

# The Effect of Gray Balance and Tone Reproduction on Consistent Color Appearance

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Elena Federovskaya and Bob Chung, RIT

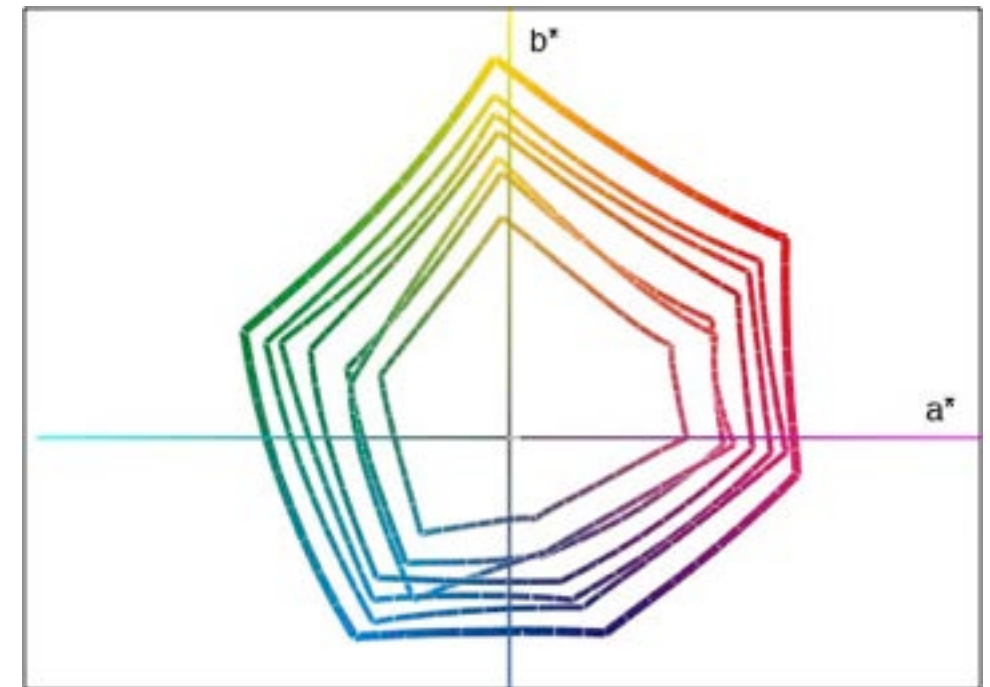
# Introduction

- CMYK image files, when output to ISO 15339-2 CRPCs, are said to have consistent or common color appearance (CCA) despite their colorimetric differences in white point and gamut volume.
- CIE Division 8 (Image Technology) proposed the study of “Consistent Color Appearance (CCA)” in 2016.
- This project explores the effect of gray balance and tone reproduction as underlying criteria of consistent color appearance.

# Theoretical Basis

- ISO 15339-2 CRPCs

| CRPC | CRPC name    |
|------|--------------|
| 1    | ColdsetNews  |
| 2    | HeatsetNews  |
| 3    | PremUncoated |
| 4    | SuperCal     |
| 5    | PubCoated    |
| 6    | PremCoated   |
| 7    | Extra Large  |



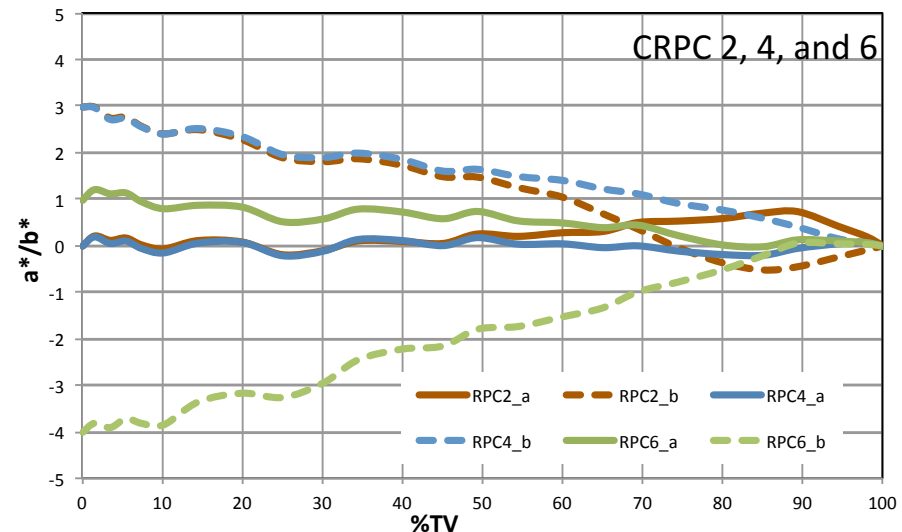
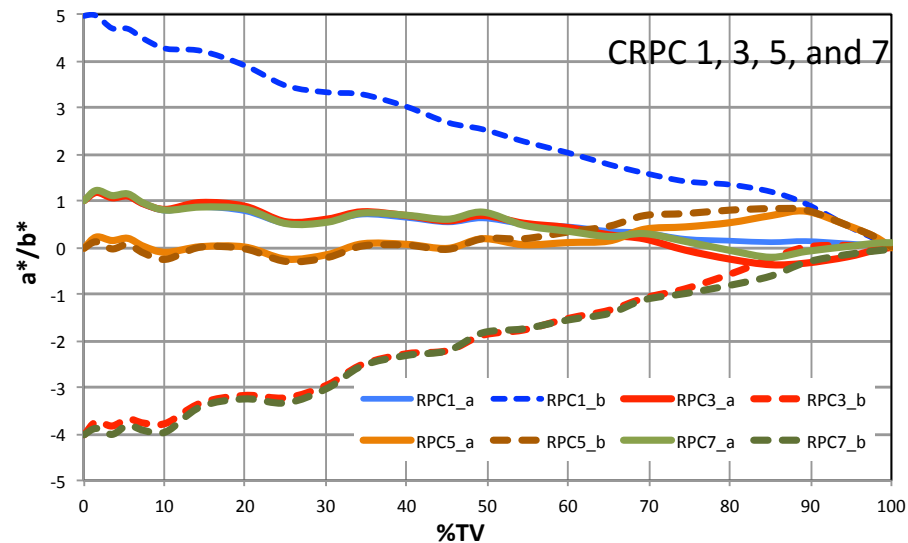
# Theoretical Basis

- Gamut volume comparison of CRPCs in ColorThink Pro3

| 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  |    |    |              |                    |

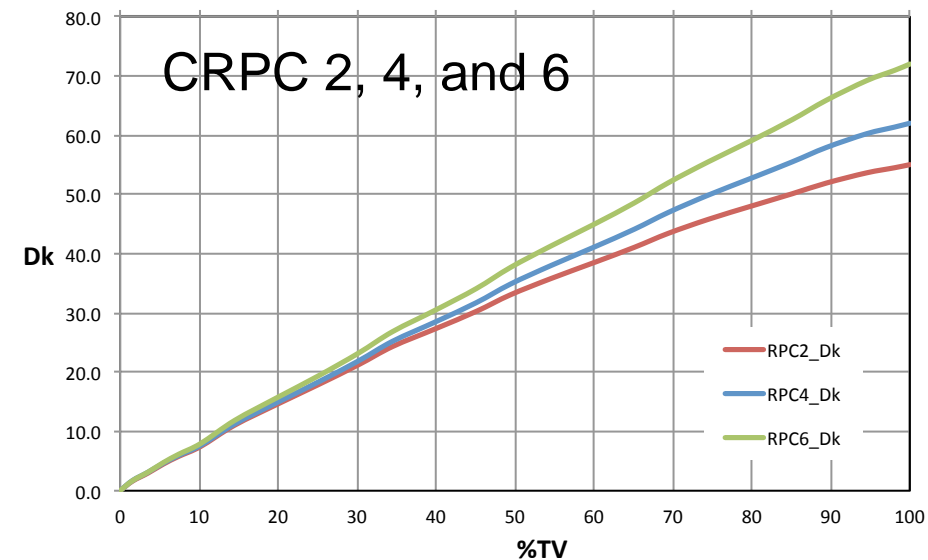
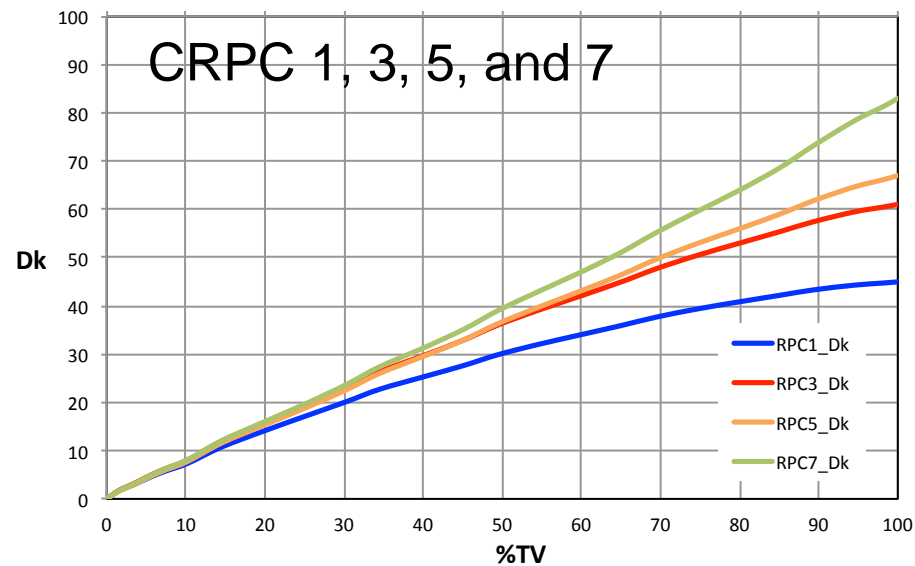
# Theoretical Basis

- Grey reproduction ramps pre-defined CMY triplets are plotted with  $a^*$  ramps as solid lines and  $b^*$  ramps as dotted lines in the same color for each CRPC.
- All CRPCs show similar converging patterns.



# Theoretical Basis

- Tone reproduction curve (TRC) can be expressed by plotting Darkness ( $100 - L^*$ ) vs %TV of the cyan.
- All CRPCs show similar highlight-to-midtone TRC.



# Pictorial Simulation of CRPC1~CRPC7 (Chung)





# Pictorial Simulation of CRPC1~CRPC7 (Hutcheson)



1 2 3 4 5 6 7



# Significance of ISO 15339-2 CRPCs

- Enable device calibration and “printing by numbers”
  - There is always a suitable CRPC to calibrate the output device to.
- Simplify prepress
  - Color images, separated for one of the CRPCs, can be printed in other CRPC calibrated printing conditions and preserving consistent color appearance.

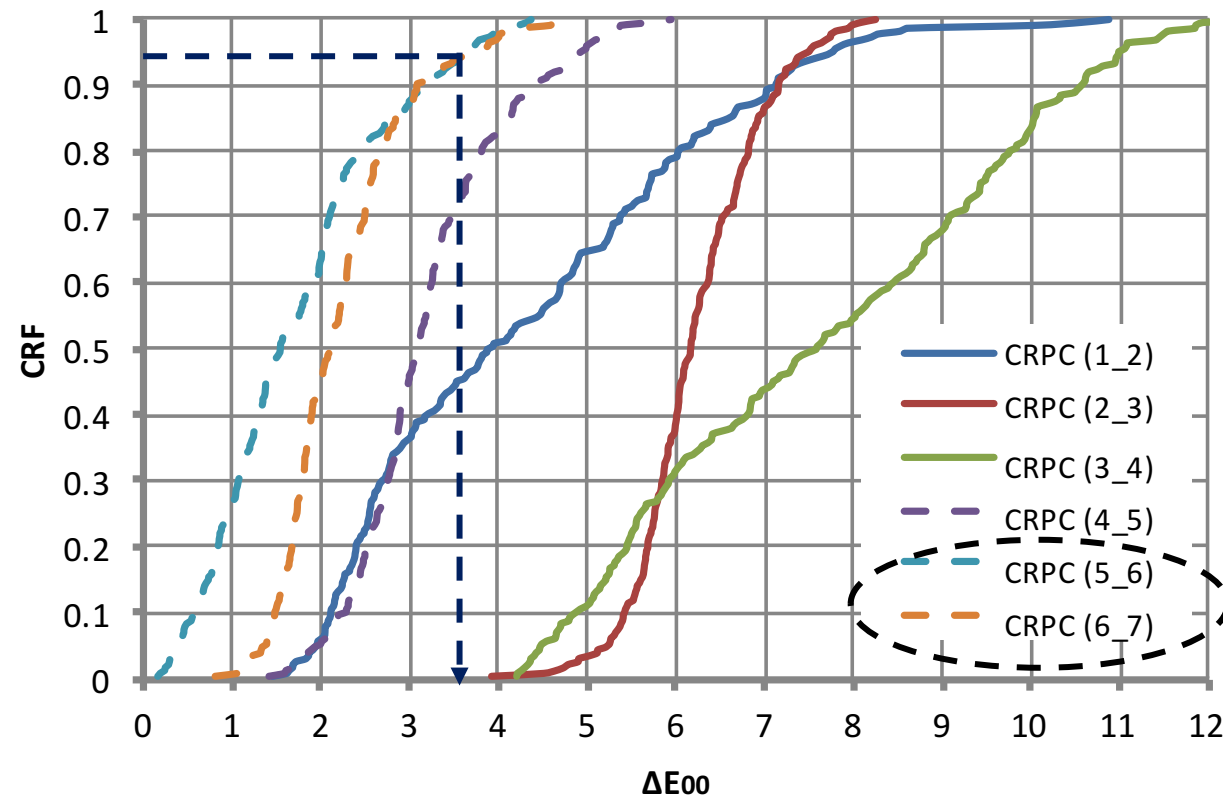
# Problem Statement and Research Question

- One problem
  - There is no rigorous study that gray balance and tone reproduction are indicative of consistent color appearance.
- One research question
  - How to devise a psychometric experiment, using standard CMYK test images and minimum ISO 15339-2 CRPC datasets, to show that gray balance and tone reproduction are underlying criteria of consistent color appearance?

Note: To study consistent color appearance, the minimum number of datasets is "3" where the color differences between the two adjacent datasets are the same.

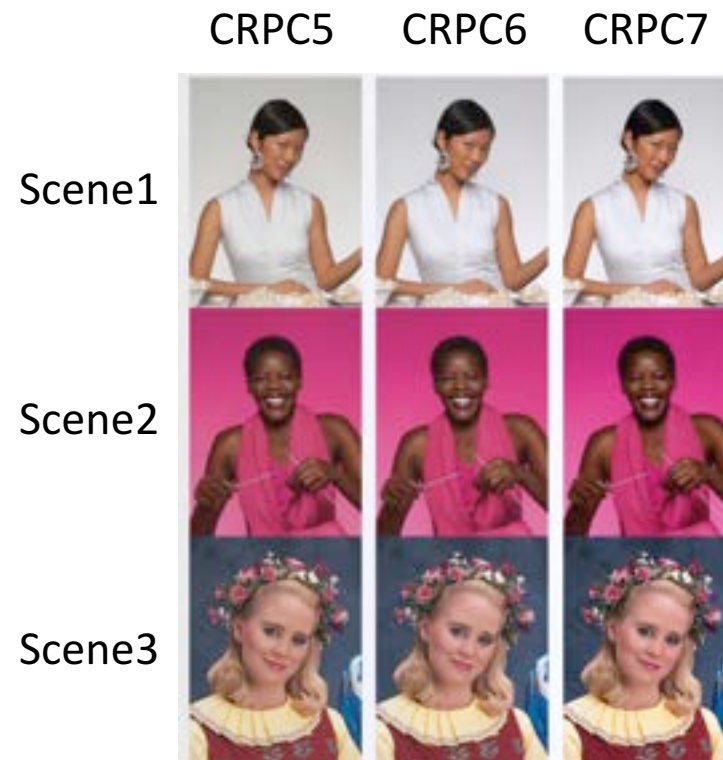
# Experimental Procedures

1. CRPC5, 6, and 7 are chosen because the 95th percentile CRF  $\Delta E_{00}$  colorimetric differences between CRPC6 and the two adjacent CRPCs (outer gamut) are similar.



# Experimental Procedures

2. Prepare test images in CRPC5, 6, and 7 conditions to depict consistent color appearance.



# Experimental Procedures

3. Adjust gray balance and tonal reproduction of CRPC6 test images, including the IT8.7/4 target and the P2P25 target, such that 95th percentile  $\Delta E_{00}$  between the CRPC6 and altered-CRPC6 datasets is the same as the 95th percentile  $\Delta E_{00}$  between adjacent CRPC datasets.

| Adjustment      | Amount                        | Ave $w\Delta Ch$<br>(Tol. 1.5) | Max $w\Delta Ch$<br>(Tol. 3.0) | Ave $w\Delta L^*$<br>(Tol. 1.5) | $\Delta E_{00}$ (95 <sup>th</sup> )<br>(Tol. 4.5) |
|-----------------|-------------------------------|--------------------------------|--------------------------------|---------------------------------|---|
| GB1             | C+20                          | 1.9                            | 3.2                            | 0.2                             | 2.6   |
| <b>GB2</b>      | <b>M+20; Y-20</b>             | <b>2.9</b>                     | <b>5.2</b>                     | <b>0.8</b>                      | <b>4.5</b>  |
| TRC1            | Mid+5                         | 0.2                            | 0.4                            | 1.6                             | 3.7   |
| <b>TRC2</b>     | <b>Mid+10</b>                 | 0.3                            | 0.6                            | <b>3.5</b>                      | 7.5   |
| <b>GB2+TRC2</b> | <b>M+20; Y-20;<br/>Mid+10</b> | <b>3.2</b>                     | 6.2                            | <b>2.8</b>                      | 7.3   |

# Experimental Procedures

4. Conduct psychometric experiments by asking, “which pictorial image of the same scene looks more different than the other three,” due to altered gray balance and tone reproduction characteristics?

CRPC7



CRPC5



CRPC6

CRPC6  
altered



# Experimental Procedures

5. We can also test “which pictorial scene looks more different than the other three scenes?” due to altered gray balance and tone reproduction characteristics of a particular CMYK image.

Note: We'll need more than three pictorial scenes to accomplish this objective.