# Underlying Factors for Consistent Color Appearance (CCA) and developing CCA metric

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CRPC1 CRPC2 CRPC3 CRPC4 CRPC5 CRPC6 CRPC7

Visual Simulation of CRPC1~CRPC7

CMYK pictorial color images, outputted to ISO 15339-2 CRPC1~CRPC7 reference printing conditions, are assumed to have consistent color appearance despite their colorimetric differences in white point and gamut volume

- We plan to test this assumption and use the variables underlying the CRPCs to deviate from CCA.
- In this way we can experimentally quantify the effects of Gray Balance, Tone Scale and hue angles of CMYRGB solids on CCA and propose a metric for the use in graphic communications.

# CCA vs. Color Image Match

| | Consistent Color Appearance | Color Image Match |
|---|---|---|
| Definition | A measure of visual consistency among multiple images (1) of the same scene reproduced in different reference printing conditions or (2)of different scenes in one reference printing condition | A measure of visual match between a reference image and a sample image of the same scene in the same viewing conditions |
| Reference(s) | Multiple reference printing conditions with similar tone and color characteristics, but different color gamut, e.g., CRPC1~CRPC7 | A specified reference printing condition, e.g., CRPC6 |
| Applications | Product campaign whereby different printing processes and substrates are used for packaging, labeling, advertising, etc. | Color proofs used in commercial and publication printing |

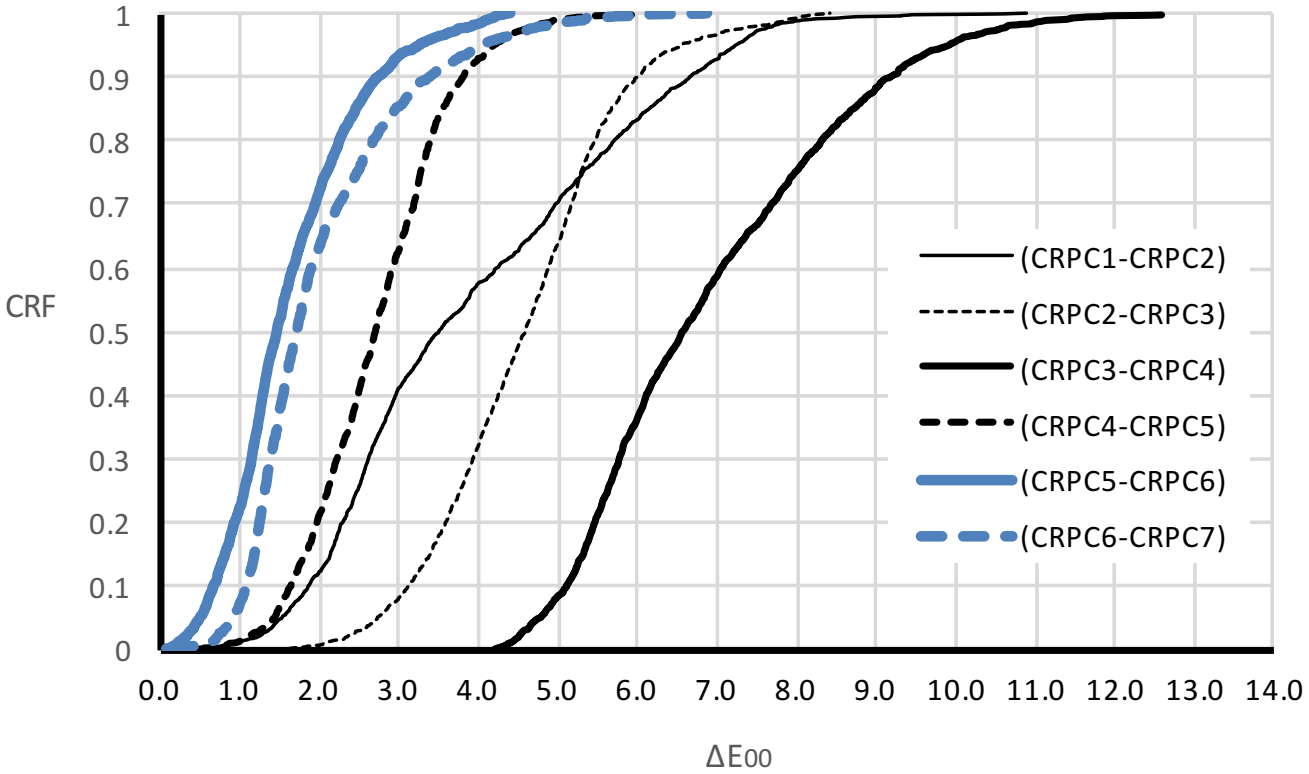
# Theoretical Basis

- Adjacent CRPCs, in terms of paper, solids, and gamut volume, are unequal.

| CRPC | Paper | | | C100 | | | M100 | | | Y100 | | | K100 | | | Gamut Volume | Gamut Volume Diff. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L* | a* | b* | L* | a* | b* | L* | a* | b* | L* | a* | b* | L* | a* | b* | | |
| CRPC1 | 85 | 1 | 5 | 59 | -24 | -26 | 56 | 48 | 0 | 80 | -2 | 60 | 37 | 1 | 4 | 84,280 | 80% |
| CRPC2 | 87 | 0 | 3 | 57 | -28 | -34 | 52 | 58 | -2 | 82 | -2 | 72 | 30 | 1 | 2 | 151,311 | |
| ΔEab | 3.0 | | | 9.2 | | | 11.0 | | | 12.2 | | | 7.3 | | | | |
| CRPC2 | 87 | 0 | 3 | 57 | -28 | -34 | 52 | 58 | -2 | 82 | -2 | 72 | 30 | 1 | 2 | 151,311 | 10% |
| CRPC3 | 95 | 1 | -4 | 60 | -26 | -44 | 56 | 61 | -2 | 89 | -3 | 76 | 32 | 1 | 1 | 165,764 | |
| ΔEab | 10.7 | | | 10.6 | | | 5.0 | | | 8.1 | | | 2.2 | | | | |
| CRPC3 | 95 | 1 | -4 | 60 | -26 | -44 | 56 | 61 | -2 | 89 | -3 | 76 | 32 | 1 | 1 | 165,764 | 53% |
| CRPC4 | 89 | 0 | 3 | 55 | -36 | -38 | 47 | 66 | -3 | 83 | -3 | 83 | 23 | 1 | 2 | 253,711 | |
| ΔEab | 9.3 | | | 12.7 | | | 10.3 | | | 9.2 | | | 9.1 | | | | |
| CRPC4 | 89 | 0 | 3 | 55 | -36 | -38 | 47 | 66 | -3 | 83 | -3 | 83 | 23 | 1 | 2 | 253,711 | 31% |
| CRPC5 | 92 | 0 | 0 | 57 | -37 | -44 | 48 | 71 | -4 | 87 | -4 | 88 | 19 | 0 | 1 | 331,416 | |
| ΔEab | 4.2 | | | 6.4 | | | 5.2 | | | 6.5 | | | 4.2 | | | | |
| CRPC5 | 92 | 0 | 0 | 57 | -37 | -44 | 48 | 71 | -4 | 87 | -4 | 88 | 19 | 0 | 1 | 331,416 | 17% |
| CRPC6 | 95 | 1 | -4 | 56 | -37 | -50 | 48 | 75 | -4 | 89 | -4 | 93 | 16 | 0 | 0 | 389,023 | |
| ΔEab | 5.1 | | | 6.1 | | | 4.0 | | | 5.4 | | | 3.2 | | | | |
| CRPC6 | 95 | 1 | -4 | 56 | -37 | -50 | 48 | 75 | -4 | 89 | -4 | 93 | 16 | 0 | 0 | 389,023 | 35% |
| CRPC7 | 97 | 1 | -4 | 54 | -42 | -54 | 47 | 78 | -10 | 90 | -4 | 103 | 14 | 0 | 0 | 525,551 | |
| ΔEab | 2.0 | | | 6.7 | | | 6.8 | | | 10.0 | | | 2.0 | | | | |

# Theoretical Basis

- CRF (Cumulative Relative Frequency of $\Delta E_{00}$ ) and the 95$^{th}$ percentile $\Delta E_{00}$ ‡ between adjacent CRPCs are unequal.




| 95th percentile ΔE 00 | |
|---|---|
| CRPC1-CRPC2) | 7.24 |
| CRPC2-CRPC3) | 6.56 |
| CRPC3-CRPC4) | 9.86 |
| CRPC4-CRPC5) | 4.18 |
| CRPC5-CRPC6) | 3.26 |
| CRPC6-CRPC7) | 4.03 |

‡ CRF and the 95$^{th}$ percentile $\Delta E_{00}$ are adopted by CGATS TR016 to assess colorimetrical color difference and print conformance.

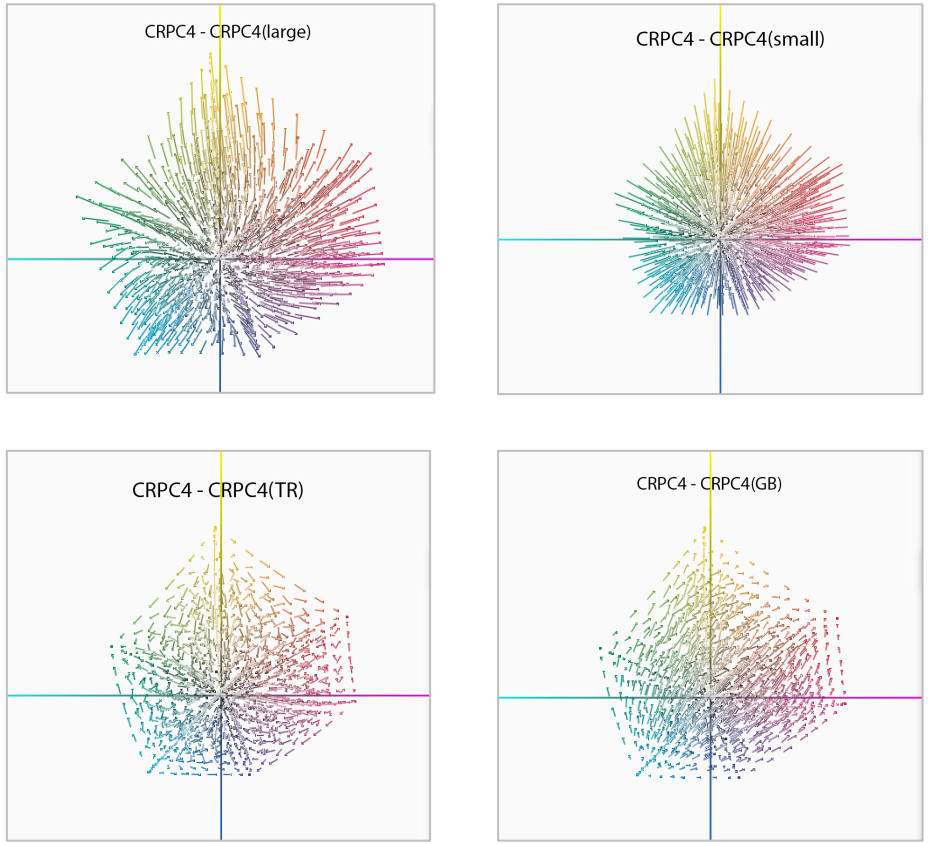
# Method

- Choose one reference printing condition – CRPC4
- Produce variations from this reference printing condition
    1) gamut changes only, thus maintaining CCA
    2) alterations of one or combination of hue angles of solids, grey balance, and tone reproduction, thus violating CCA

Any of the above datasets, 1) and 2) may be altered in its device space to produce the same colorimetric difference.

# Approach: vary printing conditions to selectively alter gamut, tone reproduction and gray balance

EXAMPLE OF COLOR DATASET CHANGES

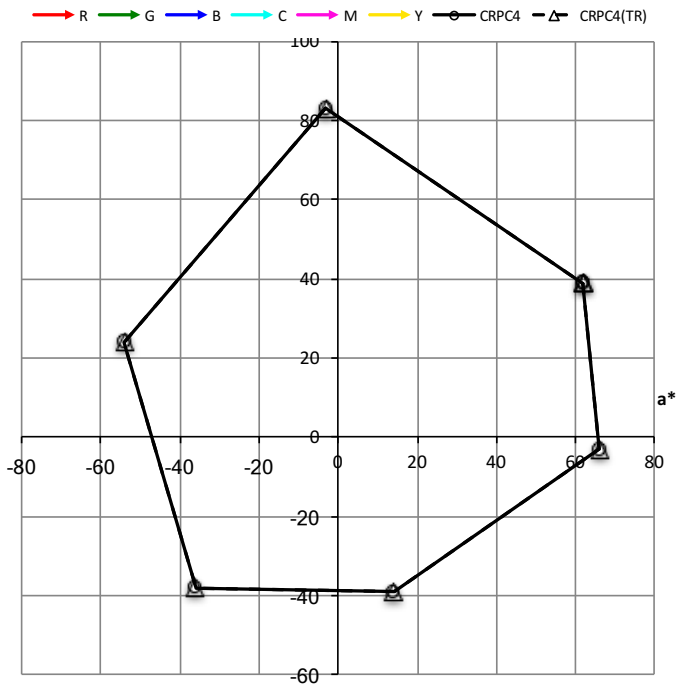


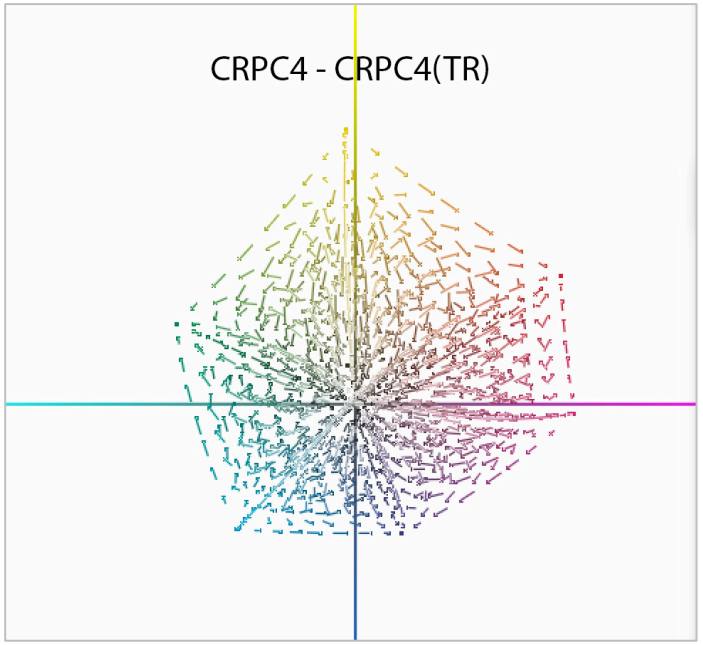

From Fedorovskaya, Chung, Hunter, Urbain, TAGA 2017

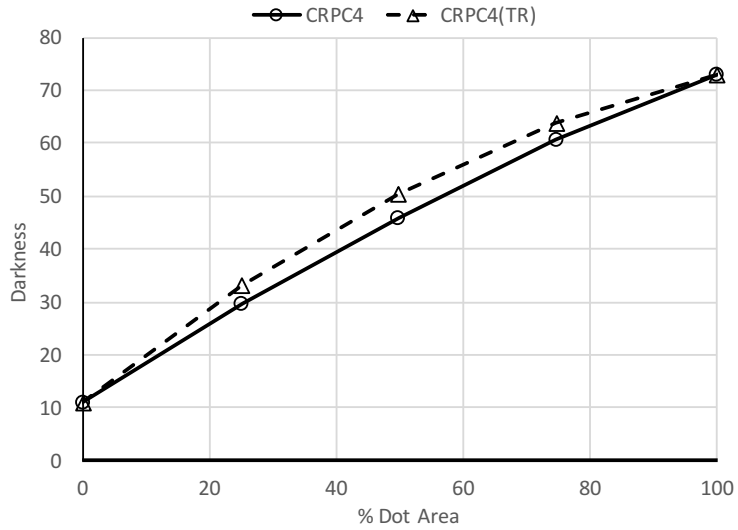
- Measure changes as equal steps using 95$^{th}$ percentile $\Delta E_{00}$
  - (Other color spaces can potentially be used)
- Print images selected by the CIE TC8-16 on different substrates including OBA
- Conduct psychometric tests asking observers to identify images with CCA from multiple variations of the same scene and different scenes
- Propose a CCA scale
- Present at the TC8-16 meeting

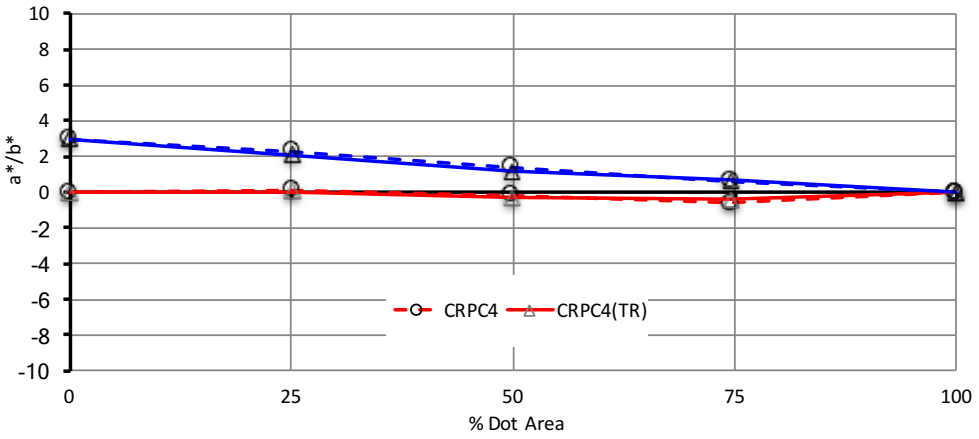
# Altering Tone reproduction of the reference CRPC4 dataset while maintaining gamut volume and gray balance using 95th percentile $\Delta E_{00}$ as a shift parameter

- CRPC4 vs. CRPC4 (Tone reproduction altered)
  - Different tone reproduction
  - Same gamut volume, 95th percentile $\Delta E_{00}$, and gray balance



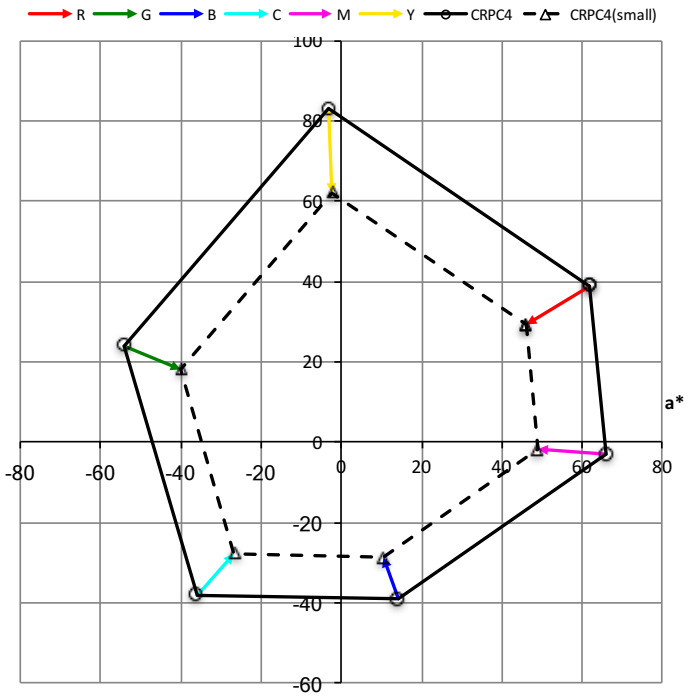



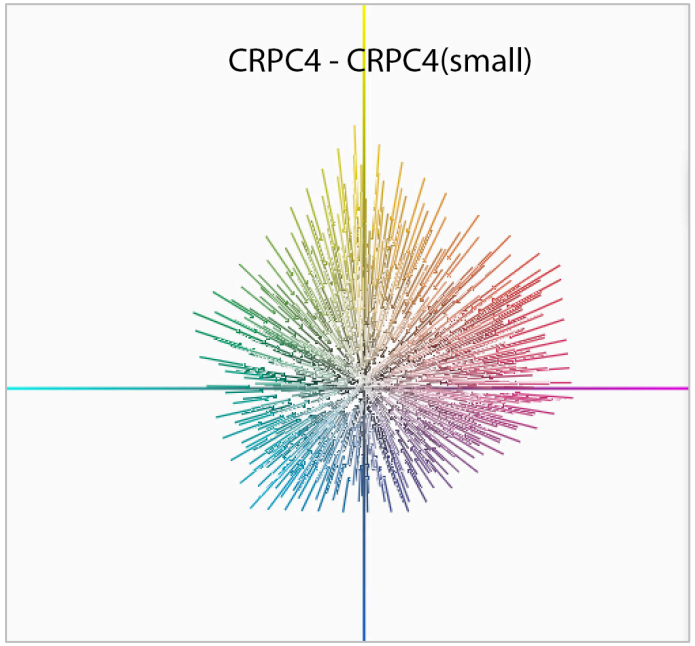



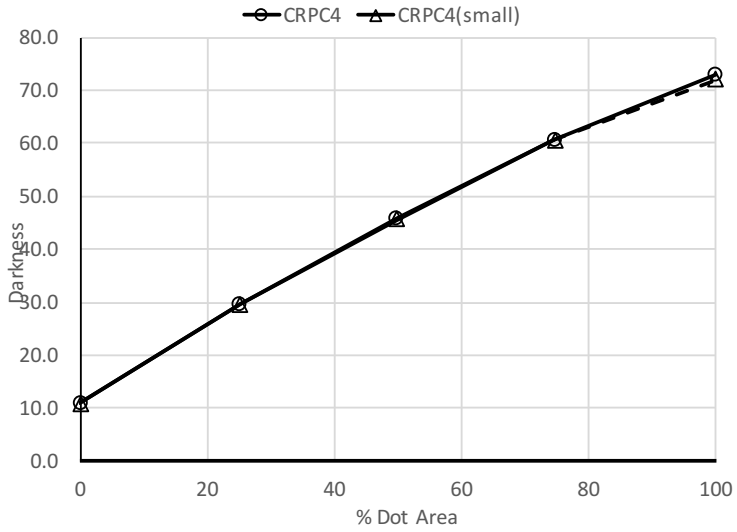



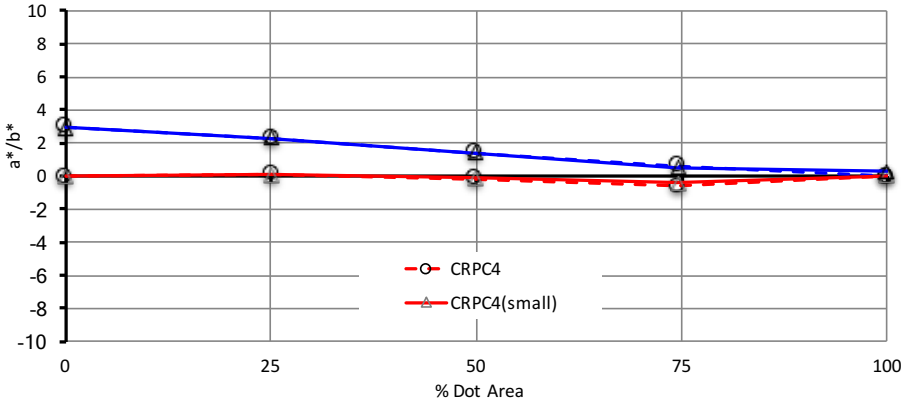
# Gamut change with constant tone reproduction and grey balance. Verification of the Altered Dataset to CRPC4

- CRPC4 vs. CRPC4 (Small)
  - Different gamut volume
  - Same 95$^{th}$ percentile $\Delta E_{00}$, tone reproduction, and gray balance [Darkness = 100 – L*]



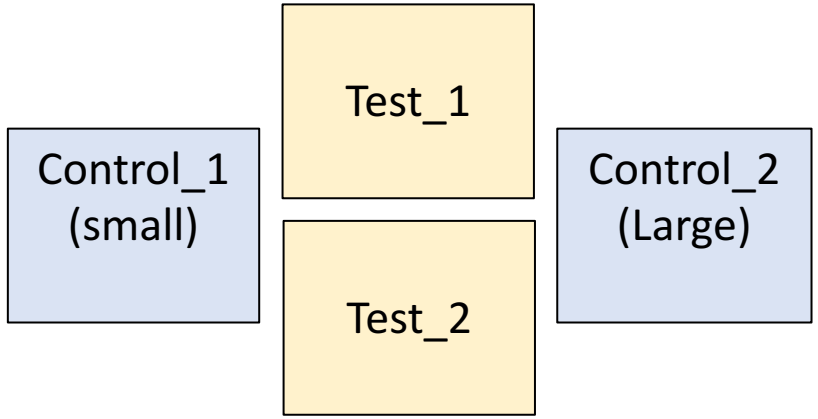



# Definitions used in the experiment

- ***Consistency of colour appearance*** *is defined as the degree of visual consistency and/or shared visual appearance that a set of images possesses albeit a presence of visual differences.*
- *This consistency varies according to printing conditions and can be affected by paper substrates, inks, environments, printing devices and printing parameters, such as, for example, colour balance and colour gamut, among others.*
- *This consistency of colour appearance is an attribute of an image set that makes the images from the set belong to the same family to a varying degree.*
- *This definition is applied to the same scene printed in different printing conditions, and also to the different scenes printed in similar printing conditions. In the latter case these different scenes can invoke a sense that they were all printed according to the same specifications, including the device gamut, inks, and the printer.*

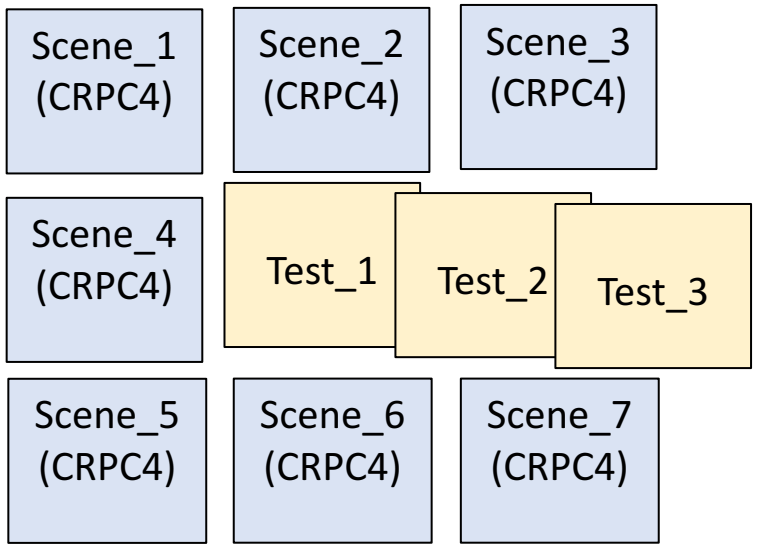
# Example experimental procedure to test CCA for a single scene

- Observers are presented with two control images (blue), and two of 3 test images (yellow) differing in TR, GB or None, of the same scene.
- Observers are asked to select a test image that appears to yield more color consistency in the triplet.
- There are three pairs per scene.
- Eight scenes are tested.




# Example of experimental procedure to test CCA of multiple scenes

- Observers are presented with seven control images (blue) of different scenes.
- Observers are asked to select one of the three test images (yellow) that appears to yield more color consistency.
- Eight scenes are tested.
- 12 Observers participated in both experiments



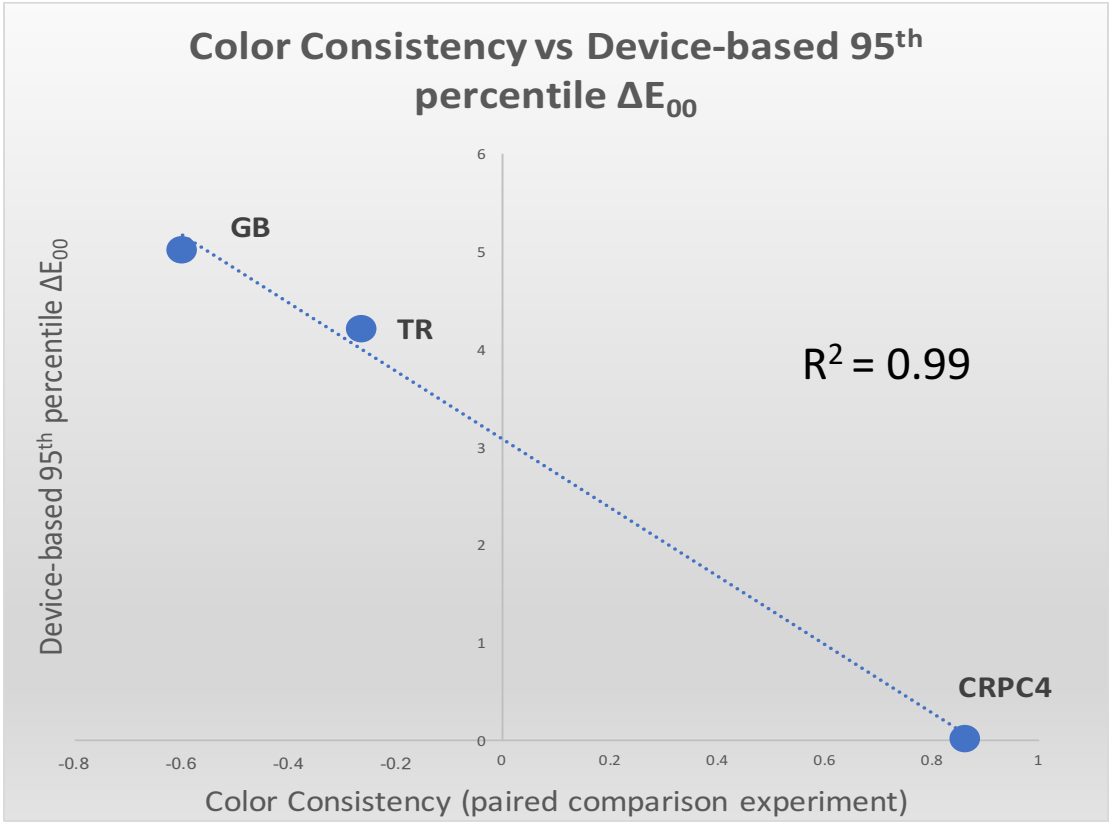

# Example of data analysis. Paired Comparison of test images for the same scene.

- For every scene, paired comparison data were collected as a 3x3 matrix across participants. Each location is the number of times the image in the $j^{th}$ column was chosen over the image in the $i^{th}$ row.
  - For example, the CRPC4 image is chosen over the GB-altered image 34 times where the GB-altered image is chosen only twice over the CRPC4 image.

**Roman16_02_midtone**

| | GRAY BALANCE | TONE REPRODUCTION | CRPC4 |
|---|---|---|---|
| GRAY BALANCE | | 29 | 34 |
| TONE REPRODUCTION | 7 | | 33 |
| CRPC4 | 2 | 3 | |

# Color Consistency vs Device-based 95$^{th}$ percentile $\Delta E_{00}$



# Study milestones

- Characterize printing conditions variations and develop ICC profiles – September – October 2017
- Produce experimental image sets - November 2017
- Run pilot experiments - December 2017
- Finalize testing methodology and conduct main experiment- January - February 2018
- Analyze experimental data – February - March 2018
- Present results - March -April 2018
- Submit paper – April-May 2018