THE VALUE PROPOSITION A Metric for the Aesthetic

By Mark D. Fairchild

> 'Colorfulness' and 'brilliance' per watt should take their place among the other metrics used to define lighting

Color scientists view the world differently than most. Some would say through "rose-colored glasses," but perhaps it is more accurate to say through a set of ever-changing and adapting spectacles. For to color scientists, more than most, color is not defined simply by a physical stimulus (spectral power distribution), but by so much more. Color is a human perception and depends on the stimulus energy distribution, but also on the surrounding stimuli in space and time (contrast and adaptation), absolute levels of light, the observer's state of being (history and adaptation) and the psychological biases of said observer. All these factors, and others, conspire to make colorimetry intensely difficult in real-world viewing situations.

In this column, three distinct phenomena are examined with respect to their impact on the selection and design of lighting: 1) the impact of overall brightness on color appearance, 2) the impact of relative brightness on appearance and 3) individual differences in color perception. Respectively, these all impact the perceptions of colorfulness, brilliance and observer variability (or metamerism), the inverse of which can be considered observer similarity.

It is well established that objects appear more colorful when the level of illumination falling upon them is increased. In fact, this phenomenon is commonly referred to as the Hunt Effect.[1] In the realm of lighting, it has also been well established that perceived brightness does not correlate directly with luminance[2] and therefore it is possible for a lighted environment to appear brighter, and therefore more colorful, in situations where the measured luminance (or illuminance) is actually lower. Color appearance models such as CIECAM02 are sometimes capable of taking these effects into account and could possibly be used as the basis metrics of illumination quality similar to proposed gamut-area indices but based on dimensions of perceived colorfulness, which grows with luminance, instead of perceived chroma, such as CIELAB C*, which does not grow with luminance. Such an improvement would be a step toward an illumination metric related to *colorfulness per watt* that would be more directly related to human impression of the illuminated environment.

Brilliance is a perceptual description of the relationship between the brightness of a stimulus and its environment.[3] It is possible for normal reflecting objects to appear as if they were fluorescent because their colorfulness and brightness is greatly impacted by the spectral energy distribution of the illumination. Imagine an orange-appearing object. If it is decreased in luminance relative to its environment, it will become brown and then black with decreasing luminance. If, instead, the luminance is increased, it will look like a brighter and brighter orange until it reaches the point it appears to glow (fluorence, or apparent fluorescence) and then eventually appear as a self-luminous source. These vast changes in appearance are measured by brilliance[4] and, as above with colorfulness, a lighting metric could be designed to summarize the impact of various design choices on object brilliance. Likewise, a *brilliance per watt* metric of illumination quality could be developed to help customers understand how a light source makes certain colors pop out from their environment. And, suffice it to say, different spectral power distributions with the same luminance and correlated color temperature (even with identical chromaticity coordinates) can produce different experiences along the dimensions of brilliance and colorfulness.

SOPHISTICATION REQUIRED

Both of the above concepts depend upon using more sophisticated color models, color appearance models, for metrics of illumination quality rather than the fundamental models of colorimetry (CIE XYZ tristimulus values and chromaticity coordinates) and color difference metrics (CIELAB). Another interesting point of concern is in the definitions of these very fundamental color metrics. They are based on the color matching functions of an average observer that were derived a long time ago with a very small sample size.

Despite these limitations, the CIE color matching functions remain as reasonably accurate representations of the mean visual response. However, they contain no information about the variability in that response amongst observers with normal color vision. Many researchers have shown over the decades that the variability amongst observers can result in very large differences in color appearance. More recently, the use of narrow band solid-state illumination and image projection systems with LEDs and lasers has led to a significant growth in the situations in which observers disagree about color appearance.

Very recently, models of individual variation in color vision have been refined to the point that it is possible to predict the range of individual color differences in metameric matches or overall appearance.[5] These could be thought of as gamuts of observer dissimilarity (or similarity) for given stimulus combinations. With such metrics, it is possible to design the spectral power distributions of light sources for image projectors or general illumination to minimize the inter-observer differences in appearance of certain types of objects or of the lighting itself. As these metrics mature, it is very reasonable to expect that one could create

An illustration of the effect of increased luminance (right) on the perceived colorfulness, brilliance and contrast of a scene.

a lighting quality metric that represents *observer similarity per watt*.

To end with a personal story, my family recently compared two LED small floods for use in our kitchen. One with lower CRI and GAI but more lumens versus the second with higher CRI and GAI and fewer lumens. Which looked brighter? The one with fewer lumens because, even though the source itself appeared dimmer, illuminated objects appeared more much colorful (and brilliant). Therefore fewer lumens turned out to be the better choice and used less energy. Those sources also appeared whiter despite their shift from the nominal Planckian locus. Perhaps the key lesson here is that even a color scientist takes the lamps home and performs a visual experiment before making a purchase. Perhaps the labels on the lamp packaging need to correlate more with what we see?

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