determine which type of colour deficient observer would have difficulty with which colours or objects.

Firefighting tasks that involve the use of colour were identified by: referring to the literature,3-5 talking to firefighters from different brigades about their jobs, and discussing the importance of tasks involving colour coded information with firefighter instructors based at the Fire Service College at Morton-in-Marsh. Additional information about colour coded objects used by the fire service was supplied by the Home Office Fire Research and Development Group and the Fire Experimental Unit also based at Morton-in-Marsh.

Colours were quantified by having their CIE co-ordinates determined. This was achieved in one of two ways either by a colour matching technique or by referring to the colour agreed by the British Standard Institute (BSI):

1. The colour of firefighting equipment was quantified by matching each colour with known Munsell reference colours. One of the authors (CGO), who has normal colour perception (determined by a battery of clinical tests), made the colour match. Colours were matched in situ, i.e. no attempt was made to clean the equipment or to alter the prevailing lighting conditions. Although this is advantageous in as much that it reflects ‘real world’ conditions it does not take into account the fact that colour appearance changes in different lighting conditions. All measurements were conducted at the Fire Service College, Morton-in-Marsh.

2. Firefighters may encounter a variety of objects that employ colour coding as a means of coding information. The colours used in these formalized colour codes are specified in a number of BSI standards. Colours used by these codes are specified in terms of Munsell reference colours or reference colours described by BS 5252. We assumed that the actual colour of these codes/objects was that specified by the appropriate
BSI standard.

CIE chromacity co-ordinates were determined from Munsell references using published data. The first stage of the analysis was to determine which colours are likely to be confused by dichromats. This was achieved by plotting the colours of objects that may be confused, for example gas cylinders, on a single CIE chromacity diagram and superimposing the isochromatic lines for dichromats. Colours that may appear the same to protanopes and deuteranopes—those that fall within a single isochromatic zone—were identified visually from the diagram.

The second stage of the analysis was to determine if these colour coded objects could be correctly identified by non-colour clues such as shape, reflectance, text or symbols.

Having established which colour coded objects appear the same to dichromats, the final stage of the analysis was to determine if the superior colour discrimination of anomalous trichromats might be sufficient to produce correct identification. This was achieved by comparing the separation of the confusion colours (within the appropriate isochromatic zone) with the separation of the colours used in a clinical test designed to grade anomalous trichromatism. If the separation of the confusion colours is greater than the separation of the colours used in the clinical test, then that test will be able to distinguish between anomalous trichromats who would see a colour difference and those who might not.

RESULTS

Identification of colour codes used in firefighting

Colour coded objects that firefighters must identify are described below. All colours used in these codes are specified numerically in terms of their CIE chromacity co-ordinates in Appendix I.

Safety signs are identified by their shape, colour and a symbol or text. The colour assigns a specific health or safety meaning, i.e. red signs are prohibitory, yellow ones indicate warning, blue ones give mandatory instructions and green signs indicate a safe condition. The colours used on safety signs must be those described BS 5378:1980.

Many firefighters drive fire appliances in emergency situations and must therefore be able to interpret road traffic signal lights. At night, signal lights must also be differentiated from other street lighting. The colour of road traffic signal lights and several common types of street lighting is described by BS 505:1971 (amended 1990) and BS 1367:1974 (amended 1982).

Firefighters must also be able to recognize colour coding used on industrial pipelines. The colour code, described by BS1710, uses colour to denote both pipeline contents and to indicate the hazard its contents represent. In particular, firefighters must be able to recognize the red band that indicates that the pipeline is to be used for firefighting.

Correct and rapid identification of gas cylinders present at the scene of a fire is of obvious importance. The contents of medical and industrial gas cylinders are primarily identified by the use of colour coding on the cylinder body. A written description of cylinders contents is provided at the top of each cylinder. However, it may not always be possible to read this in a firefighting situation where rapid identification is important. BS349 and BS1319 describe the code used on industrial and medical gas cylinders respectively; specification of the colours is provided by BS318 and BS5252.

Figure 3. Dichromatic isochromatic lines and the colours of portable fire extinguishers. Colours that fall along a single line appear the same to dichromats. (a) Colours described as cream and red fall on a single line therefore, they have the same colour appearance to protanopes. It can be seen (b) that deuteranopes will not make the same confusion.
Portable fire extinguishers are colour coded according to their contents, e.g. a cream extinguisher contains foam. Mistakes in colour identification may result in the use of an inappropriate extinguisher, e.g. the use of a water fire extinguisher on an electrical fire. The colours to be used in the code are described by BS5423.

Colour is used as the main means of identifying high and low pressure airline hoses. Power, produced by compressor, is conveyed to a variety of cutting, spreading and lifting equipment by these hoses. A representative sample of hoses have their colours quantified by the colour matching technique described earlier.

Identification of colours that will be confused by dichromats

After plotting colours of objects that might be confused on a single CIE chromacity diagram, the isochromatic zones for the two major classes of dichromatism were superimposed. An example of this analysis for the colours used on portable fire extinguishers is shown in Figure 3a and 3b. Figure 3a shows that colours described as cream and red are likely to be confused by a protanope, because the colours lie within a single isochromatic zone. Figure 3b demonstrates that a deuteranope will not make the same colour confusion.

The results of the analysis, for all colour coded information, is presented in Table 2. This table identifies all the colours that are likely to be confused by dichromats. However, this does not necessarily mean that the code or object cannot be correctly identified by a dichromatic firefighter, other non-colour clues such as reflectance, shape and symbols may be sufficient for correct identification.

Object identification by use of non-colour clues

Safety signs use colour redundantly, i.e. identification of colour is not necessary for the correct interpretation of the sign. For example a ‘no smoking’ sign is comprised of a stylized picture of a smoking cigarette on a white background upon which is superimposed a red circular band and cross bar. Although the red colour indicates that the activity is prohibited, identification of the colour is not essential for correct interpretation of the sign.

The red and amber lights used by road traffic signals and low pressure sodium street lights appear to be the same colour to dichromats. However, the colour of signal lights is not the only means by which they may be interpreted. Their relative position to each other and the sequence in which they are presented may be sufficient for correct identification. However the task of recognizing traffic signal lights is made more difficult for firefighters by two unavoidable features of their job. Firstly, in emergency situations a firefighter may have to drive at speed; inevitably this will reduce the amount of time available for the firefighter to recognize the signal light. Secondly, firefighters often have to drive at night when the task of identification is somewhat harder because the relative position of the lights is less apparent. Therefore, in some conditions, particularly when driving at speed in the dark, dichromatic firefighters may be unable to correctly identify road traffic signals or differentiate the red stop light from low pressure sodium street lighting.

### Table 2. Colours that firefighters encounter at work that appear the same to protanopes and deuteranopes

<table>
<thead>
<tr>
<th>Description of object</th>
<th>Protanope</th>
<th>Deuteranope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety signs</td>
<td>red, yellow, green</td>
<td>red, yellow, green</td>
</tr>
<tr>
<td>Retroflective safety signs</td>
<td>red, yellow</td>
<td>red, yellow, green</td>
</tr>
<tr>
<td>Road traffic signals and street lights</td>
<td>red, amber, LP sodium</td>
<td>red, amber, LP sodium</td>
</tr>
<tr>
<td>Pipeline identification</td>
<td>green, brown</td>
<td>green, brown</td>
</tr>
<tr>
<td>Safety code for pipelines</td>
<td>violet, blue</td>
<td>violet, blue</td>
</tr>
<tr>
<td>Medical gas cylinders</td>
<td>orange, grey</td>
<td>yellow, red</td>
</tr>
<tr>
<td>Industrial gas cylinders</td>
<td>violet, blue</td>
<td></td>
</tr>
<tr>
<td>Portable fire extinguishers</td>
<td>red, cream, green</td>
<td></td>
</tr>
<tr>
<td>Honda hoses</td>
<td>red, black</td>
<td></td>
</tr>
<tr>
<td>Amkus hoses</td>
<td>blue, green, black</td>
<td>blue, green, black</td>
</tr>
<tr>
<td>Nike hoses</td>
<td>red, green</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Gas cylinder colours confused by dichromats. Although dichromats confuse several colours used to code the contents of gas cylinders only a small proportion of gas cylinders are likely to be confused by dichromats. This is because they are able to use non colour clues such as shape and reflectance to distinguish between cylinders whose colour appearance is the same. The first column describes the colours that appear the same and the second column identifies cylinders that use these confusion colours. The third column indicates which cylinders are likely to be confused having considered non colour clues.

<table>
<thead>
<tr>
<th>Confusion colours</th>
<th>Gas cylinders</th>
<th>Is confusion likely?</th>
</tr>
</thead>
<tbody>
<tr>
<td>brown, green</td>
<td>helium, neon, methyl chloride, sulphur dioxide</td>
<td>no</td>
</tr>
<tr>
<td>red, green</td>
<td>carbon monoxide, coal gas, hydrogen, methane, propane, methyl chloride, sulphur dioxide</td>
<td>yes, between methyl chloride and propane</td>
</tr>
<tr>
<td>black, maroon</td>
<td>oxygen, carbon dioxide, ammonia, phosgene, acetylene</td>
<td>yes, between oxygen and acetylene</td>
</tr>
<tr>
<td>blue, black</td>
<td>argon, hydrogen cyanide, methyl bromide, oxygen, carbon dioxide, ammonia, phosgene</td>
<td>yes, between argon and oxygen</td>
</tr>
<tr>
<td>maroon, grey</td>
<td>acetylene, air, ethylene chloride, nitrogen</td>
<td>no</td>
</tr>
<tr>
<td>brown, red</td>
<td>carbon monoxide, coal gas, hydrogen, methane, propane, helium, neon</td>
<td>no</td>
</tr>
</tbody>
</table>

Several colours used to code the contents of pipelines are confused by dichromats. However, firefighters usually identify such pipelines by the text and symbols that are also displayed on the pipeline (Personal communication: G. Pearson, Fire Experimental Unit, Morton in Marsh, UK). Therefore dichromatic firefighters are no more likely to confuse pipeline contents than their colour normal colleagues.

Gas cylinders, both medical and industrial, primarily have the colour coding displayed on the cylinder to enable the identification of cylinder contents. Although dichromats make numerous colour confusions, correct identification of the cylinder may still be possible by interpretation of non colour clues: text, shape and the coloured rings found at the neck of some cylinders. In a firefighting situation it is unlikely that a firefighter would be able to get close enough to a cylinder to read the text on the cylinder neck, therefore in this analysis we disregarded text as an appropriate means of identification. Each cylinder whose body colour may be confused by dichromats was examined in order to determine if correct identification could be made by identifying non-colour clues such as the presence of a valve protecting shroud or cylinder shape. Figure 4 shows that gas cylinders may be identified by non-colour clues.

Colour confusion data, presented in Table 2, was used to identify potential cylinder confusions. Table 3 shows which confusions were considered in this analysis.

Dichromatic firefighters are unable to distinguish between cylinders containing propane (red) and methyl chloride (green), neither are they able to distinguish between argon (blue) and oxygen (black). Protanopes may also confuse acetylene (maroon) with oxygen (black). Although acetylene and oxygen cylinders are a different shape, the difference is not pronounced. Therefore, in some situations, their identity may be confused, e.g. if the cylinders have fallen over.

Despite the fact that cream (foam) and red (water) fire extinguishers have the same colour appearance to protanopes it is unlikely that they will be confused. This is because much more light is reflected from the cream extinguisher than the red one. In this example the cream extinguisher has a reflectance of 0.626 and the red one 0.144 therefore the cream colour appears relatively light while the red one appears relatively dark. Protanopes may also confuse green (halon) with cream (foam) fire extinguishers. However, the chance of such a confusion arising is again minimized by differences in reflectance (green 0.173 and cream 0.626).

Table 2 shows that dichromats are also unable to distinguish between the colours of various high pressure hoses from different manufacturers. Although correct assembly of this equipment is ensured by the use of special end connectors, which makes the colour coding in many instances redundant, correct operation
of some equipment relies upon recognition of hose colour e.g. hoses used with lift bags. These are frequently used in pairs to move heavy objects, such as vehicles, in a controlled manner so that trapped occupants may be rescued. Discussion with firefighters reveals that each bag is identified by naming the colour of the appropriate hose, i.e. a firefighter calls the colour name to a colleague who controls hose pressure.

Even after non-colour clues have been taken into consideration it appears that dichromats are still liable to confuse several colour coded objects.

Identification of colours that will be confused by anomalous trichromats

The final stage of the analysis was to determine if the superior colour discrimination of anomalous trichromats enables them to distinguish between the colour coded objects confused by dichromats. The colour of objects likely to be confused by dichromats were re-plotted on the CIE chromacity diagram and the distance between colours within isochromatic zones was compared with the separation of the colours used in the Farnsworth D15 test.

Individuals who pass the D15 test, and do not make confusions that cross the hue circle, are capable of differentiating many of the colours confused by dichromats (Table 2). In particular those passing the D15 test are unlikely to confuse the colours of portable fire extinguishers; the red stop road traffic signal with low pressure sodium street lighting; the colours of high pressure hoses supplied by Honda and Nike; the colours used on propane and methyl chloride cylinders and the colours of argon and oxygen gas cylinders. However, it is possible that mild anomalous trichromats who pass the D15 test, could still confuse the blue-green and black hoses supplied by Amkus. In addition, protanomalous individuals, who pass the D15 test, may also confuse oxygen and acetylene gas cylinders.

DISCUSSION

The three-stage analysis used in this investigation has been able to determine which objects are likely to be confused by people from each class of colour deficiency. Although both protanopes and deuteranopes make numerous colour confusions, the number of objects they are likely to confuse is reduced by the presence of non-colour clues such as shape, symbols and reflectance. Nevertheless, dichromats are likely to confuse traffic signal lights with low pressure sodium street lighting; several industrial gas cylinders; and various high pressure hoses. Any of these errors might endanger the individual firefighter, his colleague or members of the public. Consequently, we propose that dichromats are unsuitable for work in the fire service.

Anomalous trichromats who pass the Farnsworth D15 test make fewer colour confusions than dichromats. Hence many of the object confusions made by dichromats will not be made by anomalous trichromats. In addition, many of the objects that dichromats identify by non-colour clues appear to be of different colour to anomalous trichromats. This additional information may reduce the length of time it takes to correctly identify objects and possibly decrease the chance of incorrect identification. However, even with their relatively superior colour vision, deuteranomalous and protanomalous people who pass the D15 test may still be unable to distinguish between the blue-green and black hoses supplied by Amkus. More seriously, protanomalous individuals who pass the D15 test may confuse the maroon colour used on acetylene gas cylinders with the black used on oxygen ones. Unlike oxygen, which promotes combustion, acetylene is highly flammable and reacts explosively with a range of substances even without the presence of air. Although firefighters generally treat heated cylinders in a similar way, i.e. cool them with a jet of water from a distance, the potential effects of responding incorrectly to this cylinder could be catastrophic (Personal communication: G. Pearson, Fire Experimental Unit, Morton in Marsh, UK). An additional problem encountered by protanomalous people is that they are relatively insensitive to deep red light. Not only may this reduced sensitivity to red compound their difficulty in identifying the maroon acetylene cylinder but it will also reduce the length of time they have to react to red road traffic signals and car stop lights. In an investigation into road traffic accidents, Verriest et al. reported that protans have twice as many rear end collisions as normal subjects. We do not believe that protanomalous individuals who pass the D15 test are suitable for fire service work. However, deuteranomalous people who pass the D15 test should be allowed to work in the fire service despite the fact that they may confuse two of the hoses supplied by Amkus. We propose two reasons for this recommendation. Firstly, Amkus supply specialist equipment that relatively few brigades are likely to possess and secondly, it is unjustifiable that the inappropriate use of colour on one piece of equipment should prevent many individuals, approximately 2-3% of all potential recruits, from following their chosen career. We suggest that deuteranomalous people who pass the D15 test be allowed to work in the fire service and that the two Amkus hoses be withdrawn from service.

Suggested testing procedure

Recruits to the fire service should initially be tested with Ishihara plates. Individuals who pass this test have normal colour vision and are suitable for admission to the fire service without further colour vision testing. Individuals who fail the Ishihara plates should be tested with the D15 test to grade the severity of the defect. If they fail this test, by making one or more colour confusions that cross the hue circle, they have severe colour deficiency and are unsuitable for work in the
unsuitable for firefighting work. Such a standard would barred entry to the fire service. This standard does not prevent protanomalous people from becoming fire-fighters. Standards proposed by Sheedy3 are particularly inappropriate: he suggests that only dichromats are inappropriate: he suggests that only dichromats are protans should be excluded from the fire service. He suggests that this standard is appropriate because it ensures that firefighters can see various colour codes, the colour of flames and are able correctly identify road traffic signals.

Figure 5. Flow diagram showing recommended colour vision testing procedure

Although standards proposed by Sheedy and Glendill and Jamnik recognize that some colour deficient people are suitable for firefighting duties we do not agree with the standards they suggest. Neither of these investigations adequately assess the colour vision demands of the job. Glendill and Jamnik suggest that only those who fail the City University test should be barred entry to the fire service. This standard does not prevent protanomalous people from becoming firefighters. Standards proposed by Sheedy are particularly inappropriate: he suggests that only dichromats are unsuitable for firefighting work. Such a standard would allow people who are unable to distinguish the colours of basic colour codes to become firefighters.

ACKNOWLEDGEMENTS

This investigation is part of a larger study funded by the Home Office as part of their ongoing fire research programme. The authors would like to thank all those from the Fire Service College who provided advice and in particular Station Officer G. Pearson of the Home Office Fire Experimental Unit, Morton-in-Marsh for the supply of information. We would also like to thank Dr G. Scott of the Home Office Fire Research and Development Group for his assistance in the preparation of this paper.

REFERENCES

APPENDIX I: Specification of colours included in analysis

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description of colour</th>
<th>Co-ordinates, describing an area on the CIE chromacity diagram</th>
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<tbody>
<tr>
<td>Traffic signal lights</td>
<td>signal red B</td>
<td>0.670 0.320 0.680 0.320 0.700 0.300 0.690 0.300</td>
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<tr>
<td></td>
<td>signal yellow A</td>
<td>0.546 0.426 0.560 0.440 0.617 0.382 0.612 0.382</td>
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<td></td>
<td>signal green B</td>
<td>0.105 0.829 0.281 0.478 0.212 0.373 0.027 0.388</td>
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<td>Warning lamps</td>
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<td>0.543 0.457 0.543 0.428 0.618 0.382 0.612 0.382</td>
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<td>low pressure sodium discharge</td>
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<td>0.580 0.420</td>
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<tr>
<td>high pressure sodium discharge</td>
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<td>0.520 0.430</td>
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<tr>
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<th>Co-ordinates, describing an area on the CIE chromacity diagram</th>
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<tr>
<td>Safety signs</td>
<td>red</td>
<td>0.069 0.310 0.595 0.315 0.569 0.341 0.655 0.345</td>
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<tr>
<td>BS 5378: Part 2 &amp; BS 5499 Part I 'Firesafety signs'</td>
<td>yellow</td>
<td>0.519 0.480 0.468 0.442 0.427 0.483 0.465 0.534</td>
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<td></td>
<td>retro-yellow</td>
<td>0.545 0.454 0.487 0.423 0.427 0.483 0.465 0.535</td>
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<td></td>
<td>green</td>
<td>0.230 0.754 0.291 0.438 0.248 0.409 0.007 0.703</td>
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<td>0.007 0.703 0.248 0.409 0.177 0.362 0.026 0.399</td>
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<tr>
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<td>white</td>
<td>0.350 0.360 0.300 0.310 0.29 0.320 0.340 0.370</td>
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<td>0.350 0.360 0.300 0.310 0.285 0.325 0.335 0.375</td>
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<tr>
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<td>black</td>
<td>0.385 0.355 0.300 0.300 0.270 0.260 0.310 0.345 0.395</td>
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<td>fluorescent red</td>
<td>0.690 0.31 0.595 0.315 0.535 0.375 0.610 0.390</td>
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<th>Reference</th>
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<td>Fire alarms BS 5839: Part 2: 1983</td>
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<td>Portable fire extinguishers</td>
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<td></td>
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<td>Helium</td>
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<td>Nitrogen</td>
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