The Variability of Normal Trichromatic Vision and the Establishment of the "Normal" Range

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ABSTRACT

A new Colour Assessment and Diagnosis (CAD) test has been developed and optimised to measure small changes in chromatic sensitivity. In addition the test quantifies the severity of red-green and yellow-blue loss and classifies accurately even minimal congenital deficiencies. The technique employed makes use of dynamic luminance contrast (LC) noise to mask the detection of any residual LC signals in the test stimulus. The LC noise provides effective masking of LC signals without affecting the thresholds for detection of colour signals (Proc.R.Soc.Lond. B Biol.Sci. 258: 327-334, 1994). Chromatic discrimination thresholds are plotted in the CIE-(x,y) 1931 colour system. 125 normal trichromats have been tested in order to validate the CAD test and to derive a template that describes the range of normal colour discrimination sensitivity.

1. INTRODUCTION

It is well established that the severity of colour vision loss varies significantly amongst colour deficient observers[1,2]. The variation in chromatic sensitivity (CS) in normal trichromats is less well documented and can be attributed to a number of different factors. Humans with normal trichromatic colour vision possess three distinct classes of cone photoreceptors in the eye. These contain short (S), middle (M) and long (L)-wave sensitive photopigments with peak absorption wavelengths at ~420, ~530 and ~560 nm, respectively. Small genetic mutations or expression in L and / or M cone genes can cause large changes in CS. Other factors that may or may not be genetically related such as changes in the optical density of cone photoreceptors or / and variation in post-receptoral amplification of cone signals can also cause significant changes in CS[3]**.** These factors can account for much of the observed variability both within "normal" trichromats and amongst colour deficient observers[4].

A wide range of colour vision tests is available to assess different aspects of colour vision. There is no international consensus on a standard procedure for examination of colour vision and clinical assessment often relies on the use of a battery of tests[5] that often produce inconsistent results[6]. The aim of this study is to validate the new Colour Assessment and Diagnosis (CAD) test based on assessment of variability within normal trichromats. A number of colour deficient observers have also been examined in order to assess the sensitivity and specificity of the CAD test.

2. METHOD

The CAD test employs direction-specific, moving, chromatic stimuli embedded in a background of random, dynamic, luminance contrast (LC) noise. The subject's task is to report the direction of motion of the colour-defined stimulus. An efficient, four-alternative, forced-choice procedure is used to measure 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[7,8] and ensures that the subject cannot make use of any residual LC signals. The effectiveness of the dynamic, spatiotemporal LC noise in masking the detection of LC signals in the test stimulus is shown in Figure 1. As the LC noise amplitude is increased, the colour detection thresholds for the deuteranopic observer increase and finally hit the limits set by the phosphors of the display and the isoluminant constraint. 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 CS 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 225 subjects including 125 normal and 200 colour vision deficient observers. The criteria for normal trichromacy was the need to pass all the principal occupational tests of colour vision, including the Nagel anomaloscope. The age distribution of the subjects was 32.6 ± 11.8 years.

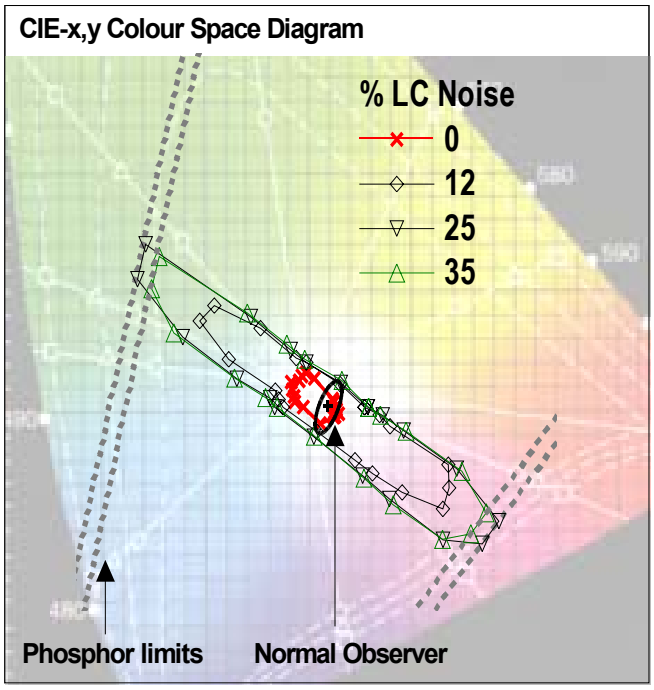

Figure 1: Chromatic threshold contours for a deuteranopic observer are shown superimposed and enlarged on the CIE-x,y chromaticity chart. The "ellipse" for the average normal trichromat is shown as a black contour. In the absence of luminance contrast noise (red symbols), the subject's thresholds for yellow-blue discrimination are actually smaller than those measured in a typical normal trichromat. His red-green thresholds (particularly towards the green region of the spectrum locus) are increased. The deuteranope can make use of residual luminance contrast signals to detect the test stimulus, more so than a normal trichromat since the test stimulus is "isoluminant" for the standard CIE normal observer. As the LC noise is increased, the deuteranope is no longer able to make use of residual luminance contrast signals and his thresholds increase systematically with LC noise. The largest chromatic displacements away from background chromaticity are set by the isoluminant condition and the limits imposed by the phosphors of the display.

3. RESULTS

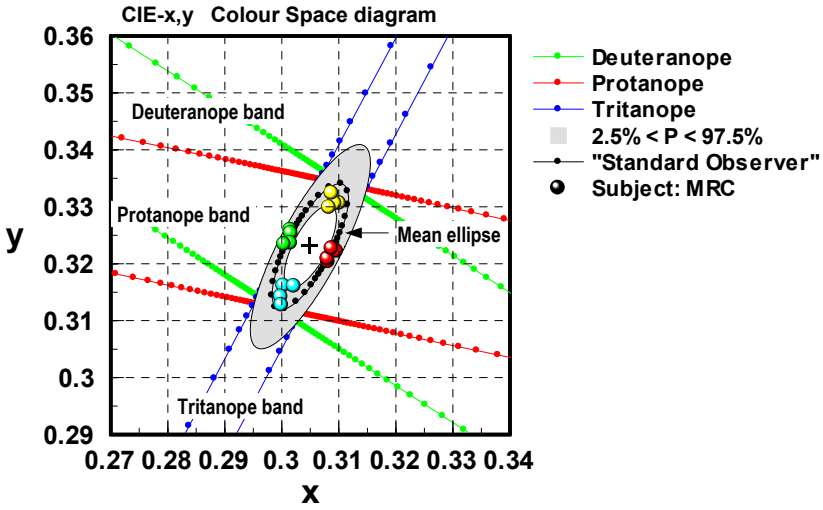

Figure 2: Preliminary data showing the statistical limits that define the "standard" normal CAD test observer. The dotted, black ellipse is based on the mean red-green and yellow-blue thresholds measured in 125 observers. The grey shaded area shows the 97.5 and 2.5 % limits of variability within these observers. The deuteranopic, protanopic and tritanopic confusion bands are displayed in green, red and blue respectively. The coloured symbols show data measured for a typical normal trichromat.

The colour vision of 125 normal trichromats and 200 colour deficient observers has been studied using the CAD test and a battery of conventional colour vision tests including the Nagel Anomaloscope. CS thresholds measured in normal trichromats are used to describe the average 'normal' observer. By computing the 2.5% and the 97.5% limits of the distribution of red-green and blue-yellow thresholds in normal trichromats a template that describes the 'normal CAD observer' has been produced, as shown by the shaded grey area in Figure 2.

Congenital colour deficient subjects were classified into different types of colour deficiency and severity graded according to the value of CS loss. 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 passed all the conventional tests with the exception of the Nagel anomaloscope. Any measured data point that lies outside the grey shaded area indicates possible abnormal colour vision.

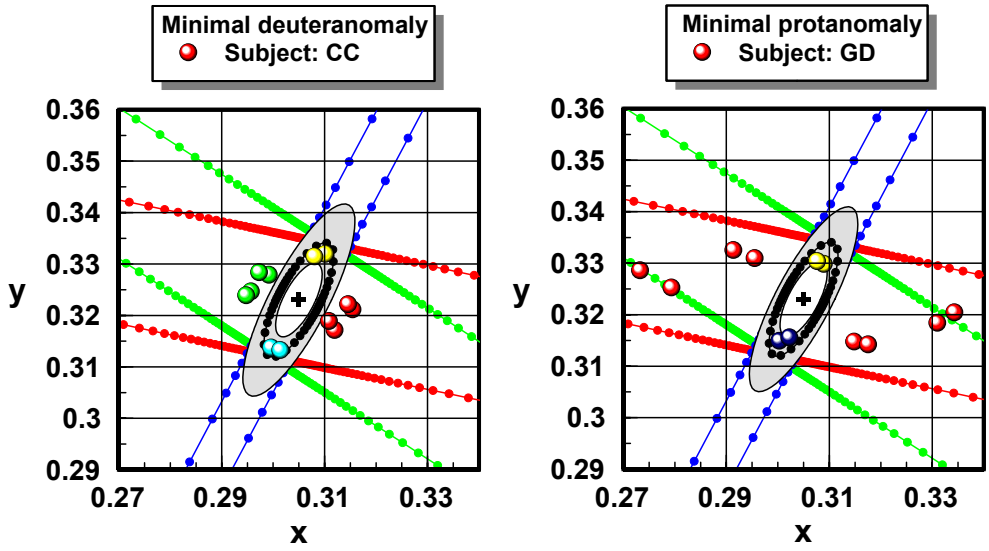

Figure 3: Examples of CAD data for subjects with minimal anomalous trichromatism. Subject CC exhibits minimal deuteranomally whilst subject GD minimal protanomally.

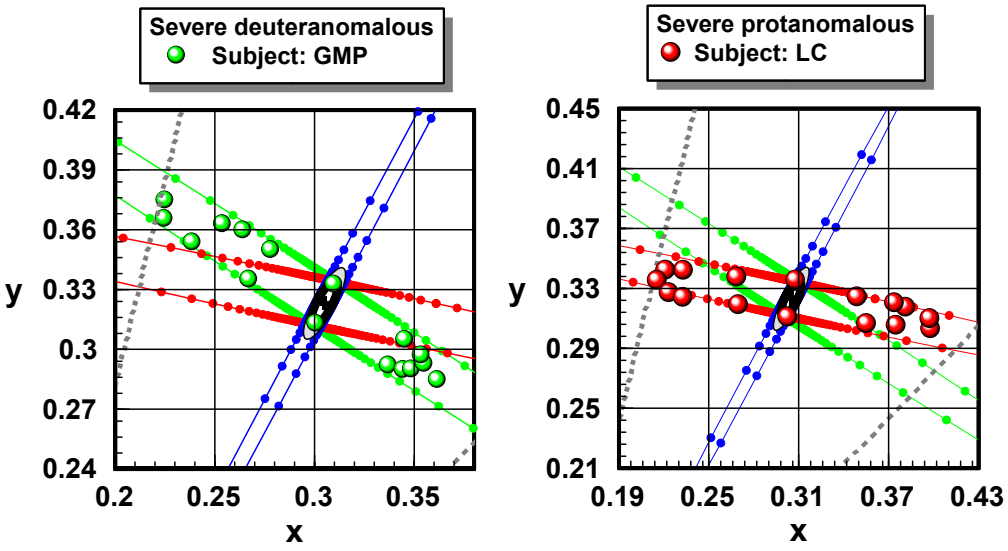

Figure 4: Examples of CAD data for two subjects with severe anomalous trichromatism. Subject GMP exhibits severe deuteranomally whilst subject LC severe protanomally.

The CAD results obtained so far show excellent agreement (i.e., 0.97) with the Nagel anomaloscope. One indicates perfect agreement and zero indicates that agreement is at chance level. The specificity of the CAD test compared to the Nagel is 98%, i.e. the number of normal trichromats correctly identified as normal on the CAD and the Nagel tests. There is no 100% agreement due to the ability of the CAD test to evaluate along the yellow-blue direction. If the analysis is restricted to abnormal colour vision, the sensitivity of the CAD test is 100% i.e., all subjects that failed the Nagel anomaloscope also failed the CAD test. The strength of the CAD test is that it detects acquired deficiencies and also quantifies the severity of red-green and yellow-blue loss.

4. CONCLUSIONS

The results obtained so far suggest that the new CAD test and in particular the specification of the standard 'normal CAD observer' provides an efficient means of detecting and classifying even minimal deficiencies, that often go undetected in conventional tests. The CAD test quantifies the severity of colour vision loss by evaluating red-green and yellow-blue colour detection thresholds using an internationally recognised colour system. The results indicate an excellent screening efficiency when compared to the Nagel anomaloscope.

Colour vision, in particular CS, is a very good indicator of the normal functioning of the retina. CS is affected most and earliest in a number of diseases of the retina and the optic nerve. The CAD test can therefore be used to monitor significant changes in both red-green and yellow-blue sensitivity due to progress of disease or the outcome of treatment.

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