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A Method for Reducing Blue Light Hazard from White Light-emitting Diodes Using Colourimetric Characterization of the Display

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Abstract

White light-emitting diodes (LEDs) are used as a light source in many liquid-crystal displays (LCDs), with blue light generated as a spectral distribution characteristic of white LEDs being potentially harmful to the human retina. We propose a method for reducing the blue light only by calibration and profiling without adjusting. Specifically, this paper attempted to verify the efficacy of colourimetric characterisation for reducing or controlling the blue light. Based on the test results of LCD monitors that use a variety of LED light sources, the white LED exhibited maximal blue light emission at 450 nm, and using colourimetric characterization reduced this emission by ~36%. The proposed method is a novel approach for examining the relationship between display technologies and the human retina.

Keywords: *Blue-light, High energy visible light, Liquid crystal display, Light-emitting diode, Backlight unit, Flat-panel display, Display, Calibration, Monitor, Colourimetric Characterisation*

1. Introduction

Liquid crystal displays (LCDs) are the most commercially successful flat panel displays (FPDs) and are used in a variety of devices including mobiles, laptops, and television sets. LCD monitors use backlight units (BLUs), and the BLUs light sources have evolved from cold cathode fluorescent lamps (CCFLs) to light-emitting diodes (LEDs). This is because the LED BLUs are characterized by high efficiency and long life, and are also environmentally friendly owing to their exclusion of mercury and other toxic chemicals [1].

When reproducing white light in LED BLUs, the traditional method used is to coat blue LEDs with yellow phosphor [2]. In this case, because the blue light spectrum contains higher energy wavelengths compared with other colours, the emission of blue light is expected to be harmful to the human retina. In ophthalmology, high energy visible (HEV) light in the 400 to 500 nm range is considered to be a cause of age-related macular degeneration (AMD) [3]. In addition, international organizations such as the International Standards Organization (ISO) [4] and International Electronics Committee (IEC) [5] provide guidelines related to the harmful effects of blue light, and concerns regarding these harmful effects have been expressed in online forums related to smartphone and tablet device [6-8].

Based on the blue light related standards provided by American National Standards Institute (ANSI), Illuminating Engineering Society of North America (IES) RP-27 [9] and

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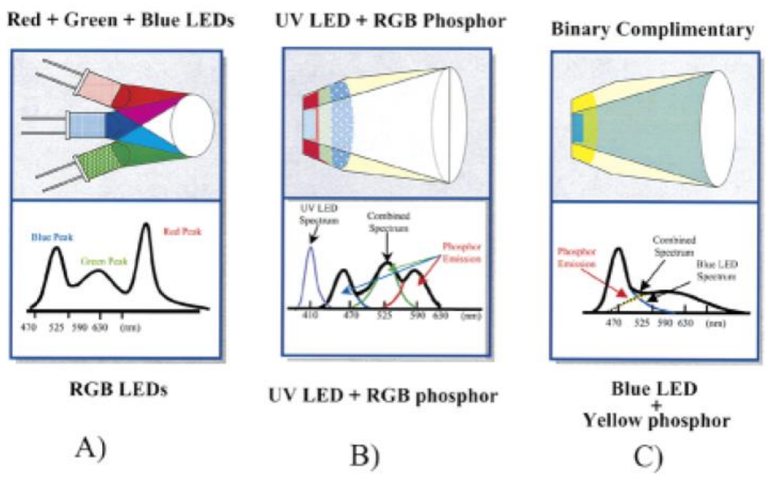
European IES 62471 [5], we analysed the extent of blue light energy used in the LCDs by LED BLUs. This paper proposes colourimetric characterisation as a method for reducing this potentially harmful energy emission. Our finding shows that the white LED sources, used in many LCD displays, emit more blue light than light sources using red, green and blue (RGB) LEDs. In addition, we verified the efficacy of colourimetric characterisation and its effects on blue light emission reduction in white LEDs. Identifying potential harmful factors of display devices and proposing a method for reducing this effect without the need for BLU adjustment, our proposed methods may provide significant implications both in academia and in the industrial fields.

2. Theoretical Background

2.1. Spectral Distributions for Different White LED Technologies

LEDs are used in monitors and other devices as light sources because of their high intensity and high efficiency properties. In commercial lighting products, three main LED technologies are used for reproducing white light. They are: 1) a technology that combines RGB LED light for reproducing white light (Figure 1A), 2) a technology that uses RGB phosphor in LEDs (Figure 1B), and 3) a technology that uses yellow phosphor in blue LEDs (Figure 1C) [2]. As shown in Figure 1, the spectral distributions for the three technologies differ.



Source: Daniel et al. [2]

Figure 1. Three Methods for Generating White Light from Leds, And Their Corresponding Spectral Distributions

2.2. Blue Light Hazard

The blue light hazard refers to the potential chemical damage that the HEV light in the 400 to 500 nm range can inflict on the human retina. Through animal testing in ophthalmology, the harmful effects of blue light have been confirmed [3], but there is still a lack of human testing for determining the harmful effects on the human retina. Yet, blue light has been considered a cause of AMD, which is a major cause of blindness in the elderly population. Through related research, factors such as aging, family history, genetics, high blood pressure, cholesterol, obesity, smoking habits and lack of Vitamin D were determined to be among the causes of AMD, and it has been predicted that exposure to blue light, which is generated from sunlight, could also be a major cause of AMD.

There are mixed research results on verifying the harmful effects of blue light, and Glazer-Hockstein and Dunaief [10] performed a major research claiming the harmful effects of blue light based on a test that used lenses for blocking blue light from affecting AMD patients. On the other hand, other studies reported an insignificant relationship between sunlight-derived blue light and AMD [11].

As reviewed above, there is a continuing controversy regarding the potential harmful effects of blue light on the human retina, but it is emphasized that there is a possibility that patients with ophthalmologic diseases suffer harmful effects from direct exposure of their retinas to blue light. The European Union's (EU's) CELMA-ELC standard and other lighting-related standards recommend that patients with decreased ability to filter blue light owing to their underdeveloped irises, such as toddlers and children or patients with eye diseases, should avoid being directly exposed to LED light sources [12].

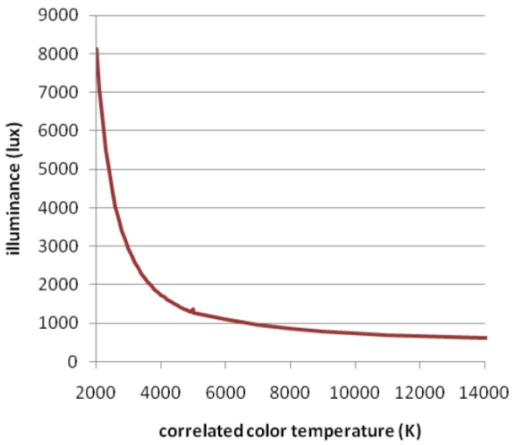
2.3. Optical Safety in LED Lighting

In the EU, the use of incandescent light bulbs will be banned starting from 2016, and it is expected that LED lights will become the most widely used source of lighting; thus, there is a need for developing detailed safety standards on blue light hazard characteristics of LEDs as indoor lighting [13]. In addition, the ANSI/IESNA RP-27 in North America [9] mentions the blue light hazard characteristics of LED light sources, and based on IEC/EN 62471, international standards have also been established. When more stringent standards on blue light hazard are examined, based on the spectral distributions of the LED light sources, IEC/TR 62778 [14] contains guidelines on the relationship between the permissible illuminance of blue light and the correlated colour temperature (CCT). As shown in Figure 2, the maximum permissible light intensity for a 2,000 K level CCT is 8,000 lux, but as CCT increases the maximum permissible illuminance level is shown to drastically decrease. However, the potential for harming the human retina actually caused by blue light must accompany the 3 conditions in Table 1, and the permissible exposure time for each condition per light source is also categorized [5, 9].

Table 1. Three Critical Factors for Injury to Occur

Spectral irradiance distribution	The proportion that falls into the action spectrum for blue light hazard is relevant, in mathematical terms: the integrated spectral irradiance distribution weighted by the action spectrum.
Radiance	At higher radiance, more photons are likely to hit the photo-pigments and cause damage.
Duration of exposure	For longer exposure times, the effects increase steadily.

Source: CELMA-ELC LED WG(SM) 011_ELC CELMA position paper [12].



Source: IEC/TR 62778 [14]

Figure 2. The Criterion for Correlation between Correlated Colour Temperature and Illuminance

2.4. Colourimetric Characterisation of Displays

According to ISO 15076-1:2010 [15], the act of characterizing the reproduction of colour in a display is to determine the characteristic of the display and saving it as a profile, and matching this to the colour of devices on an operating system (OS) or application level or display or other related devices, or to recalibrate using a target value.

Because it is technically difficult to directly alter the native white-point of white BLUs, it can be stated that the applicability of colourimetric Characterisation is high. In all white BLU LCD panels that require white-point alteration, the display industry uses the method of altering the white state by adjusting the RGB colour filter and not the BLU. Three major standards for displays are stated in Table 2.

Table 2. Three Major Standards for Displays

Standard	Illuminant White	Tone Reproduction	White Luminance	Drafter
sRGB (HDTV)	D65	Approx. 2.2 gamma	80 cd/m2	Microsoft, ITU IEC 61966-2-1:1999 [16]
AdobeRGB	D65	2.1992875 gamma	160 cd/m2	Adobe Systems [17]
BT Rec. 2020 (UHDTV)	D65	Nonlinear transfer function	n/a	ITU [18]

Source: IEC 61966-2-1:1999 [16], Adobe Systems [17], ITU [18]

3. Methodology

3.1. Experimental Design

In this experiment, as shown in Table 3, 4 monitors using different BLUs (*i.e.*, CCFL, RGB LED, GB-r-LED, and white LED) were restored to their factory settings and their white-points, gamma, and white luminance values were initialized to their original settings before conducting the experiment. All measurements for the experiment were performed in an indoor setting where the illumination was completely controlled. Referring to previous studies including Kim et al. [19], our experiment was designed.

Table 3. Sample Displays for the Experiment.

No.	Model	Size	Surface	Colour Gamut	Viewing Angle	BLU
1	HP LP3065	30 in	Antiglare	Wide	Wide	CCFL
2	HP LP2480zx	24 in	Antiglare	Wide	Wide	RGB LED
3	LG 27ea83	27 in	Antiglare	Wide	Wide	GB-r-LED
4	Samsung S27B970	27 in	Glare	Standard	Wide	White LED

For emission spectra measurements, an i1Pro 2 Rev.E spectrophotometer of X-rite was used, and for more precise measurements, the spectral radiance was measured in high resolution spectrum mode. All of the measurement equipment and the sample displays for the experiment were adequately warmed up before conducting the measurements.

3.2. Software

Spectral measurements were performed by using the Spotread function in the GNU General Public License (GPL) open sourced ArgyllCMS version 1.6.3 software environment. The 380 to 730 nm spectral range was divided into 109 bins for measuring the wavelength. In addition to the wavelength measurements, measurements of CCT and visual colour temperature (VCT) were performed simultaneously.

3.3. Sample Patch Image

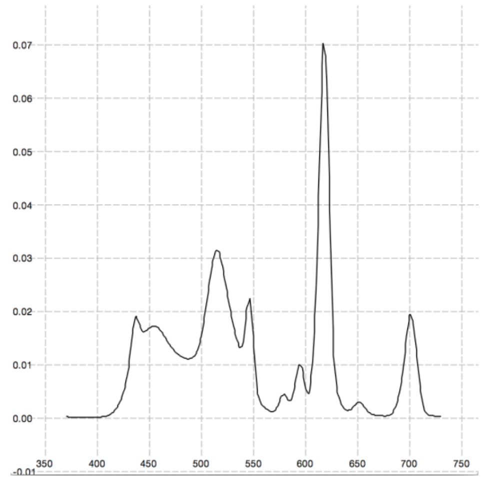
A sample patch image that had the dimensions of 20% of both the width and height for the reproduction resolution of each display was shown in the middle of the screen for conducting the experiments. The area outside of this sample patch image was black (dr = dg = db = 0) for preventing it from affecting the monitor display measurements.

4. Results

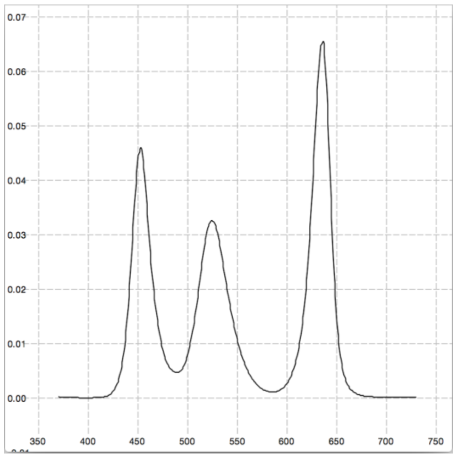
We used the blue light hazard function and spectral weight function presented by the ISO 13666:2012 and ISO 8980-3:201 standards on the spectral distribution of the display when there was a possibility of harmful wavelength emission [4].

4.1. Spectral Distributions of Different Displays

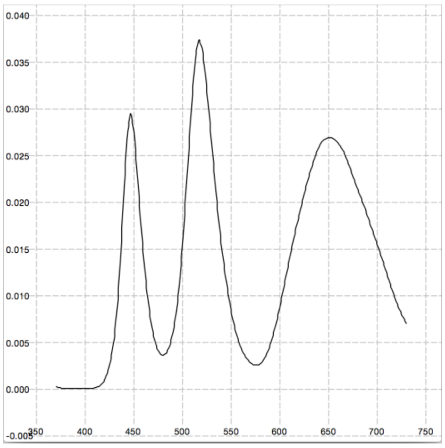
By analyzing the spectral distributions from the different tables, the white LED BLU based display that used the method of coating the blue LED with yellow phosphor was confirmed to emit the highest amount and had the highest blue light peak magnitude at the 450 nm wavelength, corresponding to the blue light hazard zone, as shown in Figure 3D.



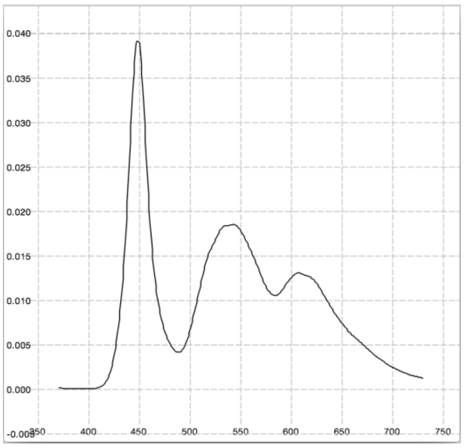
A) 1st Sample Display - CCFL BLU



B) 2nd Sample Display - RGB-LED BLU



C) 3rd Sample Display - GB-R-LED BLU



D) 4th Sample Display - White LED BLU

Figure 3. Spectral Distributions for the Sample Displays

4.2. Normalized Visible Spectra of Different BLU Sources

The white-point and sample display with the lowest luminance (190 cd/m2), that of D65, which is regulated by IEC 61966-2-1 [16], was set as the common standard, and all the sample displays were colourimetrically characterised while normalized, as shown in Table 4. The spectral distributions in Figure 4 also confirm that the blue light level of the white LED based display at 450 nm was the most prominent.

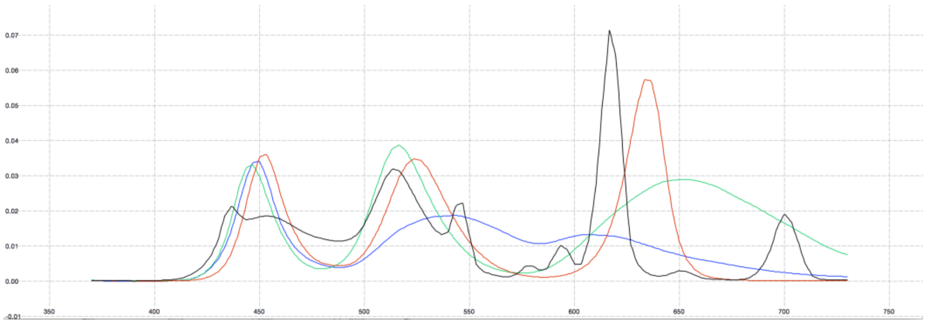


Figure. 4. Visible Range Spectra for the Different BLU Sources

Table 4. Normalized White-Points for the Different BLU Sources

Line	BLU Type	CCT	VCT
Black	CCFL	6119K	6306K
Red	RGB LED	6643K	6424K
Green	GB-r-LED	6538K	6344K
Blue	White LED	6438K	6236K

4.3. 450-nm Peak Level Changes Caused by Colourimetric Characterisation

The computer connected to the display that used the white LED as BLU was subjected to ISO 15076-1:2010 based colourimetric characterisation, and the changes in the level of blue light are shown in Figure 5.

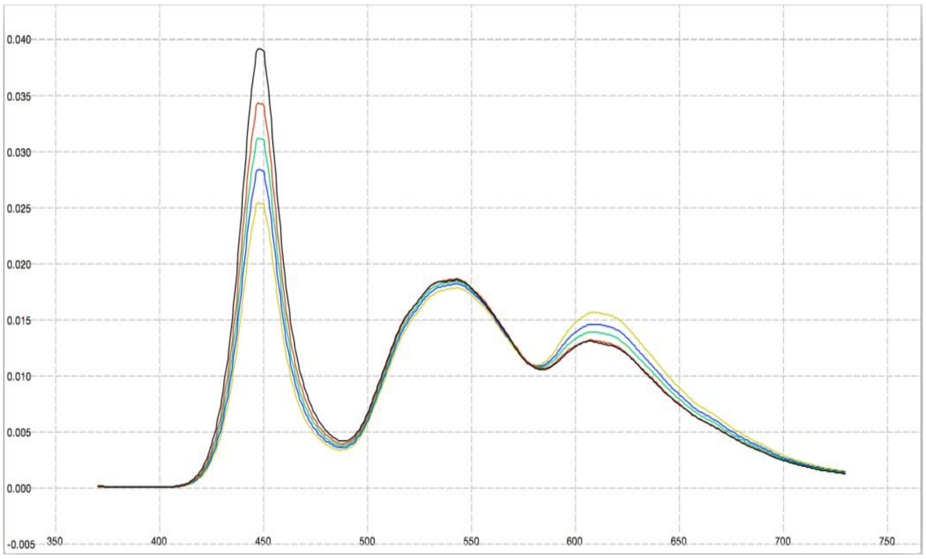


Figure 5. Blue Light Level Changes In Accordance With the Colourimetric Characterisation

When examining the blue light hazard zone (the region around 450 nm), in the native state the blue light level was shown to peak at 0.039, but after being characterised with D50, the blue light level decreased to 0.025, demonstrating ~35.9% reduction, as can be confirmed from Table 5. Stronger reduction of the white-point colour temperature yielded stronger reduction of the blue light peak. When the target white-point of the illuminance range was changed from D65 to D50, it was possible to confirm that the blue light wavelength was reduced by ~26.5% compared with that of D65.

Table 5. Relative Reduction of Blue Light Level

Line	Target white-point	CCT	VCT	450 nm blue light level	Reduced level	Reduced level compared to D65
Black	Native	7395K	7438K	0.039	-	-
Red	D65	6597K	6423K	0.034	12.8 %	-
Green	D60	5993K	5857K	0.031	20.5 %	8.8%
Blue	D55	5510K	5391K	0.028	28.2 %	17.7%
Yellow	D50	5007K	4920K	0.025	35.9 %	26.5%

5. Conclusions

We verified that LCD equipped with white LED BLUs exhibits stronger spectral distribution for blue light emission relative to displays using other BLU technologies, such as RGB LEDs. To reduce the possible harmful effects of blue light, we proposed a method for controlling the blue light level in white LED-equipped LCDs by using colourimetric characterisation.

In the situation in which there is a lack of research confirming that the blue light emitted from LCD displays can harm the human retina, a novel approach for reducing the amount of potentially harmful exposure from the LCD by using colourimetric characterisation was attempted. According to the display calibration and profiling based on ISO 15076-1:2010 [15], we can reduce or control the blue light of the displays using white LED BLUs. Furthermore, we believe that a safety option regarding blue light hazard for people who need to use a monitor for prolonged periods of time can be provided.

Although we tried to analyse each of the various BLU methods of major display manufactures in order to establish the validity and reliability of our experiments, there is a limitation to confirm the probability of the spectral distribution forms and time. In this context, we would suggest that the further research is required to consider specific effects on toddlers and children as well as the characteristics of the spectral distributions and blue light exposure time.

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