Discriminating colours under LED illumination

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ABSTRACT

We measured the discrimination efficiency of three LED clusters (RGB, RGB + Amber, cool White + Amber) using the desaturated Lanthony-Panel D15 colour vision test. Compared with a continuous spectrum illumination, all LED clusters impair colour discrimination, with a severe impairment for RGB LED cluster.

1. PURPOSE

LED technology offers light sources with narrow spectrum in the visible range. At the present time, several LED arrangements allow the production of white light, but the spectrum, although continuous, presents deficiencies.[1] Would such spectral distributions of light be acceptable to correctly render the colour of the various objects that are present in a scene, and to allow the best and easiest discrimination between the delicate shades that makes the value of pieces of interest such as a work art?

We have designed an experiment, with real colour surfaces, real light sources and real observers, to assess the quality of colour rendering of a variety of LED white lights. In this work, the discrimination efficiency of the light on the full chromaticity domain is emphasized.

2. METHODS

The experimentation consists of testing the colour discrimination of observers using the desaturated Lanthony-Panel D15 (DD15) colour discrimination test[2] illuminated with various LED clusters or by a control light.

Light sources

A light booth was used to accommodate a variety of LED clusters, as well as a conventional light source. Three types of LEDs clusters were appraised:

- RGB LED cluster (RGB),
- RGBAmber LED cluster (RGBA),
- two-phosphor cold White LED + Amber LED cluster (2PWA)

LEDs were regulated and the relative intensities of the LEDs of every cluster were driven through a proprietary interface (©LDP). The control was a light source with a continuous spectral distribution (Solux 4890 K tungsten-halogen lamp filtered with blue Lee filters). We measured the spectral power distribution of every light incident on a spectralon tile positioned in the light booth using a Minolta CS-1000 spectroradiometer (Figure 1). Test lights were set at about the same colour temperature (4500K ± 150 K) and provided about the same illuminance at the samples (660 lx ± 20 lx on a white spectralon tile) (Table 1).

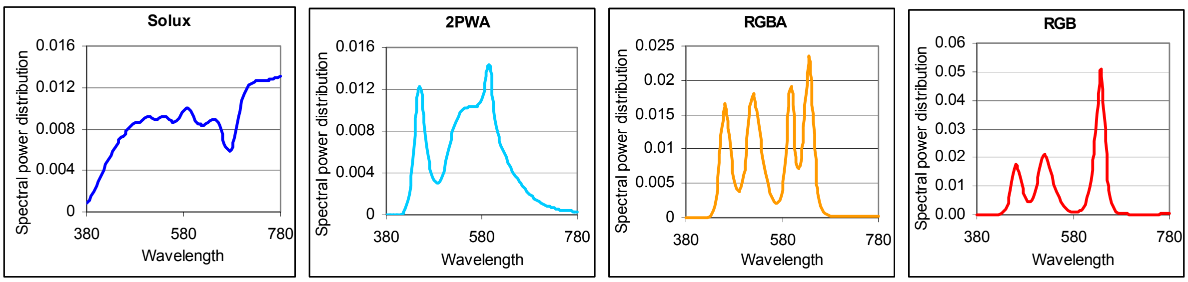

Figure 1. Spectral power distribution of the light emitted by the sources used in the experiment.

Table 1. Colour specification of the light emitted by the sources used in the experiment.

	Solux + blue filter	2PWA LED cluster	RGBA LED cluster	RGB LED cluster
Chromaticity coordinate x	0.3495	0.3611	0.3644	0.3598
Chromaticity coordinate y	0.3667	0.378	0.3611	0.352
Colour temperature T(K)	4890	4560	4370	4470
Chromaticity difference ΔC_{uv} between the test source and the control source	0.0057	0.0068	0.0025	0.0055
Illuminance (lx)	658	674	659	664

Samples

The DD15 discrimination test has been developed for screening colour vision defects. The colour caps (Munsell samples at Chroma 2) of the DD15 test cover the full hue circle and any error in ordering the caps reveals either an abnormality of the illumination spectrum or that of the observer colour vision.

We measured the spectral reflectance of every cap and computed their nominal trichromatic coordinates *x,y* under equi-energy light. Because of the low saturation of the samples and the subsequent small hue steps between them, errors in ordering the caps are likely to occur in case of irregularities of the spectral distribution of the source. It is expected that any lack of energy in one part of the spectrum could yield systematic errors for a normal colour vision observer.

Observers

68 observers having normal colour vision, as tested with Ishihara plates and Nagel anomaloscope, or with Nagel anomaloscope only, participated in the experiment. Later, observers aged > 45 years, one observer who failed the DD15 under Solux illumination by more than two inversions, and one observer exceeding the time allowed for every illumination were excluded from the panel. Finally the results of 57 observers were analysed.

Each observer was tested with the 4 types of illumination sequentially. The sequence of illumination was varied and balanced between observers. For each illumination, an observer was allowed no more than 60 seconds to perform the test. When shorter than 60 seconds, the duration of the examination was recorded. A preliminary examination either with the control light or one of the LED cluster was performed at the beginning of a session to allow the observer to become familiar with the test. The results of the preliminary examination were ignored.

3. RESULTS

CIE Colour Rendering Indices

We calculated the general colour rendering index and the special colour rendering indices according to the Test-Colour Method as recommended by CIE[3] (Table 2). Because several combinations of LED intensities of RGBA and of 2PWA clusters can yield the desired white colour, we chose to optimise at best the CRI.

- Ranking last, the RGB LED cluster yielded very low CRI.
- Although the intensity of the RGBA LED cluster was balanced so as to optimise the colour rendering, it yielded a poor CRI for five additional test-colour samples representing strong red, yellow, green, blue and human complexion colours.
- 2PWA LED cluster yielded a moderately poor CRI which conceals one extremely low additional CRI “R9”.

Colour discrimination

General counts. The 57 observers could be distributed in several classes:

- 17 observers successfully passed the test under all illuminations. Most of these observers originate from art conservation laboratories or workshops. For these expert observers, the screening power of the DD15 is not sensitive enough.

Among the observers who failed,

- 4 observers failed with the continuous spectrum light only, producing only one inversion of adjacent caps. Compared with the other classes, the number of subjects is small.

- 8 observers failed with continuous spectrum and LED illumination (1 with Solux & 2PWA, 1 with Solux, 2PWA & RGB, 1 with Solux, RGBA & RGB, 5 with all illuminations)
- 28 observers failed only with LED illumination (2 with 2PWA, 6 with RGBA, 11 with RGB, 3 with RGBA & RGB, 3 with 2PWA & RGB, 3 with 2PWA, RGBA & RGB)

Table 2: CIE Colour Rendering Indices

		Solux + blue filter	2PWA LED cluster	RGBA LED cluster	RGB LED cluster
Light greyish red	R1	95.23	67.34	55.54	-2.32
Dark greyish yellow	R2	98.12	79.98	75.48	56.97
Strong yellow green	R3	95.37	89.76	88.31	65.47
Moderate yellowish green	R4	93.00	70.39	52.95	-2.99
Light bluish green	R5	95.53	68.09	58.54	10.76
Light blue	R6	98.9	72.36	60.18	43.76
Light violet	R7	94.97	80.13	85.67	36.41
Light reddish purple	R8	90.91	44.36	68.29	-64.37
	Ra8	**95.25**	**71.55**	**68.12**	**17.96**
Strong red	R9	78.47	-60.48	24.55	-248.43
Strong yellow	R10	97.08	52.18	42.69	4.00
Strong green	R11	94.12	66.94	28.99	-25.21
Strong blue	R12	93.29	42.71	60.97	40.25
Light yellowish pink (human complexion)	R13	96.24	70.77	55.78	10.09
Moderate olive green (leaf green)	R14	96.84	94.39	91.02	75.20
	Ra14	**94.15**	**59.92**	**60.64**	**-0.03**

We show in table 3, the total number of failures for each type of illumination. All LED illumination impairs discrimination, along the yellow axis (except for one case), with the highest severity for the RGB cluster. We performed a Chi2 statistical test and found that, at the risk of 5 %, the four light tests are different (α = 1.67 %), and when taken two by two, Solux and RGB light tests are significantly different (α = 0.31 %), likewise 2PWA and RGB (α = 1.98 %).

Table 3. Total number of fails under each type of illumination.

	Solux	2PWA	RGBA	RGB
Number / 57	12	15	18	27
Percentage of fails	21.1	26.3	31.6	47.4

Amplitude of the impairment. Compared with the errors under continuous spectral illumination, which consist of inversions of adjacent caps mainly (only two out of 12 observers who failed made a two steps inversion), the errors under LED illuminations often consist of erroneous choices of caps as far as 3 or 4 steps of hue. In this case the perceptible colour difference is raised.

In order to quantify the impairment, we have computed a discrimination index based on the elevation of the average perceptible colour difference. Because the real steps between adjacent caps are not constant, and facilitate errors along the yellow axis, we computed the full colour path in L*a*b* from first cap “P” to the last cap (see figure 2). Then we computed the average of a step of the path to get a figure of the average perceptible colour (Table 4). As an example, the length of the correct colour path is 55.92 CIELAB units. The length of an erroneous colour path with an inversion between caps #11 and #12 is 58.96. This makes a difference of 3.04, or an increase of the length of the path of 5.44 %. Figures in table 4 can be smaller than in this example because all examinations were included, whether the observer passed or failed the test.

Table 4. Average total path increase in L*a*b* under each type of illumination, including all examinations

	All Solux	All 2PWA	All RGBA	All RGB
Average total path increase (%)	1.86	2.38	3.61	6.53

Direction of the impairment. Not only all LED illuminations impair hue discrimination, but the impairment is severe and specifically concentrated around greenish-blue and purple shades. Along these specific colour axes, the errors increase dramatically for the RGB LED illumination. We show in figure 2, examples of errors for each type of illumination.

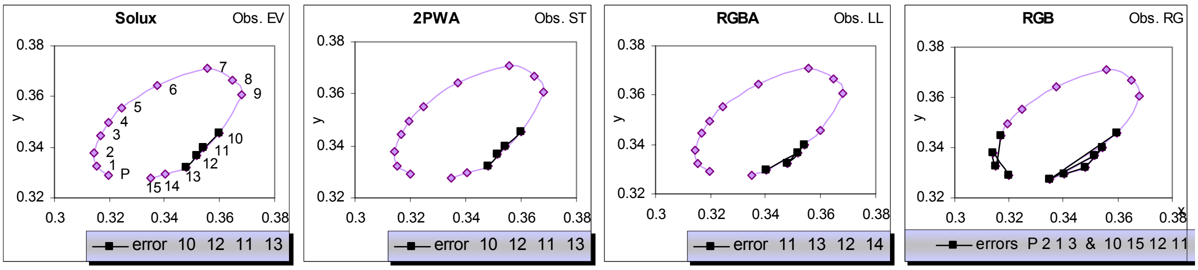

Figure 2: Examples of errors with each type of illumination. From left to right: Solux, 2PWA, RGBA, RGB. The examples have been selected among observers plots. For Solux, 2PWA and RGBA, they are representative of the most frequent errors. For RGB, the plot is chosen to exemplify the direction of the impairment.

4. Discussion

Quantification. The CIE Colour-Rendering Index of the CIE yields a figure that is difficult to interpret in the case of multiple narrow band illumination. Because the real task of the observer is to discriminate between shades, we propose to compute an index that does better represent the errors made by the observers. A CRI index based on the DD15 samples is a better representative of the observers' results than the CIE CRI index (Figure 3). The CIE CRI index is unreliable because the sample collection is sparsely distributed.

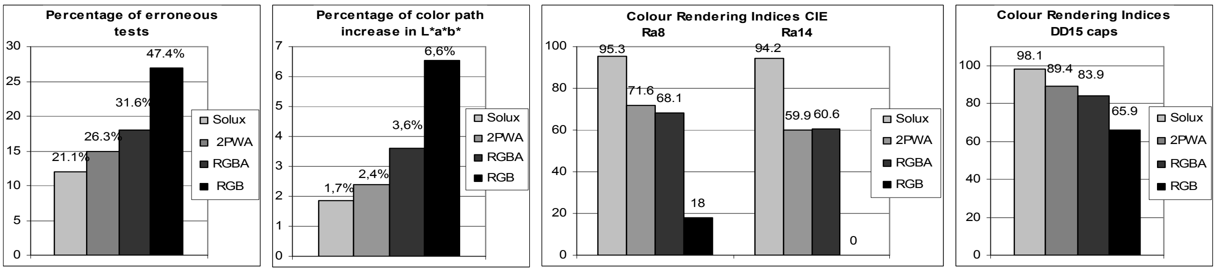

Figure 3. Percentage of erroneous examinations, percentage of colour path increase in L*a*b*, CIE CRI "Ra8", "Ra14", CRI based on DD15 colours, under each type of illumination.

Direction of impairment. Visual experiments have shown that the impairment is severe and specifically concentrated around greenish-blue and purple shades. Unfortunately, a general CRI index conceals the directional impairment that corresponds to the yellow impoverishment of the spectrum of the light. It is only by uniformly covering the full hue gamut that this direction can appear.

Visual effect of the RGB cluster. All results give a bad rating for the RGB LED light. Observers themselves have often orally reported difficulty when being tested under RGB LED light, and sometimes under the Solux light. In the last case, although the sequence of illumination was varied and balanced between observers, 7/12 erroneous tests occur under Solux light following screening under RGB light. This is a significantly biased percentage that could reveal an after effect.

5. CONCLUSION

Our experiment shows that the RGB LED cluster should be avoided.

A test of colour discrimination provides an exhaustive image of the visual impairment due to the absence of energy in parts of the spectrum as it shows that discrimination errors are made along specific colour axes. A supplementation of light should be offered in the missing parts of the spectrum to achieve the same success as the continuous visible spectrum at any colour temperature.

References

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