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UNIQUE HUE JUDGMENTS UNDER LIGHT SOURCES WITH DIFFERENT CHROMATICITIES

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Abstract

A psychophysical experiment was carried out to investigate how light source chromaticities affected unique hue judgements using Munsell samples at two chroma levels. Ten observers between 20 and 23 years of age (mean = 21, std. dev. =1) participated in the experiment. Each observer was asked to select the unique hues from the 40 V6C8 (Value 6 Chroma 8) Munsell samples and 40 V8C4 (Value 8 Chroma 4) Munsell samples under six light sources. The experiment results showed that the hue angles defined in CIECAM02 were similar to the unique red and green judgments made by the observers, but not to the unique blue and yellow judgements. For unique blue, the observers' judgements generally shifted toward green. The observers' judgements on unique yellow varied with the chroma levels of the samples and D_{uv} levels of the light sources.

Keywords: Color appearance model, Unique hues, Uniform color space

1 Introduction

Unique hue, an important concept in color science, plays an important role in developing color appearance models and uniform color spaces, which significantly affects various color-related applications, such as cross media color reproduction [1]., light source color rendition characterization [2,3], and gamut mapping [4-6]. Great efforts have been made to determine the unique hues through psychophysical experiments by asking observers to select samples with the four unique hues from a series of color samples. These experiments, however, were generally carried out under the light sources simulating standard illuminants (e.g., D65, A, F2, and F11) with chromaticities on or around the Planckian locus [7-9]. In addition, these experiments derived the hue angles using the samples with a relatively high chroma level, which cannot verify the hue linearity of the color spaces.

This study aimed to investigate how light source chromaticities affected the unique hue judgements using Munsell samples at two chroma levels. The research hypotheses included: (1) the existing uniform color spaces lack hue linearity and the hue angles of the unique hues would not be applicable to samples with low chroma levels; (2) light source chromaticities, in terms of CCT and D_{uv}, would significantly affect unique hue judgments.

2 Methods

The experiment was carried out in a viewing booth, which was illuminated using a 14-channel spectrally tunable LED device at a horizontal illuminance of 1000 lx. The intensities of the 14 channels of the LED device were carefully adjusted to produce six light sources, comprising two levels of CCT (i.e., 2700 and 3500 K) and three levels of D_{uv} (i.e., 0, -0.02, and -0.04), with the CIE General Color Rendering Index CRI R_a above 90. The relative spectral power distributions (SPDs) of these six light sources are shown in Figure 1; Table 1 shows the colorimetric characteristics of the light sources. Two circular disks, with a dimeter of 20 cm, were made, with one containing 40 V6C8 (Value 6 Chroma 8) Munsell samples and the other containing 40 V8C4 (Value 8 Chroma 4) Munsell samples, as shown in Figure 2. Each sample was 1 cm × 1 cm and subtended around 2° field of view; the 40 samples were pasted along the perimeter of the disk according to the hue. One top of the disk, a Munsell N7 paper containing 40 holes (1 cm × 1 cm) was used, with the holes being randomly numbered from 1 to 40. During

the experiment, a diffuse white tile (6 cm × 8 cm) was placed on top of the Munsell N7 paper for chromatic adaptation, as shown in Figure 3.

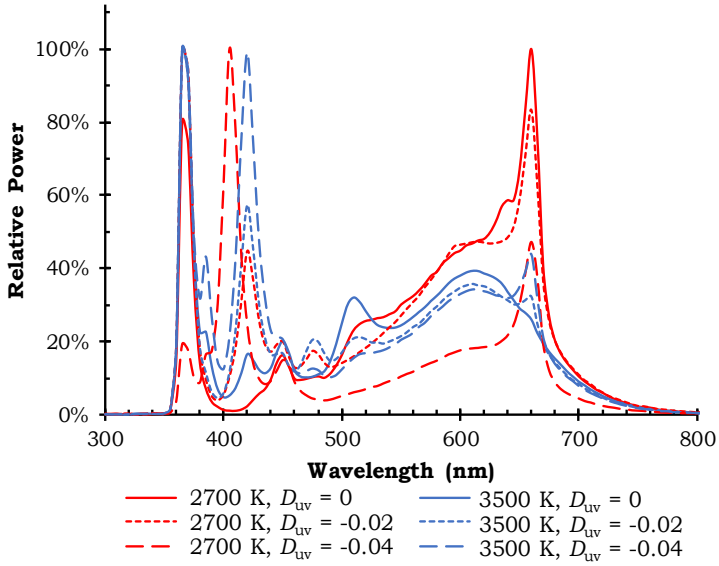

Figure 1 – The relative spectral power distributions (SPDs) of the light sources

Table 1 – Colorimetric characteristics of the light sources

Light source					
CCT	CRI R_a	D_{uv}	X	Y	Z
2674	98	0	369	328	101
2692	92	-0.019	392	325	195
2673	91	-0.04	427	326	305
3459	95	0.001	345	333	164
3519	92	-0.019	377	333	267
3436	90	-0.039	416	334	365

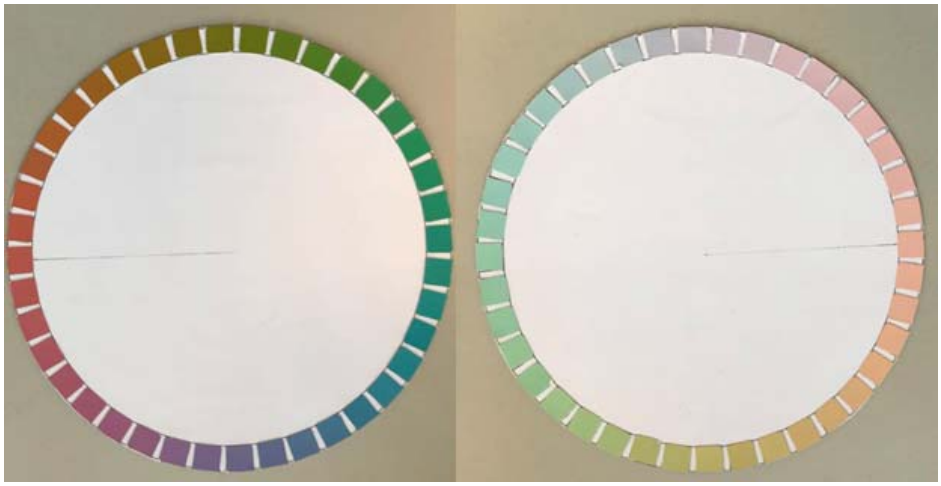

Figure 2 – Photographs of the color disks used in the experiment

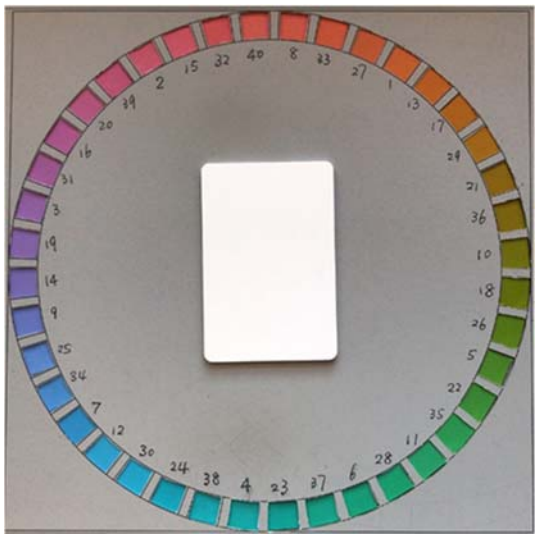

Figure 3 – Photographs of the color disk that was randomly rotated and placed below the Munsell N7 paper in the experiment

Under each light source, the observer was asked to look at the white tile for 2 minute for chromatic adaptation. Then, a color disk, together with the Munsell N7 paper, was placed below the white tile, with the color disk being randomly rotated. The observer was asked to look at the 40 samples and tell the experimenter which four samples had the four unique hues. Ten Asian observers between 20 and 23 years of age (mean = 21.0) participated in the experiment, with their chins being fixed on a rest during the experiment to ensure a similar viewing geometry. Each observer repeated the judgements under one light source (i.e., 2700 K with D_{uv} = 0).

3 Results and discussions

The intra-observer variation was evaluated by comparing the two repeated judgements that were made by each observer under the same light source; the inter-observer variation was evaluated by comparing the judgements made by each observer and the average observer under different light sources. The judgements made by the observers were characterized using the CIECAM02 hue angle. It was found that the inter-observer variations were generally twice of the intra-observer variations irrespective of the unique hues. The largest inter-observer variation happened to the unique green judgements. In addition, the inter-observer variations of the unique red and blue were larger under the sources with a larger D_{uv}, are summarized in Table 2.

Table 2 – Inter- and intra-observer variations in terms of CIECAM02 hue angles

	Light source			Saturated (V6C8)				Desaturated (V8C4)			
	CCT	CRI R_a	D_{uv}	Red	Green	Blue	Yellow	Red	Green	Blue	Yellow
Inter-	2674	98	0	5.0	15.5	3.2	7.3	5.7	13.0	5.8	5.6
	2692	92	-0.019	4.5	17.0	7.1	3.2	5.0	7.8	3.8	7.7
	2673	91	-0.04	7.4	12.5	8.1	6.7	10.4	11.0	5.7	5.2
	3459	95	0.001	3.9	11.2	4.3	9.0	5.2	12.4	3.7	8.1
	3519	92	-0.019	4.8	16.7	6.9	9.9	5.2	7.7	4.8	4.1
	3436	90	-0.039	4.8	10.7	8.7	7.8	8.8	11.2	10.5	5.5
Intra-	2674	98	0	2.3	5.0	2.1	3.6	3.1	3.8	3.1	5.2

Though the D_{uv} levels were found to have little impact on the selection of the Munsell samples, CIECAM02 did not always produce good predictions of the hue angles for the unique hues. The hue angles (20.14° as unique red, 90° as unique yellow, 164.25° as unique green, and 237.53° as unique blue) defined in CIECAM02 [10] were similar to the unique red and green judgments made by the observers, but not to the unique blue and yellow judgements. Figure 4 shows the difference between the average CIECAM02 hue angles of the unique hues judged by the observers under each light source and the unique hue angles defined in CIECAM02. For unique blue, the observers' judgements generally shifted toward green. The observers' judgements on

unique yellow varied with the chroma level of the samples and D_{uv} levels of the light sources. The unique yellow defined in CIECAM02 agreed with the observers' judgments using the saturated samples under the sources with a D_{uv} of 0 or those using the desaturated samples under the sources with a D_{uv} of -0.02 and -0.04.

Moreover, CAM02-UCS was found to have a poor hue linearity. For CAM02-UCS, the iso-hue lines of unique red generally passed through the origin, while those of unique yellow and blue did not pass through the origin. For unique green, the lines passed through the origin under the 3500 K sources, but not the 2700 K sources, as shown in Figure 5.

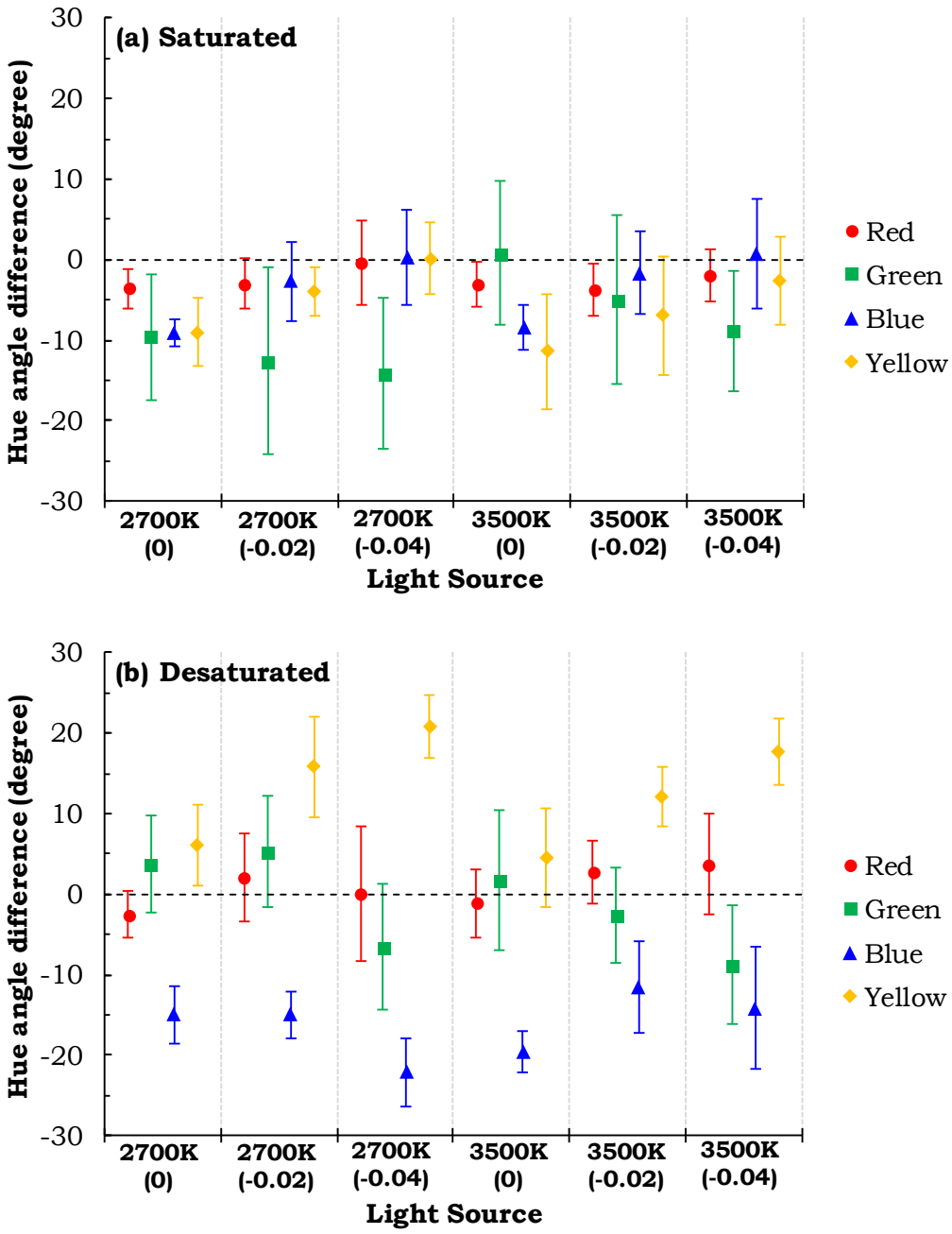

Figure 4 – Hue angle difference (the average CIECAM02 hue angles of the unique hues judged by the observers under each light source minus the unique hue angles defined in CIECAM02) (a) Saturated; (b) Desaturated

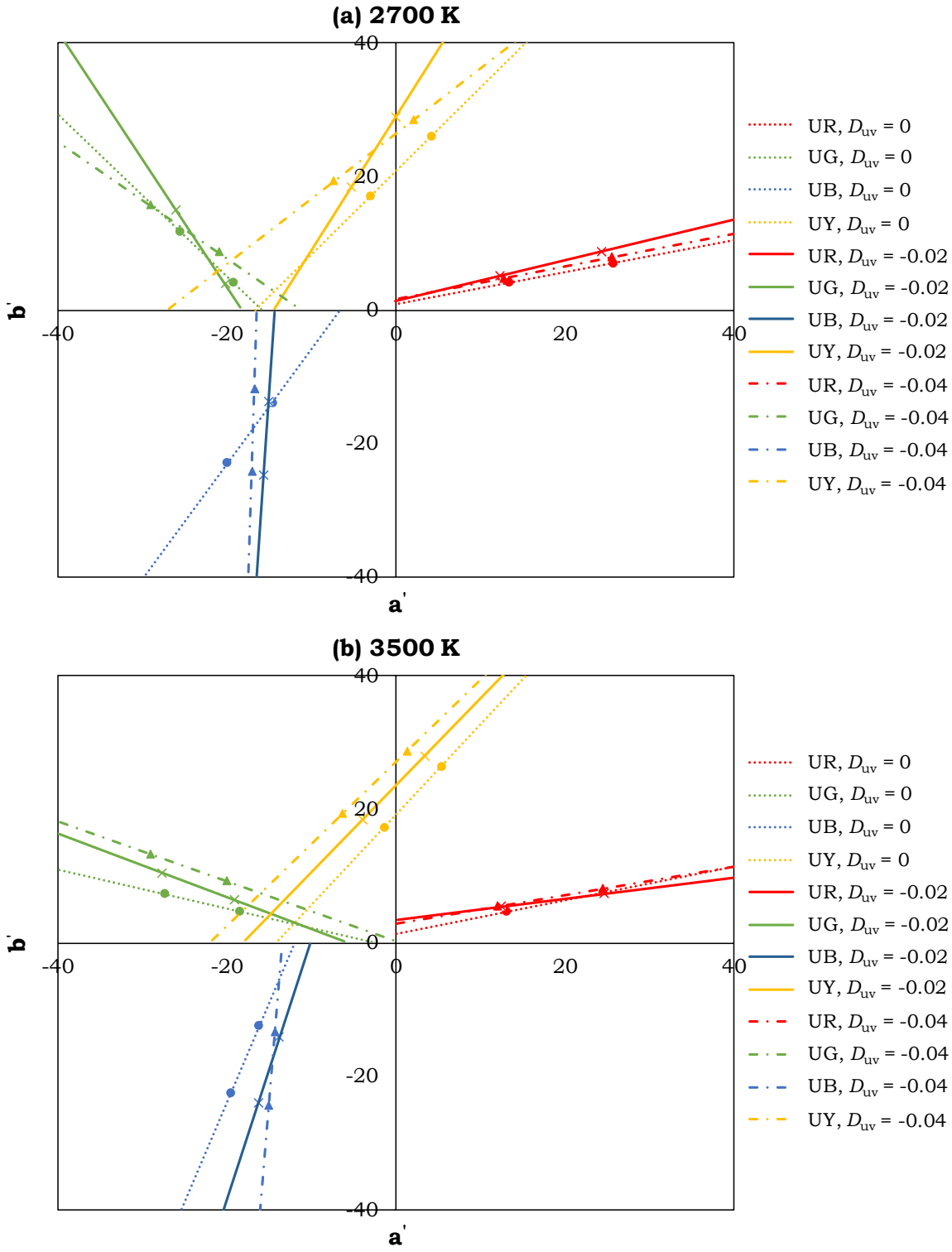

Figure 4 – The four unique hues that were evaluated by the observers and its fitted iso-hue lines under each light source in the a'-b' plane in the CAM02-UCS (a) 2700 K; (b) 3500 K.

4 Conclusions

Ten observers made unique hue judgements under six light sources, with different CCT and D_{uv} levels, using V8C4 and V6C8 Munsell samples. The unique blue and yellow judgments using the saturated and desaturated samples were significantly different, which revealed serious problems in CIECAM02 and CAM02-UCS. In addition, the iso-lines of the unique yellow, blue, and green judgments did not always go through the origins of the a'-b' planes in CAM02-UCS,

suggesting the poor linearity of the uniform color spaces. In short, future work is needed to further investigate the unique hues at different lightness and chroma levels under different light sources to revise the color appearance models and uniform color spaces.

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