The number of colors perceived by dichromats when appreciating art paintings under standard illuminants

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Abstract

The chromatic content and diversity experienced by normal observers when observing art paintings vary with the spectral composition of the illumination and can be estimated by quantities such as color rendering indices and the number of discernible colors. Can these estimates be extended to color deficient observers? The aim of this work was to investigate how the number of discernible colors perceived by dichromats in art paintings varies when the paintings are rendered under CIE standard illuminants. Hyperspectral images of eleven oil paintings were collected at the museum and the number of discernible colors perceived by trichromats and dichromats under 55 CIE illuminants was estimated for each painting. It was found that the number of discernible colors varies considerably across illuminants for all classes of observers analyzed. When comparing with CIE standard illuminant A, substantial enhancement of about 14%, 30%, 20% and 10%, could be obtained with specific illuminants for trichromats, protanopes, deuteranopes and tritanopes, respectively. These results suggest that color deficient observers may require personalized lighting conditions.

Introduction

The rich chromatic diversity of art paintings and its appreciation by normal trichromats is very dependent on the spectral composition of the illumination used [1-3]. The chromatic diversity perceived by dichromats in the context of natural scenes is considerable impaired and of about 7% [4] of the number of discernible colors perceived by normal trichromatic observers. In spite of the severe impairment in color vision due to the lack of one cone type, some chromatic enhancements can be obtained with colored filters in the context of natural scenes [4, 5]. The availability of modeling allowing the conversion of dichromatic color vision to perceptions experienced by normal trichromats [6] enables computational estimations of the chromatic diversity perceived by dichromats and to study the influence of colored filters or illuminants. The aim of this work was to investigate how the number of discernible colors perceived in art paintings by dichromats varies with standard illuminants.

Methods

Eleven oil paintings were digitalized in the Museu Nogueira da Silva, Braga, Portugal, with a hyperspectral system. The system consisted of a low-noise Peltier-cooled digital camera with a spatial resolution of 1344×1024 pixels and 12-bit output (Hamamatsu, C4742-95-12ER, Hamamatsu Photonics K.K., Japan) and a fast-tunable liquid-crystal filter (VariSpec, model VS-VIS2-10HC-35-SQ, Cambridge Research & Instrumentation, Inc., MA, USA) mounted in front of the lens (for more details on the hyperspectral system see [7]). The hyperspectral digitalization was carried out over the range 400-720 nm at 10 nm intervals. The paintings were illuminated with low level SoLux® illumination to avoid over exposition to high intensity levels and consequent painting damage. The spectral reflectance of each pixel of the paintings was estimated from a gray reference surface present near the painting at the time of digitalization. Illuminant spatial non-uniformities were compensated using hyperspectral measurements of a uniform surface imaged in the same location and under the same illuminating conditions as the paintings [2].

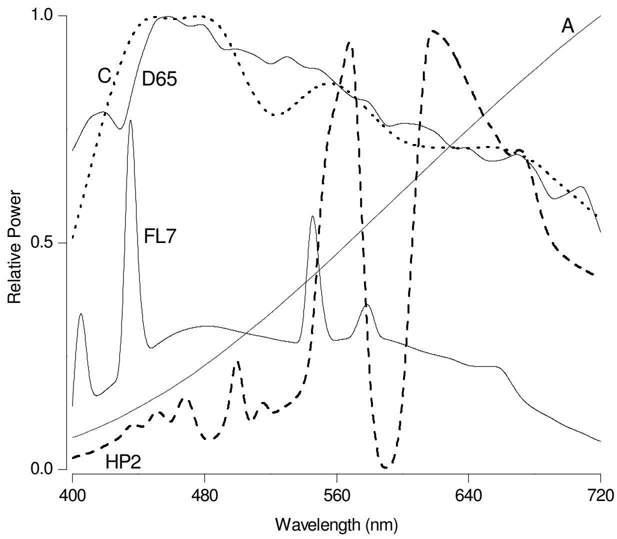

Figure 1. *Examples of some of the CIE standard illuminants used to compute the number of discernible colors. The CIE illuminant A was used as the comparison illuminant.*

The radiance spectrum reflected by each painting under several illuminants was computed using the estimated spectral reflectance functions and tabulated CIE standard illuminants. A total of 55 CIE illuminants with different correlated color temperature (CCT) were used in the computations: CIE illuminant A, C, 21 D illuminants (in the range 25,000 K to 3,600 K), 27 FL illuminants (FL1, FL2, FL3, FL4, FL5, FL6, FL7, FL8, FL9, FL10, FL11, FL12, FL3.1, FL3.2, FL3.3, FL3.4, FL3.5, FL3.6, FL3.7, FL3.8, FL3.9, FL3.10, FL3.11, FL3.12, FL3.13, FL3.14, and FL3.15) and 5 HP illuminants (HP1, HP2, HP3, HP4 and HP5) [8]. Figure 1 represents the normalized spectra of a sample of these illuminants.

For each illuminant the CIELAB color volume for normal trichromats was computed using the CIE 1931 2º standard observer [8]; the corresponding color volumes for dichromats were computed using a computational algorithm simulating for normal trichromatic observers the appearance of the paintings for dichromats [6]. The number of discernible colors in each case was estimated by segmenting the CIELAB color volume in unitary cubes and by counting the number of non-empty unitary cubes. The CIE A illuminant was used as comparison illuminant in all subsequent analysis because it probably still is the most frequently used illuminant in museum lighting [9].

Results

Consistently with the data obtained for natural scenes [4] the chromatic diversity estimated for dichromats for the analyzed paintings was found to be considerably impaired when compared to normal trichromatic observers. On average for the 11 paintings, the reduction was about 8%, 9.5% and 9% for tritanopes, deuteranopes and protanopes respectively.

***Figure 2**. Picture of the oil painting from which the data presented in Figures 3, 4 and 5 were obtained.*

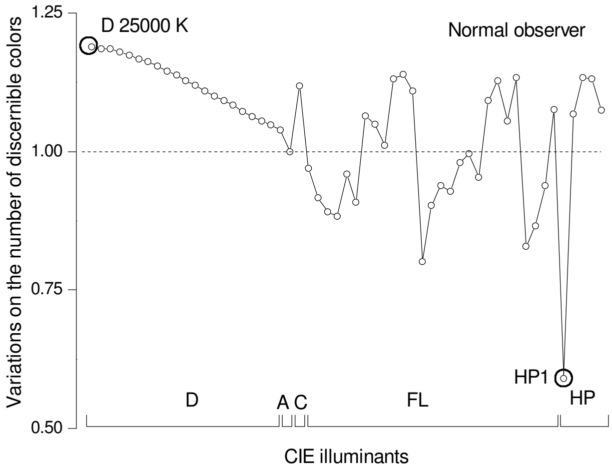

***Figure 3.** Variations in the number of discernible colors for 21 CIE illuminant D (in the range 25,000 K to 3,600 K), illuminant A, C, 27 FL illuminants and 5 HP illuminants, for the painting shown in Figure 2 and for a normal trichromatic observer. The illuminant A was assumed as the comparison illuminant. The data corresponding to the best and worst illuminants are signaled with a large circle.*

Figure 2 shows the picture of the oil painting corresponding to the data presented in Figure 3, Figure 4 and Figure 5. Figure 3 and Figure 4 represent the variations in the number of discernible colors for normal trichromats, tritanopes, deuteranopes and protanopes across all illuminants tested. In each case the data corresponding to the best and worst illuminant is signaled with a large circle. The number of perceived colors varied considerable across illuminants for normal and dichromatic observers. Similar data was obtained for the other paintings analyzed.

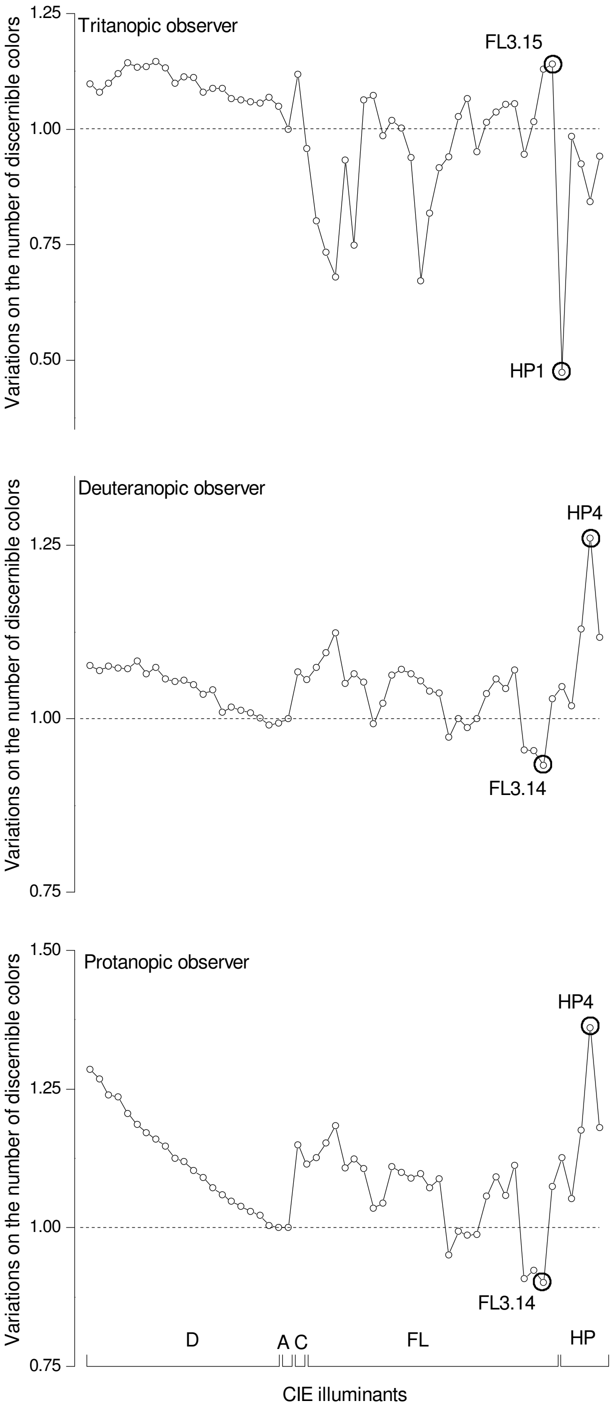

***Figure 4.** Variations on the number of discernible colors for 21 CIE illuminant D (in the range 25,000 K to 3,600 K), illuminant A, C, 27 FL illuminants and 5 HP illuminants, for the painting shown in Figure 2 and for a tritanopic (top), deuteranopic (middle) and protanopic (bottom) observer. The illuminant A was assumed as the comparison illuminant. The data corresponding to the best and worst illuminants are signaled with a large circle.*

Figure 5 shows the best and worst illuminant for the painting represented in Figure 2 for normal trichromats and dichromats. For normal observers, the CIE D 25,000K and the CIE HP1 illuminant with a CCT of 1,959K are the best and the worst illuminants, respectively; for a tritanopic observer the CIE FL3.15 with a CCT of 6,509K and the CIE HP1 are the best and the worst illuminants, respectively; for a deuteranopic and a protanopic observers, the HP4 with a CCT of 4,002K and FL3.14 with a CCT 5,045K are the best and the worst illuminants, respectively.

Considering all eleven oil paintings analyzed, including the oil painting represented in Figure 2, the average enhancements in the number of discernible colors for trichromats, tritanopes, deuteranopes and protanopes are approximately 14% (with illuminant FL11), 10% (with illuminant FL3.14), 20% (with illuminant HP4) and 30% (with illuminant HP4) respectively.

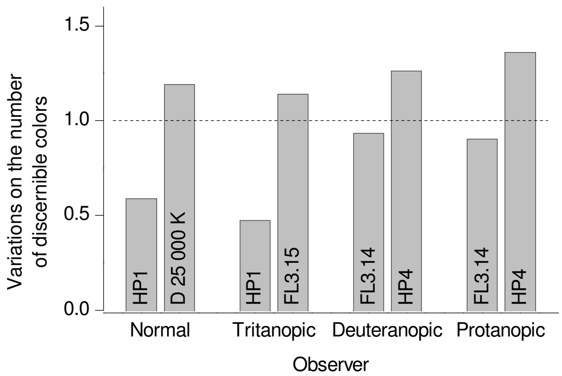

Figure 5. *Minimum and maximum variations in the number of discernible colors for a normal, tritanopic, deuteranopic and protanopic observer, for the painting shown in Figure 2 and the corresponding illuminants. The illuminant A was assumed as the comparison illuminant.*

Discussion

The impairment of the chromatic diversity perceived by dichromats when appreciating artistic oil paintings is equivalent to the impairment estimated with natural scenes despite the differences in the color gamut between the two types of stimuli. Nevertheless, the data reported here suggests that it may be possible to improve color vision using adequate personalized illumination, with spectral profile adjusted to each particular painting.

The results reported here were based on a model of dichromatic color perception which is known to describe incompletely dichromatic color vision; furthermore the computation of the number of discernible colors by segmentation of the color volume is done in the CIELAB color space known by its non-uniformity in particular in blue and gray areas [10, 11]. Also, the segmentation of the color volume into unitary cubes assumes that all colors inside the same cube could not be distinguished, but in fact some pairs have a color difference $\Delta E^{*}_{ab}>1$. The use of unitary spheres to segment the color volume can partially overcome this limitation, but some studies [12] suggests that the relative estimates of the number of discernible colors are robust in relation to other methodologies that can be use to compute with great accuracy the number of discernible colors.

Despite these limitations the variations obtained in the chromatic content of oil paintings rendered under several CIE standard illuminants may indicate that some illuminants are better than others, which is in agreement with the findings of variations of chromatic content of natural scenes with colored lens in dichromatic observers [4].

The development of tunable broad spectrum lighting [13] (for example OL 490 Agile Light Source, Optronic Laboratories, Orlando, FL, USA) will enable the design of psychophysical experiments to test the validity of the computational results reported in this paper and may provide new opportunities for richer experiences to color deficient observers, in particular when appreciating art paintigs.

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Author Biography

João Linhares received his MPhil in Optometry and Neuroscience from The University of Manchester, UK, (2006) and is currently a PhD Student at the Minho University, Portugal. His work has focused on trichromats and dichromats chromatic diversity of hyperspectral images of natural scenes.

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