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# An Analysis of M0 and M1 Measurement Conditions

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The increased use of optical brightening agents (OBAs) in substrates for printing is well documented, as are the complications surrounding spectrophotometric color measurement when OBAs are present. In an effort to better address measurement of OBAs, the International Standards Organization (ISO) has published ISO 13566:2009, where the illuminations utilized in spectrophotometric instrumentation is more clearly defined than in previous standards. It is recognized that moving ahead the illuminant utilized in spectrophotometers should be able to better correlate to standardized viewing conditions, including the amount of ultra-violet (UV) present in the illuminant, as the effect of the OBAs is dependent on the amount of UV.

Of particular note, ISO 13655:2009 recognizes measurement condition M0 as a 'legacy' condition, representative of the wide range of spectrophotometers utilized in the field. Condition M0 instruments illuminants correspond to illuminant "A," while measurement condition "M1" specifies that that the instrument illumination corresponds to D50, which is better correlated to standardized viewing conditions and has a more clearly defined UV component. One goal of M1 is to achieve better agreement between various manufacturers and models of instrumentation.

While M1 instruments are being utilized more and more frequently in the field, there is a large population of legacy M0 instruments also in use. For those interested in understanding the variation that can be expected in the comparison of various instruments, the question of how much variation can be eliminated through the exclusive adoption of M1 instruments is especially germane.

Methods

The present study examines difference readings of both M0 and M1 instruments. As instruments capable of reading M1 include the ability to read the M0 condition, three measurement conditions were examined, as follows:

1. M0 Legacy: M0 readings from instruments not capable of reading the M1 measurement condition

2. M0: M0 readings from instruments capable of reading the M1 measurement condition

3. M1: M1 readings from instruments capable instruments.

Forty different spectrophotometers were utilized: twenty M0 Legacy instruments and twenty instruments capable of reading both M1 and M0.

In selecting samples with which to measure color differences, criterion included sample pairs with small color differences that would remain stable over the time needed to record the measurements. To meet these criteria, two LAB-REF's™ were purchased from IDEAlliance. Each IDEAlliance LAB-REF™ includes the following colors:

Table 1

*Colors Represented by IDEAlliance LAB-REF™*

| | | |
|---|---|---|
| White | Black | Cyan |
| Magenta | Yellow | Gray |
| Red | Green | Blue |
| Brown | Purple | Pastel |

As the LAB-REF™ does not include OBAs, two paper samples were also selected to be measured: one with OBAs and the other with no OBAs.

It is important to note that for the present study there is no presumption of a standard reference of known colorimetric values for the purpose of the comparison; the study is limited to examining the variance in the difference of each measurement condition between the 12 color pairs represented by the two LAB-REF's™ and the two papers.

The study addresses the following research question: Is there a difference in the colorimetric variance between M0, M1 and M0 legacy instruments for the selected sample pairs?

Spectral data were collected over a seven month period beginning in September, 2014. Instruments utilized included various models of instruments commonly used in the graphic arts from Konica Minolta, Techkon and X-Rite. All instruments were directional geometry (0/45 and 45/0). Spectral readings were taken with each sample pair, and difference information was calculated and reported as Delta-E CIE2000 ($\Delta E_{00}$)

Metrics:

To examine the equality of variances among M0 Legacy, M0 and M1, Levene's Test was utilized. Commonly used as a post-hoc test to meet the conditions of Analysis of Variance (ANOVA) and other statistical tests, Levene's tests for homogeneity of variance. An examination of boxplots and histograms of the raw $\Delta E_{00}$ values indicated that they data for many of the samples included outliers, and were non-normally distributed. Therefore, a non-parametric Levene's Test as advanced by Nordstokke and Zumbo (2010) was utilized.

As previously indicated, a major motivating factor underlying the development of the M1 measurement condition is the prevalence of OBAs, the present study provides a detailed analysis of the results of the paper samples measured, namely the paper with OBAs compared to the paper sample without OBAs. Summary data is presented for the comparison of the two IDEAlliance LAB-REF's™.

**Measurement of OBA and Non-OBA Paper with M0 Legacy, M0 and M1**

As a reminder, the present analysis does not presume standard values to judge instrument accuracy, but rather examines the variance in instrument measurement condition when measuring the same sample pairs. Hence, the means of the instrument readings is not analyzed in favor of examining the variances represented. When examining the difference readings between the OBA and non-OBA paper samples, the null and alternative hypotheses are as follows:

$$H_o: \text{var(M0 Legacy)} = \text{var(M0)} = \text{var(M1)}$$

$$H_1: \text{var(M0 Legacy)} \neq \text{var(M0)} \neq \text{var(M1)}$$

The $\Delta E_{00}$ values were normally distributed, as assessed by Shapiro-Wilk's test ($p > 0.05$). An assessment of a boxplot, however, did indicate outliers greater than 1.5 box-lengths from the edge of the box in the instance of M0 Legacy, as shown in Figure 1. The decision was therefore made to utilize the non-parametric Levene's test (Nordstokke and Zumbo, 2010), which has demonstrated to be robust in instances where outliers are present and the data are not normally distributed.

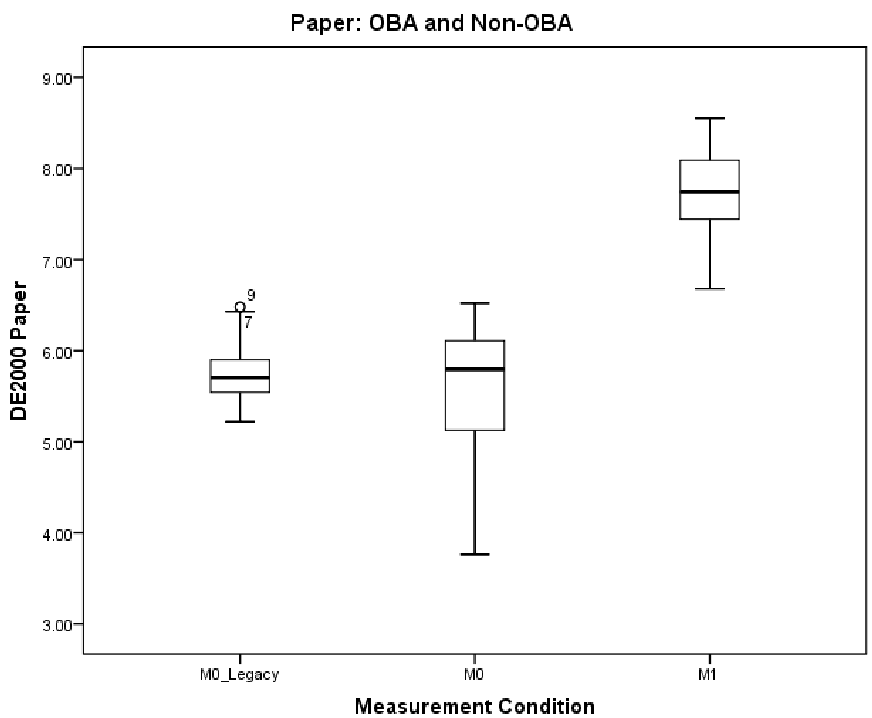


*Figure 1*. Boxplots of $\Delta E_{00}$ readings for OBA and non-OBA paper samples by measurement condition.

The non-parametric Levene's test dictates pooling the data from the groups, ranking the scores, placing the rank values back into their original groups, and conducting the Levene's test on the ranks (see Nordstokke, Zumbo, Cairns and Saklofske, 2011).

The ranked $\Delta E_{00}$ values for each measurement condition were examined for normality and outliers prior to attempting the Levene's test for homogeneity of variance.

The ranked $\Delta E_{00}$ values were normally distributed, as assessed by Shapiro-Wilk's test ($p > 0.05$). An assessment of a boxplot, did not indicate outliers greater than 1.5 box-lengths from the edge of the box as shown in Figure 2.

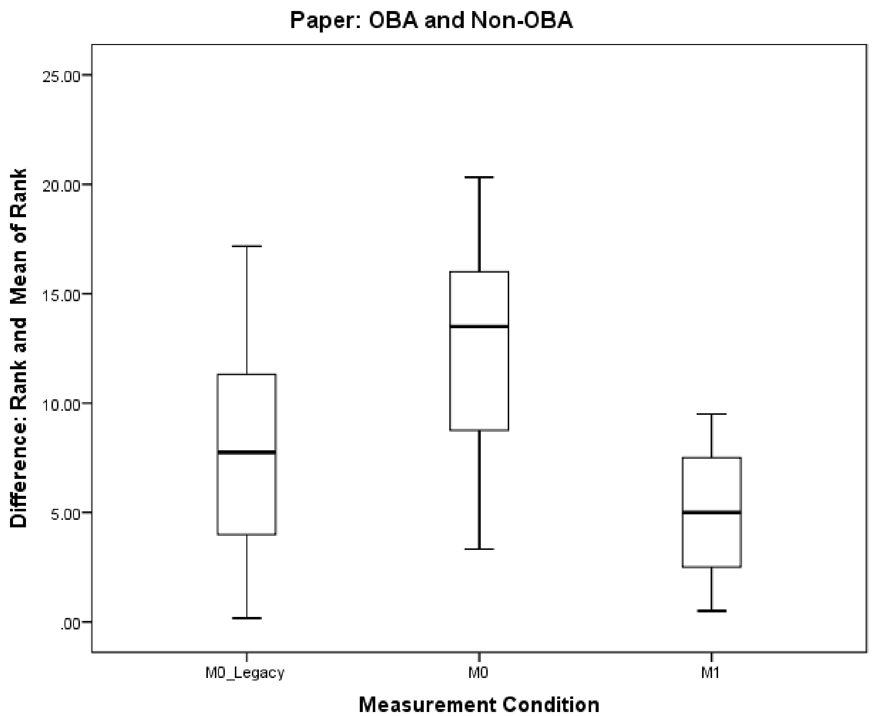


*Figure 2*. Boxplots of $\Delta E_{00}$ readings for ranked OBA and non-OBA paper samples by measurement condition.

For the ranked $\Delta E_{00}$ data, homogeneity of variances was violated, as assessed by Levene's test ($p = 0.04$). If we examine the standard deviation of each measurement condition as shown in Table 2 and the boxplots of the ranked data as shown in Figure 2, it is suggested that when measuring the difference between the utilized OBA and non-OBA papers and ranking the resultant data the M1 measurement condition results in less variance than either the M0 Legacy or the M0 measurement conditions.

Table 2

*Paper: OBA and Non-OBA Ranked $\Delta E_{00}$*

| | M0 Legacy | M0 | M1 | Levene's Test *p* |
|---|---|---|---|---|
| Variance | 29.02 | 25.51 | 8.68 | 0.04 |

**Measurement of OBA and Non-OBA Paper with M0 Legacy, M0 and M1**

Results of the ranked color difference for each of the colors samples included with the IDEAlliance LAB-REF™ is demonstrated in boxplot form in Figure 3 and Table 3. For each color pair, the Levene's test for homogeneity of variances resulted in p values > 0.05, indicating that there was no statistically significant difference in the variances among the measurement conditions tested.

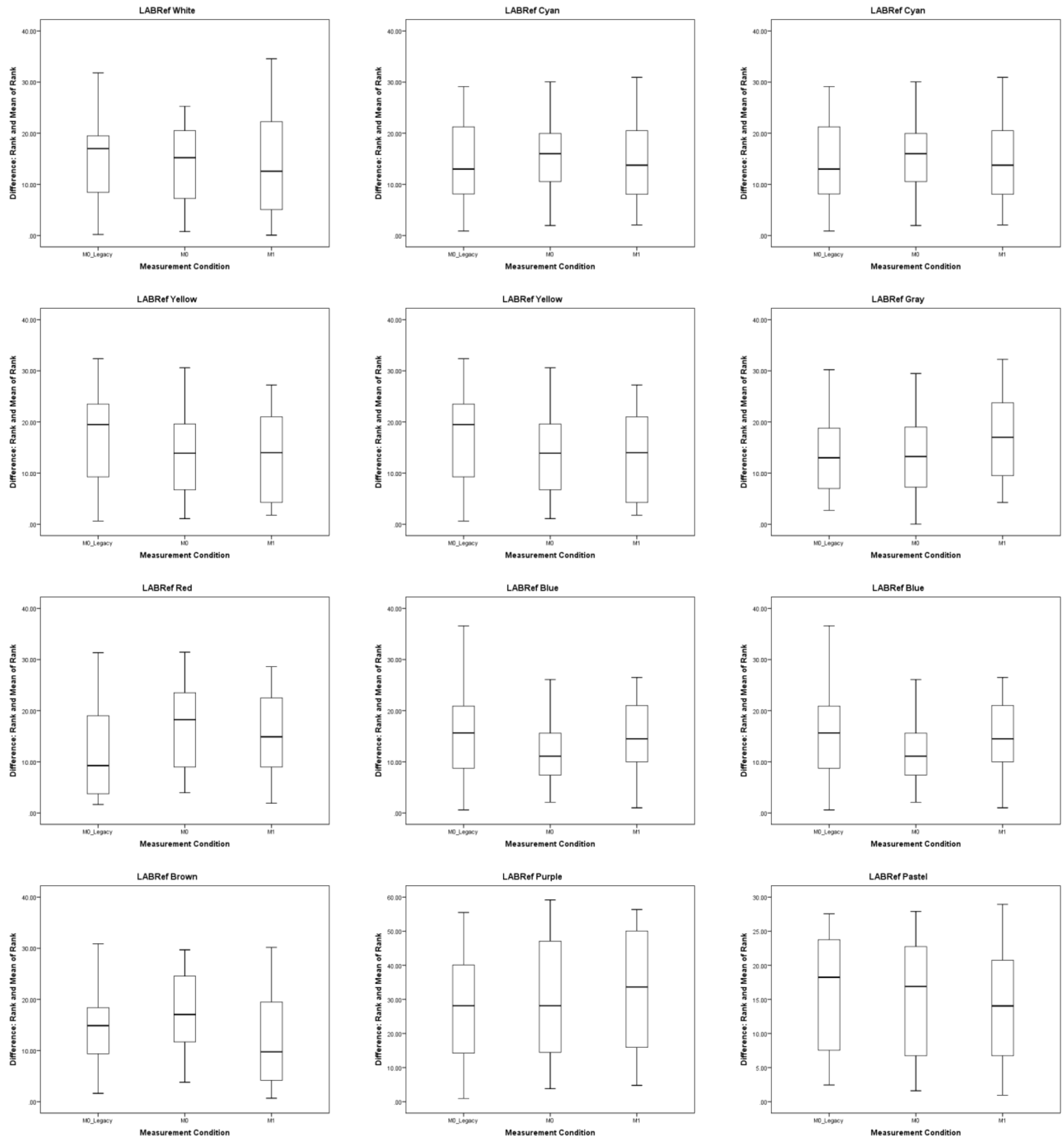


*Figure 3*. Boxplots of $\Delta E_{00}$ readings for ranked LAB-REF™ samples by measurement condition.

Table 3

*IDEAlliance LAB-REF™ Ranked ΔE$_{00}$*

| | M0 Legacy | M0 | M1 | Levene's Test *p* |
|---|---|---|---|---|
| White Variance | 65.68 | 56.64 | 87.15 | 0.64 |
| Black Variance | 70.21 | 55.07 | 79.15 | 0.29 |
| Cyan Variance | 65.15 | 55.72 | 67.9 | 0.85 |
| Magenta Variance | 49.04 | 85.21 | 106.75 | 0.08 |
| Yellow Variance | 87.4 | 66.16 | 79.69 | 0.63 |
| Gray Variance | 69.03 | 72.07 | 79.73 | 0.79 |
| Red Variance | 81.63 | 74.52 | 67.69 | 0.80 |
| Green Variance | 54.87 | 72.87 | 56.69 | 0.74 |
| Blue Variance | 107.2 | 38.36 | 46.11 | 0.21 |
| Brown Variance | 71.29 | 67.3 | 85.13 | 0.54 |
| Purple Variance | 269.52 | 342.06 | 302.46 | 0.33 |
| Pastel Variance | 75.05 | 79.08 | 69.05 | 0.62 |

**Discussion**

Inter-instrument agreement is an ongoing concern, and one of the primary challenges that researchers face in the examination of the variance that can be expected here are the characteristics of the sample. Relevant concerns here include the presence of OBAs, the surface characteristics of the samples, and even the lightfastness of the samples over time.

Today, instrument accuracy in terms of inter-instrument agreement are published for readings on BCRA Series II Tiles, which are more stable than colorant-on-paper samples but are not especially well suited for replicating the surface characteristics of the products produced by the graphics industry. Ambiguity here is furthered by instrument manufacturers' lack of publishing inter-model agreement among their particular models, and more importantly a lack of consistency in the methodology which underscores their published accuracy information.

The results here underscore the recommendations that, in workflows involving multiple instruments, the measurement condition utilized to create the standard needs to be specified together with other colorimetric variables (e.g.: illuminant, observer, tolerancing method). Further, when OBAs are present, instruments utilizing measurement condition M1 may result in less variance than measurement condition M0. The present study does not support this contention with samples that do not include OBAs, as is the case with the IDEAlliance LAB-REF™.

**Future Research**

Future researchers are encouraged to build on the results presented: a larger set of samples which include OBAs would be welcome to support the data presented here. To overcome the inherent challenges for this type of study, it is suggested that collecting data at one point in time would result in greater internal validity. One way to accomplish this would be to do so at a summit wherein the manufacturers are invited to send representatives with certified instruments to measure colorant-on-paper samples representative of the type of work commonly produced by printers. Such summits, sponsored by institutions, were successful in comparing proofing technologies in the past: the nature of color measurement has reached the point where such a summit would be welcomed.

**References:**

Nordstokke, Zumbo, Cairns and Saklofske (2011). The operating characteristics of the nonparametric Levene test for equal variances with assessment and evaluation data. *Practical Assessment, Research & Evaluation, 19(5)*, 1  8.

Nordstokke, D.W. & Zumbo, B.d. (2010). A new nonparametric test for equal variances. *Psicologica, 31*, 401-430.