ESTABLISHING THE STATISTICAL LIMITS OF "NORMAL" CHROMATIC SENSITIVITY

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ABSTRACT

Measurement of colour discrimination loss is particularly important in demanding visual tasks where colour is used to enhance visual performance.

Ideally, colour vision assessment requires a test that (I). provides true isolation of colour signals, (II). is based on data that describe the statistical limits of colour discrimination in "*norma*l" trichromats, (III). has enough sensitivity to detect "minimal" deficiencies and to classify them, and (IV). can be used to detect and monitor "significant changes" in colour sensitivity.

We describe a new Colour Assessment and Diagnosis (CAD) test that exploits the CIE-(x,y) 1931 system and extends the work of MacAdam(6) using spatiotemporal luminance contrast masking techniques(4; 5). The CAD test has been optimised to fulfil the requirements stated above.

Keywords: colour vision, noise masking, chromatic sensitivity, colour deficiency

1. INTRODUCTION

Novel methods developed to assess chromatic sensitivity often yield statistically significant, inter-subject differences that can, in principle, be attributed to either congenital or acquired colour deficiencies(1; 2). The high sensitivity of such techniques can be used to monitor changes in colour vision in the same subject, a clear benefit when monitoring the progress of disease or the effects of treatment. The advantage of improved test sensitivity is however less useful in detecting minimal colour vision deficiencies, largely because of the large variance within the "normal" population and the lack of test-specific, statistical data to describe the parameters of the normal population. The variation in chromatic sensitivity in normal trichromats can be very large(8). In addition to small differences in the wavelength tuning of photopigment genes, other factors such as differences in the optical density of cone photoreceptors or / and variation in post-receptoral amplification of cone signals can also cause significant changes in chromatic sensitivity(3). Colour vision is currently assessed using a wide range of tests. In the absence of an internationally recognized standard procedure for examination of colour vision, clinical assessment relies on the use of a battery of tests that can often produce inconsistent results for a number of different reasons. The principal aim of this study was to extend the usefulness of the CAD test(7) by assessing the variability in red-green (r-g) and yellow-blue (y-b) chromatic discrimination sensitivity within normal trichromats and colour deficient observers.

2. METHODS

The CAD was implemented on a stable CRT display and employs direction-specific, colour-defined, moving stimuli that are buried in a background of random, dynamic, luminance contrast (LC) noise. The subject's task is to press an appropriate button, following each stimulus presentation, to indicate the direction of motion of the colour-defined stimulus. An efficient, four-alternative, forced-choice procedure is used to measure the subject's chromatic displacement thresholds in a number of carefully selected directions in the CIE – (x,y) chromaticity chart. This technique isolates the use of colour signals(7) by masking the detection of any LC signals that may be present in a colour stimulus (designed to be isoluminant for the CIE-1931 standard observer). When colour signals are not available, the stimulus conditions ensure that the subject remains completely unaware of the moving stimulus.

Thresholds are measured along 16 interleaved directions in colour space. These

are grouped together so as to test red-green and the yellow-blue colour sensitivity. The distribution of these points indicates any selective loss of chromatic sensitivity and provides enough information to classify even minimal deficiencies. Threshold ellipses are computed and plotted using the standard CIE 1931 chromaticity chart. Chromatic discrimination sensitivity has been measured in 488 subjects (including 238 normal trichromats and 250 colour vision deficient observers). The criteria for normal trichromacy were based on the need to pass all the principal occupational tests of colour vision, including the Nagel anomaloscope.

3. RESULTS

The colour vision of 238 normal trichromats and 250 colour deficient observers has been studied using the CAD test and a battery of conventional colour vision tests.
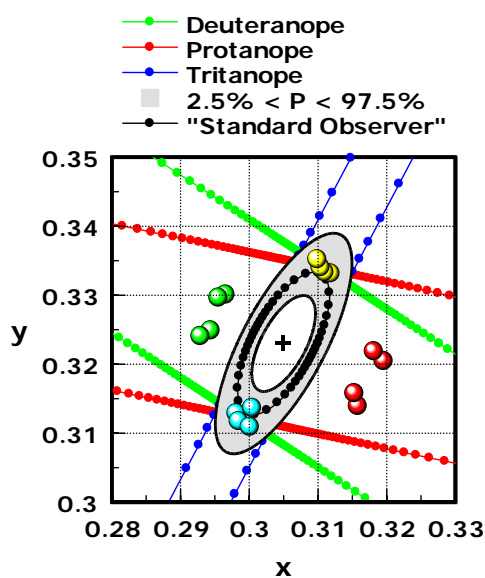

Fig. 1. The coloured discs show typical CAD test results for a subject with minimum deuteranomaly that passes the Ishihara test. The results are plotted in the CIE –(x,y) 1931 chromaticity chart. The black cross at the centre of the diagram plots the chromaticity of the white background i.e., 0.305, 0.323. The dotted black ellipse represents the median values computed from the distribution of r-g and y-b thresholds in 238 normal trichromats. The corresponding 2.5% and the 97.5% statistical limits were used to plot the innermost and outermost ellipses. Thresholds that fall within the grey region are taken to reflect "normal" chromatic discrimination sensitivity. The red, green and blue lines denote "colour confusion

bands" based on data measured in protanopes, deuteranopes and tritanopes. The distribution of the eight data points in the r-g direction changes significantly in minimal protanomaly and this makes it possible to classify accurately the class of deficiency involved.
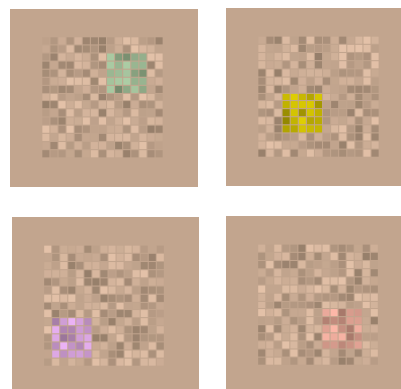

Fig. 2. The inserts show the appearance of the moving colored stimulus during the test. The subject's task is to press one of four buttons placed at the corners of a square box to indicate the direction of motion of the colored stimulus. The CAD test employs four-alternative, interleaved staircases with a chance probability of 1/16. The subject's task is to discriminate the direction of motion of a colour-defined stimulus buried in dynamic LC noise, a technique that isolates the use of colour signals(5)
http://www.city.ac.uk/avrc/colourtest.html

Analysis of the CAD data provided the statistical limits needed to describe the average 'normal' CAD observer. Ellipses that describe the median and the 2.5% and 97% limits for the group of normal trichromats are shown in Fig. 1. The data for the normal population were used to produce a template that allows immediate classification of normal and deficient colour vision (see Fig. 1). 250 colour deficient observers were also examined in order to assess the usefulness of the new template. The median values for r-g and y-b discrimination thresholds measured in normal trichromats can be used to express all data in "*standard normal*" CAD units. The data for the 238 normal trichromats and the 250 colour deficient observers (plotted in CAD units) are shown in Fig. 3. Sections B &C show the usefulness of the CAD test in separating unambiguously the subjects with minimal deficiency from the cluster of normal trichromats.
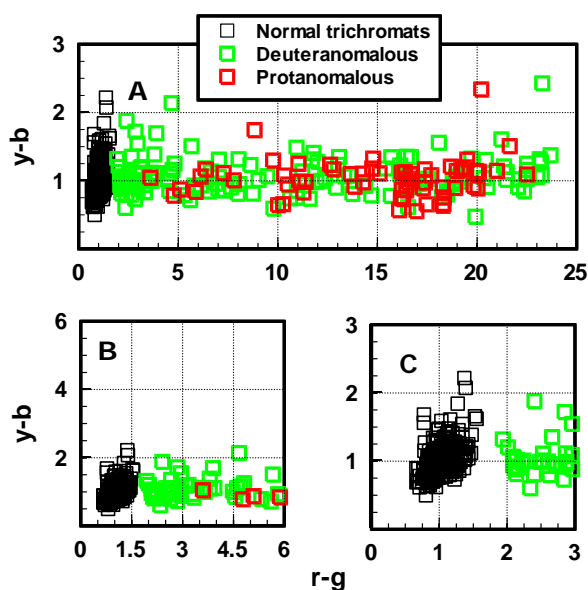
Fig. 3. **The graph (section A) shows y-b thresholds plotted against the corresponding r-g thresholds in 238 normal trichromats (black symbols) and 250 colour deficient observers (green and red symbols). The results are expressed in CAD units (i.e., median threshold values computed from measurements taken in 238 normal trichromats). The distribution of r-g thresholds is shown expanded in the range 0 to 6 units (section B) and 0 to 3 units (section C) to illustrate the clear separation between the cluster of points that define the "normal trichromats" and subjects with minimal deuteranomaly.**

Congenital colour deficient subjects were classified into different types of colour deficiency and severity graded according to their chromatic sensitivity loss expressed in CAD units. Data from deutan and protan subjects form distinct patterns that can be used to classify even minimal congenital deficiencies. The "minimal" deuteranomalous trichromats shown in Figure 3 often pass all the conventional tests with the exception of the Nagel anomaloscope. Any measured data point that lies outside the grey shaded area in Fig. 1 indicate possible abnormal colour vision.

The two most important parameters that affect chromatic sensitivity are the size of the stimulus and the luminance of background field. In order to establish how CAD thresholds vary with these two

parameters we carried out a number of tests that involved systematic changes in stimulus size and background luminance. The experiments required the use of spectrally calibrated neutral density filters in order to achieve very low background luminance levels with stable display operation.

Fig. 4 shows the effect background luminance on r-g and y-b thresholds. Fig. 5 shows similar results, but for a range of stimulus sizes.
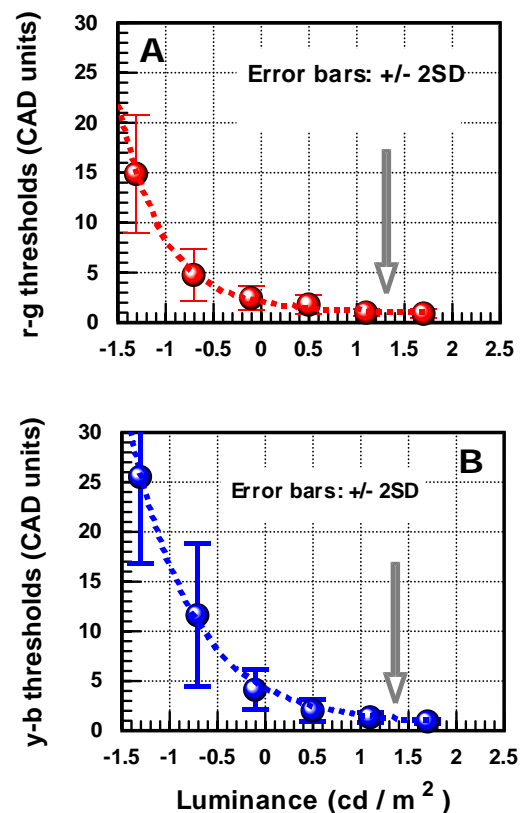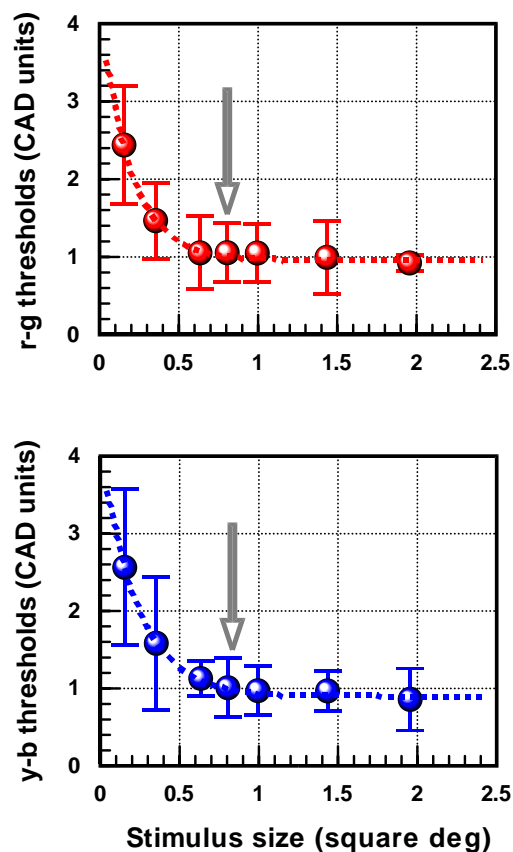

Fig. 4. Single subject thresholds for r-g (section A) and y-b (section B) colour discrimination measured for background luminances in the range 51 to 0.01cd m^{-2}. The thresholds are expressed in CAD units (i.e., median thresholds measured for 238 normal trichromats). The arrows indicate the background luminance normally employed in the CAD test (i.e., 24 cd m^{-2}).

Although both r-g and y-b thresholds increase rapidly with decreasing background luminance, yellow-blue discrimination is significantly more affected at lower luminance levels. When expressed in standard normal CAD units, stimulus size

appears to affect both r-g and y-b thresholds in a very similar way (Fig. 5). As the stimulus size is increased from 0.16 to 1.96 square degrees, a 2.5 fold increase is observed in both r-g and y-b thresholds. The stimulus size and background luminance employed in the CAD test have been selected to correspond to the asymptoted region of these response curves. An increase in either background luminance or stimulus size is not therefore likely to cause significant

recognized colour system. When expressed in standard normal units the results are easy to understand and provide an immediate indication of the severity of colour vision loss.

The test has proved particularly useful in assessing changes in chromatic sensitivity in subjects with diseases of the retina and the optic nerve and in specifying minimum colour vision requirements in occupational environments. The studies carried out so far suggest that the new test and the establishment of the standard normal CAD observer provide an accurate means of detecting and classifying deficiency, of assessing the severity of r-g and y-b colour vision loss (whether congenital or acquired) and of monitoring small changes in colour vision either in disease or treatment.

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Fig. 5. Single subject thresholds for r-g (section A) and y-b (section B) colour discrimination measured for as a function of stimulus size in the range 0.16 to 1.96 square degrees. The arrows indicate the stimulus size normally employed in the CAD test (i.e., 0.8 square degrees).

3. DISCUSSION & CONCLUSIONS

The CAD test detects minimum deficiencies and quantifies the severity of colour vision loss by evaluating both r-g and y-b thresholds in an internationally

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