Institution: City University London

Unit of Assessment: 3 Allied Health Professions, Dentistry, Nursing and Pharmacy

Title of case study: Advanced Colour Vision Test for Healthcare and Occupational Environments

1. Summary of the impact

For most jobs colour perception is not a key requirement but for some it can be a matter of life and death. The correct interpretation of air traffic landing lights, railway signals and electrical wiring is a safety-critical task for which good colour perception is vital. Research into the use of luminance contrast and colour signals in human vision led to a new Colour Assessment and Diagnosis (CAD) test that has changed colour assessment practices within many occupational environments. Within aviation, 35% of applicants with congenital colour deficiency are now allowed to become pilots and many who previously failed have passed after re-examination. The UK Civil Aviation Authority (CAA), the National Air Traffic Services Control Centre (UK), the General Civil Aviation Authority (United Arab Emirates), the South African Civil Aviation Authority and others have implemented the CAD test as the only valid, final certification procedure in cases of congenital deficiency. Transport for London (TfL) now uses the technology to screen the vision of its 3,500 train drivers. Decisions regarding fitness for work based on colour vision in these occupations are now reliable and fair. The test also enables the early diagnosis of eye disease and is used in healthcare environments to identify the need for treatment at an early stage, improve patient outcomes, monitor progression of disease and monitor treatment effects in clinical use and drug trials.

2. Underpinning research

Colour vision studies carried out during the past 20 years at City University London have examined over 1,800 subjects. Algorithms have been developed to analyse the pattern of red/green (RG) and yellow/blue (YB) loss of chromatic sensitivity and to classify automatically the colour vision involved (normal trichromacy, deutan, protan, tritan or acquired deficiency). Genetic analysis of cone pigment genes in small subgroups of subjects with protan and deutan deficiency has yielded useful insights into the mechanisms of colour vision and the parameters that cause variability in chromatic sensitivity, both within normal trichromats and in congenital deficiency. The development of the CAD test was essential for this work in order to isolate the use of colour signals[1,2,4]. The results accurately quantify the severity of both RG and YB loss of chromatic sensitivity[3]. The test relies on discoveries from basic studies on camouflage carried out by Professor John Barbur and his team for the Royal Signals and Radar Establishment. Background perturbation techniques were developed to discover how background features that could be either static or dynamic and defined by either luminance or chromatic contrast affected the threshold detection of test targets (that were again either static or dynamic and could be defined by either luminance or chromatic contrast). The key team members who undertook the research are Professor J. Barbur (at City since 1980), Dr Marisa Rodriguez-Carmona (PhD student, Research Assistant/Fellow since 2005), Alister Harlow (member of research staff, at City since 1990) and Dr Janet Wolf (member of academic staff, at City 1971–2007). Some of the work was done in collaboration with Dr G. Plant, a clinician at University College London; other team members were all City staff or PhD students.

Many combinations of parameters were investigated, with two principal findings:
1. Thresholds for the detection of moving targets defined by luminance contrast were not affected by the presence of static luminance or colour contrast noise.
2. Dynamic luminance contrast noise, on the other hand, caused a monotonic increase in luminance contrast thresholds, making it impossible to detect luminance contrast-defined moving targets, but had no effect on moving, colour-defined stimuli.

This discovery and clear demonstration of the independent processing of dynamic luminance contrast and colour provided the means to isolate fully the use of colour signals[4,6] and to develop and optimise the CAD test to achieve high sensitivity and specificity. Results obtained in 330 normal trichromats show that, when using the CAD test, the median human eye requires only 0.4% and 0.8% contrast change in long- and middle-wavelength sensitive cones, respectively. This reflects the extremely high sensitivity of the CAD test, and the data also provide the statistical limits

that define normal trichromacy[5]. Recent research has produced age-corrected CAD limits for 'normal' colour vision (from 6 to 90 years of age). Normal ageing changes can now be accounted for, increasing the specificity of the test by separating changes caused by normal ageing from those caused by disease[6]. The CAD test also detects and quantifies acquired loss of chromatic sensitivity in clinically normal subjects before the first signs of retinopathy, as recently demonstrated in a study of age-related macular degeneration (ARMD)[6]. In the absence of retinopathy, 72% of patients with diabetes (Moorfields Dubai Eye Hospital) reveal abnormal, age-corrected colour thresholds. These findings have generated wider scope for use of the system in the medical field.

3. References to the research

1. Barbur J. L., Harlow A. J., & Plant G. T. (1994). Insights into the different exploits of colour in the visual cortex *Proc. R. Soc. Lond. B.,* 258, 327-334 10.1098/rspb.1994.0181

2. Barbur J. L., Wolf J., & Lennie P. (1998). Visual processing levels revealed by response latencies to changes in different visual attributes *Proc. R. Soc. Lond. B. Biol. Sci.,* 265, 2321-2325. 10.1098/rspb.1998.0578

3. Rodriguez-Carmona M., O'Neill-Biba M., & Barbur J. L. (2012). Assessing the severity of color vision loss with implications for aviation and other occupational environments *Aviat. Space Environ. Med.,* 83, 19-29 10.3357/ASEM.3111.2012

4. Barbur J. L. (2004). 'Double-blindsight' revealed through the processing of color and luminance contrast defined motion signals *Prog. Brain Res.,* 144, 243-259 10.1016/S0079-6123(03)14417-2

5. Barbur J. L. & Connolly D. M. (2011). Effects of hypoxia on colour vision with emphasis on the mesopic range *Expert Rev. Ophthalmol.,* 6, 409-420 10.1586/eop.11.32

6. O'Neill-Biba M., Sivaprasad S., Rodriguez-Carmona M., Wolf J. E. & Barbur J. L. (2010). Loss of chromatic sensitivity in AMD and diabetes: a comparative study. *Ophthalmic Physiol. Opt.,* 30, 705-716 10.1111/j.1475-1313.2010.00775.x

The selected publications all appear in journals recognised as top in their field, either for fundamental research or in relevant professional areas. The work has been supported by research funding totalling approximately £1.5M with funders including the Ministry of Defence, CAA (three separate awards), Department for Transport, Federal Aviation Administration (USA), TfL and Colt Foundation.

4. Details of the impact

Colour vision disorders affect around 8% of males and 0.4% of females, but some individuals with a colour deficiency are able to meet the safety standards required for colour-critical jobs. In separating R/G and Y/B colour mechanisms, the CAD test accurately quantifies the severity of colour vision loss. Unlike other tests in use for occupational screening, subjects cannot use other cues to improve their performance. The application and usefulness of the test in occupational environments and in healthcare was therefore recognised. Funding was secured from the Colt Foundation (a charity that promotes and encourages research into social, medical and environmental problems) and other bodies (see section 3 above) to establish pass/fail limits for pilots, air traffic controllers and TfL train drivers.

In 2009 City established a spin-out company, City Occupational Ltd., to develop, manufacture and distribute the CAD system and other advanced vision and optometric tests for use in research, primary healthcare and demanding occupational environments. City Occupational Ltd licensed the Intellectual Property (including a patent application: WO 2008/155544). The company has sold CAD systems to a wide range of customers across the globe[1].

The CAA has used CAD since September 2009 for pilots who fail the standard Ishihara plate colour vision test[2]. According to the CAA, the adoption of CAD means that 36% of people with

deutan colour deficiency and 30% of those with protan deficiency are classed as safe to fly. The US Federal Aviation Administration uses the CAD test in each of its regional centres, and the General Civil Aviation Authority (United Arab Emirates) has adopted CAD as the only accepted test for pilots and air traffic controllers. Other air transport users include Cathay Pacific, the Italian Air Force, Lufthansa, the UK National Air Traffic Control Centre, the Norwegian Aviation Authority, the UK Royal Air Force, the Republic of Singapore Air Force and the South African Civil Aviation Authority. In South Africa the test also allows evaluation of optic nerve toxicity induced by ethambutol and other drugs used to treat AIDS and tuberculosis. The United States Air Force and Navy and many hospital departments worldwide also use the CAD test.

The impact on the aviation industry has been recognised through two unsolicited awards:

- The Arnold D Tuttle Award 2009 (awarded by the US Aerospace Medical Association for original research that has made the most significant contribution towards the solution of a challenging problem in aerospace medicine; published in *Aviation, Space and Environmental Medicine*) for application of the test in relation to hypoxia.
- The Scientific Award (Albrecht Ludwig Berblinger Prize, 2011) of the German Academy for Aviation and Travel Medicine (shared award for the best scientific contribution internationally).

TfL funded further work to establish safe colour discrimination limits in its working environment and introduced CAD for its underground train drivers in September 2011. R/G vision screening is required as safety-critical for this group of workers, but all operational staff are tested for colour vision and anyone requiring track safety certification must also be screened. The CAD test also detects and quantifies acquired loss of colour vision that is indicative of more serious problems, such as early stage glaucoma, diabetes or ARMD. TfL runs the R/G and Y/B tests to check the eye health of all its staff. According to TfL occupational physician Dr S. Reetoo, the use of CAD saves money in comparison to the previously used vision-screening programme. 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.'[3]

In October 2012 the CAA determined that it would extend the CAD approach, with Colt Foundation funding, to establish appropriate pass/fail standards for air traffic controllers in the UK. European regulations for air traffic controllers stipulate completely normal colour vision, which discriminates against applicants with colour deficiency who can carry out the colour-related tasks to the same standard as normal trichromats. The project supported by the Colt Foundation and CAA will address this through a revised definition of the pass/fail limits[2]. The International Maritime Organisation (IMO), which sets maritime safety standards, is proposing to change its standards based on the CAD system and to use the recently developed Acuity-Plus test with seafarers in low-level, mesopic lighting. The IMO, with the UK Maritime and Coastguard Agency and the Faculty of Maritime Sciences of Kobe University (Japan), is organising the first international symposium to focus entirely on vision standards for seafarers, which will take place in January 2014.

The City team has worked with several organisations to establish occupational screening standards for the degree of colour vision required to meet safety needs within the specific environment. One example is the UK Fire Service: all firefighters who undertake vision screening at City University also undertake the CAD test.

The system is employed by military medical services to assess how colour vision and functional contrast sensitivity are affected under hypoxic conditions. Users include the USA Aeromedical Research Laboratories and Federal Aviation Administration William J Hughes Technical Center, the Belgian and Swedish Armies and the Home Office.

Use of the CAD test is growing in healthcare in response to press coverage (particularly for the work with pilots, reported in June 2009 by for example BBC Online, the *Telegraph* and the *Independent*[4]) and dissemination through numerous invited lectures by Professor Barbur and Dr M. Rodriguez-

Carmona at national and international meetings on aerospace medicine and for occupational medical societies. Examples of the latter include the International Congress of Aviation and Space Medicine, the UK Society of Occupational Medicine and events in the USA, Spain, Norway, Netherlands, Germany and the UK.

Congenital Y/B deficiency is very rare (about 1 in 15,000 people), but the prevalence of acquired Y/B sensitivity is much higher and increases with age. This is often associated with systemic and/or eye disease. In ARMD and diabetes, the City research showed that loss of chromatic sensitivity can precede the clinical detection of retinopathy by several years. Very early detection of subclinical retinal changes that lead to retinopathy enables the use of treatment regimens to slow down the rate of progress of ARMD. The CAD test detects significant changes in the patient's chromatic sensitivity over time and can therefore be used to identify the need for treatment at an early stage, to monitor progression of the disease and to monitor treatment effects in clinical use and drug trials, thus improving patient outcomes. The test is used for the early diagnosis of eye disease in hospital eye clinics in Amsterdam, Antwerp, London, Cambridge, Leipzig, Maastricht and Sydney, at Moorfields (Dubai) and at the Mends Specialist Hospital and Aviation Medical Centre in Nigeria. It is also used to assess changes in colour vision in stem cell research trials at Moorfields Eye Hospital.

This research has had a wide-reaching impact in the domains of public services, healthcare practice and more generally health and welfare in wider society. Within aviation, 35% of applicants with congenital colour deficiency are now eligible to become pilots and many who previously failed now pass after re-examination. A similar percentage change has been achieved for TfL train drivers. Decisions regarding fitness for work in these occupations have become more reliable and fairer. Use of the CAD test means it is no longer possible to pass the assessment process for colour vision by using other cues, improving passenger safety. Other groups are benefiting through the use of the CAD test in the early detection of eye disease. In healthcare, practices have been improved and patients are benefiting both directly from early diagnosis and indirectly through improvements to treatment arising from drug and other trials.

5. Sources to corroborate the impact

1. www.city-occupational.co.uk/. Information on customers/sales can be provided on request to corroborate current users of CAD and Acuity-Plus tests.
2. www.caa.co.uk/default.aspx?catid=2499&pagetype=90&pageid=13879 (aircrew); www.caa.co.uk/default.aspx?catid=2499&pagetype=90&pageid=13879 (air traffic controllers).
3. Ballard, J. (2013). Colour-vision safety on track: safer and fairer colour vision testing at London Underground. *Occupational Health at Work*, *10*(1): 20–23. With thanks for permission to use extracts from the article in the case study.
4. http://news.bbc.co.uk/1/hi/uk/8103302.stm; www.independent.co.uk/news/science/colourblind-you-can-still-become-a-pilot-1707902.html.
5. Corroborating statements can be provided by:
    - Chief Medical Officer and Chief Optometrist, CAA
    - Chief, Aviation Medicine Section, International Civil Aviation Organization, Montreal
    - Chief Medical Officer, United Arab Emirates Airlines
    - Head of Occupational Health, TfL/London Underground.