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2010 **ABDUL MALIK REHAN ABBASI**

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EVALUATION OF COLOR-DIFFERENCE FORMULAE

USING CRT COLORS

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Abstract

This research work was carried out to test color difference formulae by method of adjustment. 6 different color centers (Red, Yellow, Green, Blue-Green, Blue and Violet) were chosen for this psychophysical experiment. 336 virtual sample pairs were prepared. The mean color difference was DECIELAB three units. Each pair was assessed by a panel of 5 observers using psychophysical methods called Method of Adjustment. These visual data were used to test color-difference formulae: CMC, CIE94, DIN99d and CIE2000 together with basic CIELAB, with the help of simple statistical measures to fit i.e., PF/3, Stress and Wrong Decision Criteria.

In the second step, the Lightness parametric factor k_L was optimized for CMC, CIE94, DIN99d and CIE2000 with $k_C=k_H=1$. It was found that the visual results obtained from psychophysical method of adjustment showed that CIE94 being as a simplest linear transformation of CIELAB as well as DIN99d being as a logarithmic transformation perform very well for small color differences for both, original form and optimized form.

Keywords: Color-Difference, PF/3, STRESS, Wrong Decision Criteria, Method of Adjustment, CRT colors

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1. Introduction

Color difference formulas are of considerable importance in production control of colored materials, as they offer a kind of quantitative numerical method to predict perceived differences.

Since the International Commission on Illumination (CIE) developed the CIELUV and CIELAB spaces [1], in 1976 with the primary goal of promoting uniformity of practice between the users of color-difference formulas, significant developments have been made in this field. Thus, the CIELAB system has been accepted worldwide in most industrial applications, new successful color-difference formulas based on CIELAB have been proposed such as CMC [2], CIE94 [3], DIN99 [4], CIE2000 [5] and many others.

Current formulas are based on various sets of empirical difference perception data established with different kinds of materials, under different evaluation conditions, and with different observer panels.

In this way, while significant advances are made in color-vision research, improvements have been achieved in the correlation between visually perceived and computed color differences, this being a chief industrial problem and one of the main objectives of most color difference formulas.

Instead of developing a new color-difference equation to fit new dataset, the present study investigates the performance of color-difference formulae which have already been developed. Psychophysical method of comparison so called Method of Adjustment [12] was used in this investigation to study the performance of CMC, CIE94, DIN99d and CIE2000 together with basic CIELAB color-difference equations.

This investigation is based on small color-differences including suprathreshold which is very important to study since it is these differences that the color industries especially Textile Industries deal with primarily.

To accomplish this investigation, 6 color centers, Blue, Blue-Green, Green, Red, Yellow and Violet, were selected and along each color center 56 pairs were generated by keeping in mind all possible directions of the color center i.e., Lightness, Chroma and Hue, therefore, in total 336 pairs were developed. A panel of 5 normal observers was selected for visual assessment. All of the observers were the students of Technical University of Liberec and most of them were not experienced in psychophysical visual assessments.

For the flexibility and ease of colorimetric characterization, CRT-generated stimuli were used in this study. Each pair was presented to the observer for three times and observer was asked to develop color difference on gray pair by varying lightness. The difference of lightness of the gray pair in terms of ΔV was recorded for each pair and compared with color-difference ΔE given by the formulae mentioned above, of the colored pair. PF/3, STRESS and Wrong decisions are used as a measure to fit the data.

2. Theoretical Part

Color exists only in the mind; it is a perceptual response to light that enters the eye either directly from self-luminous light sources or, indirectly, from light reflected by illuminated objects.

To visualize the color of a light or of an object, the first requirement is a source of visible electromagnetic energy. This energy is then modulated by the physical and chemical properties of an object. The modulated energy is then imaged by the eye, detected by photoreceptors, and processed by the neural mechanisms of the human visual system to produce our perceptions of color. [6]

2.1. Colorimetry

Colorimetry is the science and technology used to quantify and describe physically the human color perception. The basis for colorimetry was established by CIE (Commission Internationale de l clairage) in 1931 based on visual experiments. Even though limitations are well recognized, the CIE system of colorimetry remains the only internationally agreed metric for color measurement. All the official color-related international standards and specifications use the CIE System. The CIE system works well in most cases, but one should know the assumptions and limitations in visual conditions where the CIE system is defined.

Three attributes of color, are hue, chroma (saturation), and lightness, and are expressed in a three dimensional space. To allow accurate specification of object colors and color differences, CIE recommended three dimensional uniform color spaces – CIELAB and CIELUV in 1976. These are called the CIE 1976 (L*a*b*) color space or CIELAB color space, and the other, CIE 1976 (L*u*v*) color space or CIELUV color space, and have similar structures as the Munsell color solid.

CIELAB space is commonly used for surface colors. In CIELAB space, L* shows the lightness, and (a*, b*) the color as shown in Figure 1, the coordinate (L*, a*, b*) is calculated from the tristimulus values (X, Y, Z) of the given light and tristimulus values

(X_n, Y_n, Z_n) of the white point. Therefore, the CIELAB space has a function of correcting for chromatic adaptation to the white point, and is intended for object color and displays.

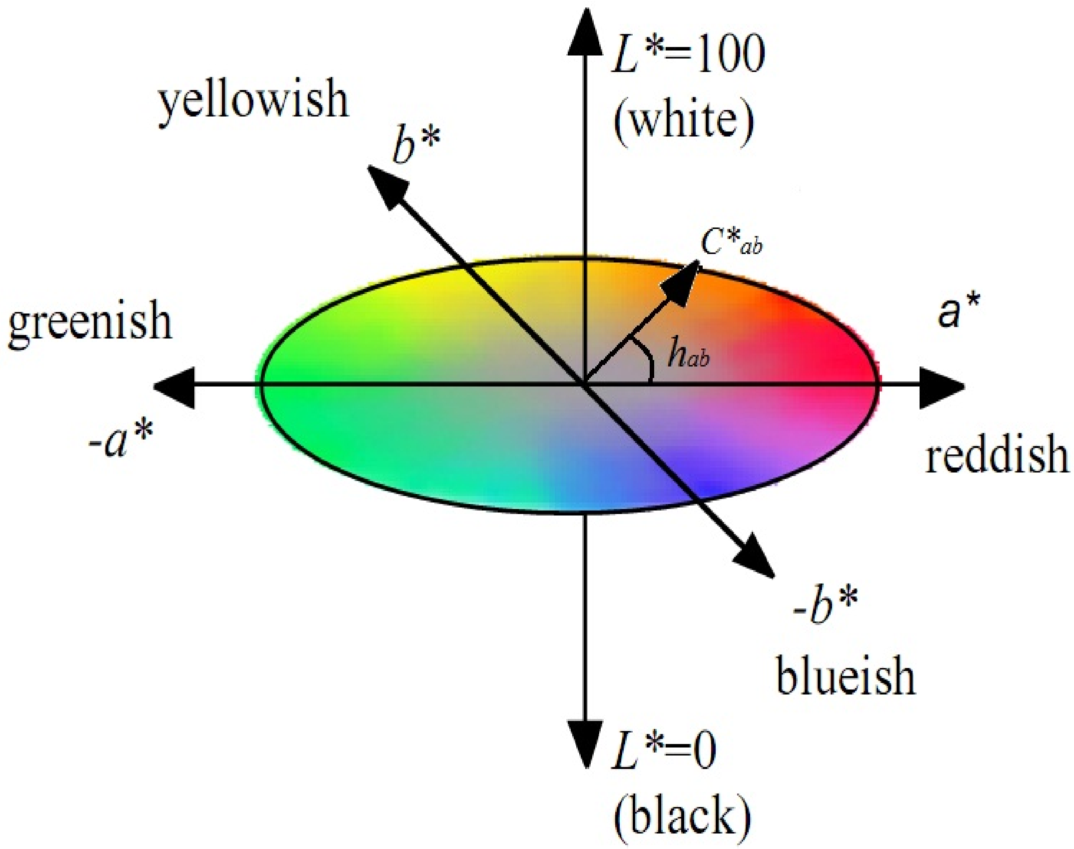

Figure 1 A three-dimensional representation of the CIELAB color space

2.2. Standard illuminants

The colors of objects change depending on the spectrum of illumination. Thus, there is a need to specify the illumination for any object color specification. For this purpose, colorimetric illuminants are standardized by CIE and ISO [1], [7]. CIE Standard Illuminant A (representative of tungsten-filament lighting with a color temperature of 2856 K) and CIE Standard Illuminant D65 (representative of average daylight with a CCT of 6500 K) are the two primary standard illuminants [7]. It is recommended that either of these illuminants be used in all applications.

2.3. Color-difference Formulae

A "color-difference formula" (sometimes also called "color-difference equation" or "color-difference metrics") is a mathematical expression providing a non-negative value ΔE, which try to be well correlated with the visually perceived difference ΔV between two given color samples with identical size and shape, simultaneously viewed under the same experimental conditions (light source, background, etc.). While ΔV is the subjective answer of the human visual system, which remains complex and unknown in many stages, ΔE is the objective result of a computation starting from the tristimulus values of the two samples, and also in a few color-difference formulas from parameters related to the visual observation conditions.

2.3.1. CIELAB

An important step in the search for an appropriate color-difference formula was achieved by the CIE in 1976 with the simultaneous recommendation of CIELUV and CIELAB [8]. Since this time the CIELAB formula has been widely adopted achieving an important 'uniformity of use' amongst different researchers and industries. This allows an easy communication amongst users, because in general results reported by different color-difference formulas are not related by scale factors or functions. The transformation of color space is mentioned in equations (1-3);

$$L* = 116\, f(Y/Y_n) - 16 \quad (1)$$

$$a* = 500\, [f(X/X_n) - f(Y/Y_n)] \quad (2)$$

$$b* = 200\, [f(Y/Y_n) - f(Z/Z_n)] \quad (3)$$

if $f(X/X_n)$, $f(Y/Y_n)$ and $f(Z/Z_n)$ are taken as $f(I)$

then $f(I) = I^{1/3}$, for $I >$ 0.008856

otherwise;

$f(I) = 7.787\, I + 16/116$

Here X, Y, Z and X_n, Y_n, Z_n are the tristimulus values of the sample and a specific reference white considered. It is common to use the tristimulus values of a CIE standard illuminant or a light source for the X_n, Y_n, Z_n values.

Correlates of hue and chroma, given in equation (4), are defined by converting the rectangular a^*, b^* axes into polar coordinates. The lightness (L^*), chroma (C^*) and hue (h_{ab}) correlates correspond to perceived color attributes, which are generally much easier to understand when describing colors.

$$h_{ab} = tan^{-1}(b^*/a^*)$$

$$C^*_{ab} = (a^{*2} + b^{*2})^{1/2} \quad (4)$$

A three-dimensional representation of the CIELAB color space is shown in Figure 1. The neutral scale is located in the centre of the color space. The L^* values of 0 and 100 represent a reference black and white, respectively. The coordinates a^* and b^* values represent redness–greenness, and yellowness– blueness attributes, respectively. The C^*_{ab} scale is an open-ended scale with a zero origin. (This origin includes all colors in the neutral scale, which do not exhibit hue.) The hue angle, h_{ab}, lies between 0° and 360°. Colors are arranged following the sequence of rainbow colors. The four unitary hues (pure red, yellow, green and blue) do not lie exactly at the hue angles of 0°, 90°, 180° and 270°, respectively.

Color difference, represented by DE^*, is given in equation (5) and is calculated as the distance between the standard and sample in the CIELAB color space.

$$\Delta E^*_{ab} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (5)$$

Or

$$\Delta E^*_{ab} = \sqrt{\Delta L^{*2} + \Delta C^{*}{}_{ab}{}^{2} + \Delta H^{*}{}_{ab}{}^{2}}$$

Where;

$$\Delta H^*_{ab} = 2\sin\left[{(h_{ab,2} - h_{ab,1})}/{2}\right]\sqrt{C^*_{ab,1}.C^*_{ab,2}}$$

And subscripts *1* and *2* represent the standard and sample of the pair considered, respectively. In the CIELAB system, a unit of color difference is intended to represent the same visual difference in each of the three attributes; lightness, hue and chroma or alternatively lightness, redness-greenness, yellowness-blueness. It is valid to express color differences that are not simply lightness differences by comparison to a lightness-difference scale.

2.3.2. CMC

McDonald [9] at J.P. Coates Company accumulated a comprehensive data set. These visual results were used to derive the JPC79 formula. At a later stage, the formula was further studied by the members from the CMC of the SDC and it was modified to correct some anomalies. The modified formula is named CMC (k_L: k_C) and is the current ISO standard for the textile industry. The formula is given in equation (6).

$$\Delta E_{CMC} = \sqrt{\left({\Delta L^*}/{k_L S_L}\right)^2 + \left({\Delta C^*_{ab}}/{k_C S_C}\right)^2 + \left({\Delta H^*_{ab}}/{S_H}\right)^2} \quad (6)$$

Where $S_L = 0.040975\, L^*_{ab,1}/(1 + 0.01765 L^*_{ab,1})$

Unless $L^*_{ab,1} < 16 \ when \ S_L = 0.511$

$$S_C = 0.638 + 0.0638\, C^*_{ab,1}\,(1 + 0.0131\, C^*_{ab,1})$$

$$S_H = S_C\,(Tf + 1 - f)$$

$$f = \sqrt{{C^*_{ab,1}}^4 / \left({C^*_{ab,1}}^4 + 1900\right)}$$

$$T = 0.36 + \left|0.4 \cos\left(h_{ab,1} + 35°\right)\right|$$

Unless $h_{ab,1}\ is\ between\ 164°\ and\ 345°$

When $T = 0.56 + \left|0.2 \cos\left(h_{ab,1} + 168°\right)\right|$

The k_L and k_C parametric factors were included to allow different weights for lightness and chroma, respectively, to be used depending on the circumstances. The best k_L and k_C values have been found to be 2 and 1, respectively, for predicting the acceptability of color differences for textiles. For predicting the perceptibility of color differences, k_L and k_C should both equal 1.

A constant *DE* according to the CMC formula equation (6) can be considered as an ellipsoid equation in CIELAB L^*, C^* and hue polar space with semi-major axes of $k_L\ S_L$, $k_C\ S_C$ and S_H, respectively. Its chromaticity ellipse points towards the achromatic axis.

2.3.3. CIE94

The CIE94 formula was a very conservative approach accounting for most robust effects in reliable experimental datasets. Equation (7) of CIE94 has a similar structure to that of CMC (k_L : k_C) but with simpler weighting functions.CIE94 included both positional corrections to CIELAB, and influence of the experimental observation conditions thorough the so-called "parametric factors". [10]

$$\Delta E_{94} = \sqrt{\left(\Delta L^* / k_L S_L\right)^2 + \left(\Delta C^*{}_{ab} / k_C S_C\right)^2 + \left(\Delta H^*{}_{ab} / k_H S_H\right)} \quad (7)$$

Where

$S_L = 1$

$S_C = 1 + 0.045\, C^*_{ab,1}$

$S_H = 1 + 0.015\, C^*_{ab,1}$

Here $C^*_{ab,1}$ refers to the C^*_{ab} of the standard of a pair of samples. For all applications except for the textile industry, a value of 1 is recommended for all parametric factors. For the textile industry, the k_L factor should be optimized and the k_C and k_H factors should be 1. The parametric factors may be defined by industry groups, depending on the typical viewing conditions for that industry.

2.3.4. DIN99d

DIN99 color space was developed in 1999 and has been adopted as the German standard. This formula applies logarithmic transformations and rescaling of the CIELAB variables L^* and C^* and calculates new basic coordinates using CIELAB hue angle h_{ab} before applying the same formula as used by CIELAB for calculating a color difference. Over the years Datacolor International tested this formula with very good success, finding that after making a modification to the internal parameters, color differences were predicted as just well as with the CIE94 formula. Starting with new basic coordinates allows those coordinates to be used as a color space for small color differences and to define a color difference as a vector.

The modifications of the new DIN99 formula are based in part on the CIE94 chroma weighting function, S_C, while keeping intact the basic structure of DCI-95, so that the color-difference formula remains in the form needed for an associated uniform color space (UCS), similar in form to the familiar CIE $L^*a^*b^*$ space. A modification was added to the ratios of the red/green and yellow/blue coordinates to provide a better fit of the experimental data for neutral colors. The results for the absolute color coordinates differ from those of CIELAB. The great advantage of the new formula is the possibility of using the same form of the color-difference metric that everybody is used to using with the straight CIELAB formula (including axes similar to the popular a^* and b^* color coordinates). Cui et al [11] in 2001 proposed modifications in DIN99 formula and those are currently being used as it was proposed. Their proposed formula is represented in equation (8).

$$\Delta E^*_{99d} = \frac{1}{k_E}\sqrt{{\Delta L_{99d}}^2 + {\Delta a_{99d}}^2 + {\Delta b_{99d}}^2} \qquad (8)$$

Where

$$L_{99d} = 325.22\ln(1 + 0.0036L^*)$$

$$a_{99d} = C_{99d}\cos h_{99d}$$

$$b_{99d} = C_{99d}\sin h_{99d}$$

$$C_{99d} = 22.5\ln(1 + 0.06G)$$

$$h_{99d} = \arctan(f/e) + 50^\circ$$

$$G = \sqrt{e^2 + f^2}$$

$$e = a^*\cos 50^\circ + b^* sin 50^\circ$$

$$f = 1.14\,(-a^*\sin 50^\circ + b^*\cos 50^\circ)$$

and $X' = 1.12X - 0.12Z$

2.3.5. CIE2000

Color difference research has culminated with the recently published CIEDE2000 color difference formula [5]. The equation (9) of CIE 2000 is based on CIELAB color space. It includes five modifications to CIELAB: a lightness weighting function, S_L, a chroma weighting function, S_C, a hue weighting function, S_H, an interactive term, R_T, between chroma and hue differences for improving the performance for blue colors, and a factor, $1 + G$, for re-scaling the CIELAB a^* scale to improve performance with grey colors.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}\right)} \quad (9)$$

Where

$$S_L = 1 + \frac{0.015 \left(\bar{L'} - 50\right)^2}{\sqrt{20 + \left(\bar{L'} - 50\right)^2}}$$

And $$S_C = 1 + 0.045\, \bar{C}'$$

And $$S_H = 1 + 0.015\, \bar{C}' T$$

Where

$$T = 1 - 0.17 \cos\left(\bar{\mathrm{h}'} + 30°\right) + 0.24 \cos\left(2\bar{\mathrm{h}'}\right) + 0.32 \cos\left(3\bar{\mathrm{h}'} + 6°\right) - 0.20 \cos\left(4\bar{\mathrm{h}'} - 63°\right)$$

And

$$R_T = -\sin(2\Delta\theta)\, R_C$$

Where

$$\Delta\theta = 30 \exp\left\{-\left[\left(\bar{\mathrm{h}'} - 275°\right)/25\right]^2\right\}$$

And

$$R_C = 2\sqrt{\bar{C}'^7 / \bar{C}'^7 + 25^7}$$

And

$$L' = L^*$$

$$a' = (1+ G)\, a^*$$

$$b' = b^*$$

$$C' = \sqrt{a'^2 + b'^2}$$

$$h' = \tan^{-1}(b'/a')$$

where

$$G = 0.5\left(1 - \sqrt{\frac{\overline{C'}^7}{\overline{C'}^7 + 25^7}}\right)$$

2.4. Psychophysics

"*Psychophysics* is the scientific study of the relationships between the physical measurements of stimuli and the sensations and perceptions that those stimuli evoke". [6]

Visual psychophysics concerns the study of stimulus-response relationships. These techniques have produced most of our knowledge of human color vision and color appearance phenomena. These are the underpinnings of colorimetry and its extension through color appearance models. Also, psychophysical techniques are used to test, compare, and generate data for improving color appearance models.

Visual experiments tend to fall into two broad classes:

- Threshold and matching experiments, designed to measure visual sensitivity to small changes in stimuli (or perceptual equality)
- Scaling experiments, intended to generate a relationship between the physical and perceptual magnitudes of a stimulus [6]

In a paired comparison experiment, all samples in all possible pairs are presented and the observer is asked to make a magnitude estimation of the perceived difference between each pair. The resulting estimates for each pair wise combination can then be subjected to Multidimensional Scaling (MDS) analyses. [6]

2.4.1. Method of Adjustment

The method of adjustment asks the subject to control the level of the stimulus, instructs them to alter it until it is just barely detectable against the background noise, or is the same as the level of another stimulus. This is repeated many times. This is also called the method of average error. In this method the observer himself controls the magnitude of the variable stimulus beginning with a variable that is distinctly greater or lesser than a standard one and he varies it until he is satisfied by the subjectivity of two. The difference between the variable stimuli and the standard one is recorded after each adjustment and used for statistical analysis.

In visual color assessment, the total perceived color difference between two non-self luminous specimens is compared as an equivalent lightness difference between two neutral gray specimens on a gray scale. A fundamental assumption is made that the total color difference can be so evaluated in terms of an equivalent lightness difference. [12]

3. Methodology

3.1. Monitor Calibration

The CRT monitor EIZO Flex Scan® F730 was used to generate the stimuli for the visual observations. The monitor was always turned on 30 min before taking the visual measurements. The Datacolor Spyder2 (Display Calibrator) was used in conjunction with Datacolor Envision Pro (software) to perform the monitor calibration, to adjust the color displayed on the monitor.

The first step in calibrating a display, before commencing colorimetric correction, was to set its operating state to some predetermined standard. For a CRT this involved degaussing (or demagnetizing) and adjusting the color purity, convergence, focus, DC-offset and gain controls.

For calibrating the monitor a colorimeter is attached flat to the display's surface, shielded from all ambient light. The calibration software sends a series of color signals to the display and compares the values that were actually sent against the readings from the calibration device. This establishes the current offsets in color display. Depending on the calibration software and type of monitor used, the software either creates a correction matrix (i.e. an ICC profile) for color values before being sent to the display, or gives instructions for altering the display's brightness/contrast and RGB values through the on-screen display. This tunes the display to reproduce fairly accurately the in-gamut part of a desired color space. [13]

3.2. Color Vision Test for Observer

A panel of 5 observers was selected for visual assessments. All the observers were tested according to Farnsworth-Munsell 100 Test. It was found that all the observers had normal color vision and no one had color deficient vision.

3.2.1. Farnsworth-Munsell 100 Test

Farnsworth Munsell 100 Hue test gave an easy-to-administer but highly effective method for measuring any individual's color vision. The test consists of four trays containing a total of 85 removable color reference caps (incremental hue variation) spanning the visible spectrum. Color vision abnormalities and aptitude are detected by the ability of the test subject to place the color caps in order of hue.

Method of scoring the color arrangement test was invented by Vingrys [14] and King-Smith and provides a more quantitative assessment. It involves determining the angles of adjacent colors in color space, producing a "color difference vector".

The analysis produces three important values:

- "Angle" indicates the axis of confusion and therefore the type of color deficiency.
- "C-Index" is the Confusion-Index, which is a measure of the severity of the color deficit.
- "S-Index" is the Scatter-Index, which is used to assess the degree of scatter, randomness or selectivity in the observer's arrangement. Vingrys and King-Smith claim that these three values are sufficient to discriminate between varieties of congenital or acquired color vision deficiencies.

The results are tabulated in Results of the FM-100 test for all 5 observersTable 1 for each observer and found that all the observers had normal color vision. The value of score for each observer was calculated by using online software [15] developed by Béla Török.

Table 1 Results of the FM-100 test for all 5 observers

	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5
TES	8	8	8	8	8
Mid-point	10	55	29	9	15
Angle-Vingrys	58.2375	48.0813	47.8791	68.7853	61.2539
Selectivity Index - Vingrys	1.2766	1.3058	1.5183	1.1716	1.2293
Confusion Index - Vingrys	1.0608	1.0638	1.1906	1.0291	1.0541
Major Radius	2.6787	2.6864	3.0064	2.5987	2.6619
Minor Radius	2.0982	2.0573	1.9801	2.218	2.1654

3.3. Experimental Environment

The experimental observations were performed in a room which was completely dark. The color stimuli, displayed on the CRT monitor of EIZO FlexScan® F730, were viewed by the observers from the distance of 550 mm.

The visual experiment was managed by the software Datacolor Envision Pro 1.1.0.467. The test stimulus pattern consisted of two color pairs, each of which included two (65mm x 65mm) anchor colored and comparison gray squares, in upper and lower positions, respectively, at the center of a cabinet gray background on the CRT display, as illustrated in the Figure 2.

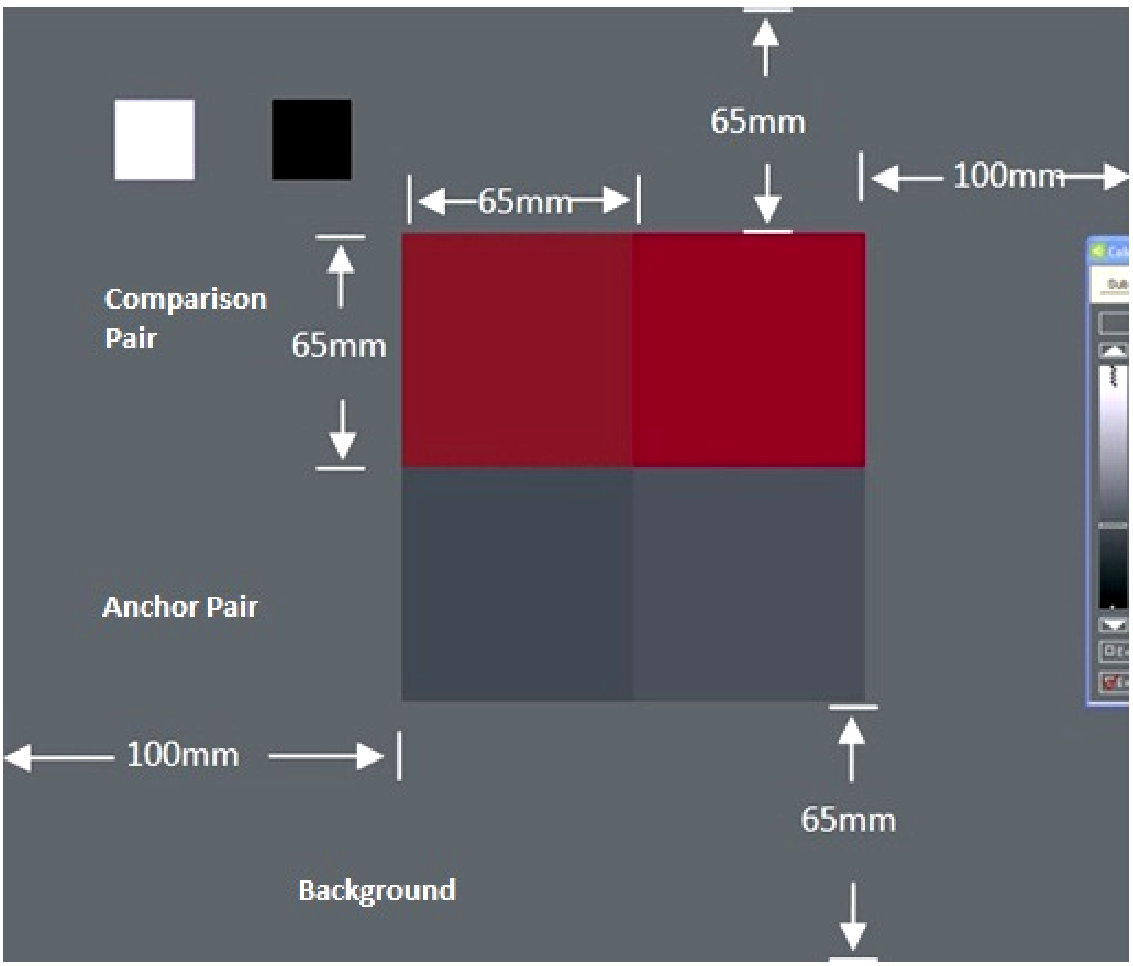

Figure 2 the test paradigm used in the present color-difference comparison experiment

The colorimetric values were then calculated under the CIE D65 Illuminant and 1964 standard colorimetric observer. Arrangement of the test stimuli was different from that chosen by Xu [16] et al., and Wilbur [17] in regard there was no gap between the stimuli. This arrangement avoided separation gap [18] effect in psychophysical evaluation. Care was taken in selecting the gray pair in order, not to have stimulus lightness same or approaches to the lightness of the background to avoid confusion between comparison pair and background. Color slider was so placed that only lightness slider was visible in the environment and rest of the part was hidden.

3.4. Generation of Pairs

6 different color centers Violet, Blue, Green-Blue, Green, Yellow and Red were chosen. The CIELAB L*a*b* values for each grade and standard under CIE D65 Illuminant and 1964 standard colorimetric observer are given in Table 2.

Table 2 the CIELab values of color centers under D65 and CIE 1964 standard colorimetric observer conditions

Color Center	L*	a*	b*	C^*_{ab}	h°
Blue	33	-2.197	-31.42	31.5	266
Green-Blue	68	-27.23	-3.827	27.5	188
Green	47	-28.94	5.20	29.4	169.8
Red	35.42	49.05	24.88	55	26.9
Violet	22.50	23.74	-14.83	28	328
Yellow	80	16.88	76.151	78	77.5

With each color center 56 pairs were generated which covered almost all directions from the color center. These samples were so produced that; in 20 pairs Lightness was not varied at all but chromaticity C_{ab}* and hue h_{ab}* values were changed in an order. The arrangement is described in Figure 3 and Table 3.

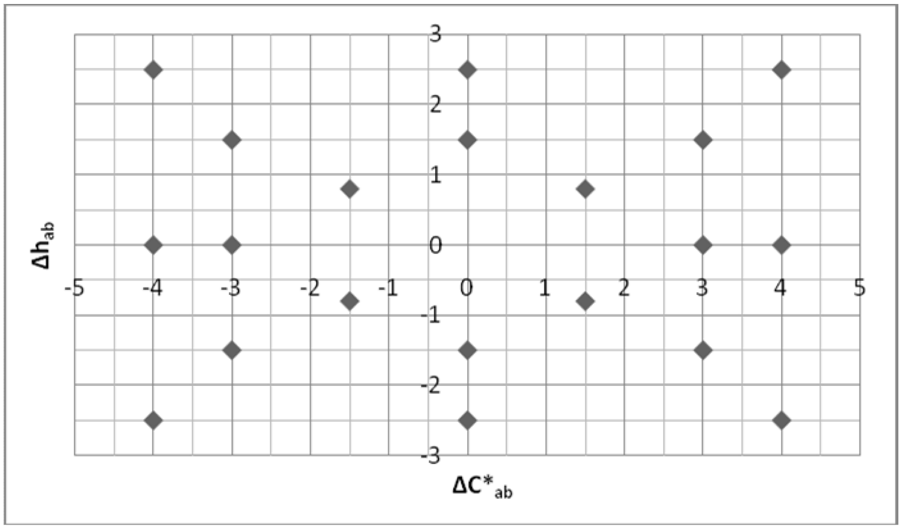

Figure 3 schematic diagram of the sample arrangement where, ΔL was kept zero

Table 3 the values which were used to develop the pairs at constant lightness

Serial No.	DL*	DC*$_{ab}$	DH*$_{ab}$
1	0.0	0.0	-1.5
2	0.0	0.0	-2.5
3	0.0	0.0	1.5
4	0.0	0.0	2.5
5	0.0	3.0	0.0
6	0.0	4.0	0.0
7	0.0	-3.0	0.0
8	0.0	-4.0	0.0
9	0.0	1.5	0.8
10	0.0	3.0	1.5
11	0.0	4.0	2.5
12	0.0	-1.5	0.8
13	0.0	-3.0	1.5
14	0.0	-4.0	2.5
15	0.0	-1.5	-0.8
16	0.0	-3.0	-1.5
17	0.0	-4.0	-2.5
18	0.0	1.5	-0.8
19	0.0	3.0	-1.5
20	0.0	4.0	-2.5

Next 8 samples were prepared with slight changes in hue and chromaticity in an order but lightness was also varied by steps $DL_{ab}*$ -0.5 and +0.5 for all 8 samples, so by this arrangement 16 samples were produced. Preparation of these comparison pairs can be understood by Table 4 and Figure 4.

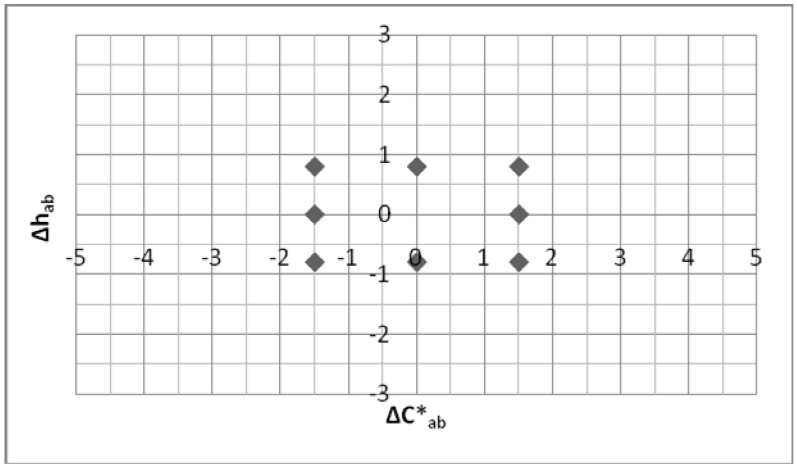

Figure 4 schematic diagram of the sample arrangement where, ΔL varied by +0.5 and -0.5

Table 4 the values which were used to develop the pairs by varying LCH all together in 2nd step

Serial No.	DL	DC^*_{ab}	DH^*_{ab}
1	0.5	1.5	-0.8
2	0.5	1.5	0.0
3	0.5	1.5	0.8
4	0.5	0.0	-0.8
5	0.5	0.0	0.8
6	0.5	-1.5	-0.8
7	0.5	-1.5	0.0
8	0.5	-1.5	0.8
9	-0.5	1.5	-0.8
10	-0.5	1.5	0.0
11	-0.5	1.5	0.8
12	-0.5	0.0	-0.8
13	-0.5	0.0	0.8
14	-0.5	-1.5	-0.8
15	-0.5	-1.5	0.0
16	-0.5	-1.5	0.8

Similarly another 8 samples were produced with variable chromaticity and hue values in different order but in this arrangement lightness was varied by steps -1.0 and +1.0 for all 8 samples, so 16 samples were produced in this way. 4 samples were produced in such a way that DC_{ab}* Dh_{ab}* were kept zero and lightness was varied in 4 steps i.e., -1.0, +1.0, - -1.5 and +1.5, therefore in total 56 different comparison pairs were produced. This sample arrangement can be understood by Figure 5 and Table 5.

Table 5 the values which were used to develop the pairs by varying LCH all together in 3rd step

Serial No.	DL	DC^*_{ab}	DH^*_{ab}
1	1.0	3.0	-1.5
2	1.0	3.0	0.0
3	1.0	3.0	1.5
4	1.0	0.0	-1.5
5	1.0	0.0	1.5
6	1.0	-3.0	-1.5
7	1.0	-3.0	0.0
8	1.0	-3.0	1.5
9	-1.0	3.0	-1.5
10	-1.0	3.0	0.0
11	-1.0	3.0	1.5
12	-1.0	0.0	-1.5
13	-1.0	0.0	1.5
14	-1.0	-3.0	-1.5
15	-1.0	-3.0	0.0
16	-1.0	-3.0	1.5
17	1.0	0.0	0.0
18	-1.0	0.0	0.0
19	1.5	0.0	0.0
20	-1.5	0.0	0.0

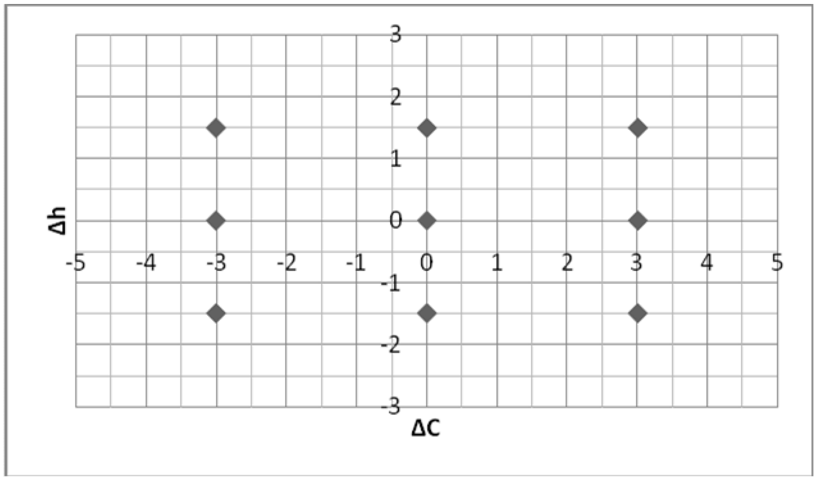

Figure 5 schematic diagram of the sample arrangement where, ΔL varied by +1.0 and -1.0

Anchor gray pairs were so produced that lightness of fixed stimulus was same as that of lightness of chosen color center except anchor gray pair of Green center which was increased to L_{ab}*= 55 so that stimulus remained distinguishable from the background gray.

3.5. Procedure

The observer's task was to establish a lightness difference on the anchor gray pair almost equal to the difference perceived in the comparison colored pair. One of the stimuli of the anchor gray pair was fixed with the lightness level of color center while the other was changed by the observer to establish the color difference. The observer could gradually increase or reduce the lightness difference in the comparison gray pair until accept it, using color slider of the software. This method of change of the anchor pair and comparison with a comparison pair is termed the method of adjustment (MOA) [12].

3.5.1. Optimizing Lightness parametric factor k_L

The weighting factor k_L was optimized for color difference formulae CMC, CIE94, DIN99d and CIE2000 for each color center. It was so optimized that ΔE and ΔV show the highest correlation coefficient.

With DIN99d the weighting factor k_E was also optimized to get the lowest possible Wrong Decisions. For optimization of k_L value, DIN99d equation (8) was modified as equation (10);

$$\Delta E^{*}_{99d} = \frac{1}{k_E}\sqrt{\left(\frac{\Delta L_{99d}}{k_L}\right)^2 + \Delta a_{99d}{}^2 + \Delta b_{99d}{}^2} \qquad (10)$$

3.6. Data Analysis tools

3.6.1. Performance factor PF/3

Three measures were used as indicators to fit uniform color spaces and to test various color models. The first one is the widely used PF/3 (10) (Performance Factor), as given in equation (11)**Error! Reference source not found.**. The PF/3 measure was used to indicate the prediction of a color space to a particular data set. For a PF/3 value of 10, it means that the disagreement between the color space predictions and the visual results is 10%.

$$PF/3 = 100\ (\gamma - 1 + V_{AB} + CV/100)/3 \qquad (11)$$

Where CV and γ were proposed by Coates [19] *et al*. and V_{AB} derived by Schultz [20] and are in (13) and (14) respectively. For a perfect agreement between the visual results and a formula's predictions, CV as calculated in equation (12) and V_{AB} should equal zero and should equal 1 respectively. Considering ΔE_i as color-difference of comparison color pair given by color difference equation and ΔV_i as visual difference of anchor gray pair perceived by observer, we can calculate;

$$CV = 100 * \frac{\sqrt{\frac{1}{N}\sum(\Delta E_i - f\Delta V_i)^2}}{\overline{\Delta E}} \qquad (12)$$

And

$$f = \frac{\sum \Delta E_i \Delta V_i}{\sum \Delta V_i^{\,2}}$$

Also

$$\log_{10}(\gamma) = \sqrt{\frac{1}{N}\sum\left(\log_{10}\left(\frac{\Delta E_i}{\Delta V_i}\right) - \overline{\log_{10}\left(\frac{\Delta E_i}{\Delta V_i}\right)}\right)^2} \quad (13)$$

And

$$V_{AB} = \sqrt{\frac{1}{N}\sum\frac{(\Delta E_i - F\Delta V_i)^2}{\Delta E_i F \Delta V_i}} \quad (14)$$

And

$$F = \sqrt{\sum\frac{\Delta E_i}{\Delta V_i} \Big/ \sum\frac{\Delta V_i}{\Delta E_i}}$$

The main reason to propose the PF/3 combined index was that sometimes different measures led to different conclusions (for example, one formula performed best regarding to CV, while another formula proved the most accurate prediction when using V_{ab}). Thus, it was considered beneficial to avoid making a decision as to which of the formula served best and to provide single value to evaluate the strength of the relationship between ΔE_i and ΔV_i.

3.6.2. STRESS

The use of PF/3 to indicate the significance of the difference between two color-difference formulae is almost impossible, because the statistical distribution followed by PF/3 is unknown. Standardized residual sum of squares (STRESS), was employed which was recommended by Garcia [21] et al. The main difference between PF/3 and STRESS is that the later allows inference loss function to weight the contribution of individual pairs of objects. This leads to the definition of STRESS as in equation (15).

$$STRESS = \sqrt{\frac{\sum(\Delta E_i - F_3 \Delta V_i)^2}{\sum \Delta {E_i}^2}} \tag{15}$$

With

$$F_3 = \frac{\sum(\Delta E_i \, \Delta V_i)}{\sum \Delta {V_i}^2}$$

Where, F_3 is not arbitrary scaling factor, but factor which minimize the STRESS.

3.6.3. Wrong Decision Criteria

In addition the percentage acceptance data, in the complete and unmodified form, were used to calculate Wrong Decision Criteria [22] in terms of percentage, which must be lower for better formula. If a sample with a higher color-difference reading than the tolerance limit was accepted, it was wrong acceptance, whereas if a sample with a lower color-difference reading than the tolerance limit was rejected, it was wrong rejection. Summation of number of wrong acceptance and wrong rejection gives us total wrong decisions made by the observer.

To calculate percentage of Wrong Decisions, formulas (i) and (ii) were used in Microsoft Excel;

Defining the wrong decision fail criteria;

$$= if(AND(DE \leq S\ limit, DV > VT\ limit), 1{,}0) \tag{i}$$

And $Wrong\ Decision\ fail\ \% = 100 * \left(\sum_{i=1}^{n} Wrong\ Decision\ Fail\right) / n$

Defining the wrong decision pass criteria;

$$= if(AND(DE \geq S\ limit, DV < VT\ limit), 1,0) \quad \text{(ii)}$$

And $$Wrong\ Decision\ pass\ \% = 100 * {(\sum_{i=1}^{n} Wrong\ Decision\ Pass)}/{n}$$

Here 'n' represents the total number of pairs observed visually in one color center which were 56.

Where S limit represents Suprathreshold Limit used in Textile Industries

And VT limit represents Visual Tolerance Limit

In this experiment both limits were set as 1.

Therefore,

Total Wrong Decisions % = Wrong Decision fail % + Wrong Decision Pass %

4. Results and Discussion

In the present study, the CIELAB color-difference formula, together with the DECMC, DECIE94, DEDIN99d and CIEDE 2000 equations, were tested with respect to their performance in predicting small visual color differences at the six color centers. The comparisons between color differences (ΔE) predicted by different formulae and the corresponding visual scales (ΔV) were carried out in terms of PF/3, STRESS and Wrong Decision measures. The evaluation was first made using the original forms of all formulae, i.e. k_L=k_c=k_h=1. The comparison results in PF/3, STRESS and WDC values are listed in Table 6 and presented graphically in Figure 6Figure 11.

4.1. Evaluation of performance of original formulae

In terms of PF/3 measure, using the original forms of weighting factors i.e., $k_L= k_c=k_h=1$, it was observed that the CIEDE94 (40.81) performed best, followed by CMC (44.8), DIN99d (45.63) and CIEDE2000 (47.02), with the CIELAB (63.39) worst, for the combined dataset of all centers. A higher PF/3 value implies a worse agreement between data sets, and a PF/3 of 40 indicates a disagreement of about 40%.

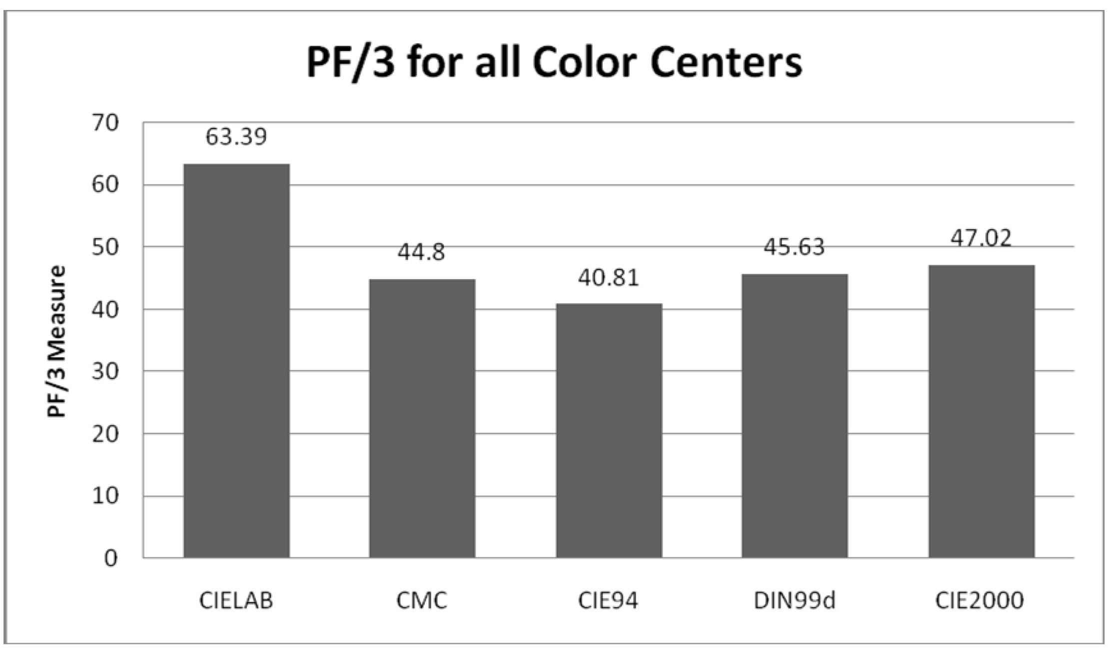

Figure 6 Comparison of color-difference formulae keeping k_L= k_c=k_h=1 by applying PF/3 measure for all color centers

Table 6 Summary of Color-difference formulae performance in PF/3, STRESS and WDC measures in their original form

Color Center		CIELAB	CMC	CIE94	DIN99d	CIE2000
For all measurement planes with $k_L=k_C=k_H=1$						
Blue	PF/3	58.09	36.09	36.2	42.76	39.13
	STRESS	43.2	29.37	29.44	35.31	31.82
	WDC	19.64	33.93	33.93	23.21	44.64
Green-Blue	PF/3	63.39	51.16	41.25	48.67	47.82
	STRESS	46.1	39.71	32.45	38.21	37.69
	WDC	21.43	41.07	32.14	26.79	39.29
Green	PF/3	65.69	47.19	42.24	47.16	42.52
	STRESS	48.74	38.4	34.55	38.38	35.07
	WDC	21.43	32.14	32.14	26.79	32.14
Red	PF/3	57.97	41.76	39.76	40.66	44.23
	STRESS	44.64	34.18	32.54	33.21	36.32
	WDC	23.21	35.71	41.07	39.29	41.07
Violet	PF/3	73.6	41.61	49.62	50.97	57.93
	STRESS	50.78	31.18	37.41	38.46	43.26
	WDC	28.57	17.86	42.86	35.71	50
Yellow	PF/3	61.58	51	35.81	43.55	50.46
	STRESS	48.31	43.49	31.69	38.17	43.38
	WDC	16.07	33.93	41.07	37.5	46.43
All Centers	PF/3	63.39	44.8	40.81	45.63	47.02
	STRESS	46.96	36.05	33.01	36.96	37.92
	WDC	21.73	32.44	37.2	31.55	42.26

For individual color centers, every formula performed differently. The CIEDE94 outperformed others at Green, Green-Blue, Red and Yellow centers. And for Blue and Violet centers, CIE94 came after CMC, but PF/3 differences between CMC, CIE94, DIN99d and CIE2000 compared with that of CIELAB were rather small, especially at Red center. The slightly poor performance of CIEDE2000 may be due to the present experimental parameters being different from its reference viewing condition.

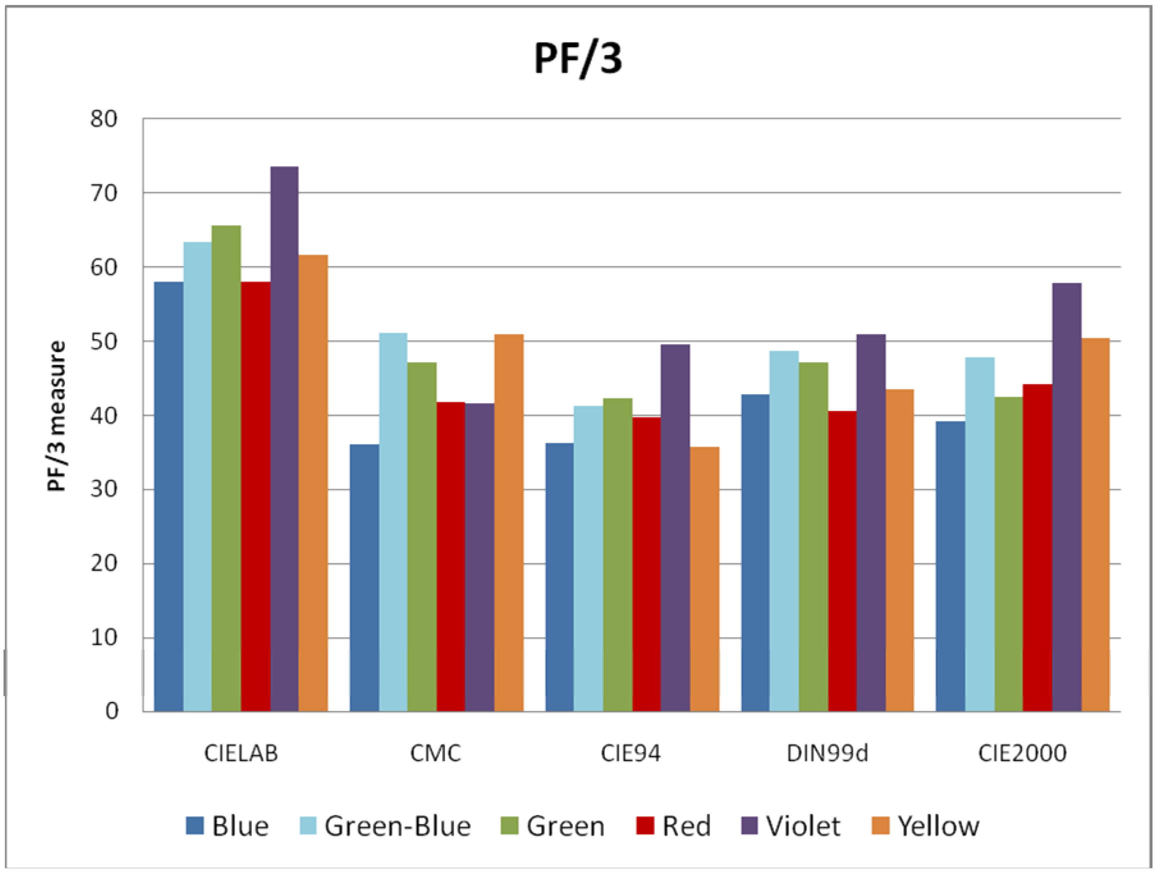

Figure 7 Comparison of color-difference formulae keeping $k_L = k_c = k_h = 1$ by applying PF/3 measure for individual color centers

Similar effect can be seen from Figure 8 while studying loss function (STRESS) between visual difference (ΔV) and color difference ΔE. CIE94 caused lowest STRESS (33.01) as compared to other formulae but differences between CMC (36.05), DIN99d (36.96) and CIE2000 (37.92) were rather negligible. CIELAB performed worst again and showed highest STRESS measure (46.96).

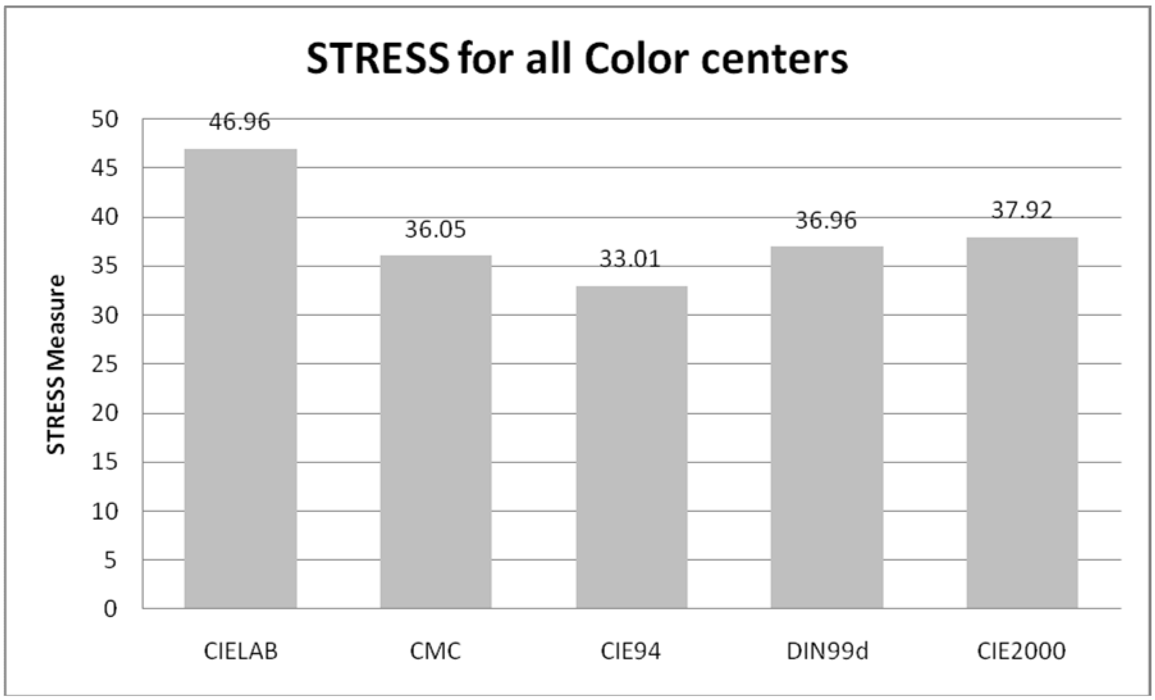

Figure 8 Comparison of color-difference formulae keeping $k_L = k_c = k_h = 1$ by applying STRESS measure for all color centers

For individual color centers similar to PF/3 measure, it is very much clear from Figure 9 that in Blue and Violet CMC color difference equation outperformed other formulae in STRESS measure, whereas for Blue-Green, Red, Yellow and Green color centers CIE94 color difference formula performed best.

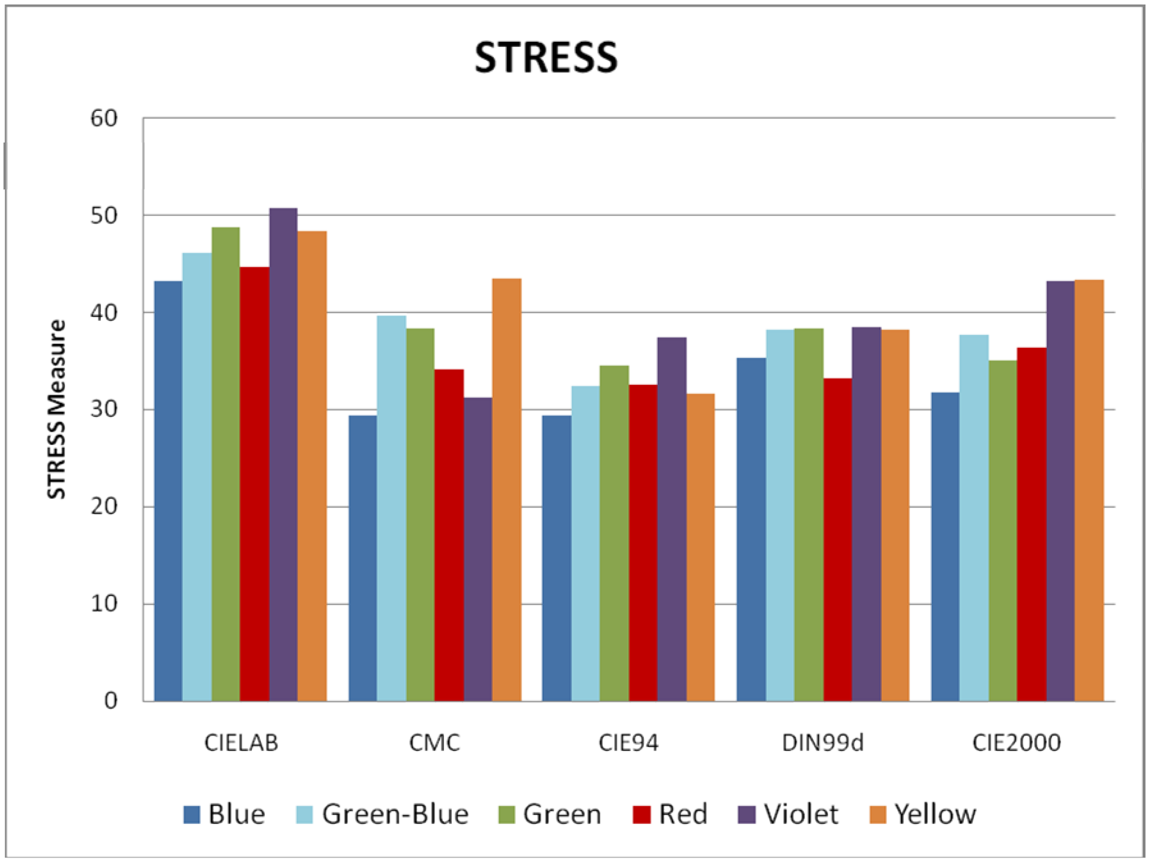

Figure 9 Comparison of color-difference formulae keeping k_L= k_c=k_h=1 by applying STRESS measure for individual color centers

From Figure 10 it can be seen that for all color centers, CIELAB outperformed other formulae regarding percentage of wrong decisions taken by the observers. DIN99d (31.55%) and CMC (32.44%) performed better next to CIELAB (21.73%) but CIE94 (37.2%) and CIE 2000 (42.26%) were the worst among all.

After analyzing number of Wrong Decisions critically, it was found that majority of the wrong decisions were made during comparison of comparison pairs having variation of lightness with ±0.5. The effect of change in lightness made huge influence on the visual sensation of the observer; as a consequence observer failed those pairs.

Similarly Hue change with degree of ±2.5 from the color center did not make huge impact on sensation of observer but according to almost all formulae it was beyond Tolerance limits.

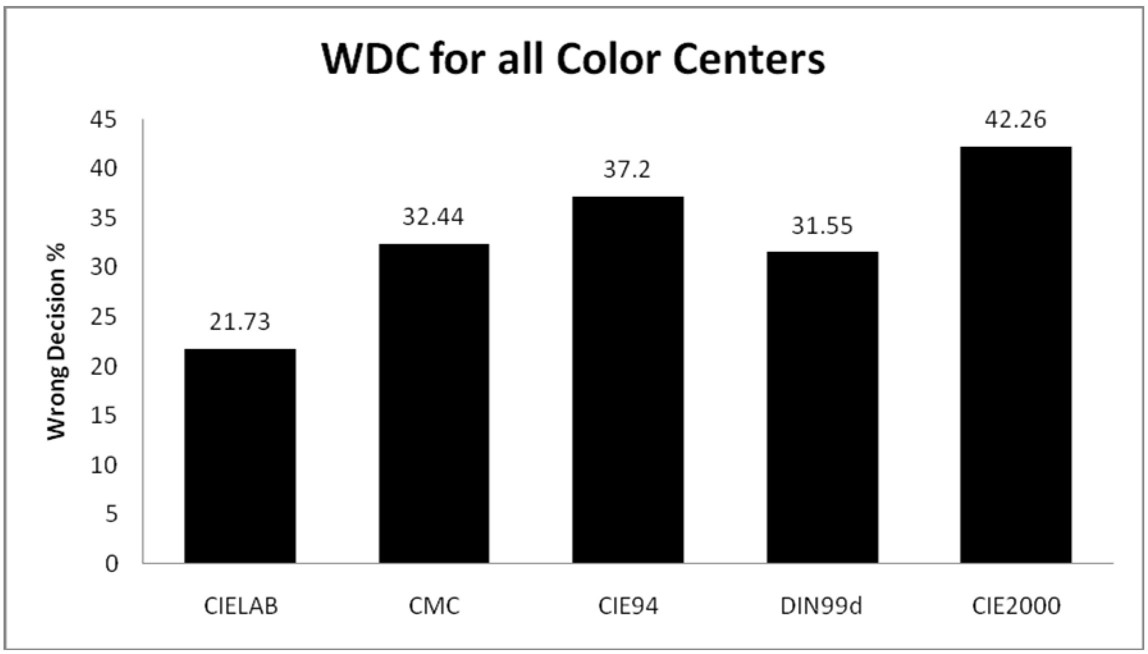

Figure 10 Comparison of color-difference formulae keeping k_L= k_c=k_h=1 by applying Wrong Decisions Criterion for all color centers

CIELAB performed best except Violet color center where CMC outperformed other formulae but CMC shows worst performance regarding to Blue-Green center. After CIELAB, DIN99d outperformed other formulae in all color centers except Red color center. The bad performance of CIE94 in Red, Violet and Yellow color centers made it worst than CMC and DIN99d which was contradictory regarding PF/3 and STRESS measures.

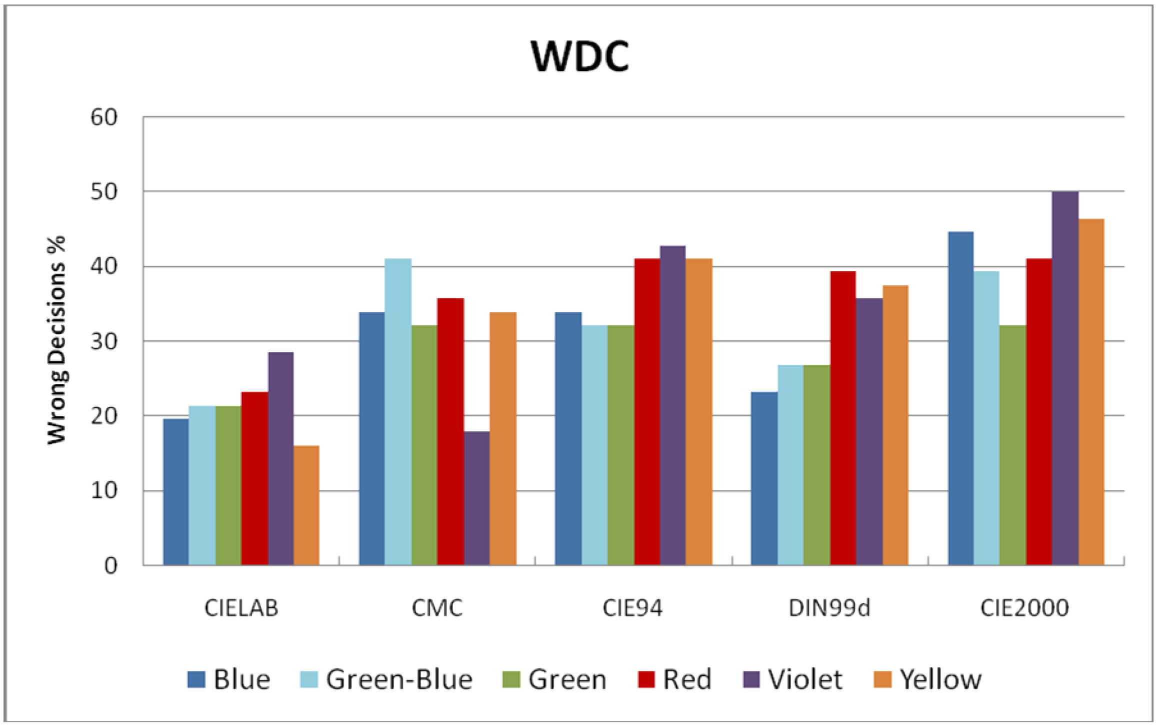

Figure 11 Comparison of color-difference formulae keeping $k_L = k_c = k_h = 1$ by applying Wrong Decision Criterion for individual color centers

4.2. Evaluation of Performance for optimizing k_L value

For each formula, the parametric factor k_L value was optimized with k_c=k_h=1 to give the best fit to the visual scales except CIELAB. The comparison results in PF/3, STRESS and WDC values are listed in Table 7 and presented graphically in Figure 12Figure 17.

For DIN99d the weighting factor k_E was also optimized along with k_L, and it was found that at 1.75 it gave lowest Wrong decisions for all color centers.

The optimized k_L value for CMC (0.31), CIE94 (0.35), DIN99d (0.29) and CIE2000 (0.27) are somewhat very near to each other and all the formulae improved their performance after optimizing concerning PF/3 and STRESS measures. This indicates that the parametric effects of the present viewing condition on lightness difference were not strong for all formulae studied here.

As far as PF/3 measure was concerned, CIE94 performed best (26.85) followed by CMC (27.06), DIN99d (27.311) and CIE2000 performed worst with (29.14) as illustrated in Figure 12.

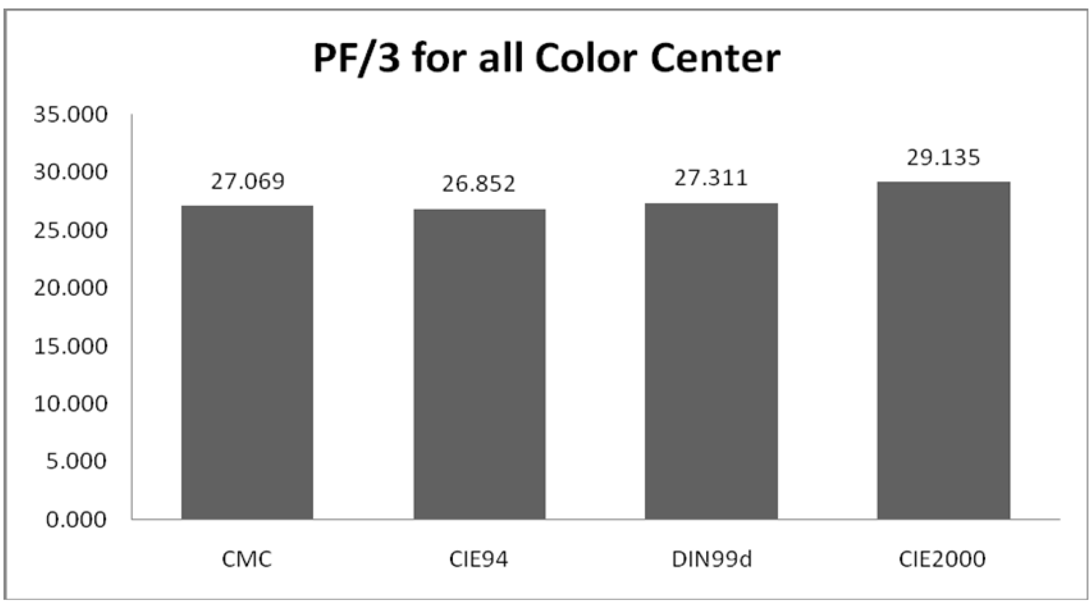

Figure 12 Comparison of color-difference formulae for optimized k_L at k_c=k_h=1 by applying PF/3 measure for all color centers

Table 7 Summary of Color-difference formulae performance in PF/3, STRESS and WDC for optimized k_L

Color Center		CMC	CIE94	DIN99d	CIE2000
For all measurement planes with optimized k_L					
Blue	k_L	*0.46*	*0.46*	*0.34*	*0.4*
	PF/3	26.23	26.27	27.75	33.20
	STRESS	22.57	22.61	24.41	26.93
	WDC	5.36	1.79	14.29	12.50
Green-Blue	k_L	*0.26*	*0.34*	*0.26*	*0.26*
	PF/3	20.89	20.48	22.20	21.13
	STRESS	16.44	16.96	17.84	17.39
	WDC	1.79	0.00	10.71	0.00
Green	k_L	*0.21*	*0.25*	*0.21*	*0.24*
	PF/3	29.16	27.83	22.94	29.38
	STRESS	22.27	22.12	19.19	22.81
	WDC	3.57	3.57	10.71	3.57
Red	k_L	*0.38*	*0.41*	*0.40*	*0.32*
	PF/3	32.42	33.43	37.45	34.21
	STRESS	27.93	28.59	31.15	28.93
	WDC	7.14	10.71	26.79	12.50
Violet	k_L	*0.35*	*0.26*	*0.26*	*0.18*
	PF/3	28.55	27.71	25.34	28.62
	STRESS	21.38	21.37	20.73	21.54
	WDC	10.71	10.71	17.86	10.71
Yellow	k_L	*0.19*	*0.36*	*0.27*	*0.20*
	PF/3	25.15	25.40	28.20	28.26
	STRESS	20.74	20.79	23.03	21.64
	WDC	5.36	12.50	14.29	10.71
All Centers	k_L	*0.31*	*0.35*	*0.29*	*0.27*
	PF/3	27.069	26.852	27.311	29.135
	STRESS	21.888	22.075	22.726	23.207
	WDC	5.655	6.548	15.774	8.333

As shown from Figure 13, in individual color centers CMC and CIE94 performed very well except Violet color center followed by DIN99d which performed worst in Red color center, where CIE2000 was better than DIN99d.

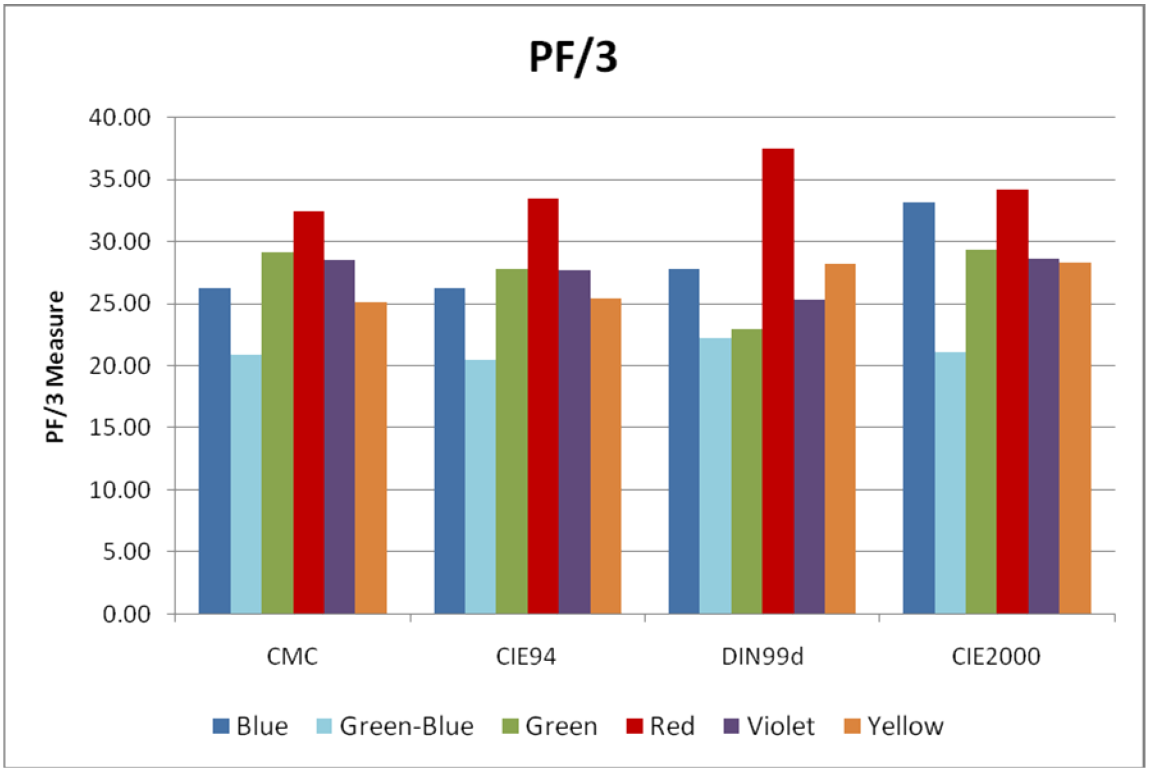

Figure 13 Comparison of color-difference formulae for optimized k_L at k_c=k_h=1 by applying PF/3 measure for individual color centers

Another interesting fact was found that after optimizing k_L value, all color-difference equations performed worst in Red color center as compared to other color centers.

CMC performed very well with (21.89) when STRESS measure is concerned for optimized color equations followed by CIE94 (22.08), DIN99d (22.73) and CIE2000 (23.21). Figure 14 shows that after optimizing k_L value all the color equations improved their performances.

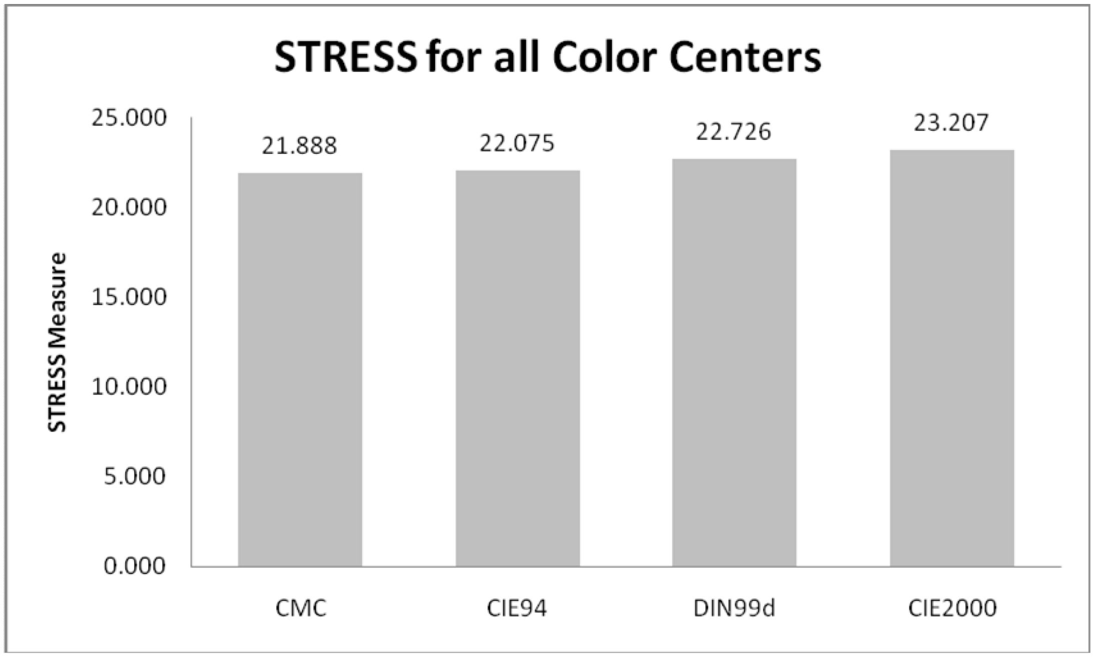

Figure 14 Comparison of color-difference formulae for optimized k_L at k_c=k_h=1 by applying STRESS measure for all color centers

For individual color centers CMC, CIE94 and CIE2000 performed almost equally except Blue and Red color center, from Figure 15 it is very clear.

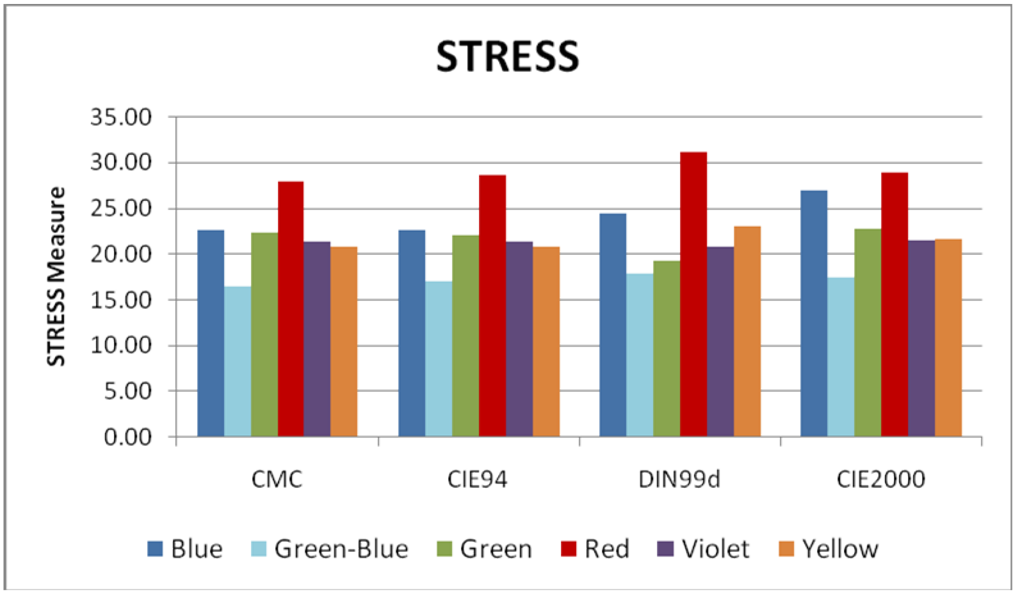

Figure 15 Comparison of color-difference formulae for optimized k_L at k_c=k_h=1 by applying STRESS measure for individual Color centers

After optimizing k_L value it was found that all the color equations improved their performances concerning wrong decision criteria. For DIN99d weighting factor k_E was also optimized but results were incomparable for having logarithmic transformation of CIELAB space.

Concerning rest of three formulae, CMC (5.66) outperformed CIE94 (6.55) as well as CIE2000 (8.33).

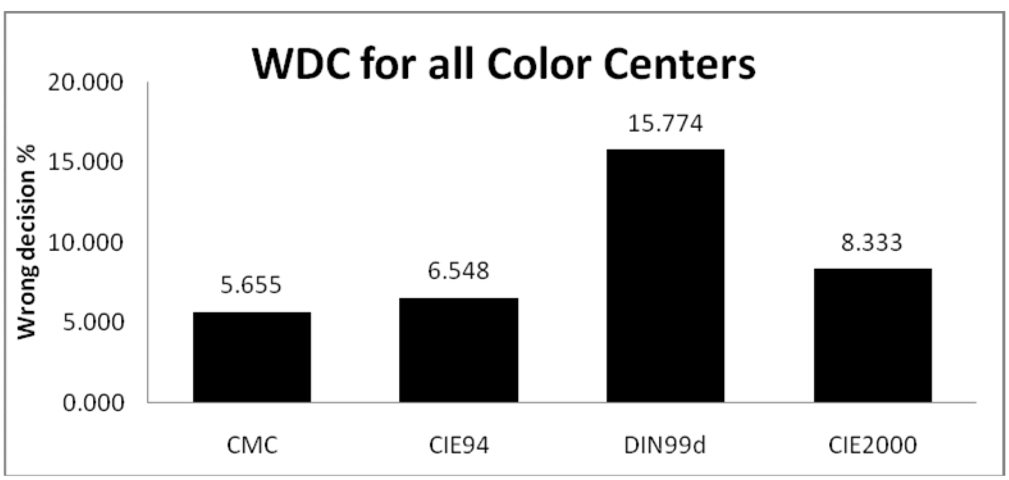

Figure 16 Comparison of color-difference formulae for optimized k_L at k_c=k_h=1 by applying STRESS measure for all color centers

For the Green and Violet color centers, all three CMC, CIE94 and CIE2000 performed equally whereas in Blue and Red color centers CIE2000 performed worst as per Figure 17. With Blue-Green color center CIE94 and CIE2000 absolutely zero wrong decision. In Yellow color center CMC performed best followed by CIE2000 and then by CIE94.

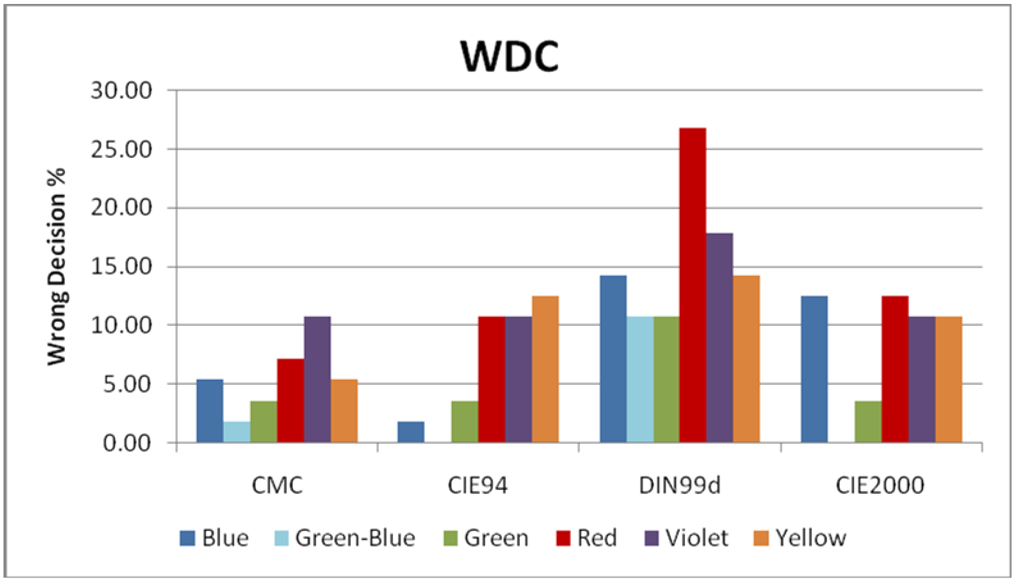

Figure 17 Comparison of color-difference formulae for optimized k_L at k_c=k_h=1 by applying Wrong Decision Criterion for individual Color center

5. Conclusion

A psychophysical method so called "Method of Adjustment" was used in this work to test the performance of color difference formulae CMC, CIE94, DIN99d, and CIE 2000 together with basic CIELAB formula on a small color difference chromatic pairs on a CRT monitor. Three criterion PF/3, STRESS and Wrong Decision percentage were employed to evaluate the results from the experiments.

In terms of PF/3 and STRESS, CIE94 performed best no matter its original form i.e., k_L= k_C=k_h=1 or with k_L value being optimized, followed by CMC and DIN99d but CIE 2000 did not perform badly also, whereas CIELAB performed worst. When considering wrong decision criteria DIN99d with its original form outperformed other formulae except CIELAB. The performance of CIELAB can be ignored in terms of low percentage of wrong decisions all because PF/3 and statistical significant analyzing tool "STRESS" values are quite high and are not comparable. By optimizing k_L value all formulae improved their performance and CIE 2000 outperformed all other formulae having lowest wrong decisions.

Finally it can be concluded that for small color differences CIE94 is being as a linear and simple transformation of CIELAB equation still performs very well, whereas DIN99d outperforms other formulae being a logarithmic transformation equation. Although CMC also performed very well but it was found that CMC can be straight away transformed into CIE94, this fact can be easily understood with the help of Figure 18.

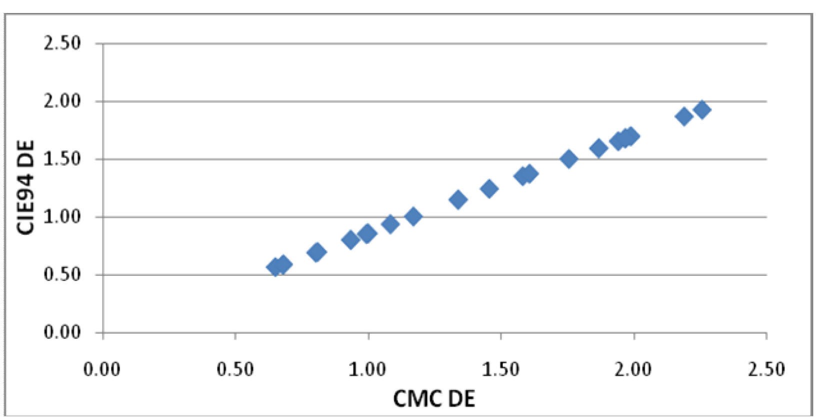

Figure 18 relation between CMC DE and CIE94 DE

6. Recommendations

The method of adjustment has the advantage that it is quick and easy to implement. However, a major disadvantage is that the observer is in control of the stimulus. This can bias the results due to variability in observers' criteria and adaptation effects. If an observer approaches the threshold from above, adaptation might result in a higher threshold than if it were approached from below. Data obtained by using method of adjustment can be used to get a first estimate of the threshold to be used in the design of more sophisticated experiments. These sophisticated experiments will lead someone to predict Accurate Threshold and Suprathreshold size in different color centers.

Comparison pairs can be so prepared that CIE DE must rang from Small to Medium and Large difference. By using measures to fit (PF/3, STRESS and Wrong Decision criterion) which were used in this research work, one will be able to investigate performance of different color-difference equations more in detail.

Along with Lightness parametric factor k_L, Chroma parametric factor k_C and Hue parametric factor k_H may also be optimized to study the actual ratio of major-semi axis to minor-semi axis of the ellipsoid.

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8. Appendices

Appendix A

Table 8a, Mean visual assessments of each of the 5 observers at Red and Green

Table 9a Mean visual assessments of each of the 5 observers at Blue and

Table 10a Mean visual assessments of each of the 5 observers at Violet and Blue-Green

Appendix B

Table 11a, DE of Blue comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

Table 12a, DE of Green-Blue comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

Table 13a, DE of Green comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

Table 14a, DE of Red comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

Table 15a, DE of Violet comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

Table 16a, DE of Yellow comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

Table 17a, Mean visual assessments of each of the 5 observers at Red and Green Color Centers

	Red					
Sr. #	1r	2r	3r	4r	5r	Mean
1	0.50	0.48	0.47	0.54	0.48	0.50
2	0.50	0.41	0.61	0.54	0.46	0.50
3	0.50	0.45	0.45	0.45	0.50	0.47
4	0.62	0.33	0.54	0.33	0.54	0.47
5	1.33	0.75	0.87	0.91	0.97	0.97
6	1.46	1.97	0.88	1.13	1.88	1.46
7	0.56	1.68	1.05	1.05	1.33	1.13
8	0.87	1.14	0.83	0.82	0.94	0.92
9	0.19	0.62	0.44	0.52	0.62	0.48
10	0.33	0.75	1.04	0.92	0.63	0.73
11	1.29	1.97	1.69	1.59	2.11	1.73
12	0.48	0.52	0.48	0.46	0.58	0.50
13	0.60	1.27	0.74	0.85	1.23	0.94
14	0.87	1.54	1.54	1.50	1.63	1.42
15	0.19	0.48	0.50	0.53	0.43	0.43
16	0.29	0.48	0.83	0.68	0.69	0.60
17	0.50	0.87	1.02	1.04	1.05	0.90
18	1.09	1.16	1.05	1.14	1.28	1.14
19	1.02	1.83	1.74	1.74	1.85	1.64
20	2.24	2.51	2.09	2.39	2.46	2.34
21	2.10	2.51	1.97	2.58	2.51	2.33
22	1.41	1.41	1.42	1.42	1.51	1.43
23	2.64	2.24	2.23	2.24	2.33	2.33
24	1.81	1.68	1.81	1.68	1.73	1.74
25	2.10	1.83	1.45	1.93	1.79	1.82
26	1.56	1.97	1.86	1.78	1.97	1.83
27	2.91	1.97	1.69	1.84	2.20	2.12
28	1.29	1.43	0.88	1.11	1.11	1.16
29	0.89	1.29	0.89	1.17	1.15	1.08
30	1.02	1.02	1.14	1.02	1.13	1.07
31	1.29	1.29	1.15	1.18	1.26	1.24
32	1.02	1.29	1.02	1.08	1.10	1.10
33	0.87	1.14	0.87	0.94	0.93	0.95
34	1.27	1.10	1.38	1.26	1.26	1.25
35	0.60	0.73	1.18	1.10	0.74	0.87
36	0.87	0.60	0.60	0.74	0.67	0.70
37	0.60	0.60	0.65	0.69	0.65	0.64
38	0.60	0.87	1.14	1.22	0.98	0.96
39	1.14	1.27	1.27	1.35	1.16	1.24
40	0.87	1.00	0.98	0.85	0.87	0.91
41	3.32	2.91	2.72	3.21	3.02	3.04
42	4.13	2.91	2.91	3.58	3.03	3.31
43	3.05	2.64	2.33	3.11	2.98	2.82
44	2.10	1.83	1.86	1.93	1.98	1.94
45	1.97	1.83	1.72	1.83	1.90	1.85
46	2.10	1.70	1.86	2.10	1.77	1.90
47	2.24	1.83	1.80	2.31	2.15	2.06
48	1.56	1.83	1.69	1.74	1.91	1.75
49	0.73	1.27	1.52	1.24	1.15	1.18
50	1.41	1.54	1.41	1.54	1.54	1.49
51	1.00	1.54	1.99	1.85	1.64	1.60
52	1.54	1.68	1.66	1.63	1.60	1.62
53	1.81	1.81	1.82	1.81	1.81	1.81
54	1.41	2.53	2.53	2.69	2.36	2.30
55	1.95	1.81	1.79	1.95	1.85	1.87
56	1.81	2.62	1.96	2.35	2.55	2.26

	Green					
Sr. #	1r	2r	3r	4r	5r	Mean
1	0.37	0.34	0.47	0.41	0.49	0.46
2	0.64	0.47	0.40	0.65	0.42	0.49
3	0.03	0.06	0.47	0.11	0.49	0.36
4	0.30	0.13	0.64	0.41	0.65	0.57
5	0.13	0.64	0.84	0.64	0.85	0.78
6	0.50	0.78	1.24	0.88	1.28	1.14
7	0.64	0.64	0.84	0.78	0.86	0.83
8	0.78	0.78	1.11	0.83	1.04	0.99
9	0.13	0.78	0.54	0.31	0.54	0.46
10	0.78	1.05	0.74	1.06	0.81	0.87
11	0.57	0.91	1.28	1.29	1.19	1.26
12	0.37	0.10	0.37	0.37	0.39	0.38
13	0.51	0.64	0.64	0.70	0.65	0.66
14	0.71	0.89	0.74	1.01	0.76	0.84
15	0.73	0.81	0.61	0.73	0.62	0.65
16	0.51	1.05	0.98	0.84	1.13	0.98
17	0.84	0.91	1.69	0.91	1.71	1.44
18	0.78	0.51	0.47	0.77	0.49	0.58
19	0.65	0.51	0.61	0.71	0.62	0.65
20	0.30	0.78	1.01	1.24	0.91	1.06
21	2.13	1.45	1.42	1.42	1.48	1.44
22	1.11	0.57	1.96	1.39	2.12	1.82
23	2.13	2.13	2.03	2.07	1.99	2.03
24	1.52	2.19	3.31	2.19	3.41	2.97
25	1.38	1.45	1.28	1.60	1.37	1.42
26	1.35	1.86	1.28	1.97	1.28	1.51
27	1.45	1.32	1.69	1.97	1.79	1.82
28	1.05	0.88	1.04	1.29	1.07	1.14
29	0.85	1.05	0.88	1.05	0.88	0.93
30	1.01	1.45	1.55	1.06	1.62	1.41
31	1.18	0.91	1.15	1.02	1.15	1.11
32	0.91	1.18	1.55	1.04	1.62	1.41
33	0.57	0.71	1.69	0.77	1.72	1.39
34	1.38	1.11	1.28	1.10	1.28	1.22
35	1.11	1.11	1.69	1.12	1.82	1.54
36	0.47	0.71	1.01	0.73	1.18	0.98
37	0.60	0.57	1.08	0.65	1.15	0.96
38	0.70	1.11	1.69	0.87	1.78	1.45
39	1.10	1.52	1.79	1.82	1.88	1.83
40	0.17	0.17	0.71	0.37	0.74	0.61
41	1.72	1.59	1.99	1.72	2.21	1.97
42	1.69	2.13	2.50	2.86	2.64	2.67
43	1.86	1.86	2.26	2.64	2.52	2.47
44	2.26	1.59	1.99	1.72	2.13	1.95
45	1.32	1.59	1.75	1.80	1.84	1.79
46	1.86	1.72	2.50	1.70	2.88	2.36
47	1.99	1.32	2.63	1.69	2.94	2.42
48	1.45	1.99	2.23	2.13	2.36	2.24
49	1.25	1.52	2.77	1.27	2.81	2.28
50	1.11	1.92	2.43	1.41	2.59	2.14
51	1.52	1.52	2.19	1.64	2.10	1.98
52	1.11	1.92	1.89	1.92	2.00	1.94
53	1.38	1.52	2.63	1.87	2.63	2.38
54	1.15	1.79	2.36	1.79	2.47	2.21
55	1.52	1.25	2.49	1.52	2.57	2.19
56	1.25	1.92	2.77	1.96	2.90	2.54

Table 18a Mean visual assessments of each of the 5 observers at Blue and Yellow Color Centers

	Blue					
Sr. #	1r	2r	3r	4r	5r	Mean
1	0.41	0.61	0.41	0.58	0.61	0.52
2	0.61	0.41	0.64	0.61	0.55	0.56
3	0.20	0.34	0.34	0.32	0.41	0.32
4	0.41	0.37	0.41	0.50	0.41	0.42
5	1.42	1.28	1.06	1.49	1.19	1.29
6	1.82	1.69	1.42	1.84	1.75	1.70
7	0.64	0.61	0.77	0.73	0.61	0.67
8	0.98	0.74	0.88	1.12	0.98	0.94
9	0.61	0.20	0.47	0.59	0.40	0.45
10	0.74	0.58	0.75	0.73	0.56	0.67
11	1.15	1.42	1.15	1.17	1.58	1.29
12	0.71	0.61	0.48	0.58	0.64	0.60
13	1.15	0.74	1.02	0.95	0.98	0.97
14	1.69	1.01	1.29	1.33	1.12	1.29
15	0.37	0.20	0.29	0.36	0.37	0.32
16	0.74	0.71	0.77	0.81	0.73	0.75
17	0.74	1.11	1.12	1.29	1.09	1.07
18	1.28	1.55	0.98	0.83	1.60	1.25
19	1.01	1.28	1.55	1.40	1.27	1.30
20	2.09	2.63	2.63	2.48	2.70	2.51
21	1.42	1.45	1.56	1.47	1.59	1.50
22	1.55	1.28	1.37	1.57	1.36	1.43
23	2.23	2.36	2.24	2.47	2.36	2.33
24	2.36	1.82	2.10	1.86	1.97	2.02
25	1.82	1.55	1.69	1.88	1.71	1.73
26	1.28	1.15	1.45	1.23	1.19	1.26
27	1.69	1.15	1.72	1.74	1.19	1.50
28	0.74	0.75	0.88	0.83	0.88	0.81
29	0.94	0.95	0.98	0.91	1.12	0.98
30	0.74	0.75	0.88	0.86	1.19	0.88
31	1.15	0.95	1.14	1.13	1.12	1.10
32	1.25	0.95	1.41	1.39	0.95	1.19
33	0.74	0.55	0.98	0.92	0.65	0.77
34	1.15	0.98	1.15	1.29	1.13	1.14
35	0.91	1.01	0.98	1.29	0.91	1.02
36	1.28	1.21	1.14	1.20	1.39	1.24
37	0.74	0.71	0.77	0.95	0.85	0.80
38	1.18	1.11	1.24	1.19	1.11	1.17
39	0.89	1.11	0.94	1.11	1.13	1.04
40	0.89	1.11	0.91	0.91	0.13	0.79
41	2.63	2.19	2.72	2.69	2.38	2.52
42	3.04	2.29	3.05	3.10	2.48	2.79
43	3.04	2.29	2.86	2.86	2.48	2.70
44	2.63	1.65	2.59	2.50	1.77	2.23
45	1.82	1.85	1.82	1.85	1.96	1.86
46	1.55	1.55	1.70	1.59	1.55	1.59
47	1.69	1.52	1.80	1.69	1.93	1.72
48	1.82	1.55	1.97	1.99	1.69	1.81
49	1.28	1.96	1.52	1.82	1.96	1.71
50	1.15	1.66	1.18	1.12	1.59	1.34
51	1.42	1.66	1.70	1.42	1.59	1.56
52	1.82	1.26	1.86	1.72	1.37	1.61
53	0.88	1.16	1.11	0.98	1.20	1.07
54	2.23	1.66	2.27	2.39	1.70	2.05
55	2.50	1.66	2.23	2.33	1.66	2.07
56	1.96	2.16	1.99	2.13	1.99	2.04

	Yellow					
Sr. #	1r	2r	3r	4r	5r	Mean
1	0.98	0.85	0.64	0.91	1.02	0.88
2	0.77	0.85	0.77	0.77	0.85	0.80
3	0.91	0.65	0.70	0.89	0.76	0.78
4	0.64	0.75	0.80	0.67	0.76	0.73
5	0.54	0.35	0.50	0.61	0.64	0.53
6	0.70	0.65	0.70	0.88	0.78	0.74
7	0.64	0.87	0.40	0.67	0.84	0.68
8	0.67	0.77	0.60	0.71	0.64	0.68
9	0.31	0.57	0.47	0.44	0.50	0.46
10	0.44	0.57	0.67	0.54	0.63	0.57
11	0.71	0.67	1.04	0.89	0.95	0.85
12	0.37	0.67	0.64	0.48	0.59	0.55
13	0.77	1.07	1.35	0.89	1.07	1.03
14	1.58	1.47	1.81	1.72	1.81	1.68
15	0.37	0.47	0.60	0.44	0.47	0.47
16	0.64	0.67	0.64	0.67	0.64	0.65
17	1.04	1.17	1.45	1.18	1.22	1.21
18	0.64	0.36	0.68	0.71	0.41	0.56
19	0.71	0.94	1.39	0.71	0.94	0.94
20	1.31	1.44	2.06	1.45	1.53	1.56
21	1.10	0.94	1.52	1.12	1.36	1.21
22	2.00	1.68	1.99	1.93	2.39	2.00
23	2.47	1.86	1.79	2.51	2.20	2.16
24	3.47	2.53	1.99	3.14	2.66	2.76
25	0.98	1.01	1.25	0.98	1.93	1.23
26	0.89	0.98	0.95	0.89	0.98	0.94
27	0.44	0.58	0.54	0.50	0.63	0.54
28	0.68	0.71	0.95	0.68	0.68	0.74
29	0.98	0.81	0.88	1.12	1.12	0.98
30	0.98	0.98	0.65	1.12	1.12	0.97
31	0.58	0.71	0.71	0.64	0.74	0.68
32	0.98	0.64	0.85	1.12	1.23	0.96
33	0.77	0.86	1.04	0.89	0.92	0.90
34	1.04	1.06	1.04	1.31	1.06	1.10
35	1.72	1.46	1.34	1.79	1.82	1.63
36	0.77	1.04	1.04	0.89	1.12	0.97
37	1.04	1.45	1.11	1.31	1.45	1.27
38	1.18	1.27	1.07	1.28	1.38	1.24
39	0.77	0.91	0.90	0.89	1.12	0.92
40	1.58	1.18	1.14	1.58	1.69	1.43
41	2.60	2.26	1.89	2.63	2.47	2.37
42	3.28	2.47	1.86	3.08	3.08	2.75
43	2.33	1.93	2.44	2.54	2.48	2.34
44	3.14	2.87	2.87	2.95	2.95	2.95
45	1.79	1.12	1.29	1.79	1.86	1.57
46	1.93	1.66	2.33	2.10	1.84	1.97
47	1.66	1.52	1.39	1.58	1.69	1.57
48	2.87	1.66	2.47	2.95	2.95	2.58
49	1.45	1.58	2.12	1.45	1.45	1.61
50	2.53	2.29	1.38	2.54	2.47	2.24
51	2.39	1.85	3.20	2.60	2.79	2.57
52	1.85	2.39	2.26	1.77	2.39	2.13
53	2.66	2.26	1.85	2.60	2.60	2.40
54	1.58	1.85	1.85	1.66	1.71	1.73
55	1.58	1.85	2.18	1.58	1.66	1.77
56	2.66	2.66	2.39	2.68	2.66	2.61

Table 19a Mean visual assessments of each of the 5 observers at Violet and Blue-Green Color Centers

	Violet					
Sr. #	1r	2r	3r	4r	5r	Mean
1	0.23	0.43	0.23	0.29	0.43	0.32
2	0.64	0.53	0.23	0.64	0.77	0.56
3	0.23	0.43	0.51	0.33	0.56	0.41
4	0.45	0.50	0.61	0.50	0.75	0.56
5	0.18	0.31	0.62	0.23	0.35	0.34
6	0.45	0.72	0.95	0.70	0.70	0.70
7	0.50	0.64	0.62	0.58	0.64	0.59
8	0.91	0.91	0.78	0.91	1.23	0.94
9	0.45	0.31	0.41	0.47	0.49	0.43
10	0.64	0.91	0.72	0.77	1.10	0.83
11	1.04	1.04	1.39	1.29	1.34	1.22
12	0.23	0.50	0.13	0.23	0.59	0.34
13	0.50	0.64	0.50	0.70	0.72	0.61
14	0.50	0.77	0.64	0.74	0.79	0.69
15	1.04	0.64	0.20	1.04	0.79	0.74
16	1.04	1.01	1.07	1.31	1.31	1.15
17	1.58	1.18	1.45	1.69	1.59	1.50
18	0.37	0.23	0.23	0.33	0.35	0.30
19	0.23	0.31	0.45	0.37	0.43	0.36
20	0.58	0.58	0.55	0.65	0.64	0.60
21	1.39	1.26	1.43	1.31	1.41	1.36
22	1.72	1.45	1.31	1.64	1.72	1.57
23	2.47	2.06	2.06	2.12	2.39	2.22
24	2.12	1.99	1.85	2.12	2.12	2.04
25	1.12	0.85	0.99	0.97	0.84	0.95
26	1.26	0.99	1.02	0.89	1.10	1.05
27	1.66	1.12	1.06	1.64	1.66	1.43
28	0.58	0.99	0.99	0.65	0.84	0.81
29	1.12	0.85	0.99	1.05	1.19	1.04
30	0.99	0.65	0.99	1.14	1.14	0.98
31	0.99	0.85	1.05	0.91	0.85	0.93
32	0.72	0.72	0.90	0.84	0.92	0.82
33	1.45	1.18	1.28	1.41	1.58	1.38
34	0.97	1.04	0.77	0.98	1.04	0.96
35	1.04	1.04	1.14	1.10	1.04	1.07
36	1.18	1.04	1.18	1.15	1.14	1.14
37	1.04	1.04	1.17	1.12	1.10	1.09
38	1.58	1.45	1.04	1.53	1.62	1.44
39	1.04	1.31	1.31	1.10	1.28	1.21
40	1.04	1.04	1.04	1.10	1.04	1.05
41	2.20	1.79	1.93	2.26	2.20	2.08
42	2.74	2.33	3.14	2.87	2.67	2.75
43	2.33	2.20	2.60	2.33	2.46	2.39
44	1.26	1.93	2.47	1.32	1.86	1.77
45	1.79	2.47	2.06	1.72	1.93	2.00
46	2.74	2.87	3.55	2.60	2.74	2.90
47	2.60	2.74	2.60	2.53	2.74	2.64
48	2.60	2.20	1.79	2.60	2.38	2.32
49	1.99	1.99	1.78	2.20	2.22	2.03
50	1.85	1.99	1.11	1.92	2.11	1.79
51	2.26	1.99	2.12	2.39	2.46	2.24
52	1.72	1.72	1.72	1.80	1.86	1.76
53	2.12	1.85	1.99	1.92	2.22	2.02
54	2.53	2.26	2.93	2.66	2.53	2.58
55	2.26	2.26	2.08	2.33	2.26	2.24
56	2.53	2.53	2.53	2.66	2.74	2.60

	Blue-Green					
Sr. #	1r	2r	3r	4r	5r	Mean
1	0.38	0.43	0.39	0.48	0.47	0.43
2	0.65	0.56	0.71	0.64	0.58	0.63
3	0.16	0.29	0.23	0.33	0.30	0.26
4	0.43	0.43	0.45	0.50	0.43	0.45
5	0.92	0.62	1.12	0.94	0.70	0.86
6	0.92	0.97	1.15	1.29	0.92	1.05
7	0.83	1.06	0.92	0.94	1.15	0.98
8	0.83	1.24	0.97	1.32	1.15	1.10
9	0.43	0.49	0.45	0.55	0.49	0.48
10	1.06	1.29	1.05	1.05	1.10	1.11
11	2.00	1.17	1.97	1.42	1.28	1.57
12	0.16	0.29	0.23	0.16	0.29	0.23
13	0.70	0.56	0.77	0.74	0.63	0.68
14	1.10	0.97	1.29	1.12	1.10	1.12
15	0.49	0.62	0.51	0.62	0.62	0.57
16	0.83	0.98	0.83	0.95	0.98	0.92
17	1.06	1.34	1.05	1.38	1.26	1.22
18	0.11	0.52	0.23	0.28	0.52	0.33
19	0.65	0.52	0.77	0.73	0.69	0.67
20	1.24	0.75	1.24	0.86	0.86	0.99
21	1.37	1.34	1.31	1.47	1.38	1.38
22	1.73	1.33	1.64	1.73	1.33	1.55
23	2.86	2.45	2.81	2.85	2.58	2.71
24	2.81	2.14	2.72	2.83	2.14	2.53
25	0.97	0.97	1.12	1.12	0.97	1.03
26	1.24	1.24	1.26	1.27	1.18	1.24
27	1.64	1.00	1.66	1.64	1.16	1.42
28	0.83	0.83	0.88	0.87	0.88	0.86
29	0.70	0.83	0.72	0.83	0.86	0.79
30	1.24	1.24	1.24	1.26	1.14	1.22
31	1.78	1.51	1.72	1.73	1.63	1.68
32	0.83	0.90	0.91	0.91	0.83	0.88
33	0.79	1.09	0.83	0.85	1.09	0.93
34	1.33	1.06	1.33	1.40	1.07	1.24
35	1.60	1.16	1.64	1.58	1.14	1.42
36	1.19	0.82	1.18	1.16	0.97	1.06
37	0.65	0.72	0.65	0.60	0.81	0.69
38	1.46	1.22	1.53	1.59	1.37	1.43
39	1.87	1.00	1.82	1.84	1.19	1.54
40	1.33	1.06	1.33	1.38	1.17	1.25
41	2.72	2.18	2.72	2.74	2.20	2.52
42	2.86	2.18	2.87	2.84	2.20	2.59
43	3.53	2.55	3.08	2.68	2.68	2.91
44	1.78	1.51	1.71	1.83	1.51	1.67
45	1.64	1.71	1.64	1.74	1.87	1.72
46	2.59	2.05	2.54	2.58	2.18	2.39
47	2.72	1.64	2.60	2.72	1.73	2.29
48	2.59	1.64	2.54	2.60	1.74	2.22
49	2.95	1.66	2.87	2.95	1.75	2.44
50	2.68	2.14	2.53	2.68	2.20	2.44
51	2.54	1.56	2.54	2.59	1.57	2.16
52	2.27	1.60	2.23	2.37	1.63	2.02
53	1.87	1.33	1.92	1.60	1.33	1.61
54	3.35	2.54	3.17	2.75	2.63	2.89
55	3.08	2.00	2.95	2.75	2.00	2.56
56	1.80	2.33	1.87	1.87	2.46	2.06

Table 20a, DE of Blue comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

	Blue Color Center														
	L	a	b	Cab*	hab*										
	33.00	-2.20	-31.42	31.50	266.00										
	Samples of Comparison Pairs					***kL***			0.46		0.46		0.34		0.40
	L	a	b	Cab*	hab*		ΔE*	ΔE CMC1	ΔE CMCopt	ΔE CIE941	ΔE CIE94opt	ΔE DIN99d	ΔE DIN99d opt	ΔE CIE00	ΔE CIE00-opt	**ΔV**
1	33.00	-3.02	-31.35	31.50	264.50		0.82	0.65	0.65	0.56	0.56	0.77	0.77	0.60	0.60	0.52
2	33.00	-3.57	-31.30	31.50	263.50		1.37	1.08	1.08	0.93	0.93	1.28	1.28	1.00	1.00	0.56
3	33.00	-1.37	-31.47	31.50	267.50		0.82	0.65	0.65	0.56	0.56	0.79	0.79	0.62	0.62	0.32
4	33.00	-0.82	-31.49	31.50	268.50		1.37	1.08	1.08	0.93	0.93	1.32	1.32	1.03	1.03	0.42
5	33.00	-2.41	-34.42	34.50	266.00		3.00	1.46	1.46	1.24	1.24	1.70	1.70	1.21	1.21	1.29
6	33.00	-2.48	-35.41	35.50	266.00		4.00	1.94	1.94	1.65	1.65	2.26	2.26	1.60	1.60	1.70
7	33.00	-1.99	-28.43	28.50	266.00		3.00	1.46	1.46	1.24	1.24	1.75	1.75	1.28	1.28	0.67
8	33.00	-1.92	-27.43	27.50	266.00		4.00	1.94	1.94	1.65	1.65	2.35	2.35	1.72	1.72	0.94
9	33.00	-1.84	-32.95	33.00	266.80		1.57	0.81	0.81	0.69	0.69	0.71	0.71	0.43	0.43	0.45
10	33.00	-1.50	-34.47	34.50	267.50		3.12	1.61	1.61	1.37	1.37	1.41	1.41	0.84	0.84	0.67
11	33.00	-0.93	-35.49	35.50	268.50		4.26	2.26	2.26	1.93	1.93	1.85	1.85	1.04	1.04	1.29
12	33.00	-1.67	-29.95	30.00	266.80		1.56	0.80	0.80	0.69	0.69	1.14	1.14	0.46	0.46	0.60
13	33.00	-1.24	-28.47	28.50	267.50		3.10	1.58	1.58	1.35	1.35	2.24	2.24	0.95	0.95	0.97
14	33.00	-0.72	-27.49	27.50	268.50		4.20	2.19	2.19	1.87	1.87	3.17	3.17	1.23	1.23	1.29
15	33.00	-2.51	-29.89	30.00	265.20		1.56	0.80	0.80	0.69	0.69	0.74	0.74	0.46	0.46	0.32
16	33.00	-2.73	-28.37	28.50	264.50		3.10	1.58	1.58	1.35	1.35	1.51	1.51	0.97	0.97	0.75
17	33.00	-3.11	-27.32	27.50	263.50		4.20	2.19	2.19	1.87	1.87	2.03	2.03	1.28	1.28	1.07
18	33.00	-2.76	-32.88	33.00	265.20		1.57	0.81	0.81	0.69	0.69	1.15	1.15	0.44	0.44	1.25
19	33.00	-3.31	-34.34	34.50	264.50		3.12	1.61	1.61	1.37	1.37	2.26	2.26	0.87	0.87	1.30
20	33.00	-4.02	-35.27	35.50	263.50		4.26	2.26	2.26	1.93	1.93	3.24	3.24	1.11	1.11	2.51
21	34.00	-2.20	-31.42	31.50	266.00		1.00	1.17	2.54	1.00	2.17	1.05	3.08	0.81	2.02	1.50
22	32.00	-2.20	-31.42	31.50	266.00		1.00	1.17	2.54	1.00	2.17	1.06	3.09	0.80	1.99	1.43
23	34.50	-2.20	-31.42	31.50	266.00		1.50	1.76	3.82	1.50	3.26	1.58	4.61	1.21	3.04	2.33
24	31.50	-2.20	-31.42	31.50	266.00		1.50	1.76	3.82	1.50	3.26	1.58	4.63	1.19	2.98	2.02
25	33.50	-2.76	-32.88	33.00	265.20		1.64	1.00	1.51	0.85	1.29	1.21	1.89	0.59	1.10	1.73
26	33.50	-2.30	-32.92	33.00	266.00		1.58	0.93	1.47	0.80	1.25	0.97	1.74	0.73	1.18	1.26
27	33.50	-1.84	-32.95	33.00	266.80		1.64	1.00	1.51	0.85	1.29	0.88	1.69	0.59	1.09	1.50
28	33.50	-2.64	-31.39	31.50	265.20		0.67	0.68	1.32	0.58	1.13	0.63	1.58	0.52	1.06	0.81
29	33.50	-1.76	-31.45	31.50	266.80		0.67	0.68	1.32	0.58	1.13	0.71	1.61	0.52	1.06	0.98
30	33.50	-2.51	-29.89	30.00	265.20		1.64	0.99	1.50	0.85	1.29	0.91	1.71	0.61	1.11	0.88
31	33.50	-2.09	-29.93	30.00	266.00		1.58	0.93	1.47	0.80	1.25	1.04	1.78	0.75	1.19	1.10
32	33.50	-1.67	-29.95	30.00	266.80		1.64	0.99	1.50	0.85	1.29	1.29	1.94	0.61	1.10	1.19
33	32.50	-2.76	-32.88	33.00	265.20		1.64	1.00	1.51	0.85	1.29	1.31	1.95	0.59	1.09	0.77
34	32.50	-2.30	-32.92	33.00	266.00		1.58	0.93	1.47	0.80	1.25	1.04	1.78	0.73	1.17	1.14
35	32.50	-1.84	-32.95	33.00	266.80		1.64	1.00	1.51	0.85	1.29	0.89	1.70	0.59	1.09	1.02
36	32.50	-2.64	-31.39	31.50	265.20		0.67	0.68	1.32	0.58	1.13	0.71	1.61	0.51	1.05	1.24
37	32.50	-1.76	-31.45	31.50	266.80		0.67	0.68	1.32	0.58	1.13	0.64	1.58	0.52	1.05	0.80
38	32.50	-2.51	-29.89	30.00	265.20		1.64	0.99	1.50	0.85	1.29	0.90	1.71	0.61	1.10	1.17
39	32.50	-2.09	-29.93	30.00	266.00		1.58	0.93	1.47	0.80	1.25	0.99	1.75	0.75	1.18	1.04
40	32.50	-1.67	-29.95	30.00	266.80		1.64	0.99	1.50	0.85	1.29	1.22	1.89	0.61	1.10	0.79
41	34.00	-3.31	-34.34	34.50	264.50		3.28	1.99	3.01	1.70	2.57	2.39	3.75	1.18	2.20	2.52
42	34.00	-2.41	-34.42	34.50	266.00		3.16	1.87	2.93	1.59	2.50	1.93	3.47	1.45	2.35	2.79
43	34.00	-1.50	-34.47	34.50	267.50		3.28	1.99	3.01	1.70	2.57	1.74	3.38	1.17	2.19	2.70
44	34.00	-3.02	-31.35	31.50	264.50		1.30	1.34	2.63	1.15	2.24	1.23	3.14	1.01	2.11	2.23
45	34.00	-1.37	-31.47	31.50	267.50		1.30	1.34	2.63	1.15	2.24	1.38	3.20	1.02	2.11	1.86
46	34.00	-2.73	-28.37	28.50	264.50		3.26	1.97	3.00	1.68	2.56	1.85	3.43	1.26	2.24	1.59
47	34.00	-1.99	-28.43	28.50	266.00		3.16	1.87	2.93	1.59	2.50	2.09	3.57	1.51	2.39	1.72
48	34.00	-1.24	-28.47	28.50	267.50		3.26	1.97	3.00	1.68	2.56	2.53	3.84	1.25	2.23	1.81
49	32.00	-3.31	-34.34	34.50	264.50		3.28	1.99	3.01	1.70	2.57	2.60	3.90	1.18	2.17	1.71
50	32.00	-2.41	-34.42	34.50	266.00		3.16	1.87	2.93	1.59	2.50	2.08	3.57	1.45	2.33	1.34
51	32.00	-1.50	-34.47	34.50	267.50		3.28	1.99	3.01	1.70	2.57	1.77	3.40	1.16	2.16	1.56
52	32.00	-3.02	-31.35	31.50	264.50		1.30	1.34	2.63	1.15	2.24	1.38	3.21	1.00	2.08	1.61
53	32.00	-1.37	-31.47	31.50	267.50		1.30	1.34	2.63	1.15	2.24	1.24	3.15	1.01	2.09	1.07
54	32.00	-2.73	-28.37	28.50	264.50		3.26	1.97	3.00	1.68	2.56	1.83	3.43	1.25	2.22	2.05
55	32.00	-1.99	-28.43	28.50	266.00		3.16	1.87	2.93	1.59	2.50	2.00	3.52	1.51	2.37	2.07
56	32.00	-1.24	-28.47	28.50	267.50		3.26	1.97	3.00	1.68	2.56	2.40	3.77	1.24	2.21	2.04

Table 21a, DE of Green-Blue comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

	Green-Blue Color Center															
	L	a	b	Cab*	hab*											
	68.00	-27.23	-3.83	27.50	188.00											
	Samples of Comparison Pairs					***kL***			0.26		0.34		0.26		0.26	
	L	a	b	Cab*	hab*		ΔE*	ΔE CMC1	ΔE CMCopt	ΔE CIE941	ΔE CIE94opt	ΔE DIN99d	ΔE DIN99dopt	ΔE CIE00	ΔE CIE00-opt	**ΔV**
1	68.00	-27.32	-3.11	27.50	186.50		0.72	0.49	0.49	0.51	0.51	0.54	0.54	0.51	0.51	0.43
2	68.00	-27.37	-2.64	27.50	185.50		1.20	0.82	0.82	0.85	0.85	0.90	0.90	0.84	0.84	0.63
3	68.00	-27.12	-4.54	27.50	189.50		0.72	0.49	0.49	0.51	0.51	0.53	0.53	0.51	0.51	0.26
4	68.00	-27.04	-5.01	27.50	190.50		1.20	0.82	0.82	0.85	0.85	0.89	0.89	0.85	0.85	0.45
5	68.00	-30.20	-4.24	30.50	188.00		3.00	1.56	1.56	1.34	1.34	1.65	1.65	1.34	1.34	0.86
6	68.00	-31.19	-4.38	31.50	188.00		4.00	2.07	2.07	1.79	1.79	2.18	2.18	1.76	1.76	1.05
7	68.00	-24.26	-3.41	24.50	188.00		3.00	1.56	1.56	1.34	1.34	1.77	1.77	1.45	1.45	0.98
8	68.00	-23.27	-3.27	23.50	188.00		4.00	2.07	2.07	1.79	1.79	2.39	2.39	1.97	1.97	1.10
9	68.00	-28.66	-4.44	29.00	188.80		1.55	0.82	0.82	0.73	0.73	0.93	0.93	0.73	0.73	0.48
10	68.00	-30.08	-5.03	30.50	189.50		3.09	1.64	1.64	1.44	1.44	1.82	1.82	1.43	1.43	1.11
11	68.00	-30.97	-5.74	31.50	190.50		4.20	2.25	2.25	2.01	2.01	2.50	2.50	1.97	1.97	1.57
12	68.00	-25.69	-3.98	26.00	188.80		1.55	0.82	0.82	0.72	0.72	0.87	0.87	0.76	0.76	0.23
13	68.00	-24.16	-4.04	24.50	189.50		3.08	1.62	1.62	1.42	1.42	1.77	1.77	1.54	1.54	0.68
14	68.00	-23.11	-4.28	23.50	190.50		4.15	2.21	2.21	1.95	1.95	2.42	2.42	2.14	2.14	1.12
15	68.00	-25.79	-3.26	26.00	187.20		1.55	0.82	0.82	0.72	0.72	0.96	0.96	0.75	0.75	0.57
16	68.00	-24.34	-2.77	24.50	186.50		3.08	1.62	1.62	1.42	1.42	1.92	1.92	1.52	1.52	0.92
17	68.00	-23.39	-2.25	23.50	185.50		4.15	2.21	2.21	1.95	1.95	2.66	2.66	2.11	2.11	1.22
18	68.00	-28.77	-3.63	29.00	187.20		1.55	0.82	0.82	0.73	0.73	0.84	0.84	0.74	0.74	0.33
19	68.00	-30.30	-3.45	30.50	186.50		3.09	1.64	1.64	1.44	1.44	1.65	1.65	1.44	1.44	0.67
20	68.00	-31.35	-3.02	31.50	185.50		4.20	2.25	2.25	2.01	2.01	2.22	2.22	1.98	1.98	0.99
21	69.00	-27.23	-3.83	27.50	188.00		1.00	0.79	3.04	1.00	2.94	0.94	3.61	0.79	3.03	1.38
22	67.00	-27.23	-3.83	27.50	188.00		1.00	0.79	3.04	1.00	2.94	0.94	3.62	0.80	3.07	1.55
23	69.50	-27.23	-3.83	27.50	188.00		1.50	1.18	4.56	1.50	4.41	1.41	5.41	1.18	4.53	2.71
24	66.50	-27.23	-3.83	27.50	188.00		1.50	1.18	4.56	1.50	4.41	1.41	5.44	1.20	4.61	2.53
25	68.50	-28.77	-3.63	29.00	187.20		1.63	0.91	1.73	0.88	1.64	0.96	1.99	0.84	1.69	1.03
26	68.50	-28.72	-4.04	29.00	188.00		1.58	0.87	1.71	0.84	1.62	0.96	1.99	0.79	1.67	1.24
27	68.50	-28.66	-4.44	29.00	188.80		1.63	0.91	1.73	0.88	1.64	1.04	2.03	0.83	1.69	1.42
28	68.50	-27.28	-3.45	27.50	187.20		0.63	0.47	1.54	0.57	1.50	0.55	1.83	0.48	1.54	0.86
29	68.50	-27.18	-4.21	27.50	188.80		0.63	0.47	1.54	0.57	1.50	0.55	1.83	0.48	1.54	0.79
30	68.50	-25.79	-3.26	26.00	187.20		1.62	0.91	1.73	0.88	1.64	1.07	2.05	0.85	1.70	1.22
31	68.50	-25.75	-3.62	26.00	188.00		1.58	0.87	1.71	0.84	1.62	0.99	2.01	0.81	1.68	1.68
32	68.50	-25.69	-3.98	26.00	188.80		1.62	0.91	1.73	0.88	1.64	0.99	2.01	0.86	1.70	0.88
33	67.50	-28.77	-3.63	29.00	187.20		1.63	0.91	1.73	0.88	1.64	0.97	2.00	0.84	1.70	0.93
34	67.50	-28.72	-4.04	29.00	188.00		1.58	0.87	1.71	0.84	1.62	0.97	2.00	0.79	1.67	1.24
35	67.50	-28.66	-4.44	29.00	188.80		1.63	0.91	1.73	0.88	1.64	1.05	2.04	0.83	1.70	1.42
36	67.50	-27.28	-3.45	27.50	187.20		0.63	0.47	1.54	0.57	1.50	0.55	1.83	0.48	1.55	1.06
37	67.50	-27.18	-4.21	27.50	188.80		0.63	0.47	1.54	0.57	1.50	0.55	1.83	0.48	1.55	0.69
38	67.50	-25.79	-3.26	26.00	187.20		1.62	0.91	1.73	0.88	1.64	1.06	2.05	0.85	1.70	1.43
39	67.50	-25.75	-3.62	26.00	188.00		1.58	0.87	1.71	0.84	1.62	0.99	2.01	0.81	1.69	1.54
40	67.50	-25.69	-3.98	26.00	188.80		1.62	0.91	1.73	0.88	1.64	0.99	2.01	0.86	1.71	1.25
41	69.00	-30.30	-3.45	30.50	186.50		3.25	1.82	3.45	1.76	3.28	1.90	3.97	1.65	3.36	2.52
42	69.00	-30.20	-4.24	30.50	188.00		3.16	1.75	3.41	1.67	3.23	1.90	3.97	1.55	3.31	2.59
43	69.00	-30.08	-5.03	30.50	189.50		3.25	1.82	3.45	1.76	3.28	2.05	4.04	1.64	3.35	3.00
44	69.00	-27.32	-3.11	27.50	186.50		1.23	0.93	3.08	1.12	2.99	1.08	3.65	0.94	3.07	1.67
45	69.00	-27.12	-4.54	27.50	189.50		1.23	0.93	3.08	1.12	2.99	1.08	3.65	0.94	3.07	1.72
46	69.00	-24.34	-2.77	24.50	186.50		3.23	1.81	3.44	1.74	3.27	2.14	4.09	1.72	3.39	2.39
47	69.00	-24.26	-3.41	24.50	188.00		3.16	1.75	3.41	1.67	3.23	2.01	4.03	1.65	3.36	2.29
48	69.00	-24.16	-4.04	24.50	189.50		3.23	1.81	3.44	1.74	3.27	2.01	4.03	1.73	3.40	2.22
49	67.00	-30.30	-3.45	30.50	186.50		3.25	1.82	3.45	1.76	3.28	1.91	3.98	1.65	3.39	2.44
50	67.00	-30.20	-4.24	30.50	188.00		3.16	1.75	3.41	1.67	3.23	1.91	3.98	1.56	3.35	2.44
51	67.00	-30.08	-5.03	30.50	189.50		3.25	1.82	3.45	1.76	3.28	2.06	4.06	1.64	3.38	2.16
52	67.00	-27.32	-3.11	27.50	186.50		1.23	0.93	3.08	1.12	2.99	1.09	3.66	0.94	3.11	2.04
53	67.00	-27.12	-4.54	27.50	189.50		1.23	0.93	3.08	1.12	2.99	1.08	3.66	0.94	3.11	1.67
54	67.00	-24.34	-2.77	24.50	186.50		3.23	1.81	3.44	1.74	3.27	2.14	4.10	1.72	3.42	2.92
55	67.00	-24.26	-3.41	24.50	188.00		3.16	1.75	3.41	1.67	3.23	2.00	4.03	1.66	3.39	2.64
56	67.00	-24.16	-4.04	24.50	189.50		3.23	1.81	3.44	1.74	3.27	2.00	4.03	1.74	3.43	2.06

Table 22a, DE of Green comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

	Green Color Center															
	L	a	b	Cab*	hab*											
	47.00	-28.94	5.21	29.40	169.80											
	Samples of Comparison Pairs					***kL***			0.21		0.25		0.21		0.24	
	L	a	b	Cab*	hab*		ΔE*	ΔE CMC1	ΔE CMCopt	ΔE CIE941	ΔE CIE94opt	ΔE DIN99d	ΔE DIN99dopt	ΔE CIE00	ΔE CIE00-opt	**ΔV**
1	47.00	-28.79	5.96	29.40	168.30		0.77	0.52	0.52	0.53	0.53	0.63	0.63	0.51	0.51	0.46
2	47.00	-28.68	6.46	29.40	167.30		1.28	0.86	0.86	0.89	0.89	1.05	1.05	0.84	0.84	0.49
3	47.00	-29.06	4.45	29.40	171.30		0.77	0.52	0.52	0.53	0.53	0.62	0.62	0.51	0.51	0.36
4	47.00	-29.13	3.94	29.40	172.30		1.28	0.86	0.86	0.89	0.89	1.04	1.04	0.85	0.85	0.57
5	47.00	-31.89	5.74	32.40	169.80		3.00	1.51	1.51	1.29	1.29	1.51	1.51	1.28	1.28	0.78
6	47.00	-32.87	5.91	33.40	169.80		4.00	2.01	2.01	1.72	1.72	2.00	2.00	1.69	1.69	1.14
7	47.00	-25.98	4.68	26.40	169.80		3.00	1.51	1.51	1.29	1.29	1.62	1.62	1.38	1.38	0.83
8	47.00	-25.00	4.50	25.40	169.80		4.00	2.01	2.01	1.72	1.72	2.19	2.19	1.86	1.86	0.99
9	47.00	-30.49	5.05	30.90	170.60		1.56	0.80	0.80	0.71	0.71	0.90	0.90	0.71	0.71	0.46
10	47.00	-32.03	4.90	32.40	171.30		3.11	1.60	1.60	1.41	1.41	1.76	1.76	1.39	1.39	0.87
11	47.00	-33.10	4.48	33.40	172.30		4.23	2.21	2.21	1.97	1.97	2.45	2.45	1.91	1.91	1.26
12	47.00	-27.53	4.56	27.90	170.60		1.55	0.80	0.80	0.70	0.70	0.80	0.80	0.72	0.72	0.38
13	47.00	-26.10	3.99	26.40	171.30		3.09	1.58	1.58	1.39	1.39	1.62	1.62	1.45	1.45	0.66
14	47.00	-25.17	3.40	25.40	172.30		4.17	2.16	2.16	1.91	1.91	2.23	2.23	2.02	2.02	0.84
15	47.00	-27.39	5.32	27.90	169.00		1.55	0.80	0.80	0.70	0.70	0.92	0.92	0.73	0.73	0.65
16	47.00	-25.85	5.35	26.40	168.30		3.09	1.58	1.58	1.39	1.39	1.83	1.83	1.47	1.47	0.98
17	47.00	-24.78	5.58	25.40	167.30		4.17	2.16	2.16	1.91	1.91	2.57	2.57	2.04	2.04	1.44
18	47.00	-30.33	5.90	30.90	169.00		1.56	0.80	0.80	0.71	0.71	0.78	0.78	0.70	0.70	0.58
19	47.00	-31.73	6.57	32.40	168.30		3.11	1.60	1.60	1.41	1.41	1.53	1.53	1.38	1.38	0.65
20	47.00	-32.58	7.34	33.40	167.30		4.23	2.21	2.21	1.97	1.97	2.09	2.09	1.89	1.89	1.06
21	48.00	-28.94	5.21	29.40	169.80		1.00	0.95	4.52	1.00	4.00	1.00	4.76	0.98	4.09	1.44
22	46.00	-28.94	5.21	29.40	169.80		1.00	0.95	4.52	1.00	4.00	1.00	4.78	0.97	4.04	1.82
23	48.50	-28.94	5.21	29.40	169.80		1.50	1.43	6.79	1.50	6.00	1.50	7.14	1.48	6.16	2.03
24	45.50	-28.94	5.21	29.40	169.80		1.50	1.43	6.79	1.50	6.00	1.51	7.17	1.45	6.03	2.97
25	47.50	-30.33	5.90	30.90	169.00		1.64	0.93	2.40	0.87	2.12	0.93	2.51	0.86	2.16	1.42
26	47.50	-30.41	5.47	30.90	169.80		1.58	0.89	2.38	0.82	2.10	0.92	2.50	0.81	2.14	1.51
27	47.50	-30.49	5.05	30.90	170.60		1.64	0.93	2.40	0.87	2.12	1.03	2.55	0.86	2.16	1.82
28	47.50	-28.86	5.61	29.40	169.00		0.65	0.55	2.28	0.58	2.02	0.60	2.41	0.56	2.06	1.14
29	47.50	-29.01	4.80	29.40	170.60		0.65	0.55	2.28	0.58	2.02	0.60	2.41	0.56	2.06	0.93
30	47.50	-27.39	5.32	27.90	169.00		1.63	0.93	2.40	0.86	2.12	1.04	2.55	0.88	2.17	1.41
31	47.50	-27.46	4.94	27.90	169.80		1.58	0.89	2.38	0.82	2.10	0.94	2.51	0.83	2.15	1.11
32	47.50	-27.53	4.56	27.90	170.60		1.63	0.93	2.40	0.86	2.12	0.95	2.51	0.87	2.16	1.41
33	46.50	-30.33	5.90	30.90	169.00		1.64	0.93	2.40	0.87	2.12	0.93	2.51	0.86	2.14	1.39
34	46.50	-30.41	5.47	30.90	169.80		1.58	0.89	2.38	0.82	2.10	0.92	2.51	0.81	2.13	1.22
35	46.50	-30.49	5.05	30.90	170.60		1.64	0.93	2.40	0.87	2.12	1.03	2.55	0.86	2.15	1.54
36	46.50	-28.86	5.61	29.40	169.00		0.65	0.55	2.28	0.58	2.02	0.60	2.41	0.56	2.04	0.98
37	46.50	-29.01	4.80	29.40	170.60		0.65	0.55	2.28	0.58	2.02	0.60	2.41	0.56	2.04	0.96
38	46.50	-27.39	5.32	27.90	169.00		1.63	0.93	2.40	0.86	2.12	1.04	2.56	0.88	2.15	1.45
39	46.50	-27.46	4.94	27.90	169.80		1.58	0.89	2.38	0.82	2.10	0.94	2.52	0.83	2.13	1.83
40	46.50	-27.53	4.56	27.90	170.60		1.63	0.93	2.40	0.86	2.12	0.95	2.52	0.87	2.15	0.61
41	48.00	-31.73	6.57	32.40	168.30		3.26	1.86	4.80	1.73	4.24	1.83	5.00	1.69	4.32	1.97
42	48.00	-31.89	5.74	32.40	169.80		3.16	1.78	4.77	1.63	4.20	1.81	5.00	1.61	4.29	2.67
43	48.00	-32.03	4.90	32.40	171.30		3.26	1.86	4.80	1.73	4.24	2.02	5.07	1.70	4.32	2.47
44	48.00	-28.79	5.96	29.40	168.30		1.26	1.08	4.55	1.13	4.04	1.18	4.80	1.11	4.12	1.95
45	48.00	-29.06	4.45	29.40	171.30		1.26	1.08	4.55	1.13	4.04	1.18	4.80	1.11	4.12	1.79
46	48.00	-25.85	5.35	26.40	168.30		3.25	1.85	4.79	1.71	4.23	2.09	5.10	1.77	4.35	2.36
47	48.00	-25.98	4.68	26.40	169.80		3.16	1.78	4.77	1.63	4.20	1.91	5.03	1.69	4.32	2.42
48	48.00	-26.10	3.99	26.40	171.30		3.25	1.85	4.79	1.71	4.23	1.91	5.03	1.75	4.34	2.24
49	46.00	-31.73	6.57	32.40	168.30		3.26	1.86	4.80	1.73	4.24	1.83	5.02	1.68	4.26	2.28
50	46.00	-31.89	5.74	32.40	169.80		3.16	1.78	4.77	1.63	4.20	1.82	5.01	1.60	4.23	2.14
51	46.00	-32.03	4.90	32.40	171.30		3.26	1.86	4.80	1.73	4.24	2.02	5.09	1.69	4.27	1.98
52	46.00	-28.79	5.96	29.40	168.30		1.26	1.08	4.55	1.13	4.04	1.18	4.82	1.09	4.07	1.94
53	46.00	-29.06	4.45	29.40	171.30		1.26	1.08	4.55	1.13	4.04	1.18	4.82	1.09	4.07	2.38
54	46.00	-25.85	5.35	26.40	168.30		3.25	1.85	4.79	1.71	4.23	2.09	5.12	1.76	4.30	2.21
55	46.00	-25.98	4.68	26.40	169.80		3.16	1.78	4.77	1.63	4.20	1.91	5.04	1.68	4.26	2.19
56	46.00	-26.10	3.99	26.40	171.30		3.25	1.85	4.79	1.71	4.23	1.91	5.04	1.75	4.29	2.54

Table 23a, DE of Red comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

	Red Color Center															
	L	a	b	Cab*	hab*											
	35.42	49.05	24.88	55.00	26.90											
	Samples of Comparison Pairs					*kL*			0.38		0.41		0.40		0.32	
	L	a	b	Cab*	hab*		ΔE*	ΔE CMC1	ΔE CMCopt	ΔE CIE941	ΔE CIE94opt	ΔE DIN99d	ΔE DIN99dopt	ΔE CIE00	ΔE CIE00-opt	**ΔV**
1	35.42	49.68	23.59	55.00	25.40		1.44	0.98	0.98	0.79	0.79	0.85	0.85	0.84	0.84	0.50
2	35.42	50.09	22.72	55.00	24.40		2.40	1.63	1.63	1.31	1.31	1.41	1.41	1.40	1.40	0.50
3	35.42	48.38	26.16	55.00	28.40		1.44	0.98	0.98	0.79	0.79	0.85	0.85	0.85	0.85	0.47
4	35.42	47.92	27.00	55.00	29.40		2.40	1.63	1.63	1.31	1.31	1.42	1.42	1.42	1.42	0.47
5	35.42	51.72	26.24	58.00	26.90		3.00	1.12	1.12	0.86	0.86	0.90	0.90	0.85	0.85	0.97
6	35.42	52.62	26.69	59.00	26.90		4.00	1.49	1.49	1.15	1.15	1.20	1.20	1.12	1.12	1.46
7	35.42	46.37	23.53	52.00	26.90		3.00	1.12	1.12	0.86	0.86	0.95	0.95	0.88	0.88	1.13
8	35.42	45.48	23.07	51.00	26.90		4.00	1.49	1.49	1.15	1.15	1.27	1.27	1.18	1.18	0.92
9	35.42	50.02	26.26	56.50	27.70		1.69	0.77	0.77	0.61	0.61	0.64	0.64	0.63	0.63	0.48
10	35.42	51.02	27.59	58.00	28.40		3.34	1.51	1.51	1.18	1.18	1.25	1.25	1.21	1.21	0.73
11	35.42	51.40	28.96	59.00	29.40		4.71	2.26	2.26	1.78	1.78	1.88	1.88	1.84	1.84	1.73
12	35.42	47.37	24.87	53.50	27.70		1.68	0.76	0.76	0.60	0.60	0.65	0.65	0.63	0.63	0.50
13	35.42	45.74	24.73	52.00	28.40		3.31	1.47	1.47	1.15	1.15	1.26	1.26	1.22	1.22	0.94
14	35.42	44.43	25.04	51.00	29.40		4.62	2.17	2.17	1.71	1.71	1.88	1.88	1.83	1.83	1.42
15	35.42	48.04	23.54	53.50	26.10		1.68	0.76	0.76	0.60	0.60	0.65	0.65	0.62	0.62	0.43
16	35.42	46.97	22.30	52.00	25.40		3.31	1.47	1.47	1.15	1.15	1.26	1.26	1.21	1.21	0.60
17	35.42	46.44	21.07	51.00	24.40		4.62	2.17	2.17	1.71	1.71	1.87	1.87	1.81	1.81	0.90
18	35.42	50.74	24.86	56.50	26.10		1.69	0.77	0.77	0.61	0.61	0.65	0.65	0.62	0.62	1.14
19	35.42	52.39	24.88	58.00	25.40		3.34	1.51	1.51	1.18	1.18	1.25	1.25	1.20	1.20	1.64
20	35.42	53.73	24.37	59.00	24.40		4.71	2.26	2.26	1.78	1.78	1.87	1.87	1.82	1.82	2.34
21	36.42	49.05	24.88	55.00	26.90		1.00	1.12	2.95	1.00	2.44	1.04	2.59	0.83	2.60	2.33
22	34.42	49.05	24.88	55.00	26.90		1.00	1.12	2.94	1.00	2.44	1.04	2.60	0.82	2.57	1.43
23	36.92	49.05	24.88	55.00	26.90		1.50	1.68	4.42	1.50	3.66	1.56	3.89	1.25	3.92	2.33
24	33.92	49.05	24.88	55.00	26.90		1.50	1.68	4.42	1.50	3.66	1.56	3.90	1.23	3.84	1.74
25	35.92	50.74	24.86	56.50	26.10		1.76	0.95	1.67	0.79	1.36	0.84	1.46	0.75	1.44	1.82
26	35.92	50.39	25.56	56.50	26.90		1.58	0.79	1.58	0.66	1.30	0.70	1.38	0.60	1.37	1.83
27	35.92	50.02	26.26	56.50	27.70		1.76	0.95	1.67	0.79	1.36	0.83	1.45	0.75	1.44	2.12
28	35.92	49.39	24.20	55.00	26.10		0.92	0.77	1.57	0.65	1.29	0.69	1.38	0.61	1.37	1.16
29	35.92	48.70	25.57	55.00	27.70		0.92	0.77	1.57	0.65	1.29	0.68	1.37	0.61	1.38	1.08
30	35.92	48.04	23.54	53.50	26.10		1.75	0.95	1.66	0.78	1.36	0.83	1.45	0.75	1.44	1.07
31	35.92	47.71	24.21	53.50	26.90		1.58	0.79	1.58	0.66	1.30	0.69	1.38	0.60	1.37	1.24
32	35.92	47.37	24.87	53.50	27.70		1.75	0.95	1.66	0.78	1.36	0.82	1.45	0.75	1.44	1.10
33	34.92	50.74	24.86	56.50	26.10		1.76	0.95	1.66	0.79	1.36	0.82	1.44	0.75	1.43	0.95
34	34.92	50.39	25.56	56.50	26.90		1.58	0.79	1.57	0.66	1.29	0.68	1.37	0.59	1.35	1.25
35	34.92	50.02	26.26	56.50	27.70		1.76	0.95	1.66	0.79	1.36	0.83	1.45	0.75	1.43	0.87
36	34.92	49.39	24.20	55.00	26.10		0.92	0.77	1.56	0.65	1.29	0.68	1.37	0.61	1.36	0.70
37	34.92	48.70	25.57	55.00	27.70		0.92	0.77	1.56	0.65	1.29	0.69	1.38	0.61	1.36	0.64
38	34.92	48.04	23.54	53.50	26.10		1.75	0.94	1.66	0.78	1.36	0.83	1.45	0.75	1.43	0.96
39	34.92	47.71	24.21	53.50	26.90		1.58	0.79	1.57	0.66	1.29	0.70	1.38	0.60	1.36	1.24
40	34.92	47.37	24.87	53.50	27.70		1.75	0.94	1.66	0.78	1.36	0.84	1.46	0.75	1.43	0.91
41	36.42	52.39	24.88	58.00	25.40		3.49	1.88	3.31	1.55	2.71	1.64	2.89	1.46	2.87	3.04
42	36.42	51.72	26.24	58.00	26.90		3.16	1.58	3.16	1.32	2.59	1.39	2.75	1.19	2.74	3.31
43	36.42	51.02	27.59	58.00	28.40		3.49	1.88	3.31	1.55	2.71	1.62	2.88	1.47	2.87	2.82
44	36.42	49.68	23.59	55.00	25.40		1.75	1.49	3.11	1.27	2.57	1.35	2.73	1.19	2.74	1.94
45	36.42	48.38	26.16	55.00	28.40		1.75	1.49	3.11	1.27	2.57	1.33	2.72	1.19	2.74	1.85
46	36.42	46.97	22.30	52.00	25.40		3.46	1.85	3.30	1.53	2.70	1.63	2.88	1.47	2.87	1.90
47	36.42	46.37	23.53	52.00	26.90		3.16	1.58	3.16	1.32	2.59	1.39	2.76	1.21	2.75	2.06
48	36.42	45.74	24.73	52.00	28.40		3.46	1.85	3.30	1.53	2.70	1.61	2.87	1.47	2.87	1.75
49	34.42	52.39	24.88	58.00	25.40		3.49	1.88	3.31	1.55	2.71	1.60	2.87	1.46	2.83	1.18
50	34.42	51.72	26.24	58.00	26.90		3.16	1.58	3.15	1.32	2.59	1.36	2.74	1.18	2.70	1.49
51	34.42	51.02	27.59	58.00	28.40		3.49	1.88	3.31	1.55	2.71	1.62	2.88	1.46	2.84	1.60
52	34.42	49.68	23.59	55.00	25.40		1.75	1.49	3.10	1.27	2.56	1.33	2.73	1.18	2.70	1.62
53	34.42	48.38	26.16	55.00	28.40		1.75	1.49	3.10	1.27	2.56	1.35	2.74	1.18	2.70	1.81
54	34.42	46.97	22.30	52.00	25.40		3.46	1.85	3.29	1.53	2.70	1.63	2.89	1.46	2.84	2.30
55	34.42	46.37	23.53	52.00	26.90		3.16	1.58	3.15	1.32	2.59	1.42	2.77	1.20	2.71	1.87
56	34.42	45.74	24.73	52.00	28.40		3.46	1.85	3.29	1.53	2.70	1.66	2.90	1.47	2.84	2.26

Table 24a, DE of Violet comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

	Violet Color Center															
	L	a	b	Cab*	hab*											
	22.50	23.75	-14.84	28.00	328.00											
	Samples of Comparison Pairs					***kL***			0.35		0.26		0.26		0.18	
	L	a	b	Cab*	hab*		ΔE*	ΔE CMC1	ΔE CMCopt	ΔE CIE941	ΔE CIE94opt	ΔE DIN99d	ΔE DIN99dopt	ΔE CIE00	ΔE CIE00-opt	**ΔV**
1	22.50	23.35	-15.45	28.00	326.50		0.73	0.54	0.54	0.52	0.52	0.72	0.72	0.48	0.48	0.32
2	22.50	23.08	-15.86	28.00	325.50		1.22	0.89	0.89	0.86	0.86	1.20	1.20	0.81	0.81	0.56
3	22.50	24.13	-14.21	28.00	329.50		0.73	0.54	0.54	0.52	0.52	0.71	0.71	0.48	0.48	0.41
4	22.50	24.37	-13.79	28.00	330.50		1.22	0.89	0.89	0.86	0.86	1.17	1.17	0.79	0.79	0.56
5	22.50	26.29	-16.43	31.00	328.00		3.00	1.54	1.54	1.33	1.33	1.49	1.49	1.31	1.31	0.34
6	22.50	27.14	-16.96	32.00	328.00		4.00	2.06	2.06	1.77	1.77	1.97	1.97	1.73	1.73	0.70
7	22.50	21.20	-13.25	25.00	328.00		3.00	1.54	1.54	1.33	1.33	1.60	1.60	1.42	1.42	0.59
8	22.50	20.35	-12.72	24.00	328.00		4.00	2.06	2.06	1.77	1.77	2.16	2.16	1.92	1.92	0.94
9	22.50	25.23	-15.28	29.50	328.80		1.55	0.82	0.82	0.72	0.72	0.90	0.90	0.73	0.73	0.43
10	22.50	26.71	-15.73	31.00	329.50		3.10	1.64	1.64	1.43	1.43	1.76	1.76	1.42	1.42	0.83
11	22.50	27.85	-15.76	32.00	330.50		4.21	2.27	2.27	1.99	1.99	2.48	2.48	1.94	1.94	1.22
12	22.50	22.67	-13.73	26.50	328.80		1.55	0.82	0.82	0.72	0.72	0.81	0.81	0.72	0.72	0.34
13	22.50	21.54	-12.69	25.00	329.50		3.08	1.62	1.62	1.41	1.41	1.64	1.64	1.46	1.46	0.61
14	22.50	20.89	-11.82	24.00	330.50		4.16	2.22	2.22	1.94	1.94	2.27	2.27	2.01	2.01	0.69
15	22.50	22.28	-14.36	26.50	327.20		1.55	0.82	0.82	0.72	0.72	0.92	0.92	0.75	0.75	0.74
16	22.50	20.85	-13.80	25.00	326.50		3.08	1.62	1.62	1.41	1.41	1.84	1.84	1.52	1.52	1.15
17	22.50	19.78	-13.59	24.00	325.50		4.16	2.22	2.22	1.94	1.94	2.59	2.59	2.11	2.11	1.50
18	22.50	24.80	-15.98	29.50	327.20		1.55	0.82	0.82	0.72	0.72	0.80	0.80	0.71	0.71	0.30
19	22.50	25.85	-17.11	31.00	326.50		3.10	1.64	1.64	1.43	1.43	1.56	1.56	1.38	1.38	0.36
20	22.50	26.37	-18.12	32.00	325.50		4.21	2.27	2.27	1.99	1.99	2.16	2.16	1.89	1.89	0.60
21	23.50	23.75	-14.84	28.00	328.00		1.00	1.52	4.33	1.00	3.85	1.08	4.16	0.71	3.97	1.36
22	21.50	23.75	-14.84	28.00	328.00		1.00	1.52	4.33	1.00	3.85	1.08	4.17	0.71	3.93	1.57
23	24.00	23.75	-14.84	28.00	328.00		1.50	2.27	6.49	1.50	5.77	1.62	6.23	1.07	5.97	2.22
24	21.00	23.75	-14.84	28.00	328.00		1.50	2.27	6.49	1.50	5.77	1.63	6.26	1.06	5.87	2.04
25	23.00	24.80	-15.98	29.50	327.20		1.63	1.12	2.32	0.88	2.05	0.96	2.23	0.79	2.10	0.95
26	23.00	25.02	-15.63	29.50	328.00		1.58	1.08	2.30	0.83	2.03	0.93	2.22	0.76	2.09	1.05
27	23.00	25.23	-15.28	29.50	328.80		1.63	1.12	2.32	0.88	2.05	1.05	2.27	0.81	2.11	1.43
28	23.00	23.54	-15.17	28.00	327.20		0.63	0.81	2.18	0.57	1.94	0.66	2.12	0.44	2.00	0.81
29	23.00	23.95	-14.50	28.00	328.80		0.63	0.81	2.18	0.57	1.94	0.66	2.12	0.44	2.00	1.04
30	23.00	22.28	-14.36	26.50	327.20		1.63	1.12	2.31	0.87	2.05	1.07	2.28	0.83	2.12	0.98
31	23.00	22.47	-14.04	26.50	328.00		1.58	1.08	2.30	0.83	2.03	0.95	2.22	0.78	2.10	0.93
32	23.00	22.67	-13.73	26.50	328.80		1.63	1.12	2.31	0.87	2.05	0.98	2.23	0.81	2.11	0.82
33	22.00	24.80	-15.98	29.50	327.20		1.63	1.12	2.32	0.88	2.05	0.96	2.23	0.79	2.09	1.38
34	22.00	25.02	-15.63	29.50	328.00		1.58	1.08	2.30	0.83	2.03	0.93	2.22	0.76	2.08	0.96
35	22.00	25.23	-15.28	29.50	328.80		1.63	1.12	2.32	0.88	2.05	1.05	2.27	0.81	2.10	1.07
36	22.00	23.54	-15.17	28.00	327.20		0.63	0.81	2.18	0.57	1.94	0.66	2.12	0.44	1.99	1.14
37	22.00	23.95	-14.50	28.00	328.80		0.63	0.81	2.18	0.57	1.94	0.66	2.12	0.44	1.99	1.09
38	22.00	22.28	-14.36	26.50	327.20		1.63	1.12	2.31	0.87	2.05	1.07	2.28	0.83	2.11	1.44
39	22.00	22.47	-14.04	26.50	328.00		1.58	1.08	2.30	0.83	2.03	0.95	2.23	0.78	2.09	1.21
40	22.00	22.67	-13.73	26.50	328.80		1.63	1.12	2.31	0.87	2.05	0.98	2.24	0.81	2.10	1.05
41	23.50	25.85	-17.11	31.00	326.50		3.25	2.23	4.63	1.75	4.10	1.90	4.44	1.56	4.20	2.08
42	23.50	26.29	-16.43	31.00	328.00		3.16	2.16	4.60	1.66	4.07	1.84	4.42	1.50	4.18	2.75
43	23.50	26.71	-15.73	31.00	329.50		3.25	2.23	4.63	1.75	4.10	2.07	4.52	1.59	4.21	2.39
44	23.50	23.35	-15.45	28.00	326.50		1.24	1.61	4.36	1.13	3.88	1.30	4.22	0.86	4.00	1.77
45	23.50	24.13	-14.21	28.00	329.50		1.24	1.61	4.36	1.13	3.88	1.29	4.22	0.86	4.00	2.00
46	23.50	20.85	-13.80	25.00	326.50		3.24	2.22	4.62	1.73	4.10	2.13	4.54	1.68	4.25	2.90
47	23.50	21.20	-13.25	25.00	328.00		3.16	2.16	4.60	1.66	4.07	1.93	4.45	1.59	4.21	2.64
48	23.50	21.54	-12.69	25.00	329.50		3.24	2.22	4.62	1.73	4.10	1.96	4.47	1.62	4.23	2.32
49	21.50	25.85	-17.11	31.00	326.50		3.25	2.23	4.63	1.75	4.10	1.90	4.45	1.55	4.16	2.03
50	21.50	26.29	-16.43	31.00	328.00		3.16	2.16	4.60	1.66	4.07	1.84	4.43	1.49	4.14	1.79
51	21.50	26.71	-15.73	31.00	329.50		3.25	2.23	4.63	1.75	4.10	2.07	4.53	1.58	4.17	2.24
52	21.50	23.35	-15.45	28.00	326.50		1.24	1.61	4.36	1.13	3.88	1.30	4.23	0.86	3.96	1.76
53	21.50	24.13	-14.21	28.00	329.50		1.24	1.61	4.36	1.13	3.88	1.29	4.23	0.85	3.96	2.02
54	21.50	20.85	-13.80	25.00	326.50		3.24	2.22	4.62	1.73	4.10	2.13	4.56	1.67	4.21	2.58
55	21.50	21.20	-13.25	25.00	328.00		3.16	2.16	4.60	1.66	4.07	1.93	4.47	1.58	4.17	2.24
56	21.50	21.54	-12.69	25.00	329.50		3.24	2.22	4.62	1.73	4.10	1.96	4.48	1.62	4.19	2.60

Table 25a, DE of Yellow comparison pairs calculated by different Formulae Vs. visual difference of anchor pairs

	Yellow Color Center															
	L	a	b	Cab*	hab*											
	80.00	16.88	76.15	78.00	77.50											
	Samples of Comparison Pairs					***kL***			0.19		0.36		0.27		0.20	
	L	a	b	Cab*	hab*		ΔE*	ΔE CMC1	ΔE CMCopt	ΔE CIE941	ΔE CIE94opt	ΔE DIN99d	ΔE DIN99dopt	ΔE CIE00	ΔE CIE00-opt	**ΔV**
1	80.00	18.87	75.68	78.00	76.00		2.04	1.28	1.28	0.94	0.94	1.12	1.12	1.22	1.22	0.88
2	80.00	20.19	75.34	78.00	75.00		3.40	2.14	2.14	1.57	1.57	1.87	1.87	2.03	2.03	0.80
3	80.00	14.88	76.57	78.00	79.00		2.04	1.28	1.28	0.94	0.94	1.13	1.13	1.22	1.22	0.78
4	80.00	13.54	76.82	78.00	80.00		3.40	2.14	2.14	1.57	1.57	1.88	1.88	2.03	2.03	0.73
5	80.00	17.53	79.08	81.00	77.50		3.00	0.97	0.97	0.67	0.67	0.71	0.71	0.66	0.66	0.53
6	80.00	17.75	80.06	82.00	77.50		4.00	1.29	1.29	0.89	0.89	0.94	0.94	0.87	0.87	0.74
7	80.00	16.23	73.22	75.00	77.50		3.00	0.97	0.97	0.67	0.67	0.73	0.73	0.68	0.68	0.68
8	80.00	16.02	72.25	74.00	77.50		4.00	1.29	1.29	0.89	0.89	0.98	0.98	0.90	0.90	0.68
9	80.00	16.12	77.85	79.50	78.30		1.86	0.84	0.84	0.61	0.61	0.76	0.76	0.73	0.73	0.46
10	80.00	15.46	79.51	81.00	79.00		3.65	1.63	1.63	1.17	1.17	1.45	1.45	1.39	1.39	0.57
11	80.00	14.24	80.75	82.00	80.00		5.31	2.55	2.55	1.84	1.84	2.28	2.28	2.24	2.24	0.85
12	80.00	15.51	74.91	76.50	78.30		1.85	0.83	0.83	0.60	0.60	0.64	0.64	0.73	0.73	0.55
13	80.00	14.31	73.62	75.00	79.00		3.61	1.59	1.59	1.14	1.14	1.22	1.22	1.38	1.38	1.03
14	80.00	12.85	72.88	74.00	80.00		5.19	2.45	2.45	1.77	1.77	1.93	1.93	2.19	2.19	1.68
15	80.00	17.60	74.45	76.50	76.70		1.85	0.83	0.83	0.60	0.60	0.75	0.75	0.73	0.73	0.47
16	80.00	18.14	72.77	75.00	76.00		3.61	1.59	1.59	1.14	1.14	1.43	1.43	1.38	1.38	0.65
17	80.00	19.15	71.48	74.00	75.00		5.19	2.45	2.45	1.77	1.77	2.24	2.24	2.19	2.19	1.21
18	80.00	18.29	77.37	79.50	76.70		1.86	0.84	0.84	0.61	0.61	0.64	0.64	0.73	0.73	0.56
19	80.00	19.60	78.59	81.00	76.00		3.65	1.63	1.63	1.17	1.17	1.22	1.22	1.39	1.39	0.94
20	80.00	21.22	79.21	82.00	75.00		5.31	2.55	2.55	1.84	1.84	1.95	1.95	2.24	2.24	1.56
21	81.00	16.88	76.15	78.00	77.50		1.00	0.74	3.87	1.00	2.78	0.91	3.36	0.69	3.44	1.21
22	79.00	16.88	76.15	78.00	77.50		1.00	0.74	3.87	1.00	2.78	0.91	3.37	0.70	3.48	2.00
23	81.50	16.88	76.15	78.00	77.50		1.50	1.10	5.81	1.50	4.17	1.36	5.04	1.03	5.15	2.16
24	78.50	16.88	76.15	78.00	77.50		1.50	1.10	5.81	1.50	4.17	1.37	5.06	1.05	5.23	2.76
25	80.50	18.29	77.37	79.50	76.70		1.93	0.92	2.11	0.79	1.52	0.80	1.81	0.81	1.87	1.23
26	80.50	17.21	77.62	79.50	77.50		1.58	0.61	2.00	0.60	1.43	0.58	1.72	0.48	1.76	0.94
27	80.50	16.12	77.85	79.50	78.30		1.93	0.92	2.11	0.79	1.52	0.87	1.84	0.81	1.87	0.54
28	80.50	17.94	75.91	78.00	76.70		1.20	0.78	2.05	0.71	1.48	0.77	1.79	0.74	1.84	0.74
29	80.50	15.82	76.38	78.00	78.30		1.20	0.78	2.05	0.71	1.48	0.73	1.78	0.74	1.84	0.98
30	80.50	17.60	74.45	76.50	76.70		1.91	0.91	2.11	0.78	1.51	0.89	1.85	0.81	1.87	0.97
31	80.50	16.56	74.69	76.50	77.50		1.58	0.61	2.00	0.60	1.43	0.58	1.72	0.48	1.76	0.68
32	80.50	15.51	74.91	76.50	78.30		1.91	0.91	2.11	0.78	1.51	0.77	1.79	0.81	1.87	0.96
33	79.50	18.29	77.37	79.50	76.70		1.93	0.92	2.11	0.79	1.52	0.77	1.79	0.81	1.88	0.90
34	79.50	17.21	77.62	79.50	77.50		1.58	0.61	2.00	0.60	1.43	0.58	1.72	0.48	1.77	1.10
35	79.50	16.12	77.85	79.50	78.30		1.93	0.92	2.11	0.79	1.52	0.90	1.85	0.81	1.88	1.63
36	79.50	17.94	75.91	78.00	76.70		1.20	0.78	2.05	0.71	1.48	0.73	1.78	0.74	1.85	0.97
37	79.50	15.82	76.38	78.00	78.30		1.20	0.78	2.05	0.71	1.48	0.77	1.80	0.74	1.85	1.27
38	79.50	17.60	74.45	76.50	76.70		1.91	0.91	2.11	0.78	1.51	0.86	1.84	0.81	1.88	1.24
39	79.50	16.56	74.69	76.50	77.50		1.58	0.61	2.00	0.60	1.43	0.58	1.72	0.48	1.77	0.92
40	79.50	15.51	74.91	76.50	78.30		1.91	0.91	2.11	0.78	1.51	0.80	1.81	0.81	1.88	1.43
41	81.00	19.60	78.59	81.00	76.00		3.79	1.79	4.20	1.54	3.01	1.55	3.59	1.56	3.71	2.37
42	81.00	17.53	79.08	81.00	77.50		3.16	1.22	3.99	1.20	2.86	1.15	3.43	0.95	3.50	2.75
43	81.00	15.46	79.51	81.00	79.00		3.79	1.79	4.20	1.54	3.01	1.68	3.65	1.56	3.71	2.34
44	81.00	18.87	75.68	78.00	76.00		2.27	1.48	4.08	1.37	2.93	1.48	3.56	1.40	3.65	2.95
45	81.00	14.88	76.57	78.00	79.00		2.27	1.48	4.08	1.37	2.93	1.41	3.53	1.40	3.65	1.57
46	81.00	18.14	72.77	75.00	76.00		3.74	1.75	4.19	1.51	3.00	1.73	3.67	1.54	3.71	1.97
47	81.00	16.23	73.22	75.00	77.50		3.16	1.22	3.99	1.20	2.86	1.17	3.44	0.96	3.51	1.57
48	81.00	14.31	73.62	75.00	79.00		3.74	1.75	4.19	1.51	3.00	1.49	3.56	1.54	3.71	2.58
49	79.00	19.60	78.59	81.00	76.00		3.79	1.79	4.20	1.54	3.01	1.49	3.57	1.56	3.75	1.61
50	79.00	17.53	79.08	81.00	77.50		3.16	1.22	3.99	1.20	2.86	1.16	3.45	0.96	3.54	2.24
51	79.00	15.46	79.51	81.00	79.00		3.79	1.79	4.20	1.54	3.01	1.75	3.69	1.56	3.75	2.57
52	79.00	18.87	75.68	78.00	76.00		2.27	1.48	4.08	1.37	2.93	1.41	3.54	1.40	3.69	2.13
53	79.00	14.88	76.57	78.00	79.00		2.27	1.48	4.08	1.37	2.93	1.48	3.57	1.40	3.69	2.40
54	79.00	18.14	72.77	75.00	76.00		3.74	1.75	4.19	1.51	3.00	1.67	3.65	1.55	3.74	1.73
55	79.00	16.23	73.22	75.00	77.50		3.16	1.22	3.99	1.20	2.86	1.16	3.45	0.97	3.54	1.77
56	79.00	14.31	73.62	75.00	79.00		3.74	1.75	4.19	1.51	3.00	1.55	3.60	1.55	3.74	2.61