# Color discrimination may be hue agnostic: a pilot study


## Tony Esposito, PhD

Philips Lighting Research North America
tony.esposito@philips.com
orcid.org/0000-0002-0308-6191


## Background

In 1972, WA Thornton introduced the concept of color discrimination as an important aspect of color quality and defined it as "the extent to which the illumination allows the observer to discriminate among a large variety of object colors simultaneously viewed" [Thorton 1972]. Thornton proposed using gamut area as a way to predict color discrimination and suggested that as gamut area increases, so does color discrimination ability.

Several studies show that this is not necessarily true for highly structured spectra (shark peak and valleys), and that increased gamut area may actually result in poorer color discrimination [Mahler and others 2009, Royer and others 2012, Wei and Houser 2012, Esposito and Houser 2017].

A recent study by Esposito and Houser [2017] explored the color discrimination ability of 24 LED light spectra with strategically varied average fidelity, average gamut, and gamut shapes. Results showed that average gamut indices all fail to reliably predict color discrimination. They found that the number of hue transpositions caused by the light source was a strong predictor of error scores, and proposed a new metric, the Total Light Source Error Score $R_\mathrm{d}$, as an objective measure of light source-induced hue transpositions. An $R_\mathrm{d}$ of 4 means the light source causes one transposition, an $R_\mathrm{d}$ of 8 is two transpositions, an $R_\mathrm{d}$ of 12 is three, and so on. $R_\mathrm{d}$ is the sum of error score for each of the four trays of the FM-100 test:

$$R_\mathrm{d} = \sum_{i=1}^{4} R_{\mathrm{d},i} = R_{\mathrm{d,A}} + R_{\mathrm{d,B}} + R_{\mathrm{d,C}} + R_{\mathrm{d,D}}$$

$$i = \mathrm{A, B, C, D}$$

where,

$R_{\mathrm{d,A}}$ is the *light source error score* for tray A;
$R_{\mathrm{d,B}}$ is the *light source error score* for tray B;
$R_{\mathrm{d,C}}$ is the *light source error score* for tray C;
$R_{\mathrm{d,D}}$ is the *light source error score* for tray D.

The Farnsworth-Munsell 100 Hue Test (FM-100) is a hue discrimination test consisting of 85 colored caps, of gradually changing hue, presented in four separate test trays. The standard Total Error Score (TES) is the sum of the error scores for each of the four test trays, and only considers the order of caps as arranged by a participant. Esposito and Houser [2017] proposed an *adjusted* total error score ($TES_\mathrm{adj}$) for the FM-100 test, which considers the interaction of the light source SPD and test chip spectral reflectance distributions (SRD). $TES_\mathrm{adj}$ reconciles the discrepancy between a light source-induced transposition and a transposition arranged by a participant performing the test, and is based on the assumption that a participant should not be penalized for correctly responding to a light source-induced transposition. $TES_\mathrm{adj}$ is the sum of the error score associated with each of the four trays of the FM-100 test:

$$TES_\mathrm{adj} = \sum_{i=1}^{4} iES_\mathrm{adj} = AES_\mathrm{adj} + BES_\mathrm{adj} + CES_\mathrm{adj} + DES_\mathrm{adj}$$

$$i = \mathrm{A, B, C, D}$$

where,

$AES_\mathrm{adj}$ is the *adjusted* error score for tray A;
$BES_\mathrm{adj}$ is the *adjusted* error score for tray B;
$CES_\mathrm{adj}$ is the *adjusted* error score for tray C;
$DES_\mathrm{adj}$ is the *adjusted* error score for tray D.

## Goals and Hypothesis

An $R_\mathrm{d}$ value of 4 indicates that a source spectra causes one transposition, but does not indicate in which hue the transposition occurs. Thus, the primary goal of this experiment was to determine if a transposition's hue location would influence mean *adjusted* error scores. The *a priori* hypothesis was that hue angle (or hue location) of the transposition would not result in significantly different mean *adjusted* error scores.

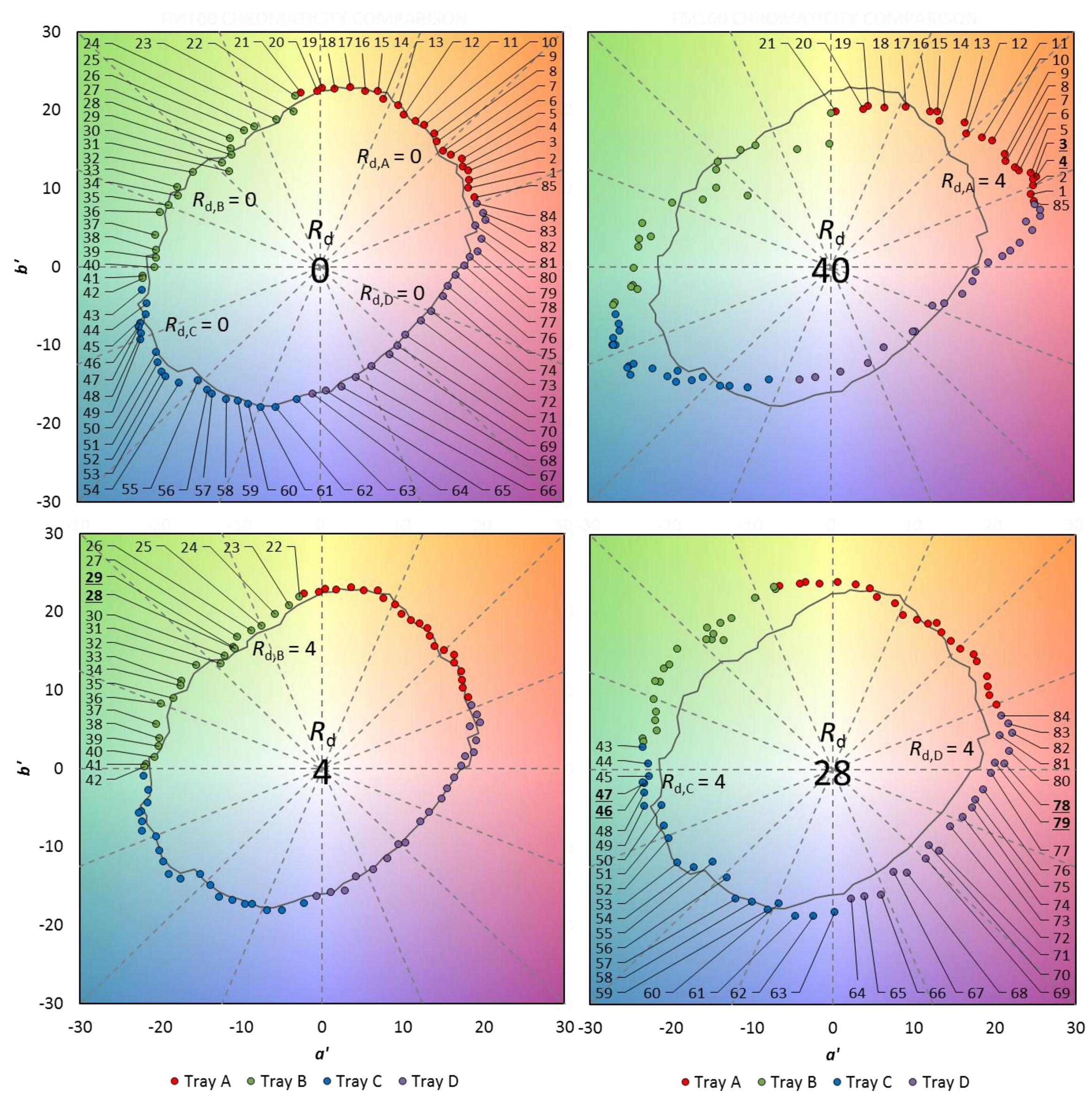
## Methodology

Four spectra were designed to achieve the following 8 conditions: $R_{\mathrm{d,A}}$ = 0, 4; $R_{\mathrm{d,B}}$ = 0, 4; $R_{\mathrm{d,C}}$ = 0, 4; $R_{\mathrm{d,D}}$ = 0, 4. One spectra did not transpose any caps ($R_{\mathrm{d,A}} = R_{\mathrm{d,B}} = R_{\mathrm{d,C}} = R_{\mathrm{d,D}} = 0$). One spectra transposed many caps, but exactly one in tray A ($R_{\mathrm{d,A}}$ = 4); one spectra transposed exactly one cap, located in tray B ($R_{\mathrm{d,B}}$ = 4); a final spectra transposed many caps, but exactly one transposition in each of trays C and D ($R_{\mathrm{d,C}} = R_{\mathrm{d,D}}$ = 4). See table below:

| | | | Light Source Error Score [Esposito and Houser 2017] | | | | |
|---|---|---|---|---|---|---|---|
| SPD ID | CCT [K] | $D_{uv}$ | $R_{\mathrm{d,A}}$ | $R_{\mathrm{d,B}}$ | $R_{\mathrm{d,C}}$ | $R_{\mathrm{d,D}}$ | $R_\mathrm{d}$ |
| 1 | 3503 | 0.0000 | ***0*** | ***0*** | ***0*** | ***0*** | 0 |
| 2 | 3498 | 0.0002 | ***4*** | 12 | 20 | 4 | 40 |
| 3 | 3487 | 0.0000 | 0 | ***4*** | 0 | 0 | 4 |
| 4 | 3502 | 0.0003 | 0 | 20 | ***4*** | ***4*** | 28 |

Characteristics of the four experimental spectra. The color discrimination values that are bolded, italicized, and underlined represent the stimuli that were used in this experiment.

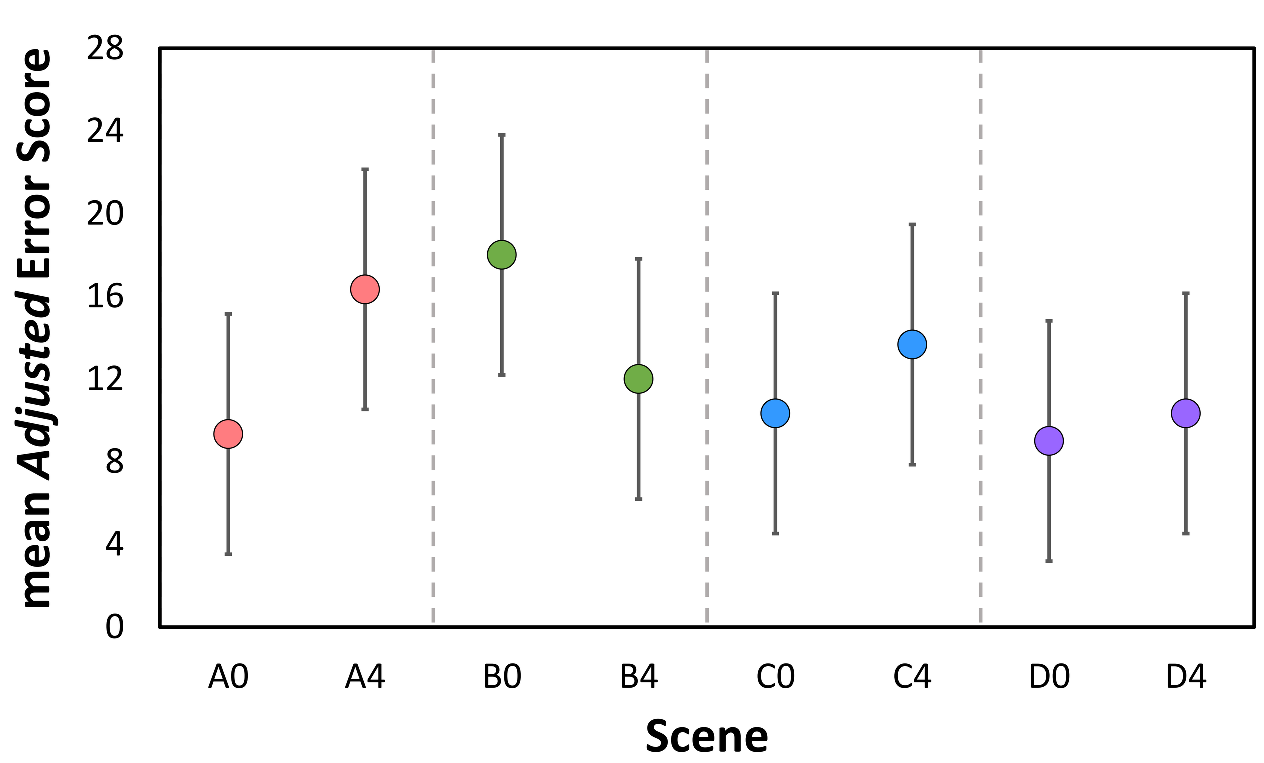
Twelve (12) people participated in this experiment; they had an average age of 27 years. All trials were performed in a 71 x 71 x 45 cm viewing booth with a horizontal illuminance of 600 lux.




Order of the caps of the FM-100 hue caps when illuminated by the four experimental spectra. Labels indicate the cap number; transposed caps are bolded and underlined. (Top left) SPD 1 which transposes no caps and has $R_{\mathrm{d,A}} = R_{\mathrm{d,B}} = R_{\mathrm{d,C}} = R_{\mathrm{d,D}} = 0$. (Top right) SPD 2 transposes many caps overall, but creates exactly one transposition (cap 3 and 4) in tray A ($R_{\mathrm{d,A}}$ = 4). (Bottom left) SPD 3 creates only one transposition overall (cap 28 and 29), which is located in tray B ($R_{\mathrm{d,B}}$ = 4). (Bottom right) SPD 4 transposes many caps overall, but creates exactly one transposition in tray C (caps 46 and 47) and one in tray D (caps 78 and 79) ($R_{\mathrm{d,C}} = R_{\mathrm{d,D}}$ = 4). The solid line shows the gamut area of the FM-100 hue test chips illuminated by CIE Illuminant C.

## Results

A one-way Analysis of Variance (ANOVA) shows that the four transpositions, strategically located in each of the FM-100 hue test trays, did not produce statistically different mean adjusted error scores ($p$ = 0.541). A Tukey mean comparison shows that the mean responses cluster into the same group. Additionally, spectra which transposed one cap, jointly, did not produce statistically different mean adjusted error scores than the spectra which did not transpose any caps.




Mean adjusted error scores ($iES_\mathrm{adj}$) for each of the 4 experimental conditions, plus the 4 baseline conditions. Values are an average of 12 participant responses, and error bars show the 95% confidence interval. The mean adjusted error scores were not statistically different ($p$ = 0.259).

## Conclusion

Results of the current study show that source-induced cap transpositions in each of the four trays of the FM-100 hue test do not produce statistically different mean adjusted error scores. If we assume the FM-100 hue test is indicative of color discrimination ability, and cap transpositions are predictive of the error scores of the FM-100 hue test, the results of the current study suggest that color discrimination ability may not depend upon hue. A follow up investigation should be performed with a larger sample size (to increase the power of the statistical test) and with a motivated set of participants (to reduce variability).