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Colour-vision safety on track

Safer and fairer colour vision testing at London Underground

Conventional colour assessment tests, such as Ishihara plates, have high sensitivity, but fail to quantify accurately the severity of colour vision loss and cannot be used to determine exactly who does, and does not, have the required level of colour vision for safety-critical work. New technology, originally developed for air traffic safety, has now been introduced by Transport for London to assess its underground train drivers. John Ballard reports.

FOR most jobs colour perception is not a key requirement, but for some it can be a matter of life and death. Correct interpretation of railway signals, electrical wiring and air traffic landing lights are safety-critical tasks where good colour perception is essential. But conventional colour vision screening is a somewhat blunt instrument to determine who is and is not fit to carry out such critical work. Until now it has discriminated unfairly against people with a colour vision deficiency but whose vision is not in fact so poor as to create a risk to safety. Thanks to technology developed by the Applied Vision Research Centre at City University London, fit-for-work decisions can now be reliable and fair. I visited Transport for London (TfL), where the technology has been introduced to screen the vision of its 3,500 train drivers.

CAD TESTING

Colour vision disorders are not uncommon, affecting around 8% of males and about 0.4% of females (see box on p.21), but not everyone with a colour deficiency has eyesight so poor that they cannot meet the safety standards required for colour-critical jobs. Anomalous trichromats – ie those with deuteranomaly and protanomaly – can detect colour across the spectrum, but do they have sufficient colour vision to perceive a colour difference, for example in traffic signals, particularly when the light intensity is low? Setting the bar too high would mean denying employment choice unfairly to many people with mild colour vision deficiency, whereas setting it too low could put rail or air passengers at risk.

Industries such as aviation and rail transport have previously used Ishihara plates as the primary test for colour vision, and a battery of secondary tests such as lanterns (Holmes-Wright, Spectrolux, Beyne or Farnsworth) or the Nagel anomaloscope (a colour matching test) for those who fail the Ishihara. None assesses the severity of colour vision loss and research at City University has highlighted considerable variation between the tests, including inconsistency in passing and failing the same individuals[2]. Even people with normal trichomatic vision can sometimes fail the standard tests (though, conversely, none of the tests have been found to pass individuals with severe colour deficiency)[1]. A reliable test that was both sensitive and specific was required.

Research over the past decade at the university, led by John Barbur, professor of optics and visual science, has perfected the Colour Assessment and Diagnosis test (CAD), which is based on knowledge drawn from studies on camouflage. Developed initially for the aviation industry, CAD is more sophisticated than its predecessors but simple and relatively quick to use in practice. It is claimed to be 100% specific and 100% sensitive in detecting and separating normal trichromats from subjects with congenital colour deficiency. The test also quantifies accurately the threshold for both red/green and blue/yellow colour vision.

The test requires the subject to observe a visual display screen on which is shown a 15 x 15 grid of flickering small grey squares of different and changing luminance and greyness. The grid provides dynamic background 'noise'. Superimposed on this large grid is a moving image comprising a square outline of 5 x 5 coloured checks, each small check having exactly the same dimension as the background squares. The colour-defined moving block, also flickers, but the hue remains within a particular colour range – roughly corresponding to, green, red, blue and yellow (see figure 1 on p.22) (see also http://goo.gl/Y34E5). The dynamic background noise masks luminance signals in the coloured stimulus, so that in the absence of colour vision the subject is totally unable to see the moving image.

The coloured block appears to enter the flickering screen and then leave by one of the four corners. The subject simply has to indicate on a hand-held remote control box whether the moving block leaves the screen on the top right, top left, bottom left or bottom right corner of the screen. Sometimes the block is so faint that even someone with normal colour vision cannot tell which way it has left the screen and subjects need reassuring that it is not intended that they answer 100% correctly. There are many hundreds of image traverses and the software measures how often the subject answers correctly and analyses the nature of any errors.

A demonstration movie clip, provided by City

Colour vision deficiency

Photoreceptors in the retina called cone cells are responsible for colour perception. There are three types of cones: those sensitive to long-wavelength light (L cones with a spectral sensitivity peaking in red region of the spectrum); those sensitive to medium wavelength light (M cones, peaking in the green part of the spectrum); and those sensitive to short wavelength light (S cones, peaking in the blue region). Human vision thus depends on three colour signals, termed trichromacy.

There are small differences between racial groups and genders; for example, around 8% of Caucasian men and 0.4% of women have impaired colour vision. There are many forms of colour vision deficiency, some due to a lack of cone cells receptive to certain frequencies, and others due to the cones having altered spectral sensitivity. The extent of colour vision deficiency varies from having almost no effect on daily life to 'total colour blindness' (monochromacy). A complete lack of colour vision is extremely rare.

The most common forms of colour vision deficiency are:

Deutan colour vision deficiency (6% of males and less than 0.4% of females)
- deuteranopia inability to see green hues owing to a complete lack of the cones receptive to medium wavelength light (1% of males)
- deuteranomaly or 'green weakness' due to defective cones receptive to medium wavelength light (5% of males)

Protan colour vision deficiency (present in 2% of males and 0.05% of females)
- protanopia – red/green colour deficiency due to a complete lack of long-wavelength cones (1% of males)
- protanomaly red/green deficiency with 'red weakness', or a shift towards seeing more green hues, owing to a deficiency in their long-wavelength cones (1% of males)

Tritan colour vision deficiency (rare in either sex)
- tritanopia or blue/yellow deficiency due to a lack or cones receptive to short-wavelength light (extremely rare)
- tritanomaly – deficiency in the cones receptive to short-wavelength light (rare)

People with deuteranomaly and protanomaly do have vision across the colour spectrum, but it is weaker in the green or red colour perception, and they thus confuse some red/green colours. These individuals are known as anomalous trichromats. Normal trichromats have vision across the three primary colours, but can also vary in their ability to discriminate red/green colour differences, and there is a 2.2-fold variation between the most and least sensitive subjects within this group.[1]

University, is posted on the At Work Partnership website and gives an idea of what the test looks like in practice[3].

During the initial research phase, the CAD test was performed by 330 normal trichromats and 250 individuals with colour vision deficiency. The normal trichromat population was used to define a 'normal CAD observer'[4] (figure 2 on p.22) and the severity of any red/green or blue/yellow vision loss quantified in terms of 'standard normal CAD units'. These standard units provide a simple description of the extent of colour deficiency – the threshold of red/green or blue/yellow colour vision being described as x number of standard normal CAD units from the normal trichromat vision.

Figures 3 and 4 (on p.22) show the test result from a normal trichromat and mild deutan, respectively.

The City University team used laboratory simulation of various safety-critical tasks to establish threshold levels below which an individual would not be able to perform the task with the same accuracy as a normal trichromat. These included perception of the precision approach path indicator (PAPI) lights to achieve the correct approach angle when landing an aircraft, and more recently track signalling lights on the London Underground.

CAD ON TRACK

London Underground has a standardised system of tunnel track lights for most of its lines. Its main automatic signals have green or red lights, telling the driver either to proceed (green) or stop/wait (red). Some signs also have yellow lights, which are 'repeater' signals giving advance warning of the signal ahead, such as a stop signal. Other tunnel signals are: white (junction route signals); and red and white shunt signals (used to ensure that the train proceeds safely where a train is already on the same stretch of track). There are some variations on the automatic train operation lines (Victoria and Central Lines) but red and green remain the key colours.

Subjects taking the CAD test are scored for their red/green and blue/yellow vision. If they score above the threshold levels required for the particular task then they

Figure 1: CAD screen shots corresponding to the red/green and blue/yellow axes

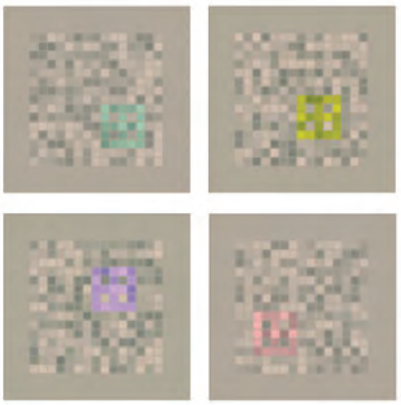


Figure 2: CAD thresholds

The centre ellipse shows the thresholds for the standard CAD observer. The arrows indicate displacement directions corresponding to pure red/green and blue/yellow stimulation.

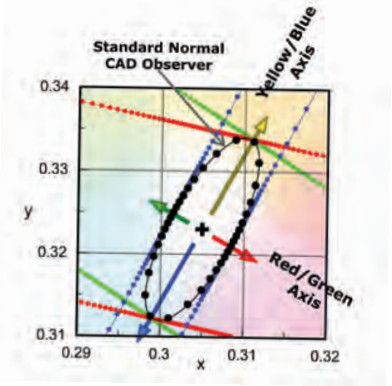


Figure 3: CAD results for a typical, normal trichromat

The grey region indicates the 2.5% and the 97.5% normal limits.

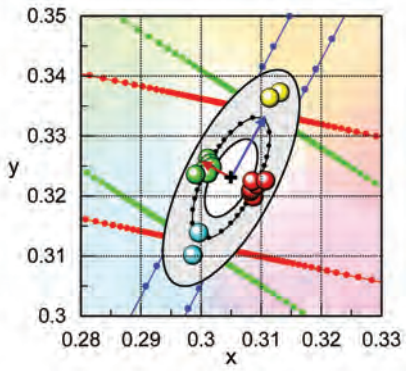
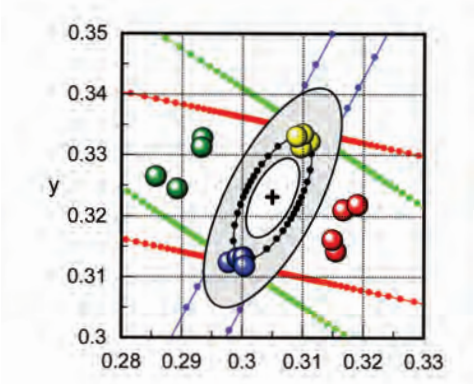


Figure 4: CAD results for a subject with mild, congenital deutan deficiency

The red/green thresholds are well outside the normal range.



All images: City University London.

are passed fit. The test itself is failsafe, as you cannot learn to use other cues to improve your performance.

The test in fact has two functions: first, to assess whether the individual can meet the safety-critical standard; and second, to assess colour vision deficiency changes that may be indicative of more serious problems, such as glaucoma, diabetes or early stage age-related macular degeneration.

At TfL, the safety critical part of the train drivers' assessment is only the red/green vision – for distinguishing between the red and green track signals. The blue/yellow test is not safety critical for train drivers – though it may be relevant for other safety-critical workers, such as trackside electricians – but is used to check eye health. In addition to its train drivers, all of London Underground's operational staff are tested for colour vision, and anyone requiring track safety certification must also be screened.

When I took the CAD assessment, at TfL's occupational health department in Westminster, the first step was to take a learning test to make sure I was familiar with the equipment. I then took a 'fast CAD' test (figure 5 on p.23), which is now given to current drivers every five years, or yearly after age 60, and then the full CAD (figure 6 on p.23), which is for all new recruits or where an existing employee needs follow-up testing.

The fast CAD takes just 40 seconds and simply gives a pass or fail rating for the red/green perception. The full CAD test lasts 14 minutes and gives a measurement of both red/green and blue/yellow colour perception. The test also classifies accurately the subject's class of colour vision as normal trichromacy, deutan- or protan-like deficiencies or acquired deficiency. TfL uses a higher red/green threshold than used by the Civil Aviation Authority (CAA) because the laboratory simulations showed that track signal safety could tolerate a slightly greater loss of colour vision than for the PAPI lights. The CAA sets the maximum threshold at six 'CAD units' of normal vision, whereas at TfL colour vision must be within seven units.

Because of the rapidity at which the screen images move across the screen it can be quite nerve-wracking

Figure 5: fast CAD test results at TfL

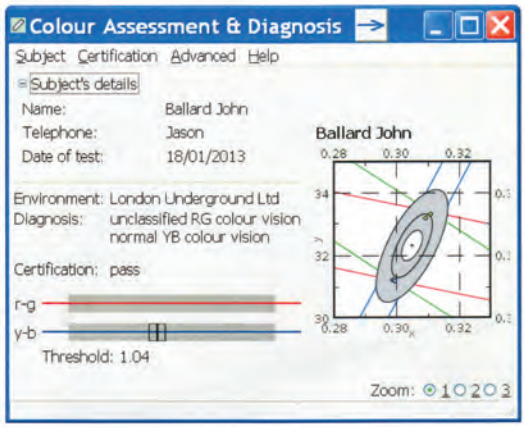
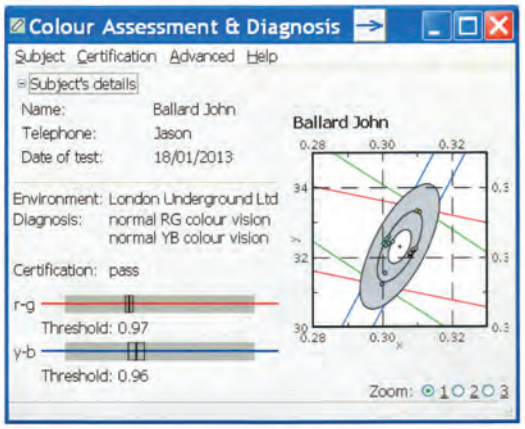


Figure 6: full CAD test results at TfL



and it is easy to imagine how stressful the test could be for an individual who knows that his/her job depends on passing the test. That said, the test is more accurate and fairer than previous tests and has been fully supported by trade unions at TfL.

The CAA has used CAD since September 2009 for those who failed the Ishihara plate test. It was introduced by TfL for its underground train drivers in September 2011. According to the CAA, the adoption of CAD means that 36% of people with deutan colour deficiency and 30% of those with protan deficiency would be classed as safe to fly[5]. Similarly, TfL says that around one-third of individuals who would previously have been screened out following their vision test can now be passed fit.

The start-up costs of the new equipment are in the region of £5,000. There are additional costs for staff training in the use of the technology and interpretation of the results but the tests can be carried out swiftly and there is much less need for specialist referral (and its associated costs).

CONCLUSIONS

- **Correct** interpretation of railway signals, electrical wiring and air traffic landing lights are safety-critical tasks where good colour perception is essential
- **Conventional** colour vision screening, using Ishihara plates, lanterns and anomaloscopes, may screen out individuals whose level of colour perception is not so impaired that they cannot carry out safety-critical visual tasks
- **The Colour** Assessment and Diagnosis test (CAD) test, developed at City University London from studies on camouflage, is 100% specific and 100% sensitive
- **Use** of CAD at London Underground has meant that up to a third of people who would previously have been prevented from working as a train driver are now passed fit

According to TfL occupational physician Dr Soodesh Reetoo, the department is 'already saving money' by using CAD compared to its previous vision-screening programme. But the benefits go beyond enhanced track and train safety. 'By its very nature, and the way we carry out the CAD test in the department, we are now in a position to pick up acquired colour vision defects as a result of subclinical retinal changes that lead to retinopathy before the clinical onset of local and/or systemic diseases, such as diabetes. This will have implications in early recognition and better health management of medical conditions for our staff,' says Reetoo.

With the advantages of improved accuracy and the avoidance of unfair discrimination, positive feedback from employees who have taken the test, and the potential to contribute to the future health of the workforce, CAD is proving to be an excellent investment. ■

John Ballard is editor of Occupational Health [at Work].

Notes

1 Barbur JL, Connolly DM. Effects of hypoxia on colour vision with emphasis on the mesopic range. Expert Review of Ophthalmology 2011; 6 (4): 409–420.

2 Squire TJ, Rodriguez-Carmona M et al. Color vision tests for aviation: comparison of the anomaloscope and three lantern types. Aviation, Space, and Environmental Medicine 2005; 76(5): 421–429.

3 CAD demonstration movie, http://goo.gl/Y34E5 (Movie file courtesy of City University London. For demonstration only.)

4 Barbur JL, Rodriguez-Carmona M, Harlow AJ. Establishing the statistical limits of 'normal' chromatic sensitivity. Proceedings of the ISCC/CIE Expert Symposium 2006: '75 Years of the CIE Standard Colorimetric Observer', 16–17 May 2006, Ottawa, Ontario, Canada.

5 Minimum colour vision requirements for professional flight crew: recommendations for new colour vision standards. CAA Paper 2009/04. London: The Stationery Office, 2009.