HIGH SCHOOL EDITION
Journal of Student Research

Volume 10 Issue 4 (2021)

Blue Light Intensity in Organic Light-Emitting Diode and Liquid-Crystal Display Televisions

Neekon Nejad[1] and Ushma Kothari[#]

[1]Dobyns-Bennett High School, Kingsport, TN, USA
[#]Advisor

ABSTRACT

Exposure to artificial blue light from screens, especially at evening or nighttime hours, can suppress melatonin production, throw the circadian rhythm off balance, and lead to general difficulty falling asleep. This study sought to investigate the difference in blue light intensity in organic light-emitting diode (OLED) and liquid-crystal display (LCD) screens, specifically in the form of televisions. An observational and quasi-experimental method was used, using a photometer to measure light intensity and a longpass optical filter to block out light ranging from 415 to 515 nanometers, serving as the wavelength of blue light for this study. Two televisions—one OLED and one LCD—were used, with five colors being displayed on each one, one at a time. The LCD television contained more relative blue light than the OLED television for four out of the five colors displayed. On average for all colors, the LCD television emitted 24.92% more blue light than the OLED television, relative to their overall brightnesses. Limitations in scope and the potential of confounding variables interfering with data prevent any definitive conclusions from being drawn, however this study still contributes to the current body of knowledge with evidence towards a trend of lessened blue light intensity in OLED screens compared to LCD screens, which correlates with speculation by other researchers. This study sets the ground for future research investigating the potential of OLED technology in lowering exposure to blue light, thus lessening the negative impacts it can have on individuals.

1 Introduction

Numerous studies and experiments have been conducted on the effect of blue light on health. Various studies have particularly examined the effect of artificial blue light, emitted from manmade light sources such as screens, on sleep. Two of the most commonly used screens today are organic light-emitting diode and and liquid-crystal display screens (Chen, Lee, Lin, Chen, & Wu, 2018). A broad trend comparing blue light intensity in these two types of screens has not been experimentally identified. Many researchers have found that artificial blue light can impact melatonin production and throw the circadian rhythm off balance, leading to those exposed experiencing difficulty in falling asleep (Chang, Aeschbach, Duffy, & Czeisler, 2015; Cajochen et al., 2011; Sasseville, Paquet, Sévigny, & Hébert, 2006). This issue raises a question: what is the difference in blue light intensity between organic light-emitting diode and liquid-crystal display televisions?

2 Literature Review

2.1 Existing Research and Studies

Many researchers analyzing the impact of blue light and artificial light on health have conducted studies on live human subjects, following an experimental design. A crucial assumption for these studies is that with enough factors held constant or accounted for, the impact of light exposure on some aspect of health, such as sleep, can be analyzed. Data is predominantly quantitative in many of these studies. For example, a 2011 study by Cajochen et al. for the *Journal of Applied Physiology* exposed 13 young male volunteers to artificial blue light from light-emitting diodes, or LEDs, over an elongated period of time. The impact of this exposure on various aspects of the volunteers' health and cognitive functions was then assessed. One of the most notable trends found was a decrease in melatonin production and general difficulty falling asleep correlating with heightened exposure to artificial light, especially at evening or nighttime hours. This study, along with other studies that have drawn similar findings, indicate that this is an issue that may affect anyone who is exposed to artificial blue light on a regular basis, especially at later hours.

As screens are a primary source of artificial blue light, a multitude of researchers have compared various aspects of two of the most commonly used types of screens today: organic light-emitting diode, or OLED, screens, and liquid-crystal display, or LCD, screens (Chen et al., 2018). A study for the journal *Light: Science & Applications* found data which indicated that many LCD screens thrive in functionality lifetime, price, resolution, and brightness, while OLED screens succeed in black state, panel flexibility, and response time (Chen et al., 2018). As technology around screens evolves and changes, so does the discussion around it. A 2017 study for the journal *Advanced Functional Materials*, for example, investigated the potential for newer, more efficient blue OLEDs to be introduced to and integrated into screens in the market in the near future (Im et al., 2017). Various aspects of LCD screens that can also be improved, such as backlight configuration for color gamut, to maintain market prevalence in the future were outlined in a 2019 study for the journal *Liquid Crystals Today* (Chen & Wu, 2019). These studies highlight the current and ongoing discussion surrounding technology used in OLED and LCD screens.

2.2 Common Findings and Trends

Many studies have found that exposure to artificial light or blue light at later hours suppresses melatonin production and throws the circadian rhythm off balance (Chang, Aeschbach, Duffy, & Czeisler, 2015; Cajochen et al., 2011; Sasseville, Paquet, Sévigny, & Hébert, 2006). A 1980 study for the journal *Science* found that while light intensity does impact melatonin production, humans require a higher intensity of light than other species do for this impact to occur, signifying a potential adaptation to artificial light (Lewy, Wehr, Goodwin, Newsome, & Markey, 1980). More recent studies, however, have not advanced this finding or expanded on this trend. Though most researchers agree that exposure to blue light at later hours has negative effects on sleep, one study for the *Scandinavian Journal of Work, Environment & Health* found that office workers exposed to blue-enriched white light during work hours experienced improved productivity and efficiency (Viola, James, Schlangen, & Dijk, 2008). This study displays that in some circumstances, exposure to blue-enriched light may have some benefits, however the general consensus that exposure to artificial blue light at later hours is harmful still stands. Over time, confidence has grown that exposure to blue light at evening or nighttime hours suppresses melatonin production and throws the circadian rhythm off balance. OLED screens are newer technology than LCD screens, so the discussion around harmful blue light from screens has evolved as they have been introduced to and integrated into the market (Service, 2005; Im et al., 2017). Even so, technology involved in both types of screens continues to grow and expand.

One common theory among researchers is that exposure to blue light at later hours alters the brain's perception of the time of day, making it believe it is earlier than it truly is. This is likely due to the prominence of natural blue light during daylight hours. In a study for the *Scandinavian Journal of Work, Environment & Health*, Vetter, Juda, Lang, Wojtysiak, & Roenneberg (2011) found that blue-enriched light competes with natural daylight in acting as a zeitgeber, meaning that blue-enriched light acts in a dominant manner over the human sleep cycle. This study supports the idea that artificial blue light alters the circadian rhythm due to heightened blue light in natural daylight, thus providing an explanation for trends commonly seen in other studies.

2.3 Gap, Research Question, and Hypothesis

Evidence from various researchers indicates that high exposure to blue light from screens, especially at evening or nighttime hours, is an issue, as it can lead to decreased melatonin production and cause issues with the circadian rhythm. Though some aspects of OLED and LCD screens have been compared, previous research has not looked for a general difference in blue light intensity between OLED and LCD screens. Researchers for the journal *Scientific Reports* gathered data which indicated that OLEDs contain substantially less ocular toxicity than LEDs, meaning OLEDs generally place less strain on the eyes. These researchers speculated that OLEDs may emit lower blue light intensity than LEDs, which are found in LCD screens, since blue light is a form of visible light with relatively high energy and short wavelength compared to other forms of visible light (Jun et al. 2020). However, such a trend has not been explicitly investigated. This gap in the current body of literature prompts a question: what is the difference in blue light intensity between organic light-emitting diode and liquid-crystal display televisions? For the purposes of this study, televisions will be referred to as “TVs.” One study by Im et al. (2017) for the journal *Advanced Functional Materials* involved blue OLEDs used in screens, but did not form a comparison with LCD screens. The study suggests that while OLEDs generally excel in efficiency, blue OLEDs specifically often lack in efficiency, lifespan, and overall performance (Im et al., 2017). Similarly to Jun et al.'s 2020 study, this study indicates that OLED screens may emit less blue light than LCD screens, but does not explicitly form any sort of comparison to investigate that trend. Based on the findings of this study, it was hypothesized that the OLED TV would measure to have a lower overall intensity of blue light than the LCD TV, relative to their overall brightnesses. Similarly to other researchers, it was assumed that with enough factors held constant, blue light intensity between an OLED screen and LCD screen can be compared fairly and potentially applied to a greater scale. The potential impact of artificial blue light on health and sleep, evinced by previous studies, serves to display the significance and value of this research.

3 Methods

3.1 Overview

TVs were used in this study rather than some other kind of screen due primarily to availability. OLED computer monitors were heavily limited in the market at the time this study was conducted, so they could not be used. TVs also allowed for more control than technology such as cell phones would, as TVs could be connected to the same computer via HDMI cable to ensure entirely consistent software input.

This study followed a quasi-experimental and observational design. The process for collecting data was partially observational as the difference in blue light intensity was measured, but not caused. Both TVs already contained their respective screens before any data was collected. While the data was extracted from the screens through a defined and controlled process, the screens themselves were not actually altered by this process (Leedy & Ormrod, 2018).

This study was also experimental as it included distinguishable independent and dependent variables as well as various control factors. The independent variable for this experiment was the type of screen, either OLED or LCD. The dependent variable was the intensity of blue light measured. Factors held constant included screen size, screen resolution, the distance the photometer was held from the screen, what colors were displayed, and external lighting conditions. The study was quasi-experimental rather than experimental or true-experimental due to the presence of certain factors that could not be explicitly controlled, such as slight manufacturing differences or differences in physical layers within the screens (Leedy & Ormrod, 2018). This lack of explicit control stemmed mainly from the TVs belonging to different brands, which was due to limitations in availability for OLED TVs.

The methods employed align with studies conducted for the journals *In Vitro Cellular & Developmental Biology Plant* and *Biotechnology for Biofuels* which also involved light intensity, as they followed experimental designs to collect quantitative data (Neto, Chagas, Costa, Chagas, & Vendrame, 2020; Nzayisenga, Farge, Groll, &

Sellstedt, 2020). This study also stood on the basis that despite differences in individual screens, general trends between OLED and LCD technology can be made with enough control in place, which correlates with Chen et al.'s 2018 study, where various aspects of OLED and LCD screens were compared on a broad scale. For this study, solely quantitative data was collected and organized within numerous homogeneous groups, indicating stratified organization, based on what color was being displayed, which screen it was displayed on, and whether or not the optical filter was in place.

3.2 Method Limitations

The main limitation of the methods employed stemmed from the potential of interference from confounding variables in the quasi-experimental nature of the experiment. While many factors were controlled in contribution to forming a fair comparison, a lack of control in specific manufacturing and brand differences limit the conclusiveness of this study. Any settings that would deliberately attempt to alter color composition in any way, such as energy saving or comfort viewing settings, were manually disabled. Sans any individual fault with or disparity between the physical screen layers, the experiment was still controlled to a valid degree through various control factors, consistent software input, and individual settings removing any alteration.

3.3 Instruments and Materials

The photometer used was an Amprobe LM-200 LED light meter. It collected data on light intensity, measured in lux, or lumens per square meter. The function of a photometer to measure light intensity or brightness was described in a study conducted by Budde et al. (2019) for the journal *Sensors*, which involved a phone-based dust measurement system with the use of built-in cameras and sensors. Figure 1 displays the photometer without the optical filter in place, and Figure 2 displays the photometer with the optical filter in place. Cardboard was used to ensure a consistent distance from the screen for all measurements, and tape was used along with cardboard to hold the optical filter in place. Two TVs were studied, one containing an OLED screen and the other an LED backlit LCD screen. The LCD TV model used was a TCL 55S405, and the OLED TV was an LG OLED55CXPUA. Both screens were 55 inches diagonally and 3840 by 2160 pixels, but were downscaled to 1920 by 1080 pixels via HDMI cable. The actual resolution itself didn't matter so much as consistency between the two, as the aim of the study was to form a comparison. As an additional precaution, the HDMI cable also set both TVs to a refresh rate of 60 hertz. Although refresh rate isn't likely to impact light intensity for this study since colors were displayed statically, as much control as possible was practiced to account for the aforementioned lack of control regarding other factors. Five colors were displayed, one at a time, on both screens. Colors were displayed using HEX codes to ensure consistency in software input, as the codes could be checked to ensure the same colors were used for all measurements. The HEX colors used were #000000, #ffffff, #ff0000, #00ff00, and #0000ff. These codes display black, white, red, blue, and green, respectively. These colors were chosen in order to gather data on different extremes of the RGB color spectrum. Consistently using the same colors with both TVs being connected to the same computer helped ensure that any trend in blue light intensity came from the hardware of the screens themselves, and not from a difference in what the software was attempting to display. An OD 2.0 Longpass optical filter from Edmund Optics with a 25.00 millimeter diameter was used to block visible light ranging from 415 to 515 nanometers in wavelength, which, for the purposes of this experiment, served as the wavelength range for blue light. This allowed the optical filter to isolate blue light by rejecting it, so blue light intensity could be found from the difference between measurements conducted with and without the filter. While the filter did not block all light in this wavelength range, the cutoff remained proportionally consistent, allowing for a fair comparison.

Figure 1. Photometer without optical filter in place

Figure 2. Photometer with optical filter in place

3.4 Procedure

As the purpose of this experiment was to form a comparison, great emphasis was placed on the consistency of measurements. Both TVs were connected to the same computer via HDMI cable, and then set to a resolution of 1920 by 1080 pixels and a refresh rate of 60 hertz. The photometer was held at 3 inches from the screen for all measurements, as a change in distance would impact the measured light intensity (Budde et al., 2019). As shown in Figure 1 and Figure 2, a piece of cardboard was taped to the side of the photometer to indicate this distance. The placement of the optical filter did not affect this distance in any way, as cardboard was attached to the front of the photometer in preparation for the filter, which was attached to the photometer with tape when used. A simple hold feature on the photometer was used to read and record measurements. As natural light varies in intensity and composition depending on the weather and time of day (Vetter et al., 2011), no natural light was let into the testing environment, and external lighting conditions remained consistent throughout the entire process of collecting data. HEX codes #000000, #ffffff, #ff0000, #00ff00, and #0000ff were used to uniformly display black, white, red, blue, and green onto each TV, one at a time. 25 trials were performed for each color for both TVs, both with and without the optical filter in place. A total of 500 data points were collected and analyzed.

4 Results

Table 1 displays raw data taken directly from photometer readings for all five colors from both screens. Data gathered both with and without the optical filter in place is listed. Table 2 shows data drawn through calculations and assessments on data from Table 1.

Table 1. Raw Data

Screen type	HEX color	Trial	Light intensity without filter (lux)	Light intensity with filter (lux)
OLED	#000000	1	1.5	1.6
OLED	#000000	2	1.7	1.5
OLED	#000000	3	1.6	1.3
OLED	#000000	4	1.6	1.5
OLED	#000000	5	1.2	1.5
OLED	#000000	6	1.3	1.5
OLED	#000000	7	1.6	1.5
OLED	#000000	8	1.9	1.1
OLED	#000000	9	1.6	1.2
OLED	#000000	10	1.9	1.3
OLED	#000000	11	1.5	1.4
OLED	#000000	12	1.1	0.7
OLED	#000000	13	1.2	1.2
OLED	#000000	14	0.8	1.3

OLED	#000000	15	1.0	1.3
OLED	#000000	16	1.4	1.1
OLED	#000000	17	1.5	1.0
OLED	#000000	18	1.5	1.1
OLED	#000000	19	1.3	1.2
OLED	#000000	20	1.6	1.1
OLED	#000000	21	1.3	1.5
OLED	#000000	22	1.1	1.3
OLED	#000000	23	1.3	1.2
OLED	#000000	24	1.5	1.1
OLED	#000000	25	1.3	1.1
OLED	#ff0000	1	29.1	23.2
OLED	#ff0000	2	29.4	23.2
OLED	#ff0000	3	28.7	23.8
OLED	#ff0000	4	29.4	23.6
OLED	#ff0000	5	29.2	23.3
OLED	#ff0000	6	28.8	23.5
OLED	#ff0000	7	29.8	22.7
OLED	#ff0000	8	29.3	22.0
OLED	#ff0000	9	30.0	23.8
OLED	#ff0000	10	26.5	23.7
OLED	#ff0000	11	29.1	23.8
OLED	#ff0000	12	28.6	23.8
OLED	#ff0000	13	28.8	24.4
OLED	#ff0000	14	28.6	23.4
OLED	#ff0000	15	29.2	23.7
OLED	#ff0000	16	29.2	23.9
OLED	#ff0000	17	30.1	23.4
OLED	#ff0000	18	28.9	24.0
OLED	#ff0000	19	26.8	23.7
OLED	#ff0000	20	30.1	23.5

OLED	#ff0000	21	29.1	24.5
OLED	#ff0000	22	29.5	24.5
OLED	#ff0000	23	28.7	24.1
OLED	#ff0000	24	29.1	23.0
OLED	#ff0000	25	28.9	23.8
OLED	#00ff00	1	129.7	71.4
OLED	#00ff00	2	130.9	72.1
OLED	#00ff00	3	130.1	71.8
OLED	#00ff00	4	131.1	72.7
OLED	#00ff00	5	132.4	72.0
OLED	#00ff00	6	133.2	71.6
OLED	#00ff00	7	134.5	74.9
OLED	#00ff00	8	129.3	74.5
OLED	#00ff00	9	131.2	73.6
OLED	#00ff00	10	130.3	71.8
OLED	#00ff00	11	132.1	74.3
OLED	#00ff00	12	132.2	70.9
OLED	#00ff00	13	129.1	72.6
OLED	#00ff00	14	131.0	73.3
OLED	#00ff00	15	131.6	74.3
OLED	#00ff00	16	131.1	74.7
OLED	#00ff00	17	129.5	73.0
OLED	#00ff00	18	129.1	72.4
OLED	#00ff00	19	130.7	73.9
OLED	#00ff00	20	128.0	72.3
OLED	#00ff00	21	127.1	73.4
OLED	#00ff00	22	131.2	74.4
OLED	#00ff00	23	127.3	73.3
OLED	#00ff00	24	128.8	73.4
OLED	#00ff00	25	129.0	74.9
OLED	#0000ff	1	6.4	3.8

OLED	#0000ff	2	6.4	3.9
OLED	#0000ff	3	7.6	3.6
OLED	#0000ff	4	7.6	3.4
OLED	#0000ff	5	7.1	4.0
OLED	#0000ff	6	7.3	4.0
OLED	#0000ff	7	7.4	3.5
OLED	#0000ff	8	7.2	3.0
OLED	#0000ff	9	6.8	3.7
OLED	#0000ff	10	6.8	3.5
OLED	#0000ff	11	6.9	3.3
OLED	#0000ff	12	6.4	3.6
OLED	#0000ff	13	6.7	3.3
OLED	#0000ff	14	6.2	3.5
OLED	#0000ff	15	6.2	3.4
OLED	#0000ff	16	6.2	3.4
OLED	#0000ff	17	7.3	3.4
OLED	#0000ff	18	6.8	3.2
OLED	#0000ff	19	7.8	3.0
OLED	#0000ff	20	7.5	3.2
OLED	#0000ff	21	7.9	2.8
OLED	#0000ff	22	7.9	3.8
OLED	#0000ff	23	7.5	3.4
OLED	#0000ff	24	7.7	3.6
OLED	#0000ff	25	7.1	3.4
OLED	#ffffff	1	120.7	90.9
OLED	#ffffff	2	122.2	89.5
OLED	#ffffff	3	120.9	91.4
OLED	#ffffff	4	121.2	91.5
OLED	#ffffff	5	120.9	91.8
OLED	#ffffff	6	121.1	92.6
OLED	#ffffff	7	116.2	90.3

OLED	#ffffff	8	121.7	92.7
OLED	#ffffff	9	120.3	92.8
OLED	#ffffff	10	121.1	91.3
OLED	#ffffff	11	121.2	94.0
OLED	#ffffff	12	124.9	91.6
OLED	#ffffff	13	120.5	92.6
OLED	#ffffff	14	123.0	91.7
OLED	#ffffff	15	120.7	89.5
OLED	#ffffff	16	121.4	92.2
OLED	#ffffff	17	121.2	92.1
OLED	#ffffff	18	119.4	90.8
OLED	#ffffff	19	123.3	90.0
OLED	#ffffff	20	122.8	89.1
OLED	#ffffff	21	120.7	91.9
OLED	#ffffff	22	120.8	90.6
OLED	#ffffff	23	122.7	92.2
OLED	#ffffff	24	122.6	91.3
OLED	#ffffff	25	121.6	91.7
LCD	#000000	1	2.6	1.8
LCD	#000000	2	2.5	1.9
LCD	#000000	3	2.3	1.8
LCD	#000000	4	3.0	1.9
LCD	#000000	5	2.8	1.5
LCD	#000000	6	2.3	1.8
LCD	#000000	7	2.5	1.5
LCD	#000000	8	2.8	1.5
LCD	#000000	9	2.9	1.7
LCD	#000000	10	2.3	1.3
LCD	#000000	11	3.5	2.4
LCD	#000000	12	3.0	2.2
LCD	#000000	13	2.4	1.6

LCD	#000000	14	2.6	1.9
LCD	#000000	15	2.7	2.8
LCD	#000000	16	3.3	2.4
LCD	#000000	17	3.1	2.3
LCD	#000000	18	2.7	2.1
LCD	#000000	19	2.7	1.5
LCD	#000000	20	3.6	2.4
LCD	#000000	21	2.2	3.0
LCD	#000000	22	3.3	2.5
LCD	#000000	23	3.1	2.1
LCD	#000000	24	3.1	2.3
LCD	#000000	25	3.7	2.4
LCD	#ff0000	1	26.3	22.4
LCD	#ff0000	2	26.1	22.5
LCD	#ff0000	3	25.8	23.0
LCD	#ff0000	4	25.9	23.5
LCD	#ff0000	5	25.7	23.0
LCD	#ff0000	6	26.2	23.2
LCD	#ff0000	7	26.3	23.3
LCD	#ff0000	8	26.7	23.0
LCD	#ff0000	9	25.9	23.6
LCD	#ff0000	10	26.2	22.9
LCD	#ff0000	11	26.2	23.1
LCD	#ff0000	12	25.3	23.2
LCD	#ff0000	13	25.7	22.9
LCD	#ff0000	14	26.3	22.7
LCD	#ff0000	15	25.6	22.4
LCD	#ff0000	16	25.7	23.4
LCD	#ff0000	17	25.9	22.8
LCD	#ff0000	18	26.2	22.0
LCD	#ff0000	19	25.5	23.0

LCD	#ff0000	20	26.2	22.7
LCD	#ff0000	21	25.9	23.7
LCD	#ff0000	22	26.3	23.4
LCD	#ff0000	23	26.2	23.0
LCD	#ff0000	24	26.5	22.9
LCD	#ff0000	25	25.8	23.1
LCD	#00ff00	1	117.7	63.2
LCD	#00ff00	2	117.9	62.3
LCD	#00ff00	3	116.5	62.0
LCD	#00ff00	4	118.6	62.9
LCD	#00ff00	5	119.6	62.9
LCD	#00ff00	6	118.1	63.4
LCD	#00ff00	7	117.2	63.1
LCD	#00ff00	8	116.8	62.4
LCD	#00ff00	9	119.1	63.1
LCD	#00ff00	10	118.6	63.1
LCD	#00ff00	11	118.0	62.8
LCD	#00ff00	12	118.8	63.5
LCD	#00ff00	13	117.1	62.8
LCD	#00ff00	14	116.5	63.4
LCD	#00ff00	15	117.3	63.3
LCD	#00ff00	16	115.6	63.2
LCD	#00ff00	17	118.2	63.2
LCD	#00ff00	18	119.1	63.1
LCD	#00ff00	19	117.2	63.2
LCD	#00ff00	20	118.2	63.5
LCD	#00ff00	21	112.8	63.7
LCD	#00ff00	22	115.9	63.8
LCD	#00ff00	23	116.9	62.2
LCD	#00ff00	24	116.6	63.0
LCD	#00ff00	25	117.3	62.3

LCD	#0000ff	1	14.6	6.4
LCD	#0000ff	2	15.2	6.1
LCD	#0000ff	3	14.0	5.9
LCD	#0000ff	4	14.1	5.8
LCD	#0000ff	5	14.7	5.9
LCD	#0000ff	6	14.7	5.9
LCD	#0000ff	7	14.5	6.1
LCD	#0000ff	8	15.3	6.3
LCD	#0000ff	9	14.4	6.2
LCD	#0000ff	10	14.5	6.2
LCD	#0000ff	11	14.9	6.3
LCD	#0000ff	12	14.3	6.2
LCD	#0000ff	13	14.8	5.6
LCD	#0000ff	14	15.5	6.5
LCD	#0000ff	15	14.9	6.0
LCD	#0000ff	16	14.0	5.8
LCD	#0000ff	17	14.4	5.8
LCD	#0000ff	18	14.5	6.3
LCD	#0000ff	19	14.8	6.2
LCD	#0000ff	20	13.9	5.2
LCD	#0000ff	21	14.1	5.7
LCD	#0000ff	22	13.9	6.0
LCD	#0000ff	23	14.9	6.4
LCD	#0000ff	24	14.5	6.1
LCD	#0000ff	25	14.4	6.2
LCD	#ffffff	1	151.9	88.0
LCD	#ffffff	2	150.8	86.8
LCD	#ffffff	3	149.1	87.6
LCD	#ffffff	4	144.2	86.9
LCD	#ffffff	5	148.8	87.7
LCD	#ffffff	6	149.0	84.5

LCD	#ffffff	7	149.9	86.6
LCD	#ffffff	8	152.3	86.3
LCD	#ffffff	9	152.0	87.5
LCD	#ffffff	10	149.5	88.0
LCD	#ffffff	11	150.4	86.8
LCD	#ffffff	12	149.5	85.8
LCD	#ffffff	13	150.5	86.4
LCD	#ffffff	14	150.4	83.6
LCD	#ffffff	15	151.0	85.9
LCD	#ffffff	16	146.7	85.8
LCD	#ffffff	17	147.9	85.2
LCD	#ffffff	18	151.4	85.7
LCD	#ffffff	19	149.8	86.3
LCD	#ffffff	20	144.4	84.9
LCD	#ffffff	21	145.5	84.1
LCD	#ffffff	22	150.2	86.1
LCD	#ffffff	23	146.4	86.6
LCD	#ffffff	24	147.5	84.7
LCD	#ffffff	25	147.2	86.4

In Table 2, median values are used as a measure of center due to the presence of outliers in various homogeneous color groups. This is because median values are generally resistant to outliers, while mean values are more easily influenced or skewed (Bock, Bullard, & Velleman, 2019). The “Light blocked” section displays the difference between median values with and without the optical filter in place for all five HEX colors, essentially representing the intensity of light blocked by the filter. This value on its own may be misleading however, as it does not account for a potential difference in overall brightness between the TVs. Since overall brightness can generally be adjusted, relative light intensity is better suited for comparison.“Blue light composition” represents the portion of blue light that was blocked for each HEX color, meaning it is a measurement of blue light intensity relative to the TVs’ overall brightnesses. It was calculated by dividing the “Light blocked” value of each HEX color by the original median value without the optical filter in place. While this does not represent all of the blue light for each color, it represents a consistent and proportional value that can be fairly compared. Using this rather than the “Light blocked” value eliminates any discrepancy that may be caused by differences in overall light intensity between the two TVs.

Table 2. Calculations

	HEX Color	OLED	LCD
Median light intensity (no filter) (lux)	#000000	1.5	2.8
	#ff0000	29.1	26.1
	#00ff00	130.7	117.3
	#0000ff	7.1	14.5
	#ffffff	121.2	149.5
Median light intensity (with filter) (lux)	#000000	1.3	1.9
	#ff0000	23.7	23.0
	#00ff00	73.3	63.1
	#0000ff	3.4	6.1
	#ffffff	91.6	86.3
Light blocked (median intensity without filter - median intensity with filter) (lux)	#000000	0.2	0.9
	#ff0000	5.4	3.1
	#00ff00	57.4	54.2
	#0000ff	3.7	8.4
	#ffffff	29.6	63.2
Blue light composition (light blocked / median intensity without filter)	#000000	0.133	0.321
	#ff0000	0.186	0.119
	#00ff00	0.439	0.462
	#0000ff	0.521	0.579
	#ffffff	0.244	0.423
	all (average)	0.305	0.381

Blue light composition results for each HEX color are displayed in Figure 3, organized by HEX color, with OLED and LCD values side by side for comparison.

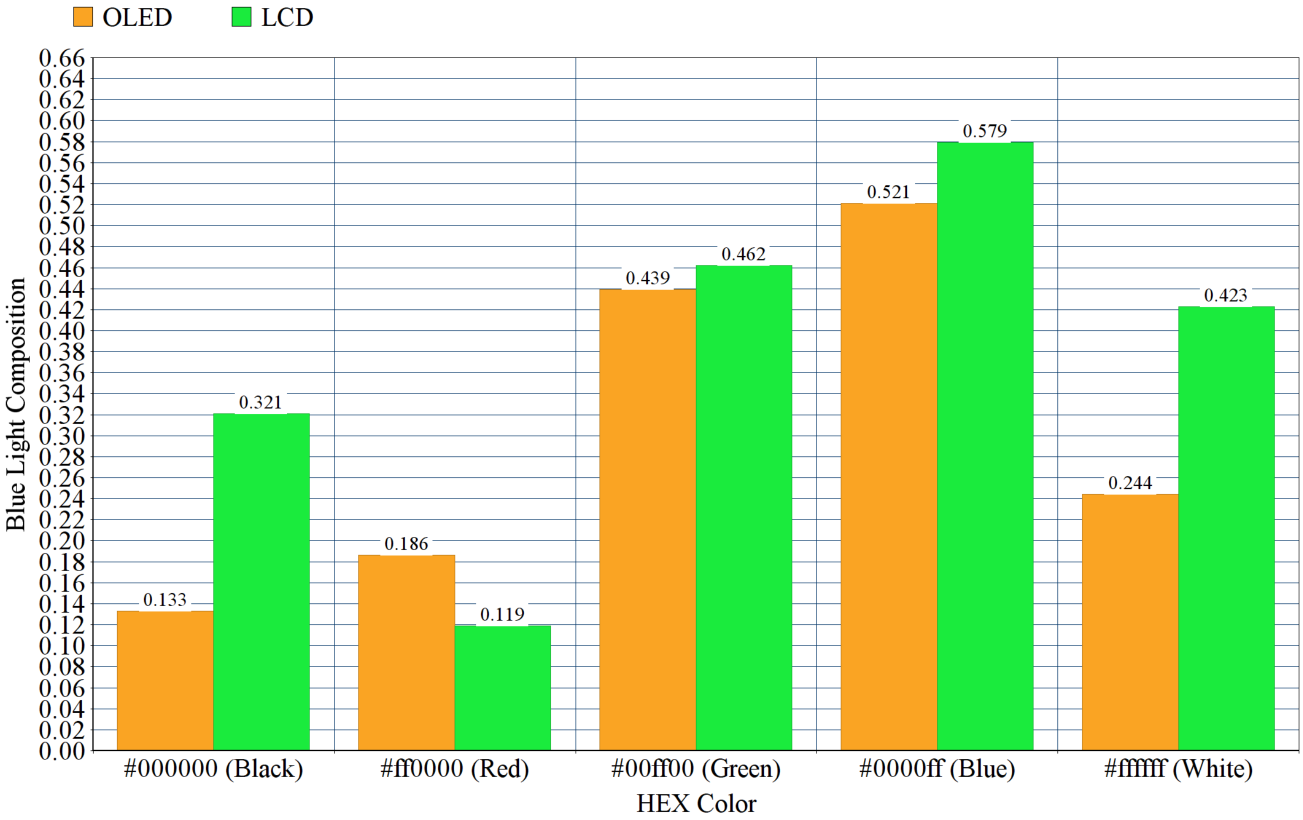

Figure 3. Blue Light Composition for both TVs among all five HEX colors

Blue light composition was lower for the OLED TV than the LCD TV for all HEX colors but #ff0000, or red. This study did not produce an explanation as to why red displayed a different trend than the other colors. As expected, blue light composition was higher for #0000ff, or blue, than for all other HEX colors for both TVs. On average for all HEX colors, blue light composition was 0.305 for the OLED TV and 0.381 for the LCD TV, meaning the LCD TV was measured to emit 24.92% more blue light on average than the OLED TV, relative to their overall brightnesses. This supported the initial hypothesis that the OLED TV would measure to overall emit less relative blue light intensity compared to the LCD TV. This same trend could also be seen to some degree in all measured individual colors but red.

5 Discussion

5.1 Significance and Implications

Past studies have conveyed how exposure to artificial blue light at later hours can negatively affect a person's health. Therefore, decreased exposure to blue light at evening and nighttime hours should lessen the impact of artificial blue light on melatonin production and sleep (Cajochen et. al, 2011). Over long periods of time, even slight differences in blue light exposure may have substantial effects. As the OLED TV was measured to emit less overall blue light among the five chosen HEX colors, the data suggests that OLED screens emit less blue light than LCD screens, however further research is needed to draw a definitive conclusion regarding this trend. This study still contributes evidence to the current body of knowledge which supports a potential trend of decreased blue light intensity in OLED screens compared to LCD screens. This evidence corresponds to speculation by Jun et al. (2020), who cite decreased blue light in OLEDs as a potential reason for decreased ocular toxicity in OLEDs compared to LEDs. This trend would make OLED screens a beneficial choice for those looking to lessen their exposure to artificial blue light without the use of external products or settings.

5.2 Data Limitations

Measurements were heavily limited in scope, as only two TVs were used—one OLED and one LCD. This limitation mainly stemmed from time and financial restraints. Limitations in price and availability also prevented both TVs from being of the same brand, which led to a lack of control regarding factors such as manufacturing or physical layers within the screens. The data was also limited in part by its simplicity. A photometer was used rather than a spectrometer or similar instrument mainly due to lower cost and increased availability. However, this meant that data points were only singular numerical values rather than more nuanced and detailed spectrographs. Therefore, analysis of data could not be performed in great depth. This study also did not designate an entirely consistent location on each screen where the photometer was pointed. Ideally the screen location should not influence measurements in any way, since each color was displayed uniformly throughout the entire screen. Nevertheless, this study still did not explicitly ensure that screen location did not have any effect on light intensity. Additionally, this study only displayed five different colors on each TV, which only covered extremes of the RGB color spectrum. Expanding the data to cover a larger set of colors would have strengthened the results, as daily screen usage often involves a variety of colors. While this study does contribute evidence and data to the existing body of knowledge, it is ultimately unable to outright prove any trends due a lack of scope, time, and resources.

5.3 Future Studies

There is extensive room for future research surrounding this topic. Studies could exhibit more control regarding elements that could not be explicitly addressed in this study. This control could be attained by using screens of the same brand or screens known to be manufactured consistently, or physical screen layers could even be dismantled and manipulated. Studies could also use instruments such as spectrometers or spectroradiometers to generate more nuanced data and allow for more in-depth analysis. Im et al. (2017) describe the possibility of blue fluorescent and phosphorescent emitters being used in the future to improve the efficiency and lifespan of blue OLEDs. Future studies could investigate how the implementation of these emitters would impact overall blue light intensity within OLED screens.

6 Conclusion

This study followed a quasi-experimental and observational design to investigate a potential difference in blue light intensity between OLED and LCD TVs. Data was taken from one OLED TV and one LCD TV, with various factors held constant between the two as basis for comparison. Due to decreased blue light efficiency in OLEDs, it was hypothesized that the OLED TV would measure to emit less blue light intensity overall than the LCD TV (Im et al., 2017). The data collected supported this hypothesis, as the OLED TV was found to emit less blue light than the LCD TV for four out of five measured HEX colors, with the LCD TV displaying 24.92% more blue light than the OLED TV on average, relative to both TVs' overall brightnesses. While this does provide evidence towards a trend in decreased blue light intensity in OLED screens compared to LCD screens, limited scope, time, resources, and the potential of confounding variables prevent any definitive conclusions from being drawn without further research.

Acknowledgments

I would like to thank Ushma Kothari for instructing me on the principles of research.

References

Bock, D. E., Bullard, F., & Velleman, P. F., (2019). Stats: Modeling the world. Boston?: Pearson.

Budde, M., Leiner, S., Köpke, M., Riesterer, J., Riedel, T., & Beigl, M. (2019). FeinPhone: Low-cost Smartphone Camera-based 2D Particulate Matter Sensor. *Sensors* (14248220), 19(3), 749. https://doi.org/10.3390/s19030749

Cajochen, C., Frey, S., Anders, D., Späti, J., Bues, M., Pross, A., ... & Stefani, O. (2011). Evening exposure to a light-emitting diodes (LED)-backlit computer screen affects circadian physiology and cognitive performance. *Journal of Applied Physiology*, 110(5), 1432-1438.

Chang, A., Aeschbach, D., Duffy, J., & Czeisler, C. (2015). Evening use of light-emitting eReaders negatively affects sleep, circadian timing, and next-morning alertness. *Proceedings of the National Academy of Sciences of the United States of America*, 112(4), 1232-1237. Retrieved September 9, 2020, from https://www.jstor.org/stable/26454261

Chen, H. W., Lee, J. H., Lin, B. Y., Chen, S., & Wu, S. T. (2018). Liquid crystal display and organic light-emitting diode display: present status and future perspectives. *Light: Science & Applications*, 7(3), 17168-17168.

Chen, H., & Wu, S.-T. (2019). Advanced liquid crystal displays with supreme image qualities. *Liquid Crystals Today*, 28(1), 4–11. https://doi.org/10.1080/1358314X.2019.1625138

Im, Y., Byun, S. Y., Kim, J. H., Lee, D. R., Oh, C. S., Yook, K. S., & Lee, J. Y. (2017). Recent progress in high-efficiency blue-light-emitting materials for organic light-emitting diodes. *Advanced Functional Materials*, 27(13), 1603007.

Jun, I., Han, S. J., Shin, H.-S., Kim, J., Kim, E. K., Kim, T., Yoon, S. C., & Seo, K. Y. (2020). Comparison of ophthalmic toxicity of light-emitting diode and organic light-emitting diode light sources. *Scientific Reports*, 10(1), 1–10. https://doi.org/10.1038/s41598-020-68565-3

Leedy, P. D., & Ormrod, J. E. (2018). Practical Research: Planning and Design (Twelfth ed.). Pearson.

Lewy, A., Wehr, T., Goodwin, F., Newsome, D., & Markey, S. (1980). Light Suppresses Melatonin Secretion in Humans. *Science*, 210(4475), 1267-1269. Retrieved September 9, 2020, from http://www.jstor.org/stable/1684491

Neto, A. R., Chagas, E. A., Costa, B. N. S., Chagas, P. C., & Vendrame, W. A. (2020). Photomixotrophic growth response of sugarcane in vitro plantlets using different light intensities and culture vessel types. *In Vitro Cellular & Developmental Biology Plant*, 56(4), 504–514. https://doi.org/10.1007/s11627-020-10057-0

Nzayisenga, J. C., Farge, X., Groll, S. L., & Sellstedt, A. (2020). Effects of light intensity on growth and lipid production in microalgae grown in wastewater. *Biotechnology for Biofuels*, 13(1), 1–8. https://doi.org/10.1186/s13068-019-1646-x

Sasseville, A., Paquet, N., Sévigny, J., & Hébert, M. (2006). Blue blocker glasses impede the capacity of bright light to suppress melatonin production. *Journal of Pineal Research*, 41(1), 73–78. https://doi.org/10.1111/j.1600-079X.2006.00332.x

Service, R. F. (2005). ELECTRONICS: Organic LEDs Look Forward to a Bright, White Future. *Science*, 310(5755), 1762–1763. https://doi.org/10.1126/science.310.5755.1762

Vetter, C., Juda, M., Lang, D., Wojtysiak, A., & Roenneberg, T. (2011). Blue-enriched office light competes with natural light as a zeitgeber. *Scandinavian Journal of Work, Environment & Health*, 37(5), 437-445. Retrieved September 9, 2020, from http://www.jstor.org/stable/23064905

Viola, A., James, L., Schlangen, L., & Dijk, D. (2008). Blue-enriched white light in the workplace improves self-reported alertness, performance and sleep quality. *Scandinavian Journal of Work, Environment & Health*, 34(4), 297-306. Retrieved September 9, 2020, from http://www.jstor.org/stable/40967721