

A Colour Rendering Index for Dichromats

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ABSTRACT

We propose a method of evaluating the colour rendering quality of light sources tailored to dichromatic vision. To the best of our knowledge, the proposed color rendering index (CRI) is the first such index to be specifically designed for dichromats. Previous CRIs have been defined only for trichromats and they generally rely on measuring ΔE colour differences in a standardized uniform colour space such as CAM02-UCS. Since these spaces are defined only for trichromatic colour vision these methods do not generalize to the case of dichromatic colour vision. The proposed dichromat CRI is based on the metamer mismatch index, which applies to both the trichromatic and dichromatic cases.

KEYWORDS: *dichromatic colour rendering index, light source evaluation, metamer mismatch index.*

INTRODUCTION

Various methods of evaluating the colour rendering quality of light sources for normal trichromatic vision have been previously established, but none for dichromatic vision. The colour rendering indices developed by both the CIE [1] and more recently (2016) by the Illumination Engineering Society (IES) [4] are based on comparing the average change in colour of a standardized set of surface reflectances induced by a change in illumination from a test light source to a blackbody (or D-series daylight) spectrum of the same correlated colour temperature. In terms of the IES R_f fidelity index, the colour change is evaluated in terms of the mean ΔE in the CAM02-UCS color space over a special set of test reflectances. Unfortunately, these methods do not extend in any straightforward way to the case of dichromatic vision since there is no equivalent to the ΔE colour difference formula for dichromats; and hence there is thus far no CRI specifically designed for dichromats.

A very different CRI based on measuring the extent of metamer mismatching created by a change in lights was recently introduced by Mirzaei and Funt [6] and further tested by Funt et al. [2]. That method too was designed for trichromatic vision but it is more straightforwardly adapted to the dichromatic case. It is based on measuring the degree of potential metamer mismatching (i.e., the extent to which two reflecting surfaces that make a metameric match under the first illuminant can differ in colour under the second illuminant).

THEORY

As defined by Eqns. (1) and (2), for trichromats the MMCRI [6] (metamer mismatching color rendering index) is specified as one minus the cube root of the ratio of volume of the metamer mismatch body associated with a change from the test to reference illuminant normalized by the volume of the object colour solid.

$$MMVI = \frac{\text{volume of the metamer mismatch body for the given illuminant pair}}{\text{volume of the object color solid under the second illuminant}} \quad (1)$$

$$MMCRI = (1 - \sqrt[3]{MMVI}) \times 100 \quad (2)$$

The cube root is included to make the index relate to the linear ‘diameter’ of metamer mismatch body (MMB) rather than its volume.

In the dichromatic case, the MMB and object colour solid (OCS) both reduce to planar regions (see Figure 1) so the normalization becomes a ratio of areas: the ratio of the area of the MMB to that of the OCS. Hence, we define the dichromatic metamer mismatching color rendering index (DMMCRI) as one minus the square root of the ratio of these areas.

$$DMMVI = \frac{\text{area of the metamer mismatch body for the given illuminant pair}}{\text{area of the object color solid under the second illuminant}} \quad (3)$$

$$DMMCRI = (1 - \sqrt{DMMVI}) \times 100 \quad (4)$$

Dichromatic indices for protanopia (DMMCRI_P), deuteranopia (DMMCRI_D) and tritanopia (DMMCRI_T) are defined by calculating the metamer mismatch bodies using cone pairs M and S, L and S, L and M, respectively.

The IES CRI R_f [4] is based on comparing the test illuminant to a reference illuminant, where the reference illuminant depends on the correlated colour temperature (CCT) of the test illuminant. For CCT up to 4500K the corresponding blackbody spectral power distribution is used. For CCT beyond 5500K, the SPD of the corresponding CIE D-series daylight is used, and for $4500 < CCT < 5500$ an SPD that is a weighted combination of blackbody and daylight SPDs is used. In terms of defining a CRI for dichromats the question arises as to what reference illuminant should be used. For a given test illuminant, the blackbody that is ‘closest’ in terms of its chromaticity will, in general, not be the same for the dichromat as the trichromat. This issue will be discussed in more detail in a future publication. Suffice it to say here that our testing showed that whether the trichromat’s CCT or the dichromat’s CCT is used to select the reference illuminant the DMMCRI results are qualitatively very similar.

RESULTS AND DISCUSSION

Figure 1 shows two examples of test-reference illuminant pairs with the corresponding MMB inside the OCS of the reference illuminant. The OCS is determined as described in Logvinenko et al. [5]. However, the method for computing the MMB described there does not extend to the 2-dimensional, dichromatic case. The MMBs were calculated instead using a linear programming method with code provided by C. Godau [3]. Figure 1 (d) shows how significant the metamer mismatch can become in that the LS ‘colour’ of flat grey under the spiky SPD of IES test light #318 (Figure 1 (c)) could map to any one of the LS pairs within the green area. This is possible because, except at the spikes, the SPD is almost zero. This allows many possible reflectances to be metameric to flat grey under #318; which, when lit instead by the reference illuminant, will lead to a wide variety of LS values. This example illustrates the intuition behind using the degree of metamer mismatching as a measure of the colour rendering properties of a test light. Test light #318 has poor colour rendering properties because its SPD provides the observer very limited information about the surfaces it illuminates.

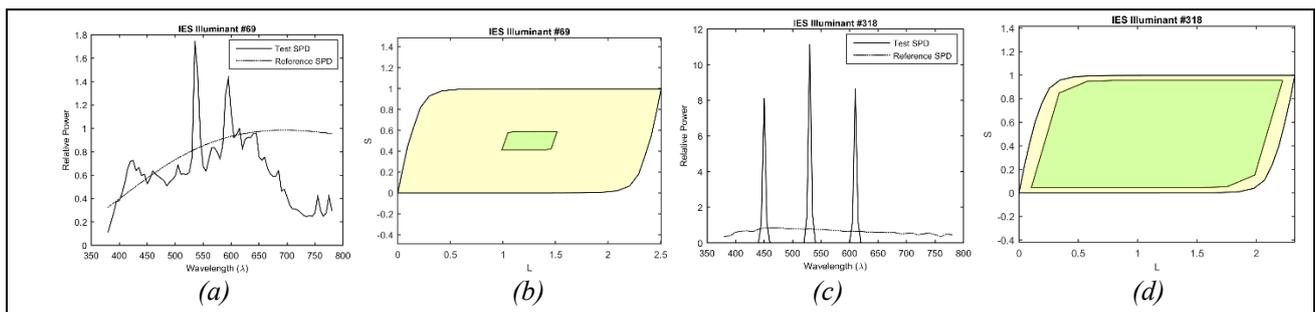


Figure 1: Examples of the SPDs of the test and reference lights and the corresponding metamer mismatch bodies (green) inside the object colour solids (yellow). (a) Test light IES #69, CCT=4168; (b) relatively small MMB inside OCS for #69; (c) Test light IES #318 CCT=6458; (d) very large MMB inside OCS for #318.

Figure 2 compares IES R_f to DMMCRI and illustrates how the IES R_f for trichromats often does not agree with the DMMCRI for dichromats, whether deuteranopia or protanopia.

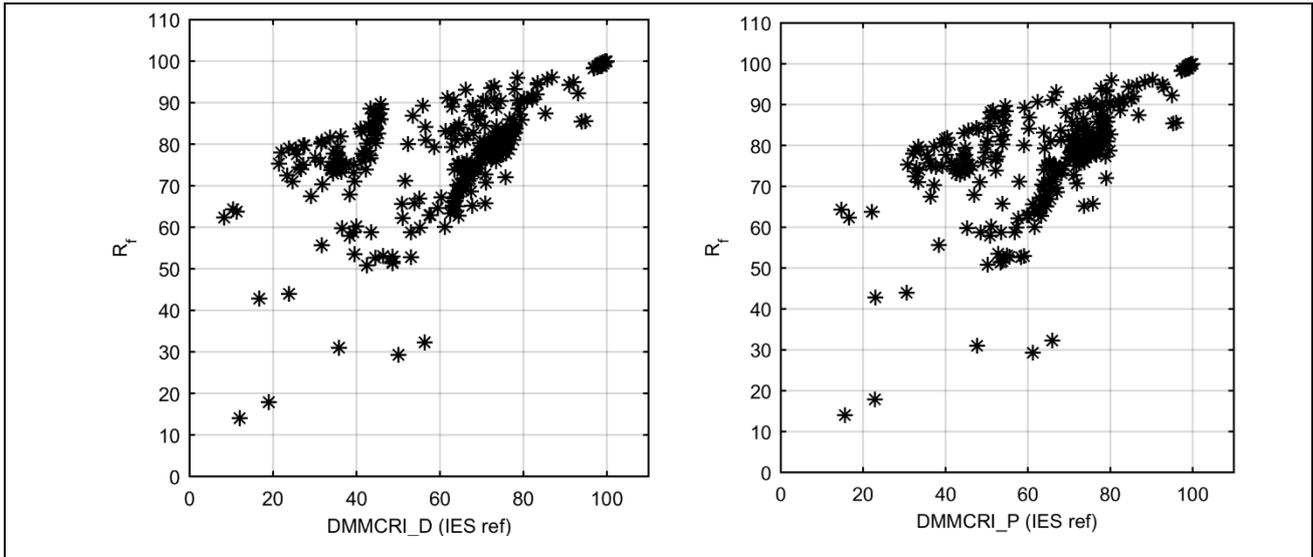


Figure 2: Comparison of color rendering indices for dichromats versus trichromats. (left) R_f (trichromat) versus DMMCRI_D (deuteranope); (right) R_f (trichromat) versus DMMCRI_P (protanope).

Figure 3 shows three test-reference illuminant pairs. Figure 3 (a) is a case for which DMMCRI and R_f are similar. Figure 3 (b) is interesting in that $DMMCRI > R_f$. Figure 3 (c) shows the reverse with $R_f > DMMCRI$.

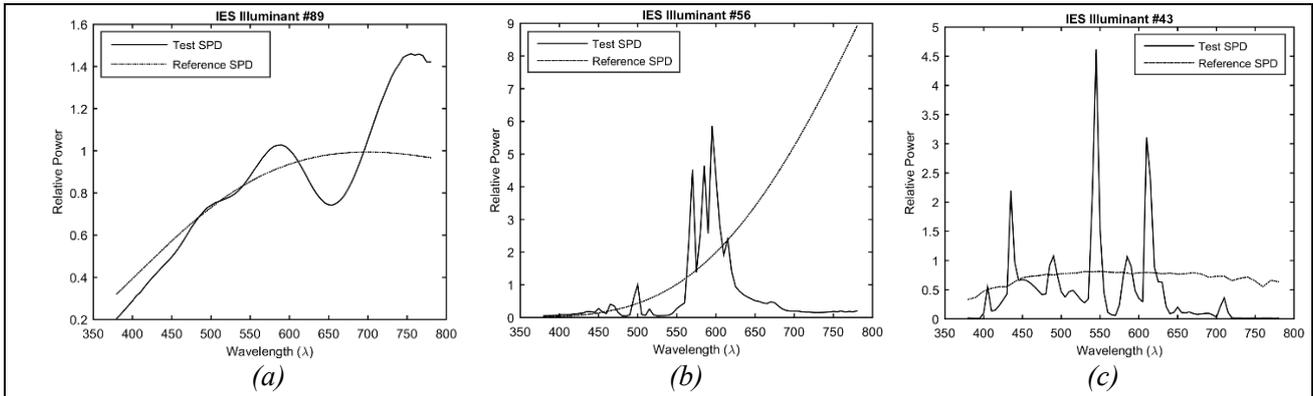


Figure 3: Examples of test-reference illuminant pairs for which DMMCRI_D and R_f agree/disagree. (a) IES #89 CCT=4144, $R_f=92$, DMMCRI_D = 93; (b) IES #56 CCT=1971, $R_f=32$, DMMCRI_D = 56; (c) IES #43 CCT=5072, $R_f=84$, DMMCRI_D = 41.

CONCLUSION

The proposed DMMCRI colour rendering index is specifically designed for dichromatic colour vision. The IES R_f CRI does not generalize to the case of dichromatic vision because, at its core, it is based on the measuring colour differences in the CAM02-UCS colour space, which is specifically for the case of normal trichromatic colour vision. The proposed metamer mismatching index evaluates the theoretical range of the colours that can be produced by a change from one given light to another. Since metamer mismatching is not limited to trichromatic vision, it provides a means to evaluate the colour rendering properties of lights as they affect dichromatic vision. Separate indices are easily defined for protanopia, deuteranopia and tritanopia. Comparison of the proposed dichromatic DMMCRI to the trichromatic IES CRI across the 318 illuminant spectra from the IES database show that a light that provides good colour rendering for a trichromat may provide poor colour rendering for a dichromat and vice versa.

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