

Comparison of Perceived Brightness and Colorfulness for Different Display Technologies

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Different display technologies have different color gamuts, therefore, due to the Helmholtz-Kohlrausch (HK) effect, appear with different perceived brightnesses while at same luminance. We study this effect subjectively with 20 subjects. One result is that an RGB OLED with 56 cd/m² is perceived brighter than an TN LCD with 65 cd/m². This can be used to improve color perception of displays.

1 Introduction

Displays are widespread nowadays and are also used in modern cars even becoming larger [1]. Furthermore, LCDs (edge-lit, local dimming, quantum dot backlight) compete with OLEDs and in future with micro-LEDs. Different display technologies typically have different color coordinates (saturation, purity), which results in varying perceived brightness, readability and colorfulness. This phenomenon is explained by the Helmholtz-Kohlrausch (HK) effect [2]: Even if the luminance remains the same, colors appear brighter with an increase in purity and have higher colorfulness [3]. We examine this phenomenon using a specialized setup to compare various display technologies.

2 Displays and Setup for HK Evaluation

We used four modern displays: Edge-lit LCDs (TN, IPS, and IPS with Quantum Dot {QD} backlight film) and RGB OLED. They have an aspect ratio of 16:9 and sizes ranging from 10" to 11" but all aligned to 10" by a checkerboard mask, see Fig. 1 left (our evaluation set-up). The four displays, which have different color coordinates, were calibrated to the minimum common color gamut (CCG), see Fig. 1 right, to D65 (white point), and to a gamma (γ) value of 2.2 (relevant for GUIs and photos).

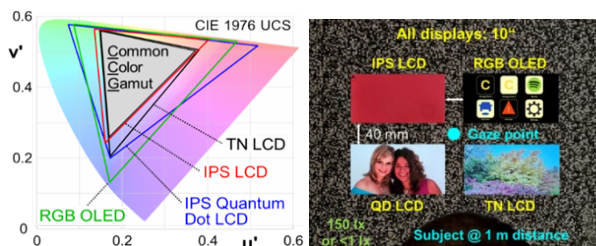


Fig. 1 Left: Setup for evaluation with all four displays. Right: Color gamut of the four displays and the (minimum) common color gamut (CCG) for CIE 1976 UCS.

We mounted the four displays leaving a 40 mm distance due to their bezels. A random monochrome

checkerboard surrounds them to avoid possible disturbance to the human eye. We used 150 lux (illumination of the display wall in a dark room w/o reflection on the displays, $L_{White} = 80$ cd/m² for CCG) as well as dark room conditions (< 1 lux). Four identical PCs incl. same graphics adapters drive the displays. The observer distance was set to 1 m and the eye height was adjusted to the display center (gaze point) minimizing possible viewing angle effects.

We used three different categories of test patterns, which are visualized also in Fig. 1: 1. Full screen test patterns for RGBW and CMY; 2. Automotive GUI with typical icons and colors; and 3. Photos with two women and colored leaves. During the evaluation, the same test patterns were shown in parallel on all displays.

Different methods were used to create the test patterns: Same measured luminance for the CCG for full screen test patterns, automotive GUI and photos (also different saturation). Second method: Displays adjusted to the same perceived brightness by three experts for CCG and measurement of luminance for full screen test patterns and automotive GUI. Third method: Same measured luminance for maximum saturated (purity) RGB (one grey level to adjust luminance, the other two levels are zero).

The evaluation was started with an initial training phase and afterwards the subjects had to evaluate 36 test patterns in total for office lighting environment and dark room (only RGB full screen). The subjects had e. g. to rank the displays from brightest to darkest and compare neighboring displays regarding "display x is brighter" and their perceived brightness difference like a "clearly brighter". For automotive GUI the subjects ranked the displays based on the perceived quality (perception) and readability of icons. In case of photos subjects judged on the impression and natural appearance.

3 Results of Evaluation

A pre-test with 20 participants was used to fine-tune the test patterns. Our main user study also used 20

subjects (50% of whom were different to the pre-test). The method for the evaluation was acc. to ITU-R BT.500-13: Double-stimulus impairment scale (DSIS) method with five steps for direct comparison of neighboring displays as well as ranking of the displays from brightest to darkest.

The most important results are:

- Luminance calibrated colors for CCG: Blue was ranked as brightest for OLED (see Fig. 2 left) by 45% of the subjects. This is in accordance with the color coordinates (purity), see Fig. 1, and confirms the HK effect. The differences observed for green and white were less varying than for blue but the TN LCD was always ranked as darkest.
- As expected, the brightness-calibrated test patterns show fewer variations. The outcome allows to judge on the measured luminance differences: 21.8 cd/m² of the IPS LCD is perceived roughly the same as 23.1 cd/m² for the IPS display. When the luminance of the IPS LCD is reduced to 19 cd/m² (difference 4 cd/m²) the QD LCD is clearly perceived as being brighter. The OLED with 59 cd/m² was judged darker than the IPS LCD at 64 cd/m² for CCG green.
- The test patterns with maximum saturation for each display (Fig. 2 right) were adjusted to the same luminance value of 40 cd/m². Fig. 2 (right) shows the results for green: Subjects ranked the QD LCD as the brightest (60% ranked it first and 40% as second). The RGB OLED followed with nearly the same figures, but in reverse order compared to the QD LCD. All subjects except one ranked the IPS LCD third and the TN LCD darkest. These results prove the HK effect and indicate the need for display technologies with a large color gamut. Brightness is perceived via luminance (spectra weighted by $V(\lambda)$) and color perception via Color Matching Functions (weighted by CMF).
- The preference for maximum saturation rendering for the photos was rated best for the IPS LCD. It was perceived as having a "high natural appearance" for faces and leaves by ~90% of subjects, compared to ~50% for the QD LCD and the RGB OLED. When rendered in CCG, which is similar to the IPS LCD gamut and covers reflective colors in nature, all displays appear the same without significant differences. A "simple" reduction in saturation e.g. to 70% of the maximum was rarely preferred.
- There was hardly any significant difference in the ranking for CCG RGB between 150 lux and dark room conditions.
- Perception of gear wheel of the settings icon of the automotive GUI: 80% stated that the OLED

shows the darkest black and 95% judged the TN LCD as the brightest black. This clearly proves that "true black" of OLEDs can be perceived.

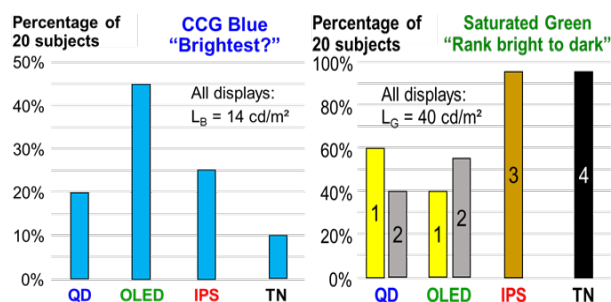


Fig. 2 Selected evaluation results: CCG blue (left) and saturated green (right), adjusted to the same luminance across the four displays, as reported by the subjects.

Our evaluations confirm the HK effect (compare with [4]). These findings can be used to select displays for "better appearance" in addition to "traditional" parameters such as luminance.

4 Summary

We successfully implemented a test setup that compares display technologies with respect to the perceived brightness and colorfulness of various colors, automotive GUIs, and photos, and that incorporates the Helmholtz-Kohlrausch effect: Displays with a larger gamut exhibit higher perceived brightness at the same (measured) luminance. This can be used to reduce power consumption and improved color perception.

5 Acknowledgement

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