A numerical comparison of indices of illuminant-induced metameric mismatch

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The Metameric Uncertainty Index, $R_t$


The Metamer Mismatching Color Rendering Index, MMCRI

Sample Set: \( R_t \)

The 99 CES of IES TM-30
Sample Set: \( R_t \)

The 99 CES of IES TM-30

**MMCRI**

\( n \) optimal square reflectance functions with 5 transition points
Concept:

\( R_t \)
Concept:

$R_t$

MMV, Metameric Mismatch Volume

Object Color Solid (test illuminant)

MMV, Metameric Mismatch Volume

$(D_{65} \rightarrow A)$
SPD set:

SPD Set
Spectral Width of Structural components (FWHM)

“Mono”
(1 nm)

“Narrow”
(2 to 11 nm)

“Medium”
(20 to 50 nm)

“Wide”
(50 to 100 nm)

Structural Components
("Primaries")

SPD Subset

3

4

5

6

7

Background
Methods
Results
Discussion
Conclusion
### SPD set:

**SPD Set**  
Spectral Width of Structural components (FWHM)

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100k SPDs
Results: $R_t$
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Results: $R_t$
Results: MMCRI
Results: comparison
Results: comparison
Results: comparison
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Results: comparison
**Results: characterization of SPDs**

**Two-sample Kolmogorov–Smirnov test (K-S)**

A nonparametric test of the equality of continuous one-dimensional probability distributions,

\( H_0: \) the two samples are drawn from the same distribution

\( H_0 \) (rephrase): \( R_i \) and MMCRI are equivalent assessments of illuminant-induced metameric mismatch.
Results: K-S test

$p < 0.0001$ for all comparisons

* The distributions for $R_t$ nearly overlap, so only the distribution for the Wide SPD set is shown to avoid clutter.
Results: K-S test

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* The distributions for \( R_t \) nearly overlap, so only the distribution for the Wide SPD set is shown to avoid clutter.
Discussion

Wavelength range stability
MMCRI varies substantially as a function of the wavelength range of an SPD. $R_t$ much less so.

Computational Errors
MMCRI unpredictably produces errors in the computation of some SPDs. $R_t$ does not.

Computation Time
With default settings, MMCRI takes 600 times as long to compute at $R_t$.

Determinism
With default settings, MMCRI is not deterministic. $R_t$ is.

Sample Set
MMCRI uses mathematical (square) SRDs that are not found in the real world. $R_t$ uses SRFs from real objects.
Looking forward

What is the role of SRF shape in calculations?

Does metameric uncertainty vary throughout color space? (i.e., does neutral grey capture everything?)

What is the role of metameric uncertainty in practice?

What wavelength range is most important?

Psychophysical experimentation. How does one or both measures relate to predicting mismatch? (Statistical vs. Practical Difference)
Conclusion

• Generated SPD set strategically varying spectral width and number of structural spectral components

• $R_t$ and MMCRI behave similarly for broadband SPDs, but the relationship diminishes for more narrowband SPDs.

• Importantly, significant KS tests suggest that $R_t$ and MMCRI are significantly different quantifications of metameric mismatch

• We have demonstrated some characteristics of MMCRI that are potentially problematic for use in applied lighting (see previous slide).

• We believe that measures of color rendition should use a sample set that is balanced in color space, wavelength space, and is comprised of real objects.

• Future work in this area should include psychophysical experimentation.
Thank you!

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REFERENCE SLIDES
(Top) The number of SPDs from each SPD subset that produced an error during the MMCRI computation. On average, the number of errors is highest for SPDs with narrowband radiation and few primaries. (Bottom) The number of errored SPDs with maximum relative output at the specified wavelength. SPDs that errored during the MMCRI calculation have peak wavelengths concentrated near 560 nm, shorter than approximately 450 nm, and to a lesser extent longer than approximately 610 nm. The sharp cutoff at 400 and 700 nm is because the peak wavelengths of the generated SPDs were constrained between those two wavelengths.
SPDs from Monochromatic subset which have disproportionately high value of MMCRI. Radiation in these SPDs is concentrated at the extents of the visible spectrum.
(Left) MMCRI versus $R_t$ for light sources with $R_t \geq 70$. When constraining to $R_t \geq 70$, the relationship between MMCRI and $R_t$ is tighter and there are no SPDs with MMCRI values disproportionately higher than other SPDs in their set. (Right) The difference between the z-scores of $R_t$ and MMCRI as a function of SPD set. The differences between $R_t$ and MMCRI agree more strongly for the Med and Wide sets than for the Nar and Mono sets.
The difference between the z-scores of $R_t$ and MMCRI as a function of IES TM-30 $R_f$. The difference between $R_t$ and MMCRI is larger for narrower spectra, expressed by the large variation in z-scores for those SPD sets. The difference is particularly large for the Narrow and Monochromatic SPD sets, suggesting that $R_t$ and MMCRI characterize these SPDs differently.
Scatterplot of MMCRI versus $R_t$ for four monochromatic SPD sets generated according to the parameters of Table 2 but with varying spectral ranges. The spread of achievable MMCRI values decreases as the spectral range is narrowed. There are also more SPDs that appear to have disproportionately large values of MMCRI with wider spectral ranges.
Boxplot for $R_t$ (top) and MMCRI (bottom) for four monochromatic SPD sets generated according to the parameters of Table 2 but with varying spectral ranges. MMCRI and $R_t$ both decrease as the spectral range is narrowed, though the variation is larger for MMCRI. The large variation in MMCRI with the wider spectral range is notable, with achievable values as high as 97.
The number of times (y-axis) the indicated wavelength (x-axis) was included as a transition wavelength for each of the five transitions in the 1,000 SRFs of the MMCRI computation. Transition wavelengths are disproportionately high near 457, 546, and 604 nm which are consistent with the crossover wavelengths of metamers documented by others [Thornton [1979], Ohta [1987], Bern [1990], Finlayson (2000)].

\[
MMVI = \frac{\text{vol. of MMV}}{\text{vol of. OCS (test ill.)}}
\]