An Analysis of M0 and M1 Measurement Conditions

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- Rochester Institute of Technology
Inherent Variation

- The Hallmark of a Seasoned Professional
- New Metrics = New Challenges
Special Case of Color Measurement

- Terminology Confusion
  - Inter-Instrument Agreement
  - Inter-Instrument Disagreement
  - Inter-Model Agreement
  - Instrument Uncertainty
Manufacturers’ Perspective

- Instruments Certified Using BCRA Series II Tiles
  - Stability
  - Traceable
  - Widely Adopted

- Recertification Services
  - Recommended for ‘Normal Use’
Making a Flawed Situation
Even More Confusing

- No Consistency on HOW Specifications are Published
  - Average of 12 BCRAs, Max. on Single BCRA, or Both?
  - Tolerancing Method?

<table>
<thead>
<tr>
<th>Published Inter-Instrument Agreement Specifications for Graphic Arts Spectrophotometric Instruments</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 $\Delta E_{cmc}$ MAX</td>
<td>0.4 $\Delta E_{94}$ Average, 1.0 $\Delta E_{94}$ MAX</td>
</tr>
<tr>
<td>0.3 $\Delta E^*$ MAX, 0.15 Average</td>
<td>0.3$\Delta E^*$</td>
</tr>
<tr>
<td>0.3 $\Delta E_{ab}$ Average</td>
<td>0.25 $\Delta E^<em>$ Average, MAX 0.45 $\Delta E^</em>$</td>
</tr>
<tr>
<td>&lt; 1 $\Delta E$ MAX, &lt;0.5 $\Delta E$ Average</td>
<td>0.3$\Delta E_{00}$ Average</td>
</tr>
<tr>
<td>0.3 $\Delta E^*$, 0.15 $\Delta E_{cmc}$ Average</td>
<td></td>
</tr>
</tbody>
</table>
Green BCRA with Same Tolerance Number Using $\Delta E^*$, $\Delta E_{cmc}$, $\Delta E_{94}$ and $\Delta E_{00}$
Efforts to Drive Variance

- Internal SOPs
  - BCRAs
  - IDEAlliance LabREF
- Round Robin
- Third Party, e.g.
  - ChromaChecker
  - Vogelsong Color Ref
Motivation

- Climate Comprised of Factors Surrounding Color Measurement Accuracy
- Introduction of M1
Research Questions

- Are There Differences in Variance in M1 and M0 Readings With Instruments Capable of Measuring Both?
- Are There Differences in Variance Among M1 Instruments and M0 Legacy Instruments?
Methods

- Read and Record $\Delta E_{00}$ in Color Pairs with M1, M0 and Legacy (M0) Instruments
- Evaluate White Points of M1, M0 and M0 Legacy Instruments
- Color Pairs
  - Twelve Color Samples in IDEAlliance LabREF
  - Two Paper Samples (One OBA, One No OBA)
Data Collection

- Goal to Measure with as Many Instruments as Possible
  - Began at GraphExpo in Fall
  - Instruments at RIT
  - Customers and Vendors
## Descriptive Data: Ranges

<table>
<thead>
<tr>
<th></th>
<th>M0</th>
<th>M1</th>
<th>M0 Legacy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DE00 Paper</strong></td>
<td>2.7</td>
<td>1.9</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>DE00 White</strong></td>
<td>.38</td>
<td>.42</td>
<td>.5</td>
</tr>
<tr>
<td><strong>DE00 Black</strong></td>
<td>.74</td>
<td>.44</td>
<td>1.39</td>
</tr>
<tr>
<td><strong>DE00 Cyan</strong></td>
<td>.47</td>
<td>.48</td>
<td>.52</td>
</tr>
<tr>
<td><strong>DE00 Magenta</strong></td>
<td>.34</td>
<td>.37</td>
<td>.28</td>
</tr>
<tr>
<td><strong>DE00 Yellow</strong></td>
<td>.18</td>
<td>.19</td>
<td>.26</td>
</tr>
<tr>
<td><strong>DE00 Gray</strong></td>
<td>.82</td>
<td>.82</td>
<td>.58</td>
</tr>
<tr>
<td><strong>DE00 Red</strong></td>
<td>.33</td>
<td>.39</td>
<td>.37</td>
</tr>
<tr>
<td><strong>DE00 Green</strong></td>
<td>.6</td>
<td>.31</td>
<td>.63</td>
</tr>
<tr>
<td><strong>DE00 Blue</strong></td>
<td>.39</td>
<td>.21</td>
<td>.53</td>
</tr>
<tr>
<td><strong>DE00 Brown</strong></td>
<td>.61</td>
<td>.29</td>
<td>.49</td>
</tr>
<tr>
<td><strong>DE00 Purple</strong></td>
<td>.27</td>
<td>.21</td>
<td>.32</td>
</tr>
<tr>
<td><strong>DE00 Pastel</strong></td>
<td>.29</td>
<td>.22</td>
<td>.42</td>
</tr>
</tbody>
</table>
Evaluation of Paper Samples
Boxplots $DE_{00}$ Paper
Evaluation of Paper Samples
M1 vs. M0

- M1 Delta-E\textsubscript{00}: (\( M = 7.7, \ SD = 0.47 \))
- M0 Delta-E\textsubscript{00}: (\( M = 5.6, \ SD = 0.67 \))
- \( M =-2.05, \ 95\% \ CI[-2.44—1.68], \ t(36) = -10.97 \)
- \( p < 0.01. \)

There were 19 M0 and 19 M1 Instruments analyzed. An independent-samples t-test was run to determine if there were differences in Delta-E in reading an OBA paper and a non-OBA paper by measurement condition. There were no outliers in the data, as assessed by a visual inspection of the bloxplot. There was homogeneity of variances for Delta-E\textsubscript{00} Paper, as assessed by Levene’s test for equality of variances (\( p = 0.13 \)). Delta-E\textsubscript{00} Paper for each level of Measurement Condition (M0/M1) were normally distributed, as assessed by Shapiro-Wilk's test (\( p > 0.05 \)).
Evaluation of Paper Samples
M0 vs. M0 Legacy

- M0 Delta-E\textsubscript{00}: \( M = 5.6, \ SD = 0.67 \)
- M0 Legacy Delta-E\textsubscript{00} \( M = 5.7, \ SD = 0.38 \)
- \( p > 0.05 \)
Boxplots $\text{DE}_{00} \text{ Black}$
Evaluation of LabREF Black
M0 vs. M1 and M0 vs. M0 Legacy

- M1 Delta-E\textsubscript{00}: \((M = 0.20, SD = 0.13)\)
- M0 Delta-E\textsubscript{00}: \((M = 0.21, SD = 0.17)\)
- \(p > 0.05\)

- M0 Delta-E\textsubscript{00}: \((M = 0.21, SD = 0.17)\)
- M0 Legacy Delta-E\textsubscript{00}: \((M = 0.25, SD = 0.30)\)
- \(p > 0.05\)
Boxplots $\text{DE}_{00} \text{ Gray}$
Evaluation of LabREF Gray

- M1 Delta-E$_{00}$: ($M = 0.54$, $SD = 0.21$)
- M0 Delta-E$_{00}$: ($M = 0.52$, $SD = 0.18$)
- $p > 0.05$

- M0 Delta-E$_{00}$: ($M = 0.52$, $SD = 0.18$)
- M0 Legacy Delta-E$_{00}$: ($M = 0.53$, $SD = 0.19$)
- $p > 0.05$
Boxplots $DE_{00}$ Brown
Evaluation of LabREF Brown

- M1 Delta-$E_{00}$: $(M = 0.56, SD = 0.19)$
- M0 Delta-$E_{00}$: $(M = 0.59, SD = 0.12)$
- $p > 0.05$

- M0 Delta-$E_{00}$: $(M = 0.59, SD = 0.16)$
- M0 Legacy Delta-$E_{00}$: $(M = 0.58, SD = 0.14)$
- $p > 0.05$
Boxplots $DE_{00}$ White
Evaluation of LabREF White
M1 vs. M0 and M0 vs. M0 Legacy

- M1 Delta-E$_{00}$: $(M = 0.23, SD = 0.12)$
- M0 Delta-E$_{00}$: $(M = 0.27, SD = 0.13)$
- $p > 0.05$

- M0 Delta-E$_{00}$: $(M = 0.27, SD = 0.13)$
- M0 Legacy Delta-E$_{00}$: $(M = 0.40, SD = 0.15)$
- $p > 0.05$
White Points, M0, M1 and M0 Legacy

M0 = Brown, M1 = Cyan, M0 Legacy = Green
Conclusions: Instrument Accuracy in Workflow

- Support for Widely Recognized Realizations
  - *Difference Information is Best Method*
  - *Careful Specification of Measurement Parameters Necessary*
Implications

- Instrument Manufacturers:
  - *Provide Common Inter-Instrument Agreement Specifications for Real Comparison*
  - *Implement Black Trap Calibration*
Future Research

- Continue Data Collection with Additional Instruments
- Measurement Systems Analysis
  - Fixed Effects (Measurement Condition)
  - Random Effects (Various Instruments)
  - Restricted Maximum Likelihood (REML)
Thank You!

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  - Techkon USA
  - X-Rite