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# CIE Research:

# CIE Research Addressing Color Quality of Light Sources Related to Perception and Preference

Special Excerpt

# CIE Research Addressing Color Quality of Light Sources Related to Perception and Preference

With the development of new lighting technologies, LED light sources are increasingly used for general lighting. These light sources are creating diversity in light spectra and imposing new challenges in assessing their color quality. Youngshin Kwak, Director CIE Division 1, describes how several CIE Research Groups are joining forces, working on this topic to find new standard indices to adequately specify color quality.

**The Color Rendering Index (CRI), in particular the general color rendering index, Ra, defined by CIE Publication 133, is widely used for assessing the color rendering characteristics of light sources. It was first published in 1965 after fluorescent lamps had emerged, and was last improved in 1974. Color science has progressed considerably since then, and recognized improvements are available for many of the components used in the CRI. Nevertheless, the CRI has served fairly well for most light sources and has been well accepted over the past 40 years, though revision of the CRI was occasionally investigated (CIE Publication 135/2-1999). There are many government regulations and voluntary programs to promote energy efficient lighting products. These regulations and specifications not only specify minimum luminous efficacy (lm/W) but also minimum values of the general color rendering index, Ra, and ranges of white light chromaticity to ensure good color quality as well as energy efficiency, as both are inter-related.**

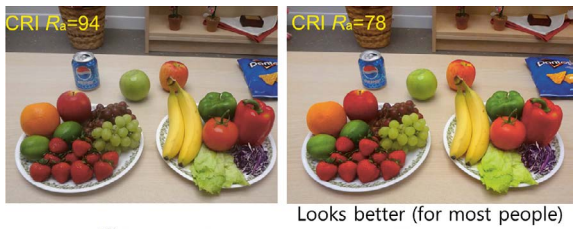
## Limitations of the CRI

Limitations of the CRI have been recently addressed, especially for solid-state light sources, whereby the Ra values do not always correlate well with visual evaluation by general users. This mismatch arises, first, from inaccuracies of the CRI in its intended role as a color fidelity index; and second, from perception-related color quality effects beyond color fidelity. The first is the inaccuracy of color appearance evaluation arising from the original 1974 CRI formulae and the small number of color test samples used in the CRI calculation. The second is a limitation of the CRI due to the fact that it is simply a color fidelity metric; that is, the CRI values are based on the color appearance of objects compared to their appearance under the defined reference illuminant. Color quality characteristics other than color fidelity are also important, and different analysis methods are required to assess them in the context of lighting applications, tasks, and user preferences. This is especially important when samples undergo chroma enhancements arising from the source's narrowband spectral features. In some experiments, subjects generally preferred illumination that slightly enhanced the color saturation of the illuminated objects they viewed, even though the chosen light sources had lower Ra values (Figure 1). Due to the nature of the CRI (or a color fidelity index), many preferred lights with increased gamut are excluded when a minimum requirement is given, e.g. $Ra \geq 80$ or $Ra \geq 90$.

## Improvement Measures

It was determined by the CIE that, for both aspects, better color quality characterization methods are needed to measure and specify white-light sources, and the work was divided into two corresponding tasks: (1) to develop a scientifically accurate color fidelity index, assigned to TC 1-90, and (2) to develop one or more perception-related color quality measures beyond fidelity, assigned to TC 1-91 for initial work.

In 2017, TC 1-90 published a Technical Report 'CIE 224:2017 CIE 2017 Color Fidelity Index for accurate scientific use' describing a general color fidelity index, Rf, as a scientifically accurate measure of color fidelity with respect to a reference illuminant, although there still remain some technical issues for further research. This color fidelity index, based on the fidelity



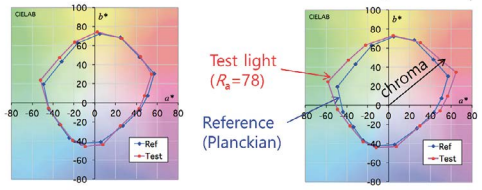




**Figure 1:**
**CRI measures color fidelity to a reference illuminant, different from color preference**

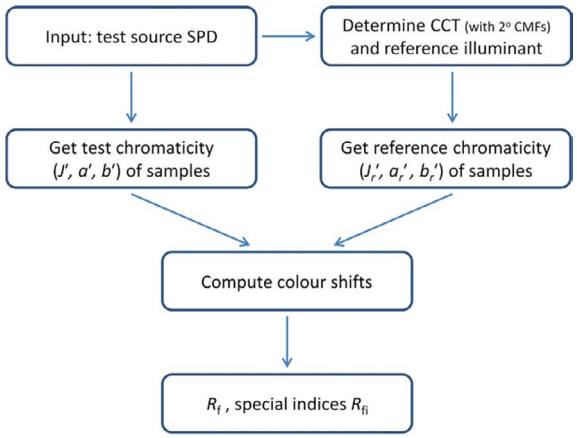



**Figure 2:**
**Calculation flow for the color fidelity index**

index of the Illuminating Engineering Society of North America, defined in TM-30-15, addresses aspects for only the first part of the limitations of the CRI – it does not address the need for perception-related color quality measure(s) beyond fidelity (Figure 2). However, it does correct several previously reported inaccuracies of the CRI as a color fidelity measure. The important improvements of this measure, relative to the CRI, are the update of the color difference calculation, in particular the object color space, and the incorporation of 99 test-color samples which provide a more uniform distribution of slope and curvature values as a function of wavelength and which have color appearance values that are more widely and uniformly distributed in the three dimensions of a uniform color space. To assess the important aspects of the color qualities of light sources other than color fidelity, in particular, those related to color preference, CIE TC 1-91 is developing a Technical Report on this subject, which will be the groundwork for developing color preference metric(s).

The CIE encourages further research on these two aspects of color quality, which may be useful inputs to the current or future work of CIE. The overall objective of the research is to develop indices for color quality other than color fidelity, especially those related to general color preference, which is the perceived or subjective judgement of color rendering (e.g. for naturalness). It is known that chroma saturation (gamut area) or shift of chromaticity from the Planckian locus has strong effects on perceived color rendering or preference, but such effects are not measured with a color fidelity index, and some preferred lights are penalized by a color fidelity index such as the general color rendering index, Ra. It seems there are general preferences in chroma saturation and chromaticity, but research data for such perception effects are still very limited. Data are lacking for various conditions, e.g. different hues, different objects viewed, different parameters (naturalness, preference), and long-term effects, in different applications, demographics (race, age, sex), or for different regions of the world. Much more research data are needed to be able to develop an index for perception-based color quality. A whiteness index also needs to be investigated as a quality index to assess white lights, in order to resolve the problems associated with objects that contain optical brightening agents. Therefore, future research is required.

## Key Research Questions

- How can "preference" (or a model for color quality perception) be clearly defined and assessed for the intended end use? It may also be affected by users' long term visual experience. How can it be addressed?
- Are the individual variations in such preferences too large to define general preference?
- Can the preference for chroma saturation and white light chromaticity be substantially different in different regions (or race of people) in the world?
- What are the relevant parameters to measure the subjective aspects of color quality and the whiteness index?
- How to design an index to measure the whiteness perception of a light source? How to apply the surface whiteness indices for lighting application?

## Conclusions

Based on the research proposed here, CIE will define standard indices that can be used with a color fidelity index, all of which will allow specifying or evaluating overall color quality of lighting products. The CIE also recommends that important lighting metrics such as the Color Rendering Index require formal international agreement.New metrics introduced at the regional level could cause confusion in the global lighting market. The process of developing CIE recommendations by scientific consensus often requires considerable time. However, since the CIE is expediting the researches on color quality, new CIE color quality metrics will be introduced in the near future. ■

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