# Comparison of color appearance changes assessed by observers versus predicted by CIECAM02

***M. Harrar* [a, d], *G. Baillet* [a], *B. Bourdoncle* [a], *H. Brettel* [b], *K. O'Regan* [c] *and F. Viénot* [d]**

[a] *Recherche & Développement, Essilor International, 94106 St Maur Des Fossés (FRANCE)*

[b] *Département du Traitement du Signal et des Images, CNRS, Ecole Nationale Supérieure des Télécommunications, 75013 Paris (FRANCE)*

[c] *Laboratoire de Psychologie Expérimentale, CNRS, EPHE, Université René Descartes Paris 5, 92100 Boulogne Billancourt (FRANCE)*

[d] *Centre de Recherches sur la Conservation des Documents Graphiques, CNRS, Muséum National d'Histoire Naturelle, 75005 Paris (FRANCE)*

Corresponding author: M. Harrar (harrar@mnhn.fr)

## ABSTRACT

We propose to validate a method for testing color appearance in a real situation and to compare these results with the predictions of a color appearance model. A light booth with filtered lamps and samples from the NCS atlas are used in the real situation. The model CIECAM02 is implemented with the appropriate parameters for the light booth. The results show that the psychophysical method designed for the real situation, based on Major/Minor Hue, is efficient to assess accurately enough color appearance changes of color patches. The color appearance model made predictions that get close to the psychophysical results but that cannot be substituted to experiment in real complex situation.

## 1. INTRODUCTION

Color appearance changes due to illuminant variations are predicted by color appearance models. These models are based on real observations and built to answer questions about multimedia (CIECAM97s, CIECAM02[1]), color constancy (Brainard[2]), or physiology (DeValois & DeValois[3]).

But the relevance of these models has to be verified when investigating real pigmented samples seen under complex illuminant situations.

Indeed, with real materials, the human visual system is facing geometrical parameters related to the illumination and 3-D reflection, spectral variations of surface reflection, and cognitive information, which can exceed the simple colorimetric specification.

The purpose of this study is, on the one hand, to propose and to validate a method for testing color appearance in a real situation, with real samples and real observers; and, on the other hand, to compare the results of the real situation with the predictions of the last version of the CIE color appearance model (CIECAM02).

The method for testing color appearance in a real situation should be sensitive enough to measure the changes of color appearance due to a realistic change in the spectral distribution of the illuminant. The color appearance model (CIECAM02) has to be implemented and to be run with the color specifications of the real material in the real situation.

## 2. METHOD

### 2.1. Real situation

A light booth is illuminated with tungsten halogen filtered lamps that provide 4300 K spectrally matched daylight and several levels of luminance on a white sample: 1700 cd/m² for the control illumination, up to a multiple of this value to still allow 1700 cd/m² luminance even with additional filters.

The light from the daylight booth ($x,y_{control}\{0,37\ 0,38\}$) is modified by one of six filters with a continuous and regular spectral transmittance, which are available commercially to reduce high illumination and known to modify the ambiance or the comfort of the illumination. Such a filtering yields broad-spectrum color illumination, which we refer to as complex illumination. Only the results for complex illuminants I, II, III are presented ($x_I,y_I\{0,35\ 0,36\}$, $x_{II},y_{II}\{0,49\ 0,42\}$, $x_{III},y_{III}\{0,31\ 0,33\}$).

Four series of samples were selected from the NCS atlas, at 0505, 0510, 0520 and 2050 Blackness Chromaticness level. The series 0505 appears like desaturated compared with the series 2050 which is strongly colored. Within each series, only the NCS Hue varies.

The chromatic appearance of the sample was assessed according to a color-naming task. Every sample was presented to the observer one at a time. The instruction given to the observer was: "Name the sample using two hues among red, yellow, green and blue. The first named hue is considered as the dominant hue of the sample". Therefore, the hue circle is apparently divided in 8 segments according to the observer's judgment. Each segment corresponds to a named dominant hue and a named secondary hue. We have called this hue combination "Major/Minor Hue" or "MMH". Any change of appearance is traceable with a shift of the border between adjacent MMHs and is quantified by calculating the perceived hue angle of the samples.

Five color normal observers took part in the experiment. During one session, an observer was asked to examine the 4 series of samples, under a different illuminant each. A session lasted about 20 minutes. All combinations of series and illuminant were planned along a Latin square distribution. All measurements were repeated 3 times. At the end of the experiment, more than 15 000 visual judgments have been analyzed.

### 2.2. Color appearance model

The color appearance model CIECAM02 was implemented on the MatLab software. The spectra of the samples were measured with the spectrocolorimeter X-Rite, and the spectra of the various illuminants were measured using the spectroradiometer Minolta CS1000 in the real situation i.e. in the light booth with the various complex illuminants.

The computation of CIECAM02 was run according to the data of the samples, the spectra of the various complex illuminants and the parameters relevant for the light booth.

## 3. RESULTS

### 3.1. Real situation

In our experiment, the observers have not divided the hue circle in 8 equal segments as defined in the NCS atlas. The control average circle obtained under the control illumination by the observers consists of 8 segments including from 3 to 7 samples.

On a hue scale with 40 steps, for each series, hue borders with a complex illuminant can shift as much as 3 steps, compared with the control illumination. Then, a given domain for a Major/Minor Hue can expand in some regions while reducing in other regions of the hue circle under the effect of the illuminant (figure 1). Only the results for illuminants I, II, III and for the series 2050 are displayed.

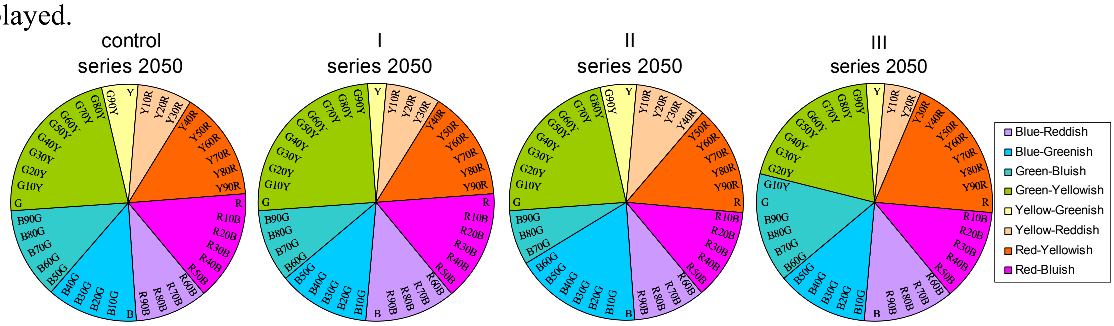


**Figure 1.** Major/Minor Hue given to the NCS 2050 series samples. All the observers' data are averaged. From left to right: control illuminant, complex illuminant I, II, III.

These psychophysical results were encoded in order to calculate their hue angle and be plotted in a hue circle. Then, we plotted the differences between each complex illuminant and the control illumination for all the series (figure 2). We observe small differences between the complex illuminant I compared with the control illumination, noticeable differences between the complex illuminant II and the control illuminant, and sizeable differences between the complex illuminant III and the control illumination through all the series.

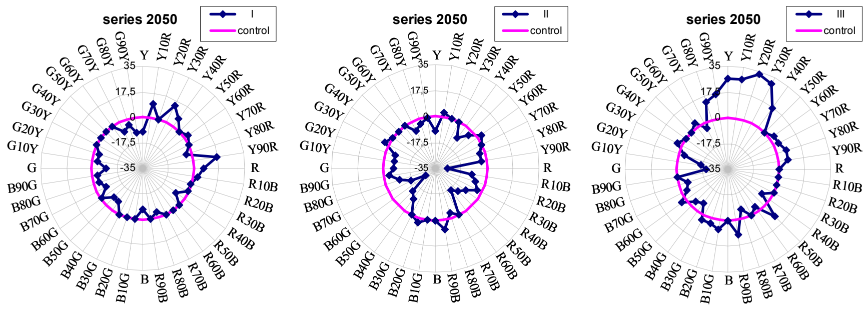


**Figure 2.** Differences of Major/Minor Hue given to the NCS 2050 series samples between the complex illuminant I, II, III and the control illuminant. Positive shift along radius indicates clockwise apparent hue change when illumination changes from control to complex. Example: NCS 2050-Y20R is perceived yellow-reddish under control illuminant and red-yellowish under complex illuminant III.

Several statistical analysis were performed:

- between the series of samples: paired comparison statistics has revealed no significant differences between the series. The typology of the changes in the MMH distribution is similar for all series. However, observers have complained about the difficulty to perform the experiment with series 0505 because of its low saturation. Indeed, the results obtained with series 0505 are noisy. Thus, we suggest ignoring this series in order to obtain reliable results.
- between the complex illuminants: paired comparison statistics shows no significant differences between the complex illuminant I and the control illumination, and shows significant differences between the complex illuminants II and III and the control illuminant. Thus, the complex illuminant I seems to not modify the color appearance compared with the control illuminant in opposition to the complex illuminants II and III which change significantly the color appearance of the colored samples of all the series.
- for each sample, between the results obtained with the complex illuminant and the control illuminant:
  * for 1 sample out of 120 (3 series of 40 hues), the results with the complex illuminant I were significantly different from results with the control illuminant,
  * for 11 samples out of 120, the results with the complex illuminant II were significantly different from results with the control illuminant,
  * for 24 samples out of 120, the results with the complex illuminant III were significantly different from results with the control illuminant.

We ensured that all the samples that are significantly different from the complex illuminant to the control illuminant correspond to the inner and outer deviations of the curves of the differences.

### 3.2. Color appearance model

The predictions of the color appearance model were represented in an angular hue circle according to the computed hue quadratures of each predicted sample. The differences between the hue quadrature predictions with the complex illuminants and the hue quadrature predictions with the control illumination were plotted in the angular hue circle for each series and for each complex illuminant (figure 3).

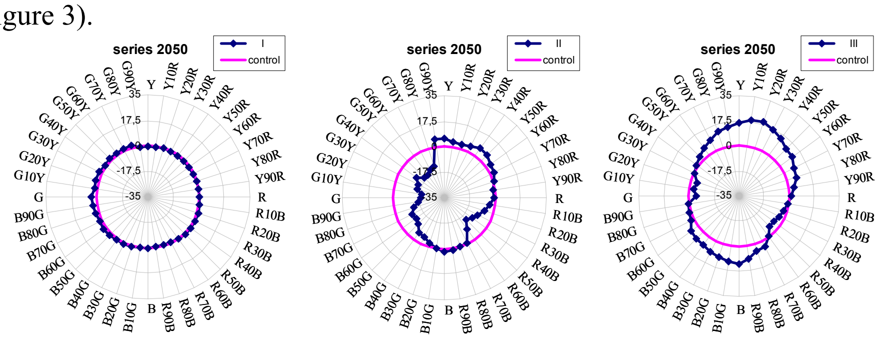


**Figure 3.** Differences of hue quadrature predictions given to the NCS 2050 series samples by CIECAM02, between the complex illuminant I, II, III and the control illuminant. Positive shift along radius indicates clockwise hue quadrature change when illumination changes from control to complex.

Similar to the psychophysical results, the predictions of CIECAM02 for the differences between the complex illuminants and the control illuminant rank in the same order: complex illuminants I, II, III yield low to high differences compared to the control illuminant.

## 4. DISCUSSION

The four series of samples selected in the NCS atlas are characterized by their various levels of Blackness and Chromaticness, which makes the test more or less sensitive. Nevertheless, the changes of color appearance under complex illumination obtained with various series of different Blackness and Chromaticness do not show significant differences. The modification of color appearance relies mainly on apparent changes of hue, despite changes in lightness and chroma.

The fact that a given domain for a MMH can expand in some regions of the hue circle while reducing in others under the effect of the illuminant indicates that although the observer totally adapts to the complex illuminant, color constancy is not perfectly achieved over the full hue circle.

Curiously, performing the plot of the psychophysical results in the angular hue circles, we noticed that the complex illuminant (illuminant II) that was unanimously quoted as non-pleasant by the observers does not seem to disturb the color appearance more than the other complex illuminations, according to the statistical analysis.

The comparison between the psychophysical results from the real situation and the predictions from the color appearance model yields a qualitative analysis. Although the differences between each complex illuminant and the control illuminant obtained with the psychophysical results and with the model results show similar patterns, we notice some deviations. Indeed:

- the psychophysical results present more noise than the results of the model,
- the color appearance changes follow only roughly the same direction
- and the predictions given by the model for the complex illuminant III present lower color appearance changes than the results in the real situation.

## 5. CONCLUSION

### 5.1. Real situation

The psychophysical method based on Major/Minor Hue distribution that we have designed is efficient to assess color appearance changes of color patches. This method can be applied to real materials. It is accurate enough to distinguish between different effects induced by various complex illuminants.

### 5.2. Color appearance model

The color appearance model CIECAM02 makes predictions, which get close to the psychophysical results in the real situation. Nevertheless, there are some differences between the results in the real situation and the predictions of the model. Color appearance models cannot take into account such factors as spectral variations of surface reflection, and cognitive information linked to the pigmented material, which exceed the simple colorimetric specification.

## References

1. CIE, "A Colour Appearance Model for Colour Management Systems: CIECAM02," Publication CIE 159:2004.
2. D.H. Brainard, BA. Wandell, "Analysis of the retinex theory of color vision," J Opt Soc Am A. 3(10), 1651-61 (1986).
3. R.L. De Valois, K.K. De Valois, "A multi-stage color model," Vision Res., 33, 1053-1065 (1993).