JOURNAL OF
EMERGING INVESTIGATORS

Article

OLED screens better exhibit the color black than LCD screens

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SUMMARY

We performed an experiment to determine the amount of light emitted from screens in order to assess the ability of organic light emitting diode screens (OLED) and liquid crystal display (LCD) screens to display the color black. These two competing screen types dominate the digital market, and the capability to exhibit black is one of many factors that should be considered when determining the better of the options. The better a screen can show black, the stronger the contrast of the screen appears to be. The mechanisms that create light within each suggest that OLED screens should be able to show the color black, while LCD screens may not. Therefore, we hypothesized that the light emitted from the LCD screen in this state would be significantly greater than in the OLED. We conducted thirty trials in an environment that eliminated all external light, allowing an accurate recording of emitted light. The results mostly supported our hypothesis: there was a significant increase in light emitted in the LCD screen compared to the OLED when both displayed identical black images at full brightness, though at minimum brightness the LCD performed with negligible difference than OLED.

INTRODUCTION

Our experiment investigated a key aspect of modern digital displays: the ability to show the color black. Almost everyone owns digital devices, making it invaluable to compare their performance. Companies continuously develop new and better screens, but a simple study into this aspect of competing types of displays can provide an insight into the current state of each. Through this, it may become easier to understand the future of these technologies and the potential for each to improve and grow. In showing a truer black, a screen appears more rich, real, and contrasted. Many users may notice this difference, which can serve as a selling point for a screen that displays it best. Less blue light emission would result in less eyestrain and circadian rhythm disruption when looking at a screen with a greater ability to show black (1).

In recent years, organic light emitting diode screens, commonly known as OLED screens, have been replacing liquid crystal displays, or LCDs, in many new gadgets and devices. Improved features such as a better electrical efficiency, a more environmentally sustainable production process, and the ability for incorporation into thinner displays make OLED screens an appealing alternative for use by competitive gadget makers (2,3). But LCDs generally remain cheaper while still performing well in many regards, creating a debate towards the future of digital displays.

These screens use entirely different mechanisms in order to show light and its vibrant colors. LCDs take advantage of a highly unique material: liquid crystals. These easily manipulated crystals exist in a state between a liquid and a solid (4). The addition or removal of heat causes bends and twists in their structure, causing polarization and filtration of certain light (4,5). So, LCD screens do not produce any light themselves. Instead, they rely on a backlight, usually a light emitting diode (LED) source, to create a uniform white light. Transistors push the crystal structures to excited and unexcited states, thus resulting in an instantaneous shifting and filtration (4). Because they do not produce light themselves, the color black is created by the filtration of all light. After first discovering the crystals in 1888, researchers are making vast improvements to their color capabilities primarily by finding new ways to stretch the crystals, creating greater polarization and filtration (6).

OLED screens, conversely, produce their own light. In these displays, multilayer polymers exist in an electric field. Influx of voltage moves electrons differently depending on intended color, and they eventually rejoin and jump across energy levels (2). The combination of polymers that produce blue, green and red light create a spectrum of colors within their devices (2). Given this ability, they should not produce any light when showing the color black, as the light simply turns off. These displays are far newer than LCDs, as the first came into the market in the 1990s. The primary improvements that were made to OLED technology allowed it to be used in far larger devices than it originally could be (7). Though minor adjustments have been made, its color capability has remained fairly constant since its creation.

The absence of light filtering in OLED displays should give them a distinct advantage towards exhibiting black. This is because, although close, no light filter is perfect. Some light, however minimal, will escape through any given filter. To evaluate this, we used a photometer device that measures light intensity to compare emission values for LCD and OLED screens when projecting the same black image. The data that was collected during this study supported our hypothesis that the amount of light emitted from a bright LCD screen when showing black is significantly greater than light emitted from a bright OLED screen, as there was a 3300 % increase in emitted light from OLED to LCD. However, under the dimmest settings of the screens, the gap was decreased and became negligible. This ability of an OLED screen to show a better black than LCD allows it to be a better competitor for personal devices as the sharper contrast and less blue light emission produce a more elegant and less straining experience.

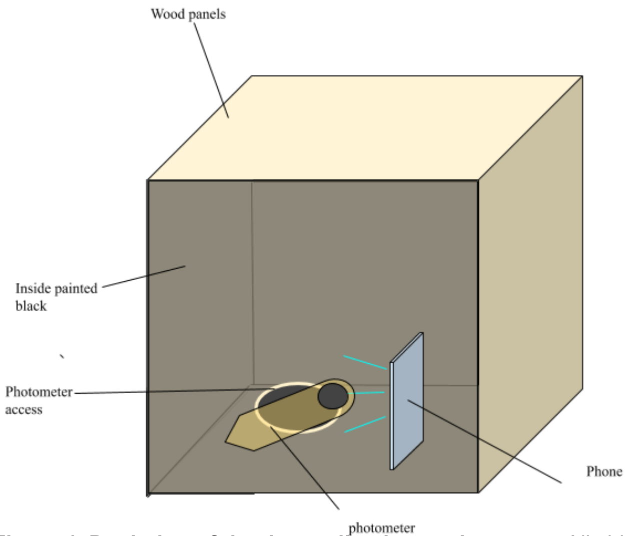

Figure 1. Depiction of the data collection environment. All sides were surrounded by black-painted walls, with only a small opening to allow for photometer access during collection.

RESULTS

In this experiment, we assessed the ability to produce the color black within an external-light controlled system. A photometer measures light intensity by reading adjusted electrical properties due to different light intensities (8). Because the color black is actually the absence of light, a photometer that informs of the intensity or presence of light was helpful and necessary in assessing the quality of black. We used a photometer and placed it directly in front of an OLED screen, LCD screen, or no screen. These screens were measured while bright, dimmed, and turned off, and were replaced by the next screen once 30 data points had been collected. In order to eliminate as much environmental light as possible, we did this in an enclosed box of plywood with black painted walls. We cut out a hole for photometer access and ensured that the roof could be moved to adjust the system (**Figure 1**).

We conducted 30 trials, each with three controls and four experimental data sets. The first control recorded a value of light with no screen present, while the second and third measured OLED and LCD screens turned off, respectively. These accounted for both errors in the measuring device and for environment light that could have reflected off of the screen. Because that light was not emitted from the screens, it was irrelevant to the data being collected. By recording values for these controls, we established a likely non-zero value to represent "no light emitted", giving a better standard to compare the experimental values against.

We took measurements for each phone screen at both the brightest and dimmest settings that the phones allowed, thus producing the four experimental groups. The conditions for each trial were essentially identical, and each displayed similar results: the light emitted from the LCD screen was significantly more than that of the OLED screen. In fact, the average value across all trials for the bright LCD screen was roughly 24 times as large as in the bright OLED (**Table 1**). Also, given the resolution of the device, resulting in a zeroth order uncertainty of ±0.005 lux, and a one-way ANOVA comparison, we concluded that the difference in values between both the dim and bright OLED screen, and either the LED or OLED screen turned off compared to any control condition, was negligible (**Table 1**). There were few outliers, and though they were not ignored when running the ANOVA test, they clearly did not impact the results greatly (**Figure 2**).

DISCUSSION

Most of the trials that we completed suggest a significantly larger amount of light being emitted from LCD screens showing the color black, supporting our hypothesis. The average of 0.68 ± 0.132 lux emitted for bright LCD screens is quite significant, and the *p*-value suggests that it is extremely unlikely that this data was statistically equivalent to that of the control groups; light was surely emitted under this condition. Seemingly, the light-filtering crystals within LCD screens were limited in their ability, and some light from the LED backlight escaped through under those circumstances. The OLED screen did not appear to emit any light, as the difference in means across this data set and the "no screen" control was insignificant. This was also true for both "turned off" control groups. Given the nature of OLED screens, this makes sense, as they have the ability to turn off individual pixels. However, the dimmed LCD screen boasted similar results to the OLED, turned off screens, and no screen. Though, based upon our hypothesis, we did not directly expect this, it does make sense. As proven by the bright LCD screen data, light-filtering is not perfect. But, techniques have improved, and given this outcome, it is clear that they are still very competitive when showing black. Dimming this screen reduced the amount of light emitted by the backlight, thus allowing the liquid crystals to filter less light. The LCD screen that we used must have been able to filter enough light in the dimmed setting to leave only a negligible amount to escape and be emitted. Therefore, in such a dimmed setting, LCD screens seem to be competitive with OLED screens. Using the dimmest setting of a display is not ideal though, as contrast is sacrificed. The OLED screen

	Recorded Amount of Light Emitted						
	No Screen	OLED (Bright)	LCD (Bright)	OLED (Dim)	LCD (Dim)	OLED (Off)	LCD (Off)
Mean Value	0.01 ± 0.013	0.02 ± 0.048	0.68 ± 0.134	0.00 ± 0.000	0.01 ± 0.008	0.00 ± 0.008	0.00 ± 0.005
High Value	0.06	0.26	1.27	0.00	0.03	0.03	0.01
Low Value	0.00	0.00	0.51	0.00	0.00	0.00	0.00
P-value	N/A	0.214695	<0.00001	N/A	1	0.19018	0.189065

Table 1. Amount of Light Emitted from OLED and LCD Screens Under Various Conditions - The amount of light, in lux, emitted from OLED and LCD screens. This was measured by a photometer in a dark and otherwise light controlled environment. The mean for each data set was calculated with a standard deviation, and a one-way ANOVA test was conducted comparing each experimental group to the controls. A significance level of 0.05 was utilized, suggesting that all data sets except for the Bright LCD were found to have statistically insignificant difference in means when compared to the 'no screen" control. The test could not be completed for the dimmed OLED screen as it had no variation in values.

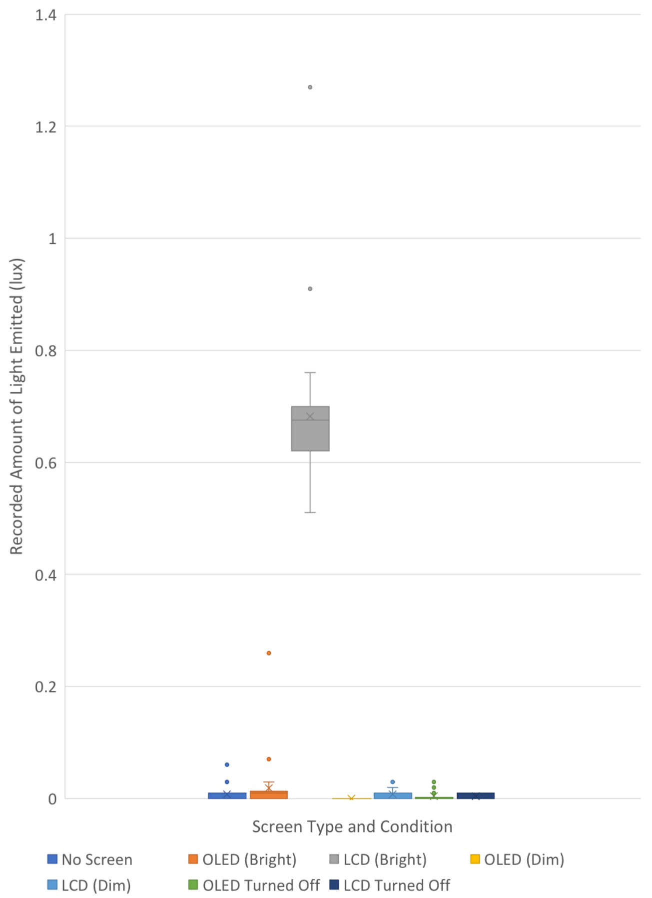

Figure 2. Comparison of light emitted. The boxes represent where the majority of the data lies, while the bars extend to show outliers present for each. Because they were so infrequent, these outliers were disregarded when making qualitative conclusions from this data, and instead attributed to error. The bright LCD screen emits much more light than any other data set.

would have its pixels turned off whether dim or bright, which explains how both the OLED dimmed and OLED bright data sets produced similar results.

Although the trends are very clear, and the similarly valued data sets do not represent significantly different measures, the values recorded are not identical for each trial despite the exact same image being shown for each. A few elements could have contributed to this. The first of these is environment light. Obviously, any light that was recorded that was not emitted from the screens hurts the reliability of data. If it entered the system, the photometer may have sensed and recorded it. However, this is unlikely, as the many measures to prevent environment light from entering the system limited the effect that it could have. Likewise, any effect it managed to have would be fairly consistent for all trials and situations, as we accounted for through our controls. The recording device could have also led to error, as we did not conduct any tests to ensure that our photometer was either reliable nor consistent. Nonetheless, its ability to get fairly similar results for 30 trials suggest that this did not occur. There were few outliers, and though they were not ignored when running the ANOVA test, they clearly did not impact the results greatly (**Figure 2**).

Understanding this, we determined that although limited by light-filtering capacity, LCD screens are still capable and competitive in showing the color black. An average of 0.73 ± 0.132 lux represents a measure of light that is still very small. For reference, most LED light bulbs claim to emit hundreds or even thousands of lumens (1 lux = 1 lumen/m2). Also, when dimmed, the limits of light-filtering seemed to become unnoticeable. Even though our data was reliable enough to conclude that LCDs generally show more light than OLEDs when attempting to exhibit black, it was not a great enough difference to warrant LCD technology a failure in this regard.

Of course, the ability to show one color is not the only determining factor in which screen is better. Further studies that examine the color saturation, vibrancy, precision and ability to adjust quickly, among others, would offer a more complete understanding of their performance overall. These could be conducted under fairly similar conditions, with different tools being used to record these other measures. Studies like these would provide a basis to determine which screen, as they exist today, has a better display for the user. Continuing to monitor these factors can help determine which, if either, are likely to be the better option to invest resources into advancing. Also, these technologies are implemented in a wide variety of places. Though in our everyday lives, they are most often seen in our phones, TVs, watches, etc. they are also used in a wide variety of machines and devices. One study published in the National Library of Medicine compared OLEDs and LCDs in order to determine which would be a better replacement for Cathode-Ray tubes in electroretinograms, which are devices that can analyze cone and rod responses within human eyes. Though it too found OLED performed better for a number of reasons, particularly its fuse threshold, showing black was not a relevant nor important metric of performance in this study (9). Although it is very relevant in deciding which screen is more attractive and vivid to a phone or TV user, this may not be an important measure for other implementations of this technology.

METHODS

The screens used to collect this data were from an IPhone 8, which has an LCD display, and an IPhone X, which has an OLED. They were released at the same time in 2017, and thus represent an equal and recent point in time in the development of each screen. The data collection system was made of ¾ inch plywood, cut into six one-foot long pieces. Each piece was carefully fitted together to create a completely closed box. Because they were cut and fit perfectly, no agent was needed to hold the pieces together. Prior to this, a hole that is large enough to fit the BTMeter BT-881E photometer was drilled into one of the six panels, and the inside of each panel was coated in two layers of Stuart Semple's Black 2.0 paint. As an extra precaution, single sheets of paper were also painted in two coats of this paint and placed to cover each corner of the box in case inconspicuous gaps in the wood were present. The lights in the room were turned off during data collection, and for each trial the photometer was placed through the hole, thus being directly in front of the display, and removed after roughly five seconds of recording a value. The top panel was slid to create an opening, and the display was switched to record the next data point. After replacing the screen, the panel was slid back into its original position. This process was repeated for all seven situations, thirty times each. When turned on, the same stock photo of the color black was shown on each screen. iPhones have a setting in which the screen brightness automatically adjusts, and so this setting was turned off and the brightness was manually adjusted to both minimum and maximum levels at the appropriate times. After completion, the data was inputted into Microsoft Excel where graphs, data tables, and ANOVA *p*-value statistical tests comparing experimental groups to the controls were completed.

ACKNOWLEDGEMENTS

I would like to thank Mr. Galster, my classmates, scientific reviewers and the Journal of Emerging Investigators for their support and guidance throughout this process.

Received:
Accepted:
Published:

REFERENCES

1. David Ramsey, MD. “Will Blue Light from Electronic Devices Increase My Risk of Macular Degeneration and Blindness?” *Harvard Health Blog,* Harvard Health Publishing, 1 May 2019, www.health.harvard.edu/blog/will-blue-light-from-electronic-devices-increase-my-risk-of-macular-degeneration-and-blindness-2019040816365.
2.Patel, Bhrijesh N, and Mrugesh M Prajapati. “OLED: A Modern Digital Display” *International Journal of Scientific and Research Publications,* vol. 4, no. 6, June 2014.
3. Luo, Zhenyue, and Shin-Tson Wu. “OLED Versus LCD: Who Wins?” *Optics Innovations*, Optics and Photonics News, Feb. 2015, lcd.creol.ucf.edu/Publications/2015/19-21-OptInnov-Feb15.pdf.
4. Williams, Marshall. “LCD Displays.” *MSU Engineering*, Michigan State University, www.egr.msu.edu/classes/ece480/capstone/spring15/group03/docs/ECE480ApplicationNote.pdf.
5.“Light Filtration” *Molecular Expressions: Science, Optics, and You: Light and Color*, Florida State University, 13 Nov. 2015, micro.magnet.fsu.edu/optics/lightandcolor/filter.html.
6. Kawamoto, Hirohisa. “The History of Liquid-Crystal Displays.” *Proceedings of the IEEE,* vol. 90, no. 4, Apr. 2002, pp. 460-500.
7.“OLED Timeline”, *Michigan State University,* msu.edu/~dunnjam7/timeline.html.
8. Measuring Light Levels / Photometry.” *Castle Group Ltd,* 29 June 2017, www.castlegroup.co.uk/guidance/light-measurements/photometry-and-light-measurement/.
9. Matsumoto CS;Shinoda K;Matsumoto H;Seki K;Nagasaka E;Iwata T;Mizota A; “What monitor can replace the cathode-ray tube for visual stimulation to elicit multifocal electroretinograms?” *Journal of Vision,* U.S. National Library of Medicine, pubmed.ncbi.nlm.nih.gov/25096155/.