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Psychophysical estimation of the best lighting for commercial counters of fruits and vegetables

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Abstract

Naturalness and aesthetic preference are two important aspects of color rendering that are difficult to capture with rendering indices. Several factors may influence observer´s choices in complex ways, e.g. color memory and the composition of the scenes, and the best illumination for specific conditions may be difficult to predict from existing indices.

The aim of this work was to estimate psychophysically the spectral composition of the best lighting for commercial food counters. Stimuli were monitor simulations of commercial food counters containing fruits and vegetables derived from hyperspectral data obtained in a local supermarket. Illuminants were synthetized from Judd's daylight spectral basis functions with variable coefficients such that their color defined a chromaticity grid over and around Planckian locus with correlated color temperature (CCT) in the range 2,222—20,000 K. Two conditions were tested: in one, the naturalness condition, observers selected the illuminant producing the most natural colors; in the other, the preference condition, observers selected the illuminant producing the most pleasant appearance.

The average CCT in the preference condition was significantly lower than that obtained in the naturalness condition, by about 2,400 K. The average chromaticity of each condition was closer to the Planckian locus than to the daylight locus.

Introduction

The color rendering properties of lighting are expressed with rendering indices [1-3]. Naturalness and aesthetic preference are two important aspects that are difficult to capture with rendering indices because several factors may influence observer´s choices in complex ways, e.g. color memory[4] and the composition of the scenes[5]. Thus, the best illumination for specific practical conditions may be difficult to predict from existing indices.

The aim of this work was to estimate psychophysically the spectral composition of the best lighting for commercial food counters. More specifically, for fruit and vegetable counters. Stimuli were monitor simulations of commercial food counters derived from hyperspectral data obtained in a local supermarket. Illuminants were synthetized from Judd's daylight spectral basis functions with variable coefficients such that their color defined a chromaticity grid over and around Planckian locus with CCT in the range 2,222—20,000 K. Two conditions were tested: in one, the naturalness condition, observers selected the illuminant producing the most natural colors; in the other, the preference condition, observers selected the illuminant producing the most pleasant appearance.

Methods

Spectral data from commercial food counters

The stimuli were simulations of food counters of fruits and vegetables from a local supermarket. The simulations were generated from the spectral reflectance of each pixel estimated from hyperspectral data. The spectral data were acquired over the range 400-720 nm at 10 nm intervals using a fast-tunable liquid-crystal filter and a low-noise Peltier-cooled digital camera with a spatial resolution of 1344×1024 pixels and 12-bit output. The spectral reflectance of each pixel was estimated from the hyperspectral data by dividing the image data for each wavelength by the spectrum of the illuminant obtained at a given reference location for the same wavelength[6]. The images acquired were compensated for optical spatial non uniformities. Figure 1 shows the setting for hyperspectral data acquisition in the fruit area of the supermarket.

***Figure 1**. Acquisition of hyperspectral data in the area of fruits in the supermarket.*

Illuminants

Illuminants were synthetized from Judd's daylight spectral basis functions[7] with variable coefficients such that their color defined a chromaticity grid over and around Planckian locus. *Figure 2* represents the grid tested expressed in the chromaticity space CIE 1960 UCS. The grid points had CCT in the range 2,222—20,000 K equally spaced in the reciprocal color temperature at an interval of 25 MK^{-1}[8]. The points in the lines orthogonal to the Planckian locus were located from –0.01 to +0.01 from the locus in chromaticity difference DC[1] at an interval of 0.002.

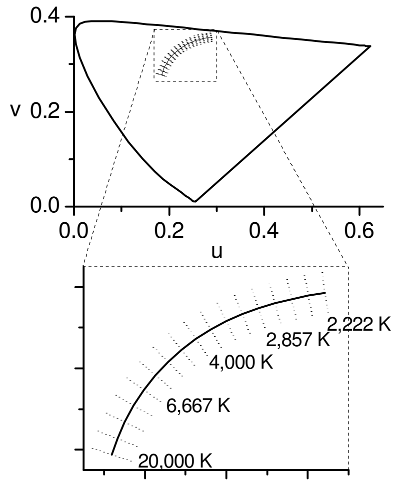

Figure 2. Illuminant chromaticities tested expressed in the chromaticity space CIE 1960 UCS. The grid points had CCT in the range 2,222—20,000 K equally spaced in the reciprocal color temperature at an interval of 25 MK^{-1}. The points in the lines orthogonal to the Planckian locus were located from +0.01 to −0.01 from the locus in chromaticity difference DC at an interval of 0.002.The illuminants were synthetized from Judd's daylight spectral basis functions.

Figure 3. Scenes tested in the psychophysical experiment.

Stimuli

Stimuli were displayed on a LCD monitor (CA750; Samsung, Seoul, South Korea) controlled by a dedicated programmable hardware and software graphics system providing 24 bits per pixel in true-color mode (ViSaGe Visual Stimulus Generator; Cambridge Research Systems, Rochester, UK). The monitor was calibrated in color and luminance with a telespectroradiometer (SpectraScan Colorimeter, PR-650; Photo Research Inc., Chatsworth, California). The images subtended 40×30 degree visual angle and were observed at 60 cm distance. The colorimetric performance of the monitor was better than a good CRT because it had a larger gamut due to a high luminance (up to 280 cd/m^2). Images were subsampled every other pixel from the original resolution of 1344×1024 pixels, then trimmed about 20-30 pixels from an edge to delete the reflectance standard from the scene. The average luminance of the displayed images was 15 cd/m^2. Figure 3 shows the scenes tested.

Figure 4 shows the histogram of the mean color error in image display expressed as the mean color difference over the image between the intended and actually displayed images chosen by the observer in each trial. The color difference for each pixel was defined as:

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2},$$

where (L^*_1, a^*_1, b^*_1) and (L^*_2, a^*_2, b^*_2) are the CIELAB coordinates of the intended and actually displayed colors, respectively. When the color of the pixels was outside the gamut the colors were clipped to the closest RGB value. The mean error for the 97% of the trials was less than 0.5 in CIELAB. Even the maximum error 1.9 was smaller than the just noticeable difference for complex images 2.3[9].

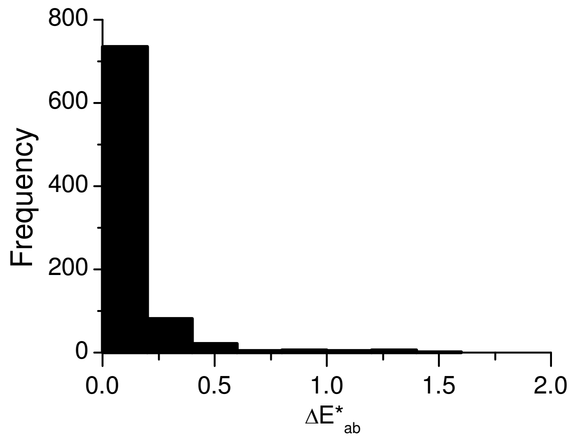

Figure 4. The histogram of the mean color error over the image for each trial. This error is expressed as the mean color difference over the image between the intended and actually displayed images chosen by the observer in each trial.

The monitor displayed the simulation of the scene rendered under an illuminant chosen from the testing grid. The initial illuminant in the grid was chosen randomly, and the observer could then select other illuminant by adjusting a joypad. When he or she was happy with the setting, pressed a button to record the setting. Two conditions were tested. In one, the naturalness condition, the observers were instructed to select the illuminant on the scenes such that the colors of the objects appear the most natural. In the other, the preference condition, observers were instructed to select the illuminant such that the appearance of the scenes was the most pleasant. The instructions to the observers were written and showed to the observers in the beginning of each experimental session.

The experiments took place in a dedicated laboratory protected from light by blackout curtains. Ambient light in the laboratory was less than 1 lx. In each trial, one of the scenes was chosen randomly and each scene was repeated 2 times in a session. The observers did 3 sessions for each experimental condition. Images and conditions were tested in random order.

Observers

There were 9 observers, all naïve to the purpose of the experiment. Each observer had normal or corrected-to-normal acuity and normal color vision accessed by Rayleigh anomaloscopy and Ishihara plates.

Results

Figure 5 shows the average setting over all the images and observers. The error bars show the standard errors across scenes and observers. The average reciprocal color temperatures (RCTs) for the naturalness and preference conditions and their standard errors were 120.7 ± 2.9 and 169.0 ± 4.4 (MK^{-1}), respectively, which correspond to CCTs of 8300 and 5900 K. The differences were significant ($p < 0.01$; two-tailed t-test) The average DCs were $5\times10^{-5} \pm 2.8\times10^{-4}$ and $-8.0\times10^{-4} \pm 2.8\times10^{-4}$, respectively, and the difference between the two conditions were not significant ($p = 0.03$; two-tailed t-test).

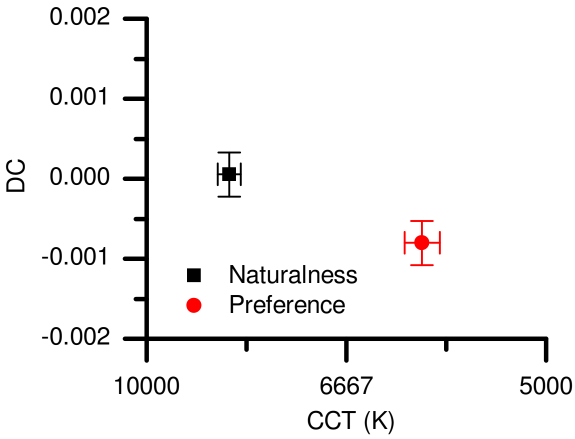

Figure 5. Average setting over all the images and observers.

Figure 6 and Figure 7 show the average CCTs obtained for each observer and each image, respectively. There were considerable individual differences among observers, but the average CCTs over observers for each image were consistently higher for the naturalness condition than for the preference condition.

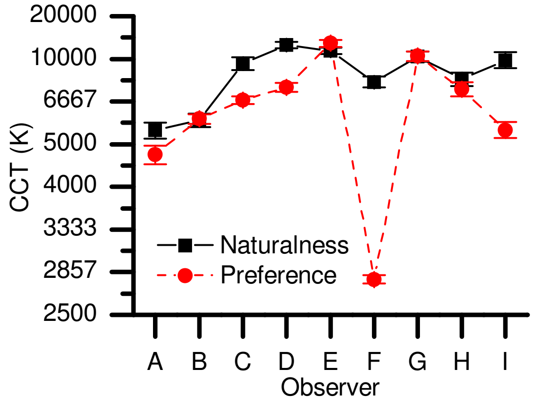

Figure 6. Average CCTs obtained for each observer.

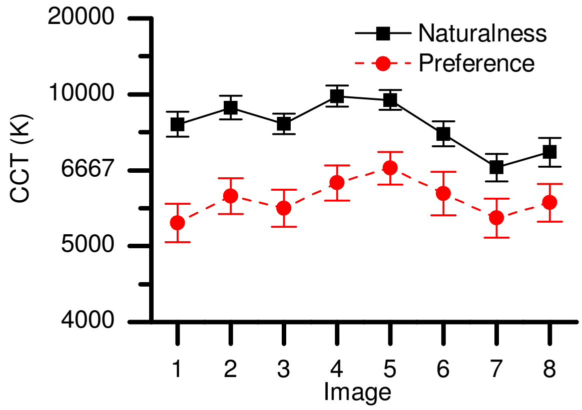

Figure 7. Average CCTs obtained for each image.

Figure 8 and Figure 9 show the average DCs for each observer and each image, respectively. The average DCs were not significantly different from each other between the two conditions ($p = 0.03$; two-tailed t-test). However, they were significantly different from the daylight locus ($p < 0.01$; two-tailed t-test). No consistent tendency over observers or images was found.

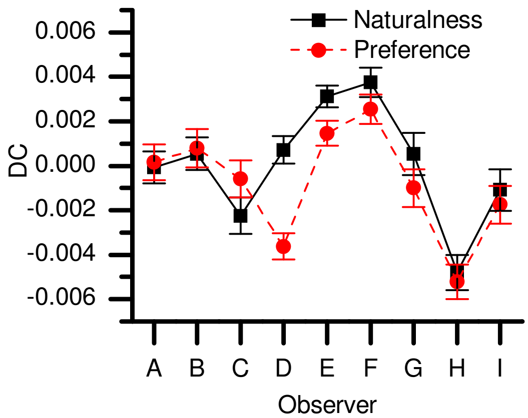

Figure 8. Average DCs obtained for each observer [OSAMU: the same as legend of figure6].

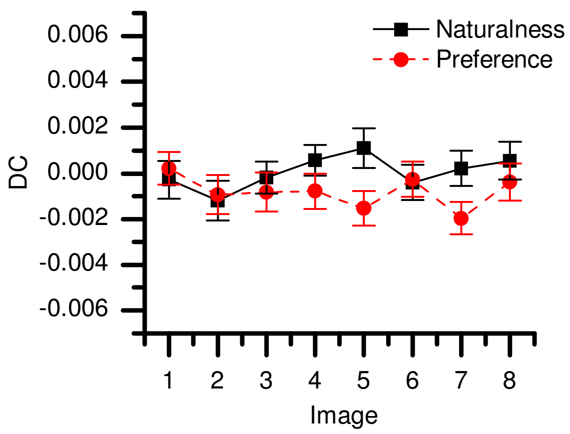

Figure 9. Average DCs obtained for each image.

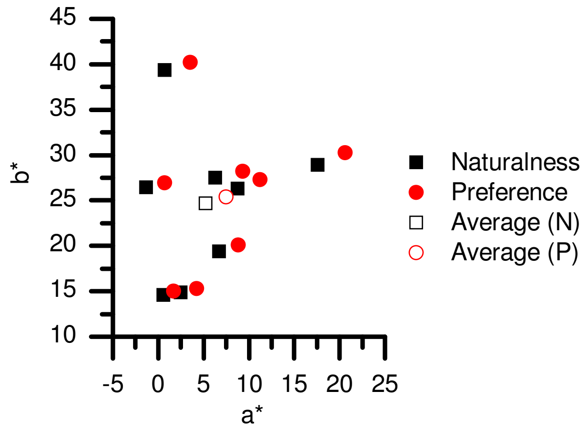

Figure 11. Average colors of the images under the illuminants for preference and naturalness in CIELAB color space. The colors averaged over images are also represented

Discussion

The average CCT preferred by the observers was about 2400 K lower than that selected to look natural. That can be because most fruits are greenish when they are unripe, but get redder as they get ripe. With lower CCT the overall colors in the scene become more reddish and therefore the fruits appear riper. Figure 10 shows the CIE 1930 (x, y) chromaticities of the colorimetrical average of each image under the illuminants with average chromaticities obtained for each criterion. The colors of the images are shifted in the direction of orange. To consider to some extent the effect of adaptation Figure 11 shows the average color of each image in the CIELAB uniform color space. The average colors of the images in preference condition are shifted further away from the white point and to the direction of orange in hue compared to the naturalness condition.

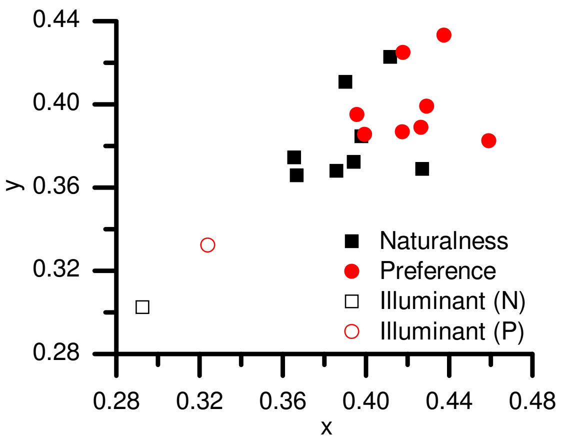

Figure 10. Average chromaticities of the images under the illuminants for preference and naturalness in CIE 1931 (x, y) chromaticity coordinates. The chromaticities of the illuminants are also represented.

In addition, the average chroma over each image in preference condition got 3.3% larger than that in naturalness condition. In Figure 12, each bar shows the average of the CIELAB chroma C^*_{ab} of each image in each criterion. The convex hull volume that the pixels of each image span in CIELAB uniform color space in each criterion was calculated as exemplified in Figure 13. Figure 14 shows that the color volumes in the preference condition are, in average, 3.2% larger than that in the naturalness condition. These results show that the images in the preference condition are not only more saturated in average than in the naturalness condition, but also got more color contrast or chromatic diversity within each single image.

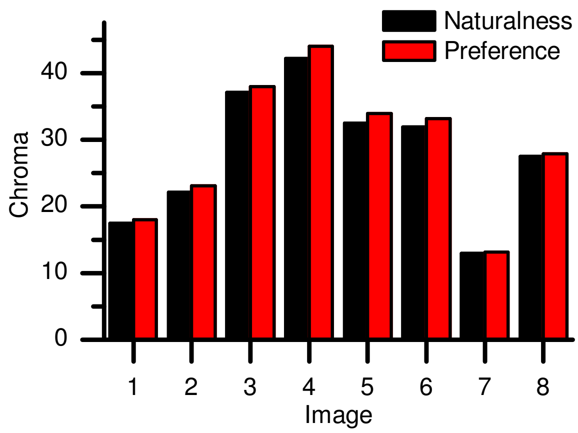

Figure 12. Average of the CIELAB chroma C^*_{ab} of each image in each criterion.

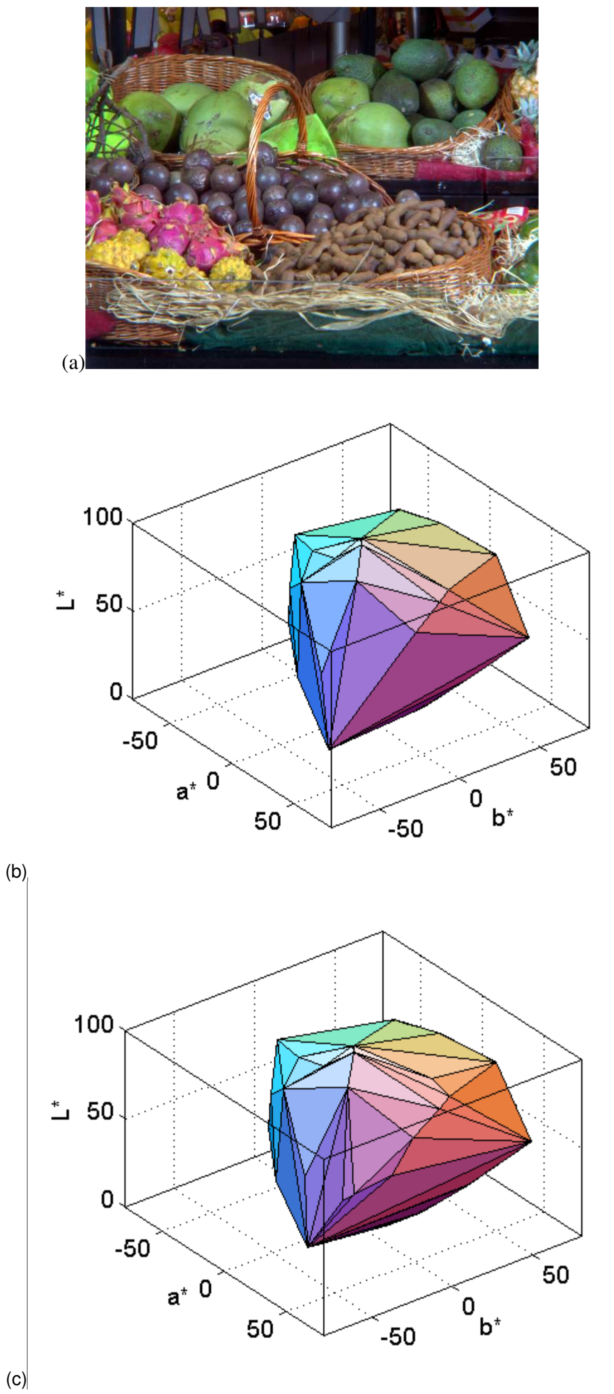

Figure 13. Convex hull volumes of the pixels of image 1 (a) in CIELAB in the naturalness (b) and preference (c) conditions

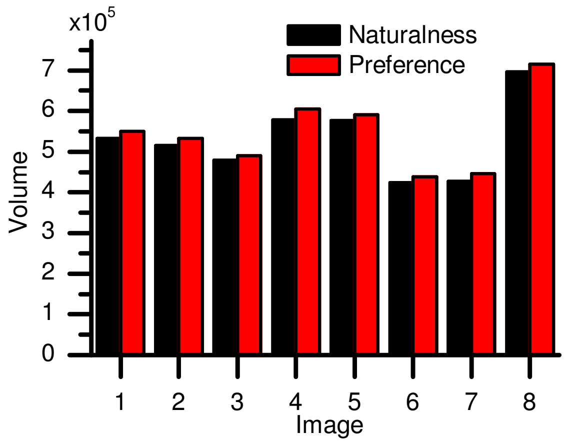

Figure 14. Comparison of the color volumes in CIELAB for the two conditions.

To confirm the generality of this consideration, the Rösch–MacAdam color solids were calculated as in Figure 15. The solid in the preference condition was 2.0% larger than that in the naturalness condition. However, the average color of the solid was less saturated in the preference condition than in naturalness condition as shown in Figure 16.

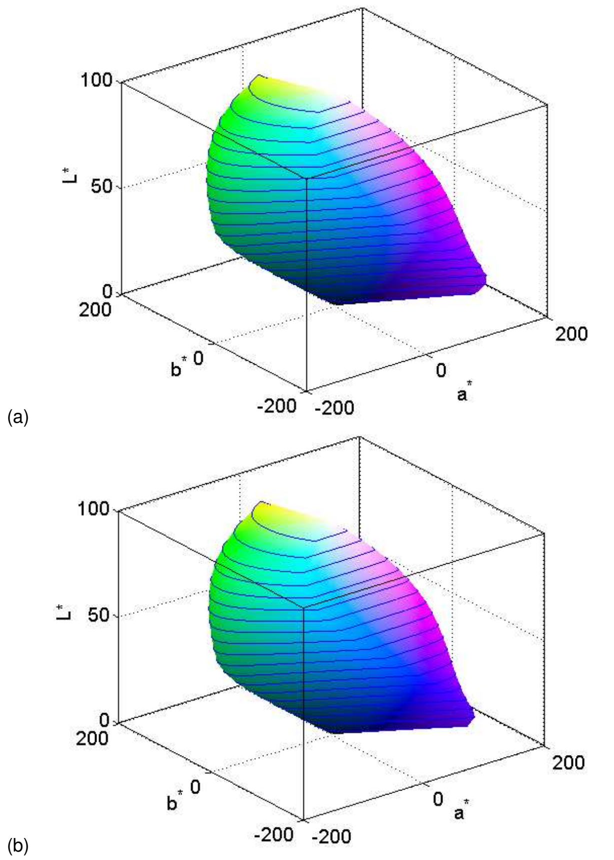

Figure 15. Rösch–MacAdam color solids in CIELAB space in naturalness (a) and preference (b) conditions.

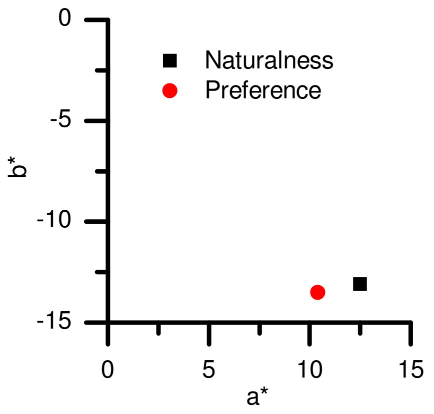

Figure 16. (a, b*) coordinates of the averaged color of the solid*

Nascimento and Masuda[10] measured, psychophysically, the spectral structures that makes natural scenes the most natural or most preferable using only metamers of D65. Although the spectrum selected in the preference condition was more structured than that in naturalness condition, the average colors of the scenes they used remained the same because the illuminants were metamers, thus had the same chromaticity. Nonetheless, the scenes preferred by the observers were chromatically more diverse than those perceived as natural. To understand which factor, the average saturation of the image or the chromatic diversity present in each image, further studies are required.

In ISO standard[11], it is recommended to use D65 as illumination for assessment of the color of the food. On the other hand, neither of natural or preferable CCTs we found in the present study was 6500K ($p < 0.01$; two-tailed t-test). The preferable CCT we found was significantly lower than the standard. In practice, TL83 warm white tri-band fluorescent lamps with the CCT of 3000K are commonly used for food display in supermarkets[12], which is much lower than the standard. However, the preferred CCT we found was not the same as this practical CCT but was more close to that preferred for the illumination of art paintings[13], suggesting a common basis for these type of judgments.

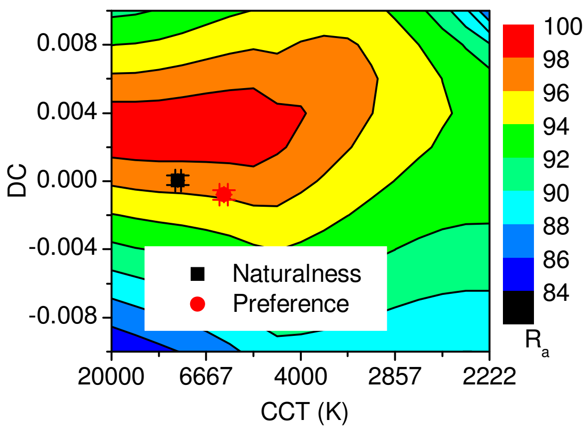

Figure 17. Comparison of the average setting with the CRIs on the grid.

Figure 17 shows the re-plot of Figure 5 with the general color rendering index (CRI) represented as a contour map on the grid. The figure shows that the maximum value of CRI and observers' selection for naturalness do not coincide. The CRI is therefore not suitable as a quality index even for naturalness.

Conclusions and comment

We found that the correlated color temperature of the illumination preferred for fruits and vegetables is considerably lower than that of the illumination producing the most natural appearance. The chromaticities of the illumination for preference or naturalness were different from those of the daylight locus and closer to the Planckian locus.

Acknowledgements

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Author Biography

Osamu Masuda received his BS (1993) and MS (1995) in Information Engineering from Niigata University, Japan and PhD (2006) in Information Processing from Tokyo Institute of Technology, Japan. He was a research official at Printing Bureau, Ministry of Finance, Japan (1995-2002), and a postdoc in University of Rochester, USA (2006-9) and Mie University, Japan (2009-10). He is currently a postdoc in University of Minho, Portugal. His primary research interest is human color vision.