LED-based projectors have a bright future - is it the H-K effect?

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As LED projectors increase their market share in the projection industry (>35% in 2019), observers are perceiving an increased brightness in LED projectors compared to lamp-based projectors [1]. This perceived brightness increase is caused by what's known as the Helmholtz-Kohlrausch (H-K) effect.

While many projector companies comply with industry brightness standards (such as American National Standards Institute lumens), many perceive a higher brightness in projectors (called "LED lumens") with LED illumination sources compared to lamp-based projectors.

There have been many publications about the H-K effect. Some articles have appeared in technical journals such as Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE), Society for Imaging Science and Technology (IS&T) and the Society for Information Display (SID), authored by SID senior members or SID fellows. In our review of these publications, we found general agreement regarding the validity of the H-K effect for LED projectors, that LED lumens are real, and that this effect is difficult to measure quantitatively with common measurement equipment. Companies that make LED-based projectors would like to promote this improvement in perceived brightness.

What is the H-K effect?

In the late 19th century, Hermann von Helmholtz observed that a color looked brighter when its purity (that is, its saturation) increased [2,3]. In other words, saturated colors appear brighter than less saturated colors – more specifically, saturated colors of red, pink or blue appear brighter than saturated colors of yellow and green [4,5]. Shih-Fang Liao also referenced the International Electrotechnical Commission (IEC) definition of the H-K effect [6] as a "change in brightness of perceived color produced by increasing the purity of a color stimulus while keeping its luminance constant within the range of photopic vision."

Industry experts agree that the H-K effect is real

Many authors discuss what is known as the "brightness-luminance discrepancy": simply put, brightness is more associated with colorimetry than photometry [2,7]. We see saturated colors as brighter than what a light meter (photometry or colorimetry) indicates [5]. Over the more than

200 years since this discovery, there have been numerous visual incidental discoveries and vision theories showing the importance of the H-K effect [2]. Thus, total perceived brightness is a function of both luminance and chromaticity.

Liao introduced the perceived brightness-to-luminance ratio, known as the B/L ratio. He determined that LED projectors provide a 25-30% perceived brightness enhancement compared to lamp projectors [6]. M. David Stone wrote that the concept of LED lumens is a meaningful concept only if LED projectors provide a higher perceived brightness most of the time. Unfortunately, not all LED projectors have equal performance due to a number of system differences [8]. LED projector manufacturers can influence the H-K effect by the choice of the dominant wavelength for the red, green and blue LEDs, the duty cycle of LED operation, the thermal management of the LEDs, and whether color overlap of the red, green and blue LEDs to create secondary colors like yellow, magenta and cyan will be used. The red, green and blue spectrum in a projector can be seen in **Figure 1**.

In our review of a range of relevant sources, we saw claims of a perceived brightness improvement factor from 1.3 times up to 2.4 times for LEDs vs. lamp-based projectors [6,9]. This large range is indicative of the difficult nature of quantifying a specific improvement over a range of products, content and use conditions. Obviously, more studies are needed with a wide variety of LED projectors to validate these perceived brightness improvement factors. More studies would be able to provide a larger sampling of LED projectors and thus be able to determine a more statistical range of perceived brightness.

Figure 1. *Light spectrum coming from a projector.*

The psychophysical response of the H-K effect

There is obviously a complex relationship between the visual cortex, the specific stimuli and the perception of brightness [3,4]. Because humans have different percentages of red, green and blue cones (our retinas' light and color sensors), the H-K effect will vary from person to person [10]. An important aspect of this effect is the asymmetry of the wavelength dependency; that is, some colors appear brighter than other colors [4,5]. Also, it is well documented that the H-K effect is affected by the surrounding color as well as the ambient light conditions – darker ambient light conditions show the effect more prominently than normal office lighting conditions [5,6,8]. To illustrate this point, in **Figure 2**, there are identical yellow color patches on top of either a red or blue background. Many of these color patches have a different perceived brightness due to the background color [5].

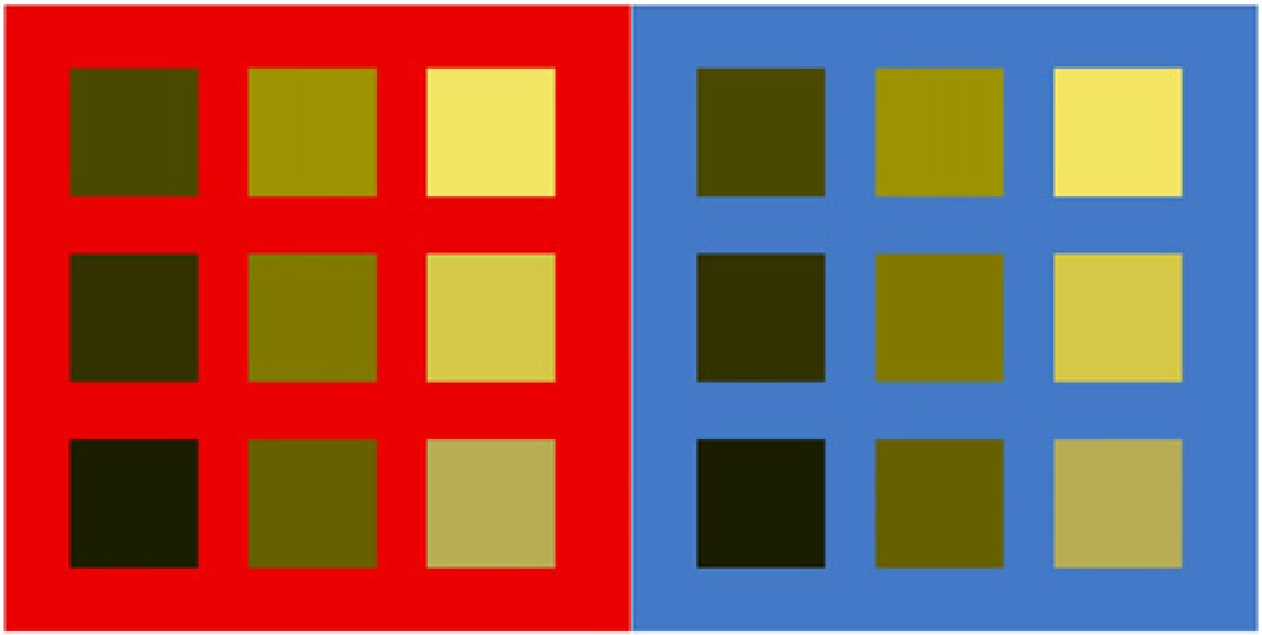

Figure 2. *Identical yellow color patches on different color backgrounds.*
[Image Source: Out of the Wood/Lightness – The Helmholtz-Kohlrausch effect]

There have been many studies to assess the impact of colored patches of different colors, saturation levels, luminance values and backgrounds on the H-K effect [5,9]. These studies all use subjective measurements, however. David Corney was the only author among those we reviewed who provided some level of quantitative analysis by measuring the retinotopic response of the visual cortex using a high-field functional MRI [4]. The primary conclusion of Corney's study was that there is a relationship between perceived brightness and retinal response. The retinal response, as measured in the visual cortex, "more closely reflected the brightness than the physical luminance" of stimuli [4].

How is the H-K effect used today?

There are plenty of military examples where lights inside airplane cockpits use more saturated light sources to enhance their perceived brightness. There are also aviation examples where ground-landing light strips use LED sources that appear brighter than filtered incandescent light sources. Automotive and lighting engineers are also well aware of the H-K effect, and are adapting automotive lighting, instrument-cluster lighting, center consoles and other displays in or outside of vehicles [2].

This increase in perceived brightness from the H-K effect provides improved perception of navigation controls and external lighting to enhance the safety for pilots and drivers alike.

Projector illumination sources

Today, projectors consist primarily of four types of illumination sources: lamps, LEDs, laser-phosphor and direct lasers. Based on the color purity of these illumination sources, it's possible to state that the H-K effect is most prominent for direct lasers, followed by LEDs, then laser-phosphor and finally lamps. DLP®Technology is one of the few projector technologies that can utilize all four illumination sources. Due to the immaturity of RGB direct lasers, DLP technology is in a strong position to make use of the advantages of LED illumination – especially in regards to the H-K effect. The H-K effect for projection technology provides for a more stimulating image. These saturated colors are exciting, dynamic and draw more attention to the viewer than desaturated colors [11].

Compared to conventional lamp-based projectors, LEDs offer [2,6]:

- Higher luminous efficiency.
- Less color and brightness decay.
- Longer life.
- A consistent trend of brightness and efficiency improvements.
- A higher perceived brightness.

Because of all of the advantages that LED illumination sources provide, an LED projector manufacturer who couples an LED illumination source with a highly reliable spatial light modulator, like DLP technology, can produce a projector with high performance and a long lifetime.

Due to the H-K effect, LED-based projectors provide content that is richer with bright and pleasing colors to the viewer.

Conclusion

We believe that the H-K effect is real; studies in regards to its effect on human vision date back more than 200 years. While many authors agree on the reality of the H-K effect, they also agree that it is difficult to quantify using photometry or colorimetry equipment. Using a high-field functional MRI of the visual cortex is impractical. It's impractical because an MRI is a machine where a human body is placed within to measure, in this case, activity in the visual cortex. MRIs typically cost around $250k. Subjecting a human to an MRI while viewing LED images can be tedious and expensive.

While we believe that there is a higher perceived brightness for projectors with LEDs compared to lamp-based illumination sources, more testing is needed to better quantify the range of perceived brightness gain. There needs to be a consistent test established that also includes a controlled and well-known ambient environment. This test needs to adequately quantify the H-K effect and its perceived brightness improvement for an LED projector manufacturer to use to establish leadership in lumens when promoting an LED projector end product.

With the benefits of LEDs regarding their improved efficiency, less performance decay, longer life and higher perceived brightness, we could see growth of LED-based projectors beyond consumer markets into many other display market segments, such as education and professional audiovisual systems.

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