COLOUR CONTRAST DETECTION IN CHROMATICITY DIAGRAM: A NEW COMPUTERIZED COLOUR VISION TEST

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ABSTRACT

Colour discrimination is one of the most important means for object detection and recognition. Acquired or congenital colour blindness may become a major cause of troubles in everyday life tasks. Digital technologies already offer some methods to overcome this impairment. However, to be efficient, these methods have to be based on a careful matching with each user's colour vision. Although the traditional Ishihara and Farnsworth tests are relatively easy to use, computerized tests seem to simplify administration and recording of colour vision tests. This work presents a new computerized colour vision test, aiming to give access to subject's detection thresholds for colour in the whole gamut of a given display device, and the preliminary works for its validation. Subjects with normal colour vision and subjects with congenital anomalous trichromacy underwent this test, and first results indicate a fairly good sensibility.

Index Terms— Colour blindness, colour contrast colour vision test

1. INTRODUCTION

In a world where digital images are becoming a substantial part of our environment, persons with colour vision deficiencies are prone to some extent to encounter difficulties in their everyday life or professional activities. Colour discrimination appears as an essential cue for object detection and recognition.

Colour vision tests such as Ishihara plates or Farnsworth D 15 Hue tests are usually performed by eye care practitioners during classical orthoptic assessment [1]. They may be sometimes administered in order to determine ability to carry out a specific occupational task. These tests have been widely studied for a long time and their reliability, reproducibility and accuracy have been proved. But for the majority of them, no quantitative data about the perception of colour contrasts are available.

This study describes a new test to give access to precise knowledge about these perception thresholds of the colour contrasts. This test is not designed for screening for congenital blindness, but the kind of information it can deliver is an important part in the design of electronic assistive devices for visually impaired or colour blind people, as they make it possible to adapt the images displayed on these devices with user visual functionalities.

This paper is organized as follows: in Section 2 we present a brief review of color blindness mechanisms, and the main types of tests for the blindness assessment are listed. Afterwards, in Section 3, our method and the experimental setup are described, and results are discussed in Section 4.

2. COLOUR VISION BLINDNESS

2.1. Colour vision mechanisms

According to World Health Organization (WHO), about 10% of the whole human population present some kinds of colour vision deficiencies, leading to the inability to distinguish characteristic sets of colours. Colour perception mechanisms start within the eye, when light absorbed by the photoreceptors is transduced to a nervous signal, this signal is then processed by the inner layers of retina, and transmitted to the visual cortex for the final steps of processing. So deficiencies may arise from photoreceptor defects, optic nerve lesion or damage occurred in the brain.

In human retina, three types of photoreceptors are involved in colour vision, depending on their maximum spectral sensitivity: S cones (short wavelengths), M cones (medium wavelengths) and L cones (long wavelengths). Colour impairment levels vary from total colour blindness (mono-

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chromacy) to a slight degradation (but not a loss) of discrimination ability. Congenital colour vision deficiencies are linked to missing or abnormal cones. Dichromacy occurs when one type of cones is missing: protanopia, deuteranopia and tritanopia correspond respectively to the lack of L, M and S cones. Anomalous trichromacy is subdivided into protanomaly, deuteranomaly and tritanomaly, which is much less likely to occur. Recent studies [2] suggest that a protanomaly is characterized by L cone lack along with two varieties of M cone pigments with slightly different peak sensitivity wavelengths, and in the same way, deuteranomaly is characterized by M cone lack along with two varieties of L cone pigments. Colour blindness may also be a consequence of diseases, stroke or trauma: for example, glaucoma is responsible for a tritan like vision [3]. In this case of acquired deficiencies, colour vision deficiencies could get worse, or possibly improve over time, while it remains stable in case of inherited colour blindness.

2.2. Colour blindness assessment tests

Colour vision testing are intended to response to different objectives: initial diagnosis of color blindness, monitoring of some disease evolution, or ability to perform tasks, involved in particular professional areas. The so-called lamp methods are devoted to this later objective: they are still in use in armed forces (for instance in Canada and India) or for railway employee recruitment [4]. The well-known Ishihara plates belong to the pseudo isochromatic plate families [5].

These tests are intended to identify the subjects with modifications on the cones M and L, without indicating their severity, and are not adapted to the detection of problems related to the cones S. Other tests in the same family have been designed specifically for children, or for tritan type deficiencies. The third type of tests are named arrangement tests, among which the most commonly used has been developed by Farnsworth: its principle relies on the subject's ability to classify coloured pawns according to their chromatic proximity [6]. The number and nature of errors in arranging the colour order make it possible to discriminate problems related to L, M or S cones and may give a quantitative assessment of their gravity [7]. Pseudo isochromatic and arrangement tests are liable to encounter the same limitations: their major issue is their dependence to lighting condition, reliable results can only be obtained with standardized light sources. Furthermore, handling with sweaty fingers may degrade the color of the plates or the pawns. And finally, result interpretation is largely based on the investigator's experience. The fourth type of tests are spectral tests, based on anomaloscopes: the subject is asked to realize metameric matches of a target coloured light spot (for instance yellow light) by mixing two monochromatic lights (for instance red and green light). Although very precise, this later type of test use is restricted to scientific research [8], because of the high cost and need for extensive training of examiner.

Computerized tests are often presented as a promising alternative to classical tests: They appear to be less expensive, allowing for automated treatment and storage and therefore less time consuming [9]. They can also be administered remotely, online: a variety of web sites propose digital versions of classical tests as Ishihara plates, or Farnsworth pawns. In a more rigorous approach, computerized tests have been validates by clinical trials and comparison with classical tests. For instance, Nakamura and al [10] have designed pseudoisochromatic plates, Shin et al [11] have developed a new kind of arrangement test.

However, these tests clearly presents some limitations, mainly due to equipment: in order to be reliable and to give precise and reproducible results, they must necessarily be administrated with computer monitors whose colorimetric characteristics are perfectly known, thanks to a precise colorimetric calibration process.

3. COLOUR CONTRAST DETECTION THRESHOLD TEST

A wide variety of electronic assistive devices, based on judiciously processed coloured images may be thought in order to help people with congenital or acquired colour vision impairment in their everyday life or professional activities. Whatever these assistive devices are, it appears interesting to be able to match displayed image characteristics with visual abilities of the user.

The notions of cones fundamentals (i.e imaginary stimuli that excite only one cone family) and dichromatic confusion lines are extensively used in colour vision research, as they are known to account for anomalous trichromacy behavior as well. All the colours that are indistinguishable for one type of dichromate people among the three are lying along lines of confusion through the chromaticity diagram. For a given dichromacy type, all the lines converge to a so-called "copunctal point", that stands for the chromaticity coordinates of the missing cone primary.

Our present work therefore concerns colour discrimination threshold measurement, for a range of colours distributed on the whole CIE31 chromaticity diagram along dichromate confusion lines.

3.1. Method

Subjects are seated at 70cm in front of a computer display. Stimuli are composed of two concentric coloured square patches, on a grey neutral background. Luminance of stimuli and background are maintained at a 20 cd/m² throughout the

test. This level is beyond the detection range of rod photoreceptors, making it unlikely that rods participate in perception. Central and peripheral patches occupy respectively 3,3° and 8,2° in the subject's field of view. At the beginning, the two patches exhibit the same color. Then, the inner patch colour is modified step by step around the initial point, its chromatic coordinates always belonging to a given confusion line. Increment has been sized to be slightly lower than Mac Adams ellipse radius. Subjects are asked to say as soon as they detect a difference between the two patches. Afterwards, another initial colour is set for the two patches, and process goes on, until the whole confusion line within the monitor gamut has been ranged. Three confusion lines (corresponding to protanopia, deuteranopia and tritanopia) are successively studied. Copunctal point coordinates are derived from Wyszecki & Stiles [12].

3.2. Materials

For the test purpose, processing and dedicated interfaces (see figure 1) have been developed under MATLAB.

Stimuli are displayed on an LCD Philips 200CS monitor, which has beforehand undergone colorimetric characterization. Spectral radiance measurements have been collected using a Konica Minolta CS-2000 spectroradiometer, enabling for the determination of monitor gamut and a precise conversion between the device dependent RGB colour space and the device independent CIE XYZ colour space.

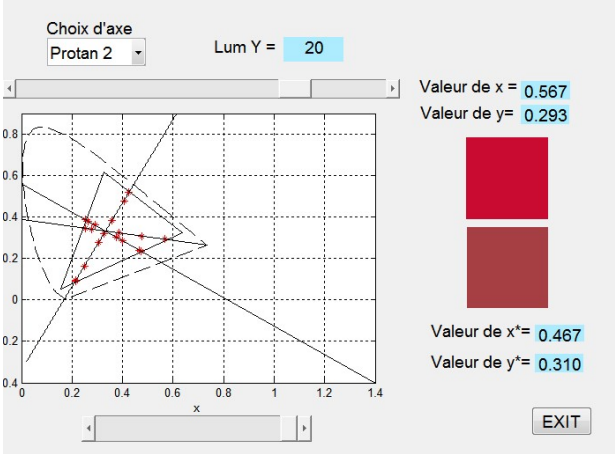

*Figure 1: examiner interface, showing confusion lines and monitor gamut. Symbol * indicates xy coordinates around whom variations of colour is performed, according to the position of the slider at the bottom*

3.3. Subjects

Ten subjects with normal colour vision (NCV), and three subjects with deficient colour vision (DCV1 to DCV3) as stated with Ishihara plate examination, volonteer to the test. All exhibit normal or corrected to normal acuity. Ages range from 18 to 59 years

4. RESULTS AND DISCUSSION

For each measurement point along the three axes, subjects indicate for which value x1 and x2 on either side of the initial point they perceive a colour difference. Distance threshold (DT) values are calculated as the distance in xy plane:

$$DT = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad (1)$$

Although the XYZ color space and the xy plane are known to be not perceptually uniform, this method has been chosen because it leads to convenient comparison with data found in literature, as it will be seen later.
Results are summarized in figure 2.

The averaged thresholds are not significantly different for each of the three axes and for all the NCV subjects.
DCV subjects perform poorer colour discrimination, with DT values two to three times higher. However, this discrimination exists, for points far away enough along the line. This result is not surprising: confusion line equations have been derived from experimental data gathered from metameric matches of 1° stimuli. For larger stimuli, when parafoveal vision is activated, it is known that confusions do no longer occur [2].

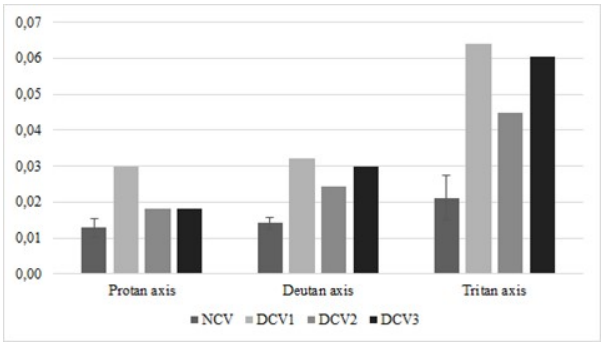

Figure 2: DT values for three confusion lines. NCV: averaged DT value for normal colour vision subjects (error bar: standard deviation). DCV1 to DCV3: DT values for the three subjects with deficient colour vision.

When looking at the relationship between color (e.g. chromatic coordinates in the CIE xy diagram) and threshold values, results are in agreement with color perception theory. The figure 3 shows the averaged DT for four points along the tritan axis within monitor gamut, whom coordinates are given in table1: distance is increasing when measures are performed from the bottom left to the top right, in agreement with increasing size of Macadam ellipses from blue to green.

x_1 y_1	0,2984	0,2633
x_2 y_2	0,3803	0,4283
x_3 y_3	0,3803	0,4283
x_4 y_4	0,4133	0,4949

Table 1: xy coordinates for four points along tritan axis

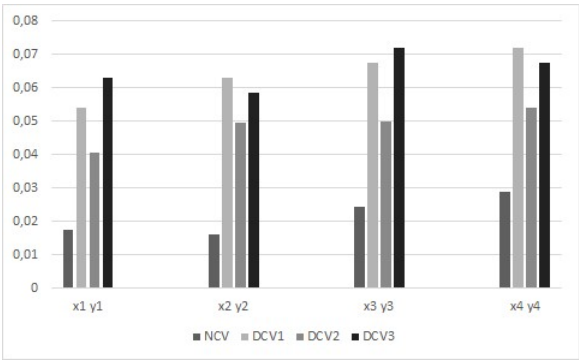

Figure 3: DT variations for four measurement points xiyi along tritan axis. NCV: averaged DT value for normal colour vision subjects. DCV1 to DCV3: DT values for the three subjects with deficient colour vision

Increase is greater for DCV subjects, and this result is also in agreement with colour perception theory: in case of anomalous trichromaticity, L and M cone wavelength sensitivity present a greater overlap than in normal vision, leading to a smaller difference between the L and M cone excitations in the medium and long wavelength parts the spectrum.

5. CONCLUSION

A precise knowledge of the colour contrast detection threshold exhibited by a given colour vision deficient person may permit the development of efficient assistive digital interfaces. This paper presents a new method for contrast detection threshold measurement, and the very first results of its implementation. For a complete validation, further investigation on a larger population, and comparison with data gathered from tests already in use in clinical vision assessment are needed. However, the first results are in good agreement with well-established notions in colour vision theories.

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