CCA RIT Team first experiment summary

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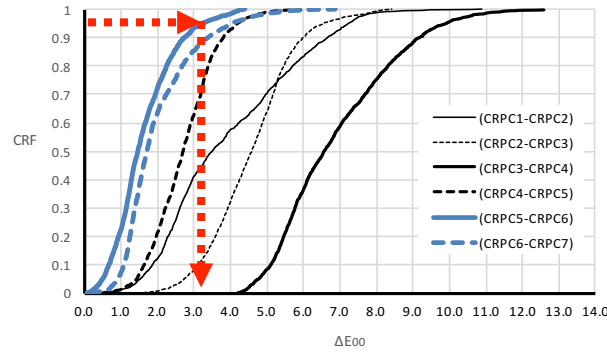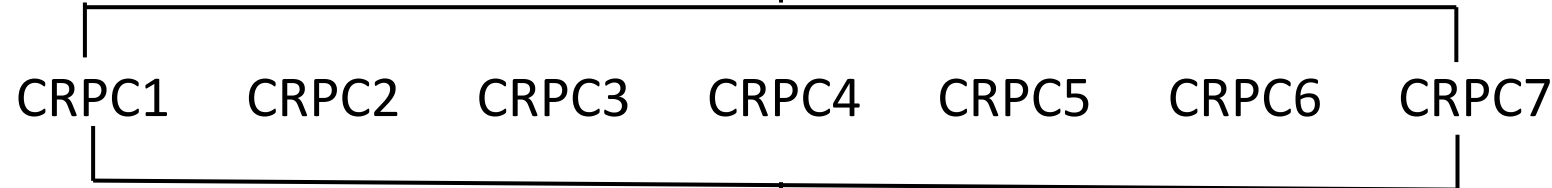
Don's hasty update, November 13, 2018

Introduction

- RIT research prompted by the seven datasets in ISO/PAS 15339-2. These CRPCs exhibit consistent color appearance but the statement lacks scientific verification.

CRPC1~CRPC7

CMYK (Pictorial, ISO 12642-2)

CRPC1   CRPC2   CRPC3   CRPC4   CRPC5   CRPC6   CRPC7

CRPC 1, 3, 5, and 7

- Different substrates and C*
- Same CMYRGB hue angles
- Same tone reproduction
- Same gray balance
- Color differences between adjacent printing conditions are unequal.
- CCA was mentioned, but not verified.

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

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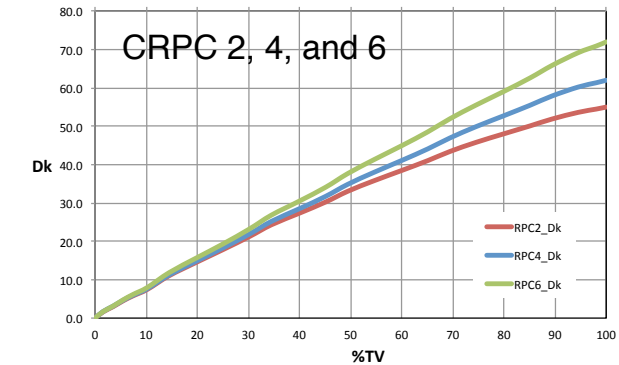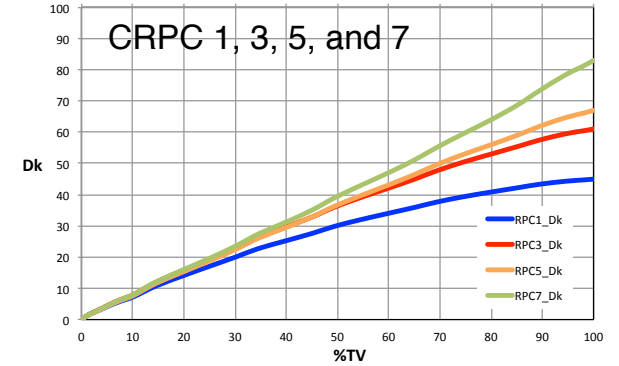
CRPC	CRPC name
1	ColdsetNews
2	HeatsetNews
3	PremUncoated
4	SuperCal
5	PubCoated
6	PremCoated
7	Extra Large

CRPC 1, 3, 5, and 7

CRPC 2, 4, and 6
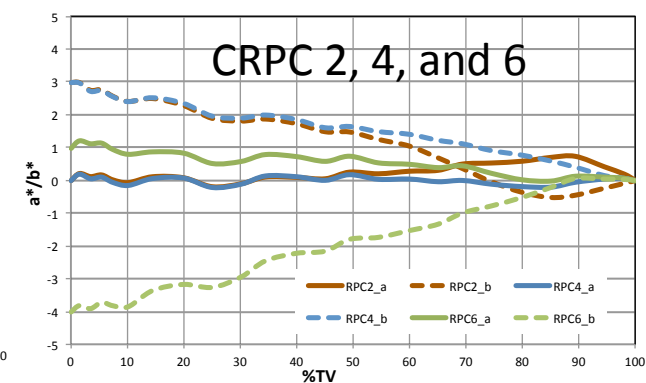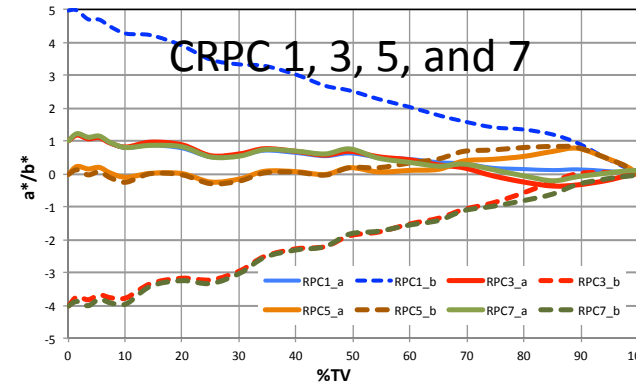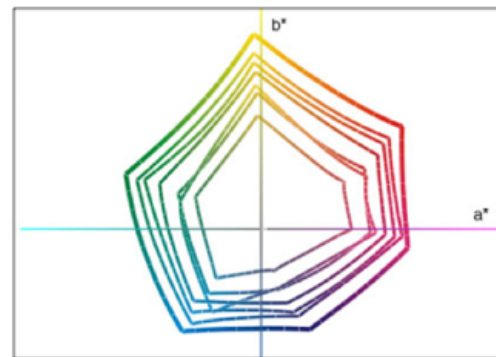
Objectives

- Test the hypothesis that CCA depends on multiple datasets with varying gamut volumes, while having consistent tonality, gray balance and hues relative to substrate.

- Examine the suitability of the 95th percentile ΔE_{00} as a CCA metric

  - 3 ΔE_{00} (95th percentile ΔE_{00}) color difference between adjacent datasets in the Control and the Experimental groups.

Experimental — Sample Preparation

- Use CRPC5 as a starting point to create 7 datasets differing in chroma and gamut volume by 3 ΔE_{00} at 95% pctl. (Control group).

- Create systematically distorted datasets in terms of

  - gray balance

  - tone reproduction

  - chroma (gamut)

- Differences 3 ΔE_{00} at 95% pctl. (Experimental group).

Control Group
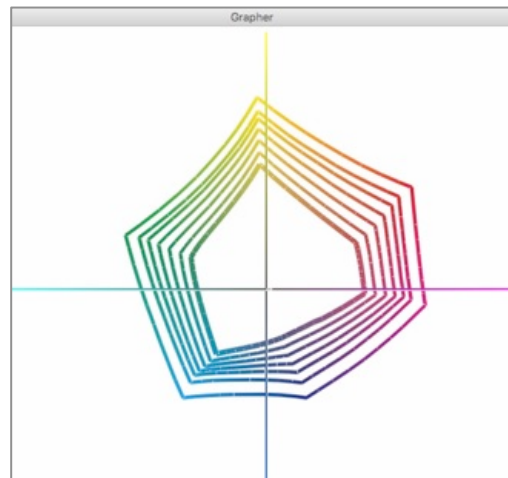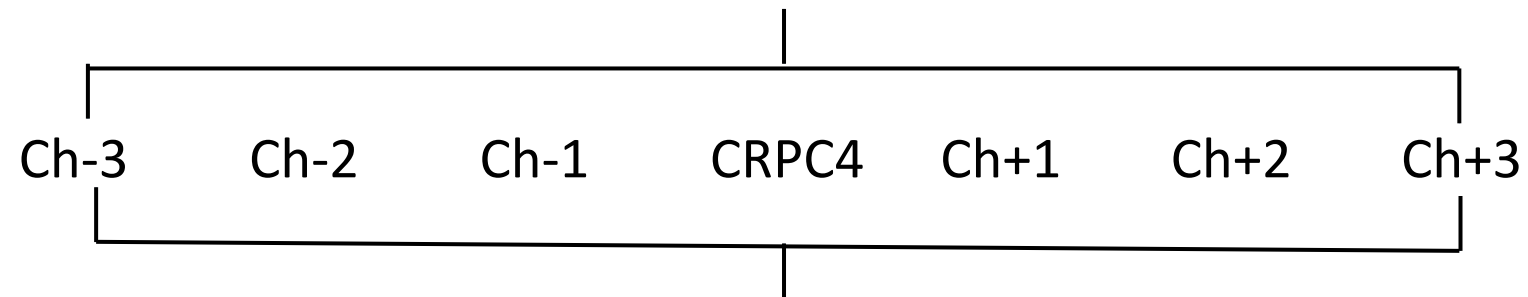
- Replace CRPC1~CRPC7 in psychometric testing

CMYK (Pictorial, ISO 12642-2)
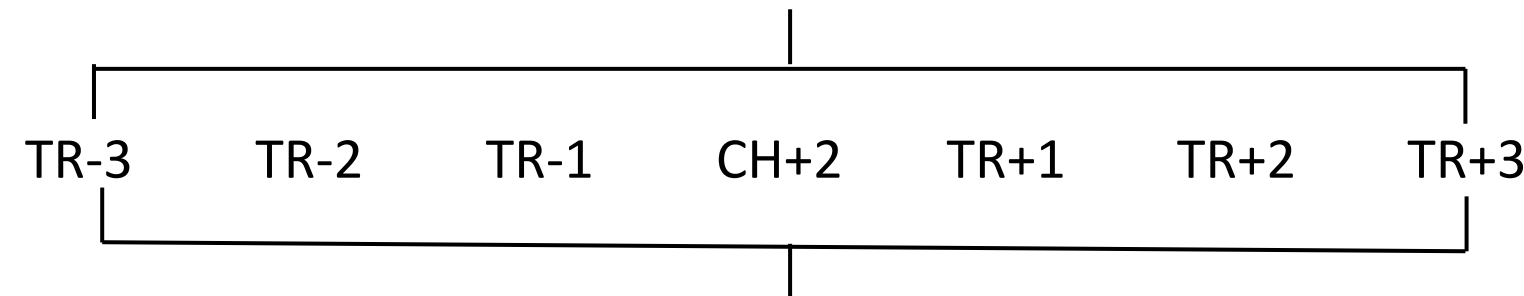
Ch-3   Ch-2   Ch-1   CRPC4   Ch+1   Ch+2   Ch+3

- Different C* and gamut
- Same CMYRGB hue angles
- Same tone reproduction
- Same gray balance
- Color differences between adjacent printing conditions are equal.

95th ΔE₀₀	-3d_G7	-2d_G7	-1d_G7	0d_G7	+1d_G7	+2d_G7	+3d_G7
-3d_G7	-----						
-2d_G7	3.1	-----					
-1d_G7	6.2	3.1	-----				
0d_G7	9.2	6.2	3.1	-----			
+1d_G7	12.3	9.3	6.2	3.1	-----		
+2d_G7	15.2	12.2	9.2	6.2	3.1	-----	
+3d_G7	16.8	13.8	10.8	7.9	5.5	3.0	-----

Experimental Groups

CMYK (Pictorial, ISO 12642-2)

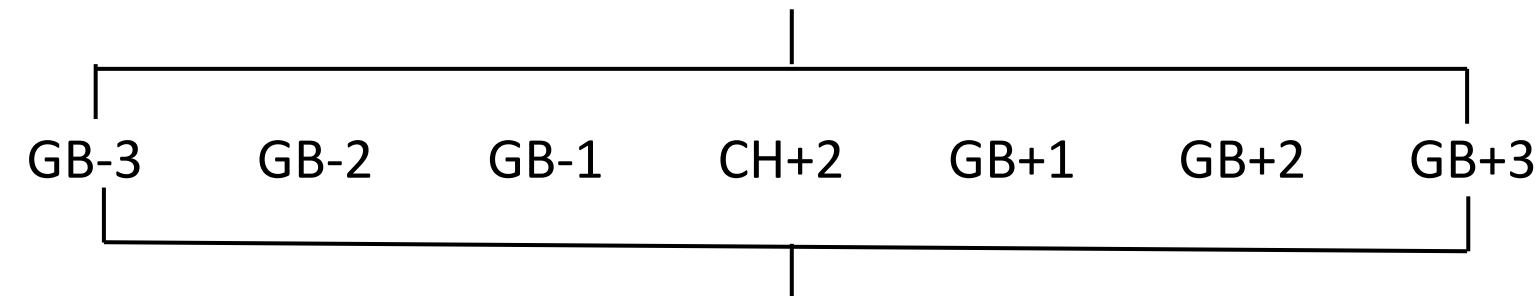| TR-3	TR-2	TR-1	CH+2	TR+1	TR+2	TR+3

- Same C* and gamut
- Same CMYRGB hue angles
- Different tone reproduction
- Same gray balance
- Color differences between adjacent printing conditions are equal.

95th ΔE00	-3TVI	-2TVI	-1TVI	0	+1TVI	+2TVI	+3TVI
-3TVI	-----						
-2TVI	3.0	-----					
-1TVI	6.1	3.0	-----				
0	9.0	5.9	3.0	-----			
+1TVI	12.0	8.9	6.0	3.0	-----		
+2TVI	14.9	11.9	8.9	6.0	3.0	-----	
+3TVI	17.7	14.9	11.9	9.0	6.0	3.0	-----

CMYK (Pictorial, ISO 12642-2)

| GB-3	GB-2	GB-1	CH+2	GB+1	GB+2	GB+3

- Same C* and gamut
- Same CMYRGB hue angles
- Same tone reproduction
- Different gray balance
- Color differences between adjacent printing conditions are equal.

| 95th ΔE00	3Y	2Y	1Y	0	1B	2B	3B
3Y	-----						
2Y	3.0	-----					
1Y	6.1	3.0	-----				
0	9.1	6.1	3.0	-----			
1B	12.2	9.1	6.1	3.0	-----		
2B	15.2	12.1	9.1	6.1	3.0	-----	
3B	18.1	15.1	12.1	9.1	6.0	3.0	-----

Grapher

Experimental — Sample Verification

- Verify all dataset and profiles (Annex C)

- Apply profiles to test images and output hard copy, per flow chart.

- Measure hard copies of the Idealliance 12647-7 digital control strip (84 patches) and calculate the 95th percentile ΔE_{00} between adjacent datasets.
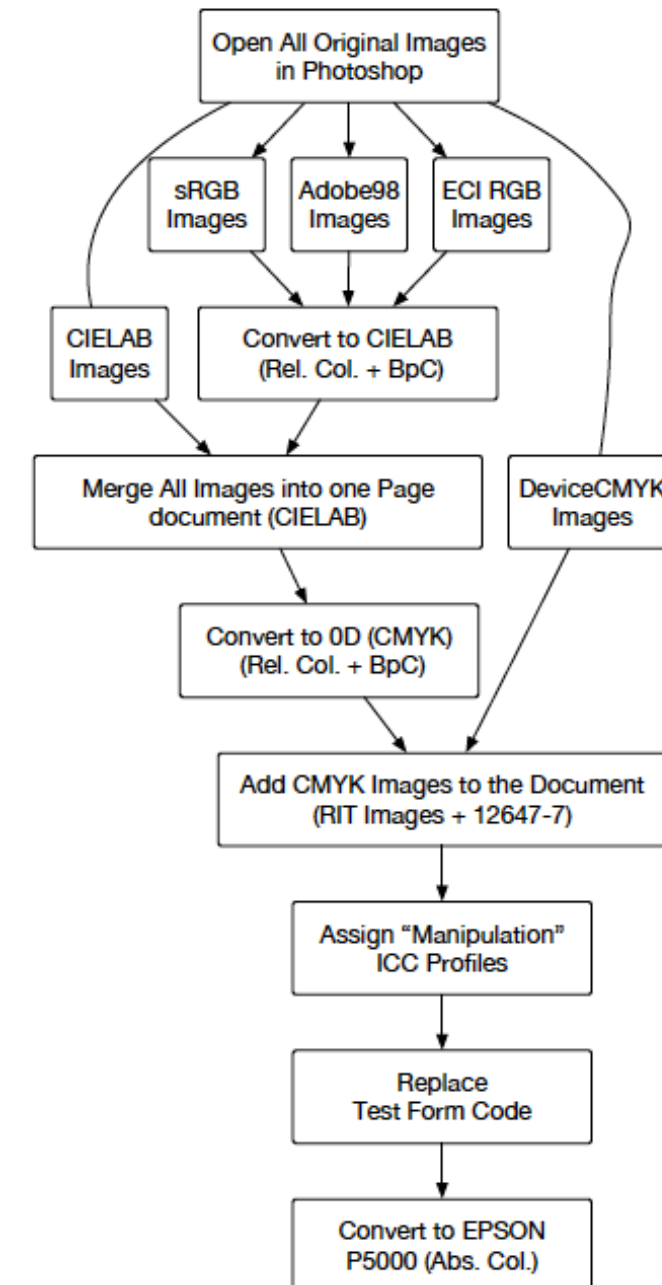
Experimental — Psychometric Testing 1

- There is a 'hole' in the Control group. Rank the candidate images that exhibit (from the most to the least) consistent color appearance in relation to the Control group.
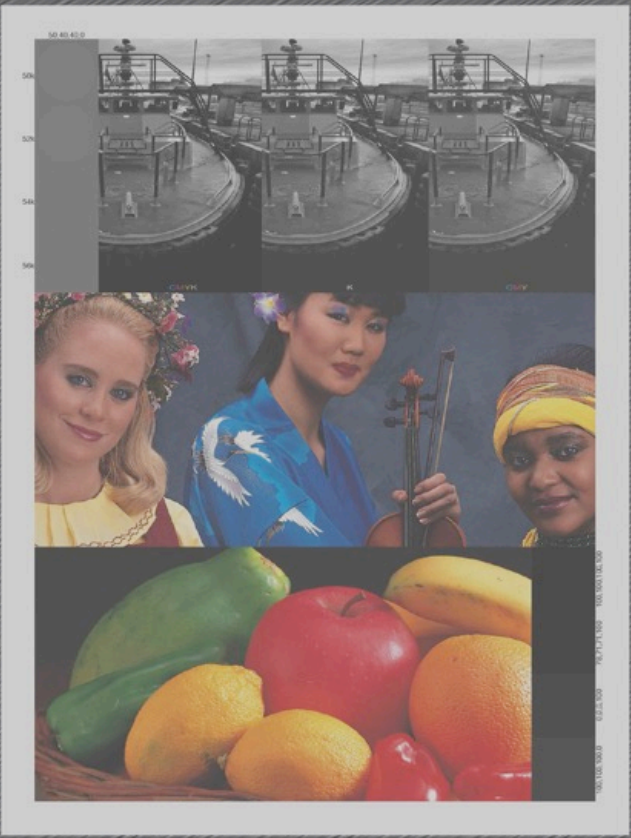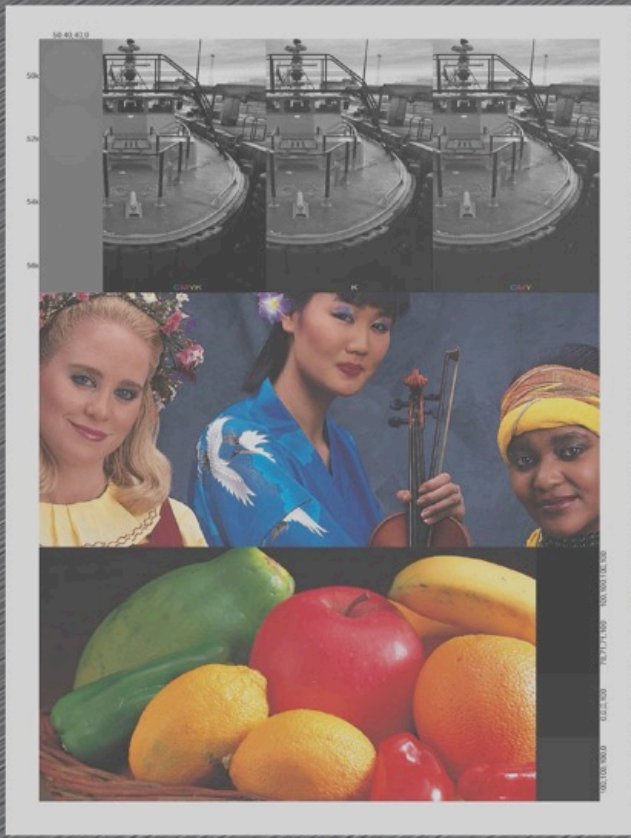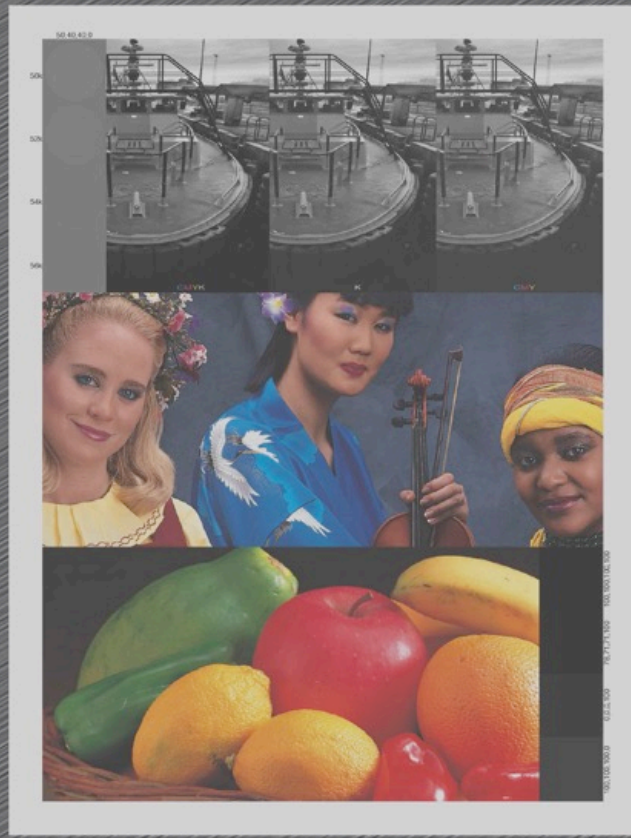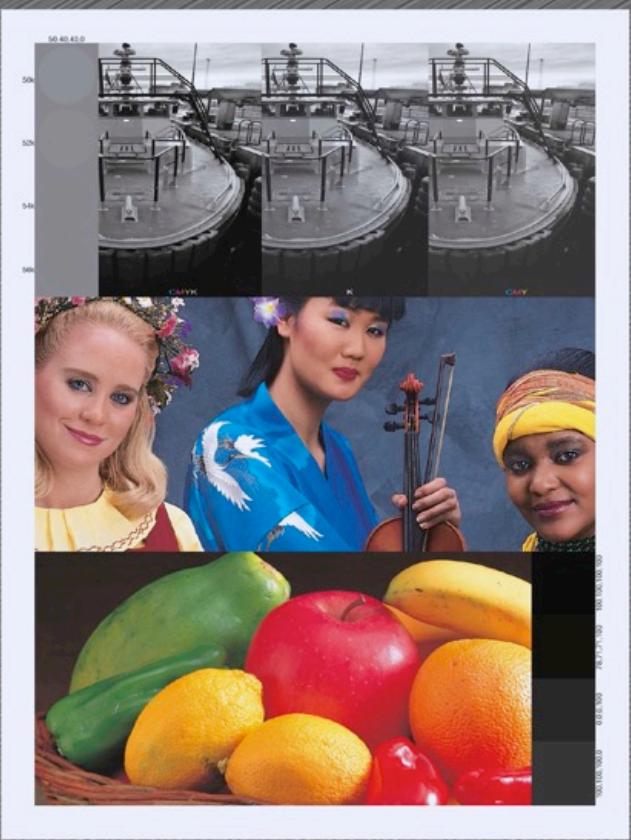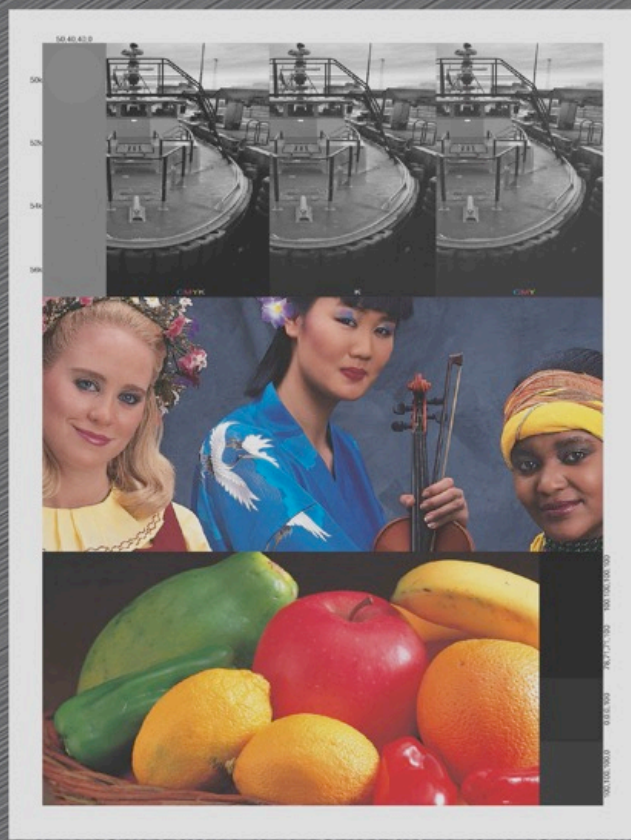

Control group
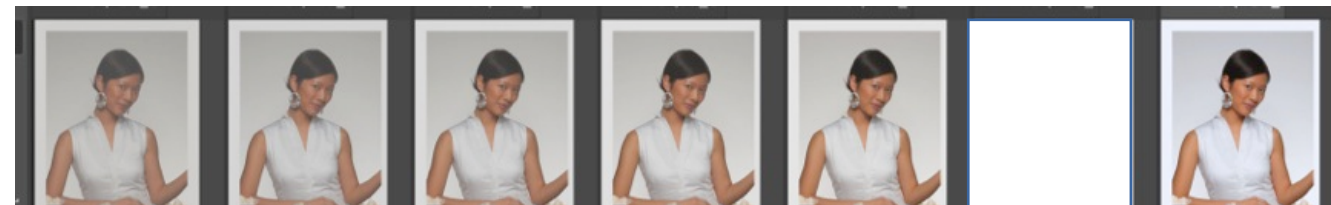
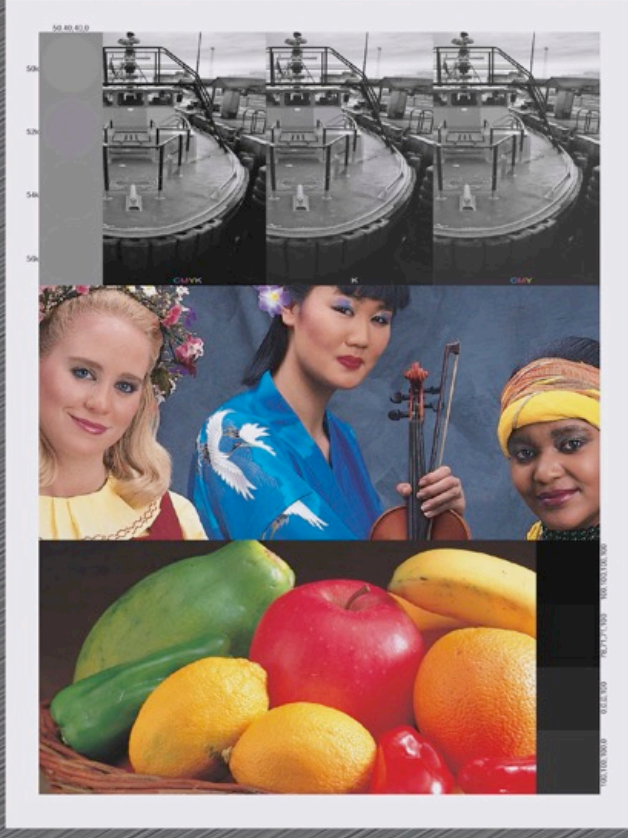Candidate Images
(randomized)

Visual Variation Between Datasets

- The next five slides visualize the seven basic datasets, and the distorted datasets (TVI, Contrast, Gray balance, Chroma)

- Each dataset in each group differs from it's neighbour by $3\Delta E_{00}$ 95th pctl.

- The left image is a nominal reference

7 datasets

TVI
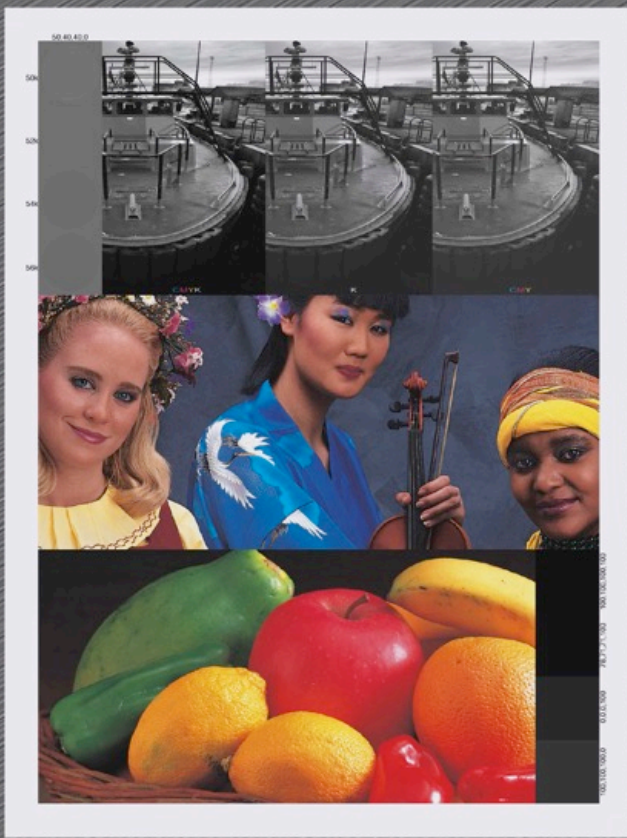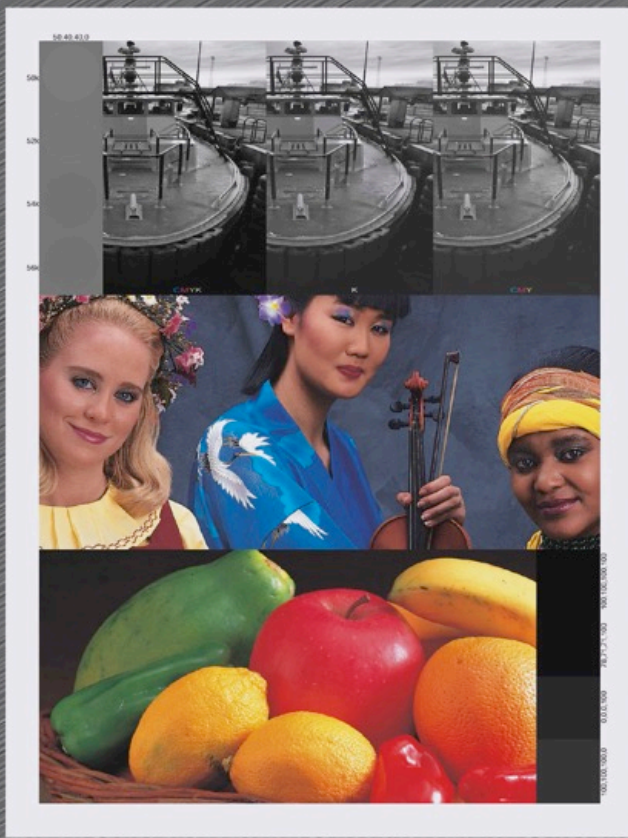
S-curve

Graybal

Chroma
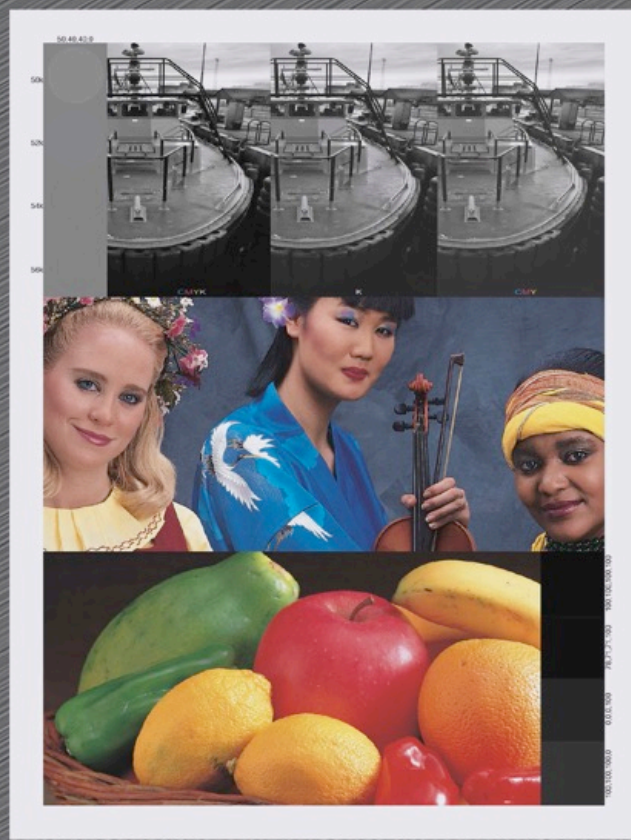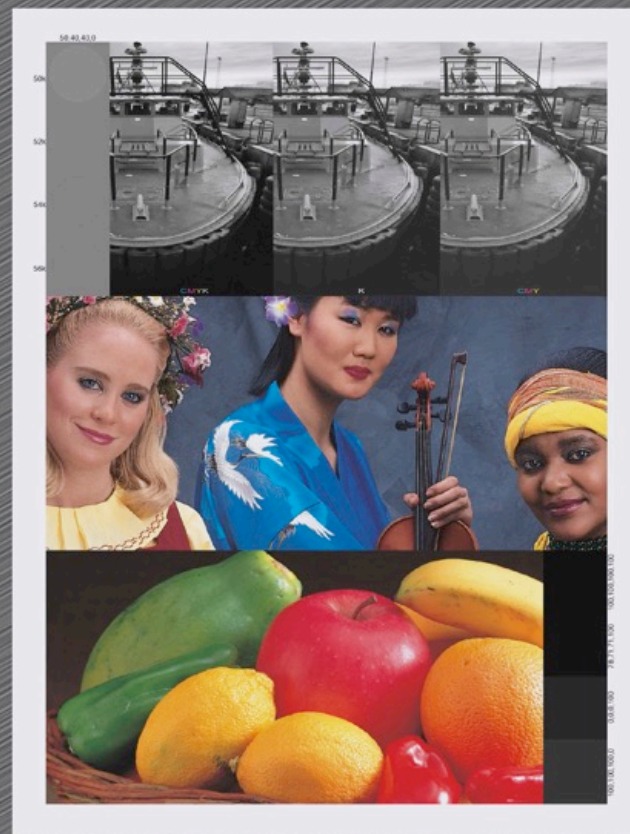
Experimental — Psychometric Testing 2

Which set in pair has higher consistency of color appearance?
Provide rating 1- excellent, 2- good, 3 –fair, 4 – poor, 5 -unacceptable

or

or

Results — Sample Verification

- Visual simulation meets expectations.

- The average 95th percentile color difference between adjacent datasets in the Control group is 3.1 ΔE_{00}.

- The average 95th percentile color difference between adjacent datasets in the Experimental group is 3.0 ΔE_{00}.

- The average 95th percentile ΔE_{00} between the Control dataset (2d_G7) and gray balance distorted group is 3 ΔE_{00}, 6 ΔE_{00}, or 9 ΔE_{00}.

Results — Visual Simulation

- ## Control group vs. CRPC1~CRPC7

  7 new datasets from CRPC5 by scaling white point, black point and chroma with constant primary hue angles, G7 tonality and gray balance, with the 95th percentile ΔE_{00} between any two adjacent datasets = 3

Visual simulation of the Control group
(-3d~3d)
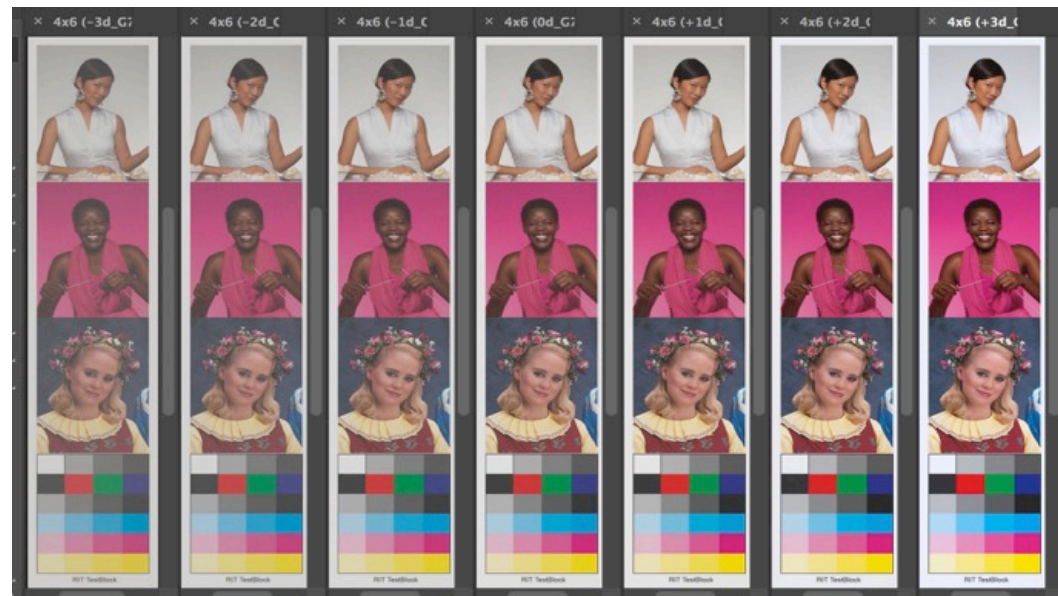
Visual simulation of the CRPCs
(CRPC1~CRPC7)
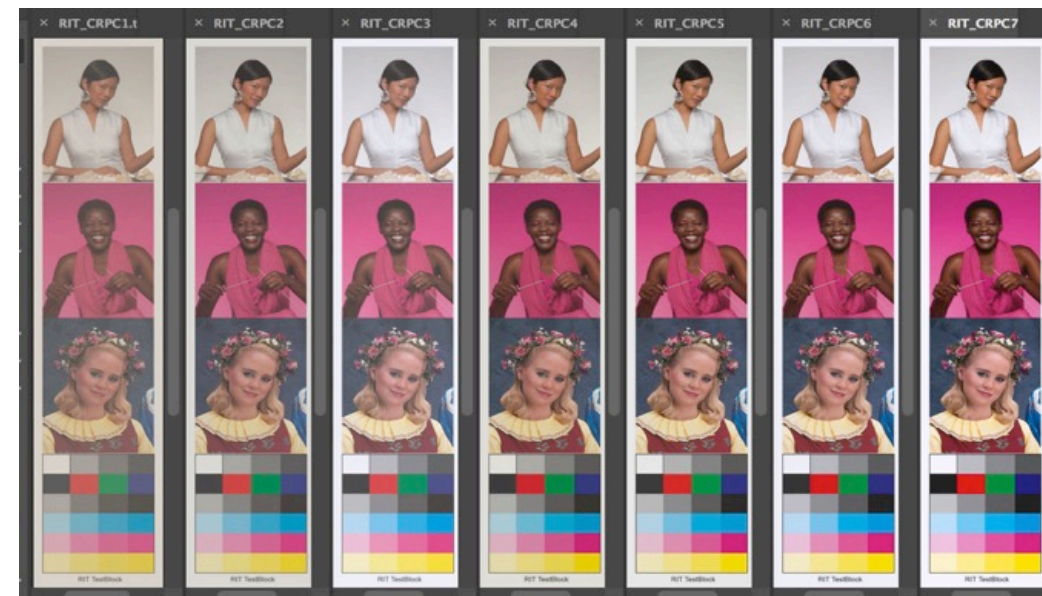
Results — Visual Simulation

- Experimental group (tonal curve shape vs. TVI)

  12 datasets varying in tonality (3 lighter, 3 darker, 3 lower contrast, 3 higher contrast) and 18 datasets with gray balance (3 each +CMYRGB) variations from one reference control dataset, with 3 95th percentile ΔE_{00} between any two adjacent datasets.

  - Visual simulation of the Experimental group (S-3 to S+3)

  - Visual simulation of the Experimental group (TVI-3 to TVI+3)

Results — Visual Simulation

- Experimental group (gray balance in complementary hue angles)

- Visual simulation of the Experimental group (GB_C-R)

- Visual simulation of the Experimental group (GB_Y-B)
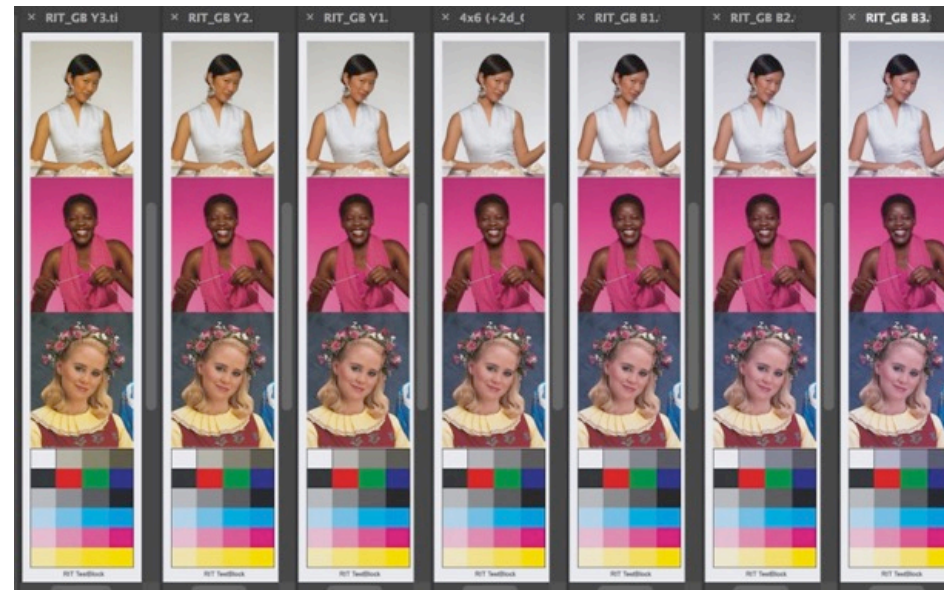
- Visual simulation of the Experimental group (GB_M-G)

Results — Analysis of the Experimental Group

- 2d vs. GB_C1 (B1, G1, M1, R1, Y1 are omitted.)
  - 95th percentile CRF: 3.1 ΔE_{00}

Results — Analysis of the Experimental Group

- 2d vs. GB_C2 (B2, G2, M2, R2, Y2 are omitted.)
  - 95th percentile CRF: 6.1 ΔE_{00}
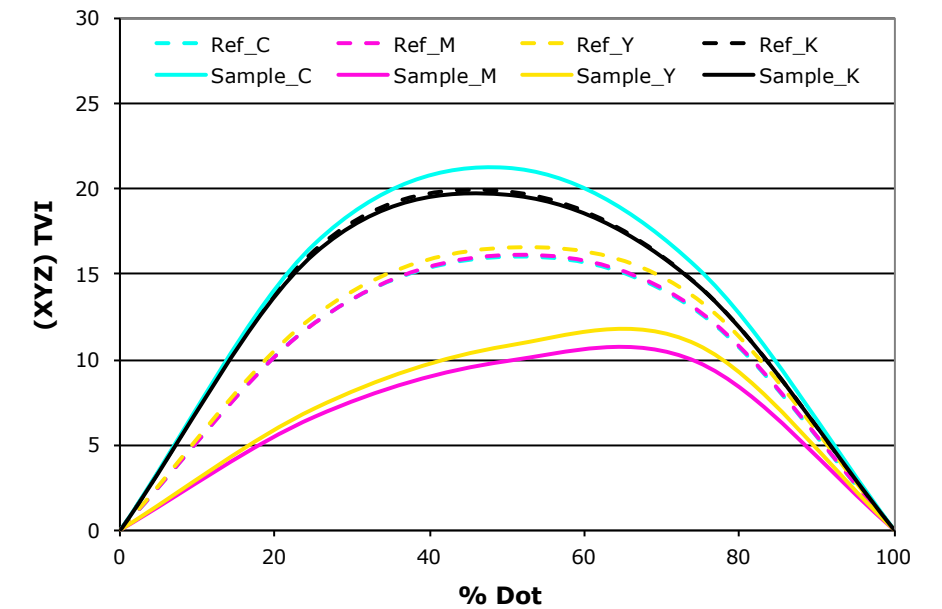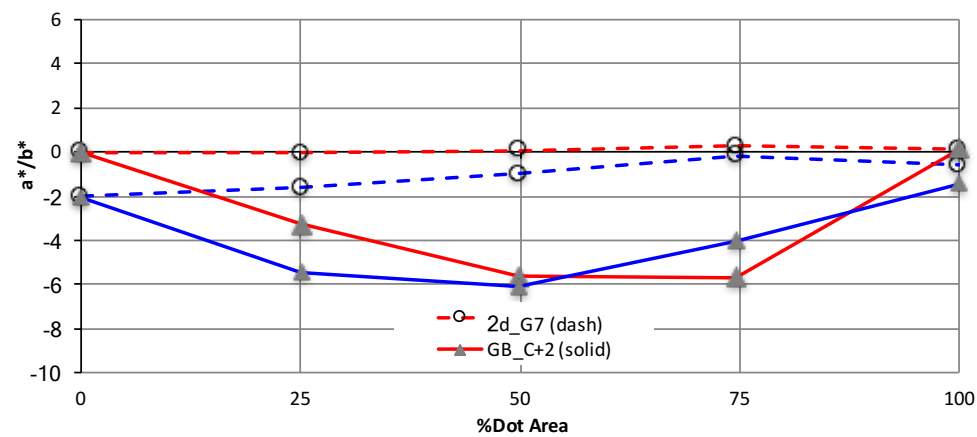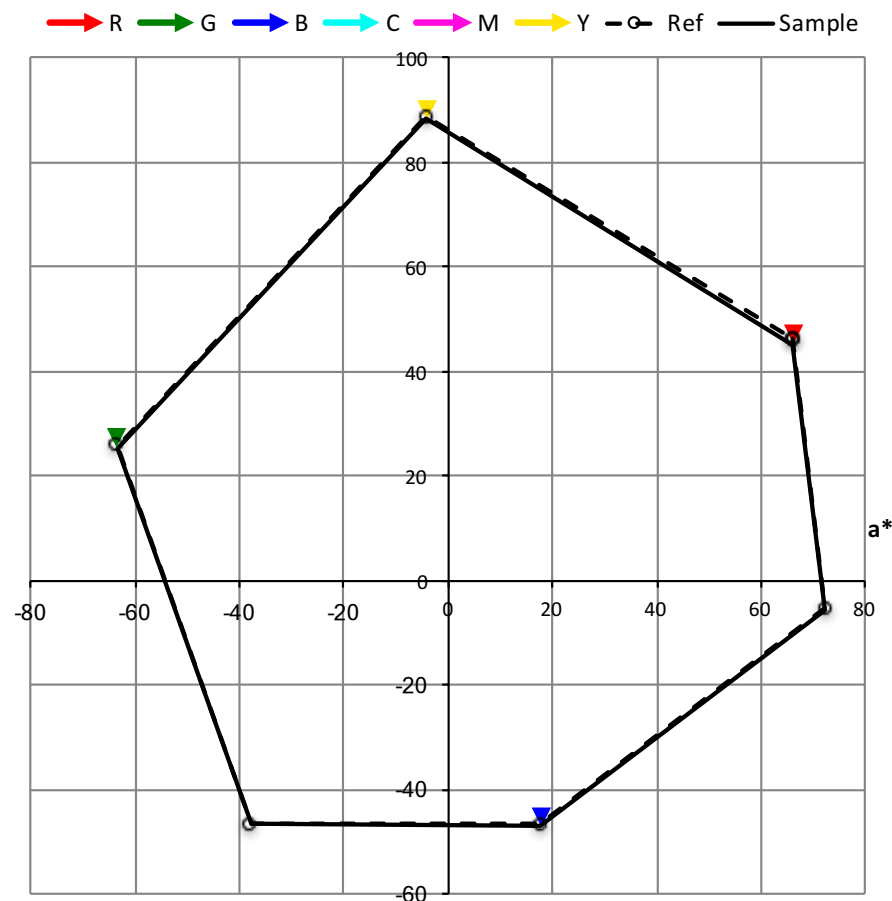
Results — Analysis of the Experimental Group

- 2d vs. S+1 (S-3, S-2, S-1, S+2, S+3 are omitted.)
  - 95th percentile CRF: 3.0 ΔE_{00}
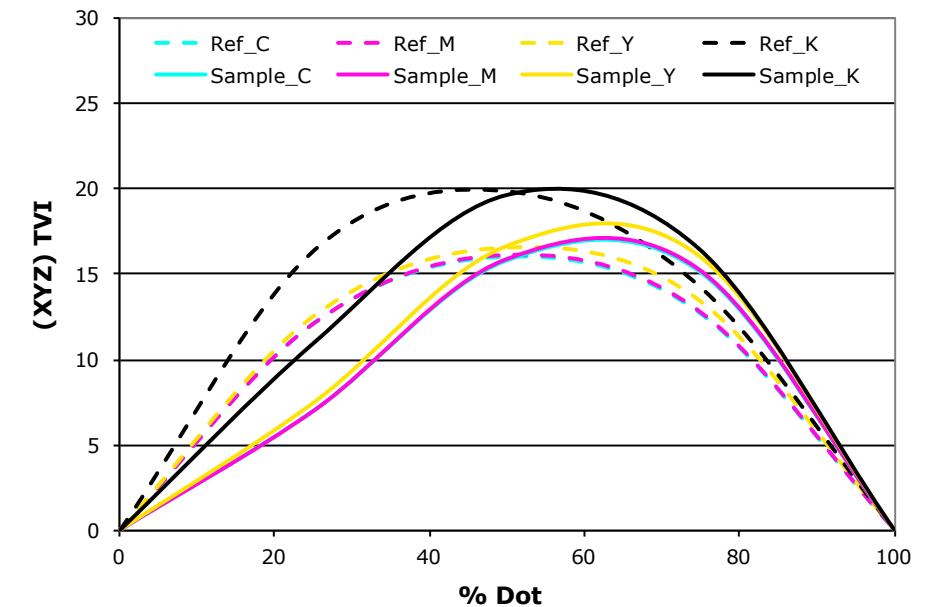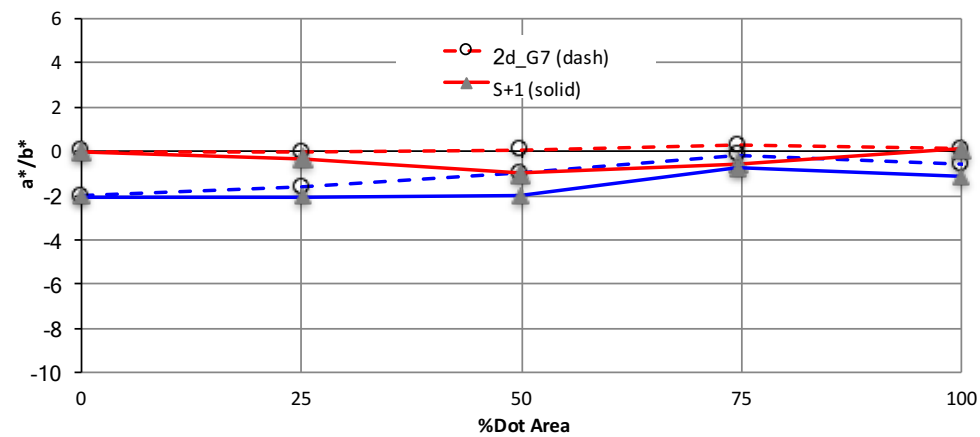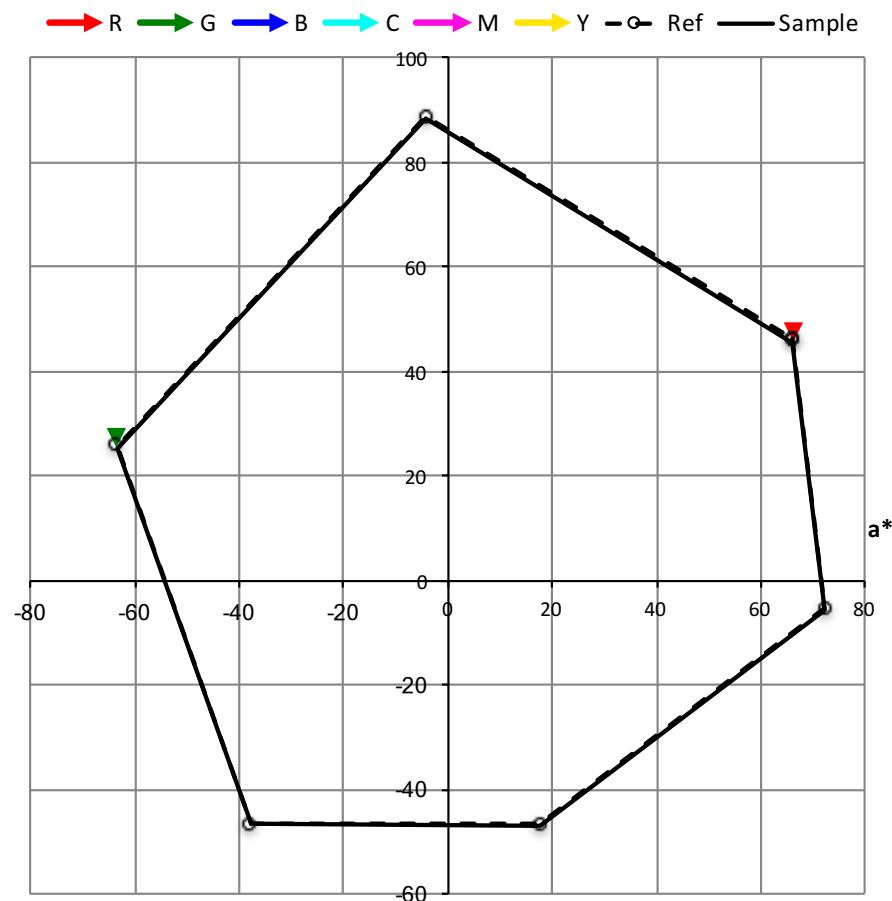
Results —95th ΔE_{00} of Adjacent Datasets

- Experimental datasets (GB_3Y~3B)
  - '0' represents '+2d_G7'

95th ΔE_{00}	3Y	2Y	1Y	0	1B	2B	3B
3Y	-----						
2Y	3.0	-----					
1Y	6.1	3.0	-----				
0	9.1	6.1	3.0	-----			
1B	12.2	9.1	6.1	3.0	-----		
2B	15.2	12.1	9.1	6.1	3.0	-----	
3B	18.1	15.1	12.1	9.1	6.0	3.0	-----

- Experimental datasets (-3TVI ~ +3TVI)
  - '0' represents '+2d_G7'

95th ΔE_{00}	-3TVI	-2TVI	-1TVI	0	+1TVI	+2TVI	+3TVI
-3TVI	-----						
-2TVI	3.0	-----					
-1TVI	6.1	3.0	-----				
0	9.0	5.9	3.0	-----			
+1TVI	12.0	8.9	6.0	3.0	-----		
+2TVI	14.9	11.9	8.9	6.0	3.0	-----	
+3TVI	17.7	14.9	11.9	9.0	6.0	3.0	-----

Results — Psychometric Testing

- Viewing booth (gti; ISO 3664-2009 compliant)

- 6 Sample sets

- 2 sessions

- 12 participants
  - 6 experts
  - 6 novices

Control set

Results — Psychometric Testing

1) Rank samples that fit in the image set for best CCA

2) Compare and rate sample sets for demonstrating CCA.

Results: CCA from ranking images for the best

corrected

image	relative CCA
Control G7 +2d	0.78
TVI-1d	0.02
GB R+1d	-0.06
GB B+1d	-0.17
S+1d	-0.25
S-1d	-0.25
GB G+1d	-0.27
GB C+1d	-0.32
TVI+1d	-0.36
GB Y+1d	-0.55
TVI-2d	-0.84
GB C+2d	-0.90
GB M+1d	-1.00
TVI+2d	-1.07
GB R+2d	-1.15
S-2d	-1.50
GB B+2d	-1.57
S+2d	-1.73
GB M+2d	-1.73
TVI-3d	-1.83
S-3d	-1.96
GB G+2d	-2.40

CCA based on ranking candidate images
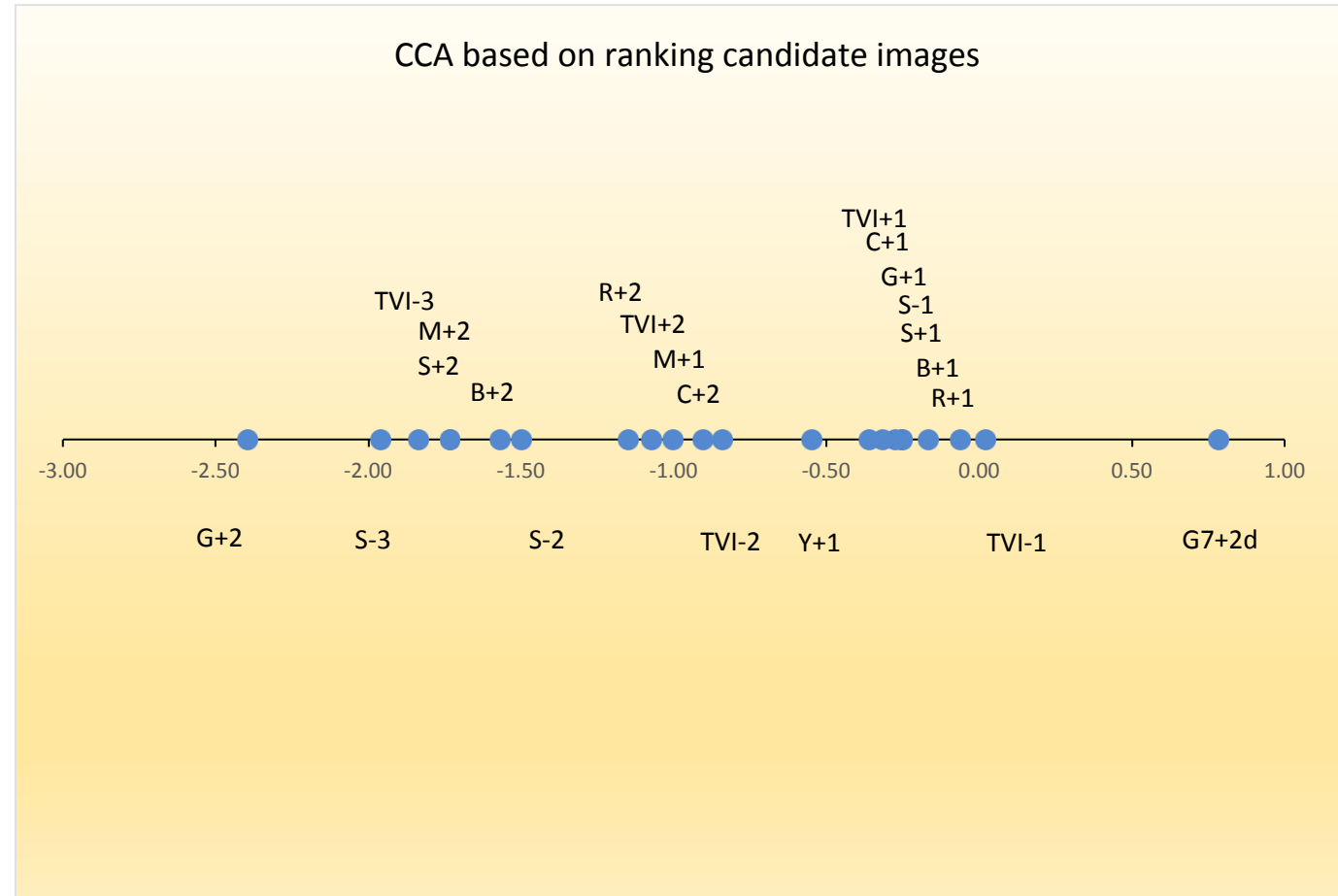
Color Consistency scale based on Thurstone's Law of Comparative Judgement, Case V (Thurstone, 1927)

Results: CCA vs measured adjacent 95% delta E00

image	relative CCA	adjacent 95%
Control G7 +2d	0.78	0.00
TVI-1d	0.02	4.12
GB R+1d	-0.06	4.69
GB B+1d	-0.17	5.38
S+1d	-0.25	3.89
S-1d	-0.25	5.47
GB G+1d	-0.27	5.21
GB C+1d	-0.32	2.87
TVI+1d	-0.36	4.77
GB Y+1d	-0.55	3.93
TVI-2d	-0.84	6.77
GB C+2d	-0.90	8.11
GB M+1d	-1.00	10.46
TVI+2d	-1.07	5.54
GB R+2d	-1.15	7.95
S-2d	-1.50	7.16
GB B+2d	-1.57	8.57
S+2d	-1.73	7.88
GB M+2d	-1.73	9.82
TVI-3d	-1.83	10.95
S-3d	-1.96	13.80
GB G+2d	-2.40	12.92

Relative CCA vs Adjacent 95% delta E 2000

$y = -3.7717x + 3.5494$
$R^2 = 0.8093$
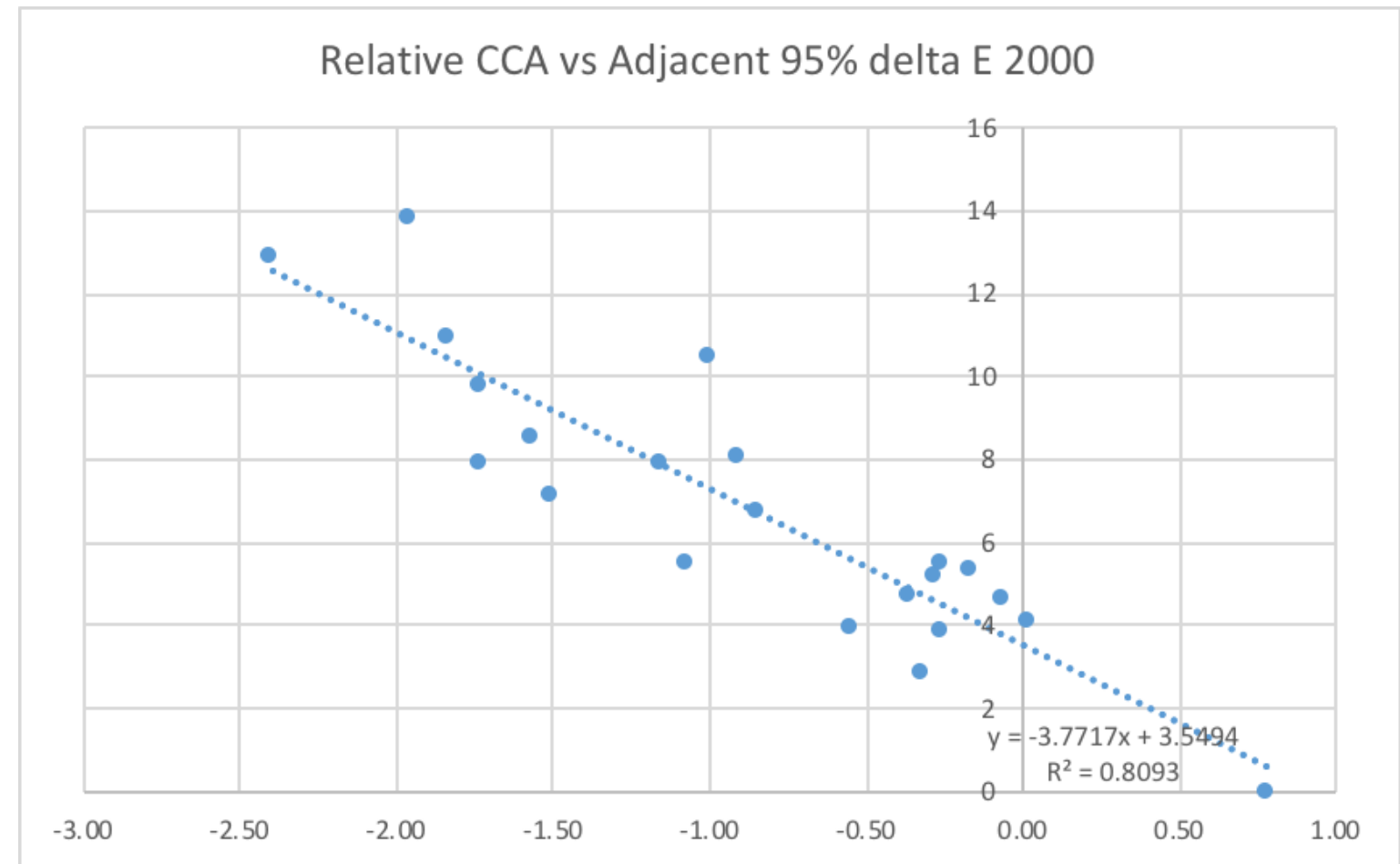
Results: Measured 95% delta E00 vs relative CCA

image	cummulative
Control G7 +2d	0.00
TVI-1d	4.12
GB R+1d	8.81
GB B+1d	14.19
S+1d	18.08
S-1d	23.55
GB G+1d	28.76
GB C+1d	31.63
TVI+1d	36.40
GB Y+1d	40.32
TVI-2d	47.09
GB C+2d	55.20
GB M+1d	65.65
TVI+2d	71.19
GB R+2d	79.15
S-2d	86.31
GB B+2d	94.87
S+2d	102.76
GB M+2d	112.58
TVI-3d	123.52
S-3d	137.32
GB G+2d	150.24

Relative CCA vs cummulative sum of measured adjacent 95% delta E00

$y = -0.0173x + 0.179$
$R^2 = 0.9539$
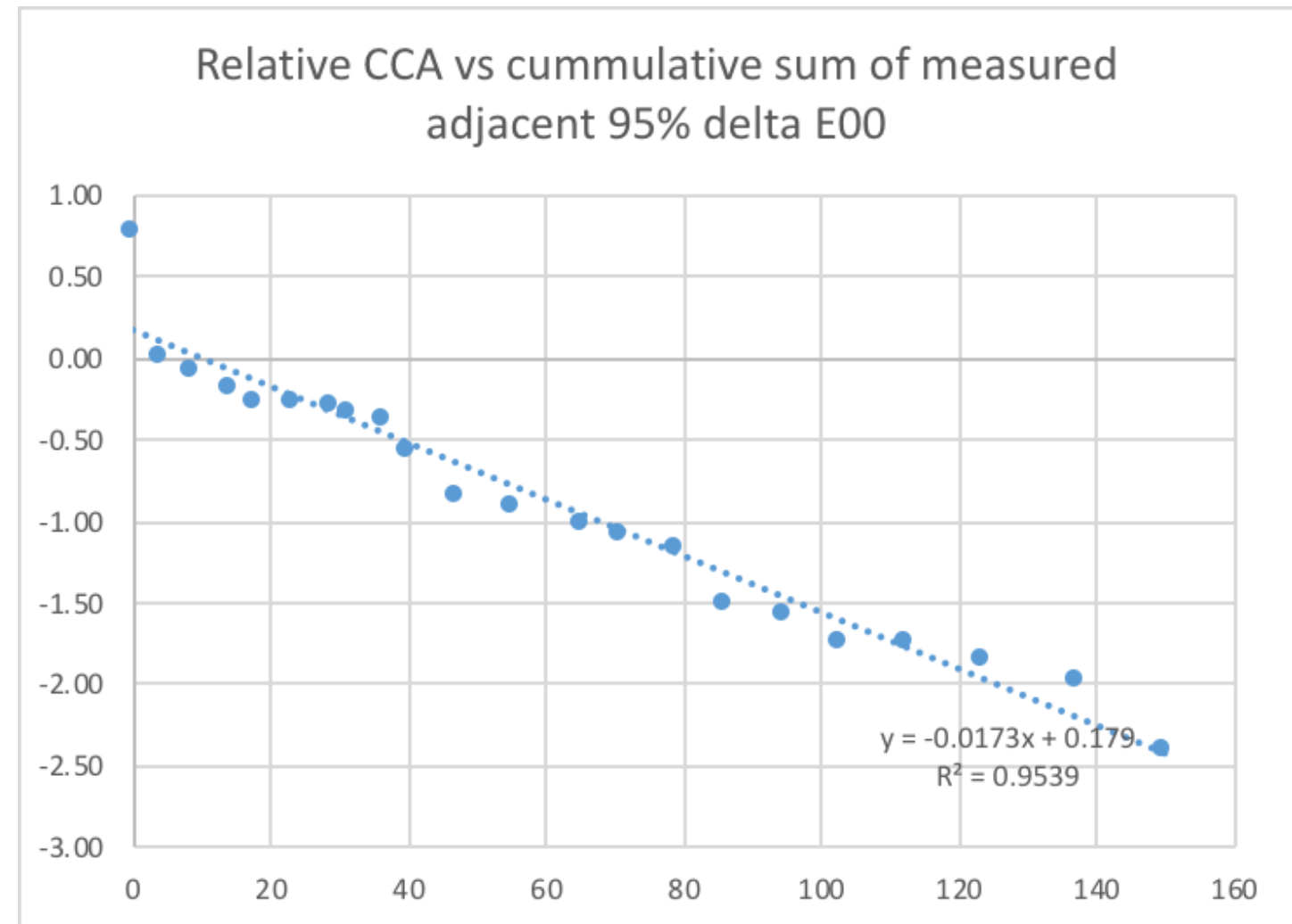
Results: Consistency of Color Appearance from Ratings of Sets of Images
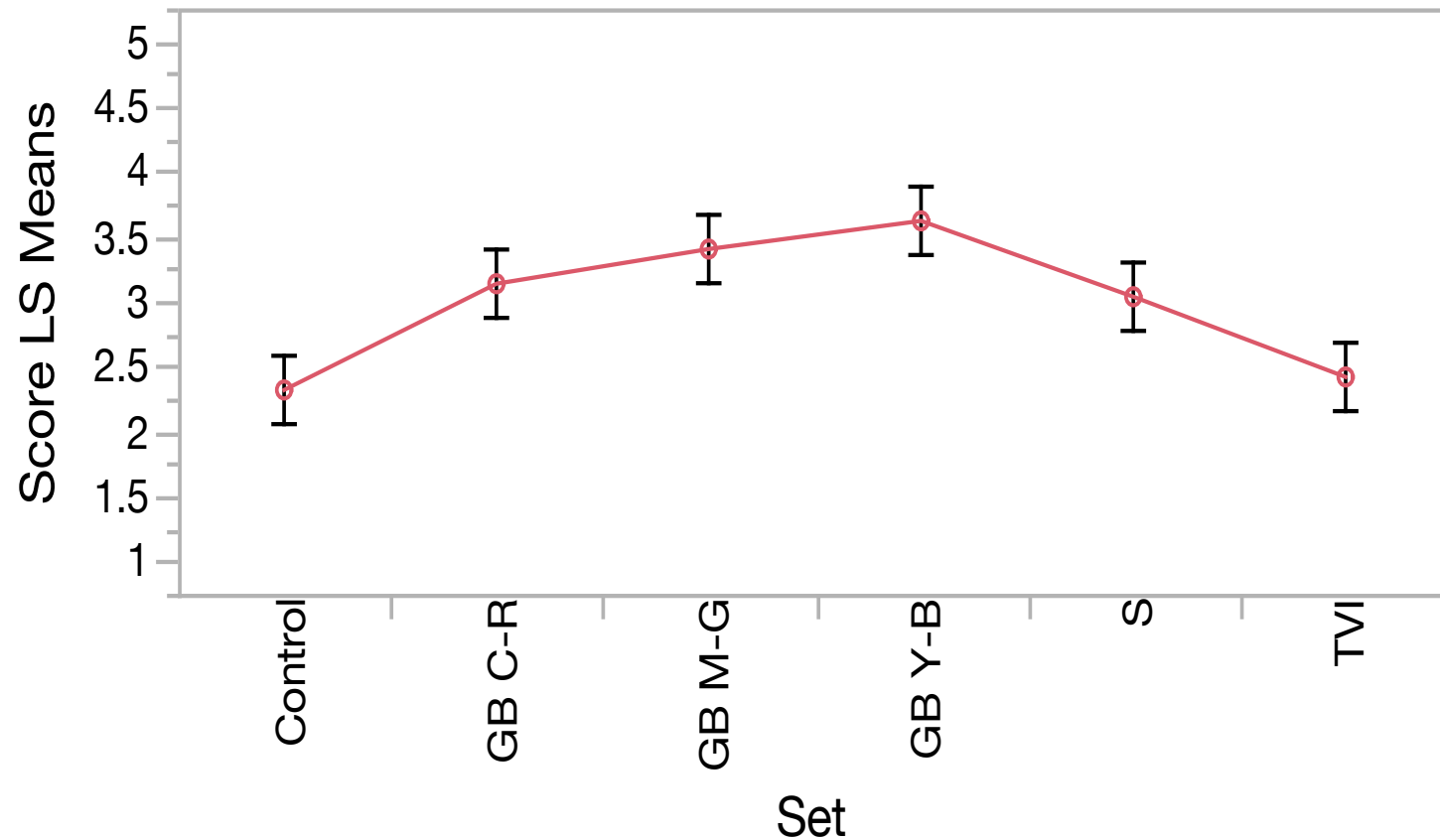
All 12 participants

LSMeans Differences Tukey HSD

α= 0.050   Q=   2.8654

Level			Least Sq Mean
GB Y-B	A		3.62
GB M-G	A	B	3.40
GB C-R	A	B	3.13
S		B	3.03
TVI		C	2.42
Control		C	2.32

Levels not connected by same letter are significantly different.

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F

Results: Comparison of Color Appearance Ratings for Sets of Images
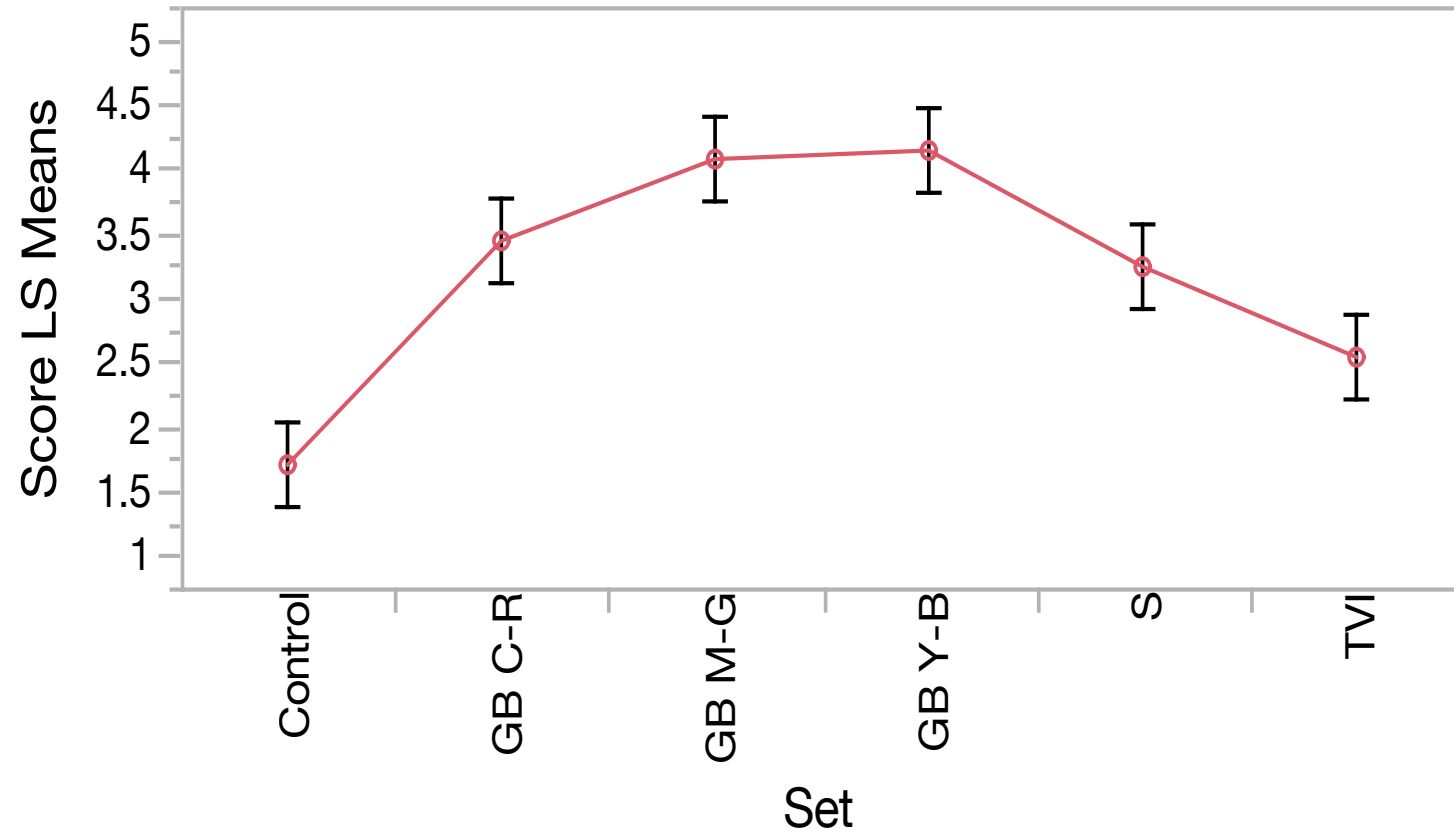
EXPERTS ONLY (6 participants)

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F

LSMeans Differences Tukey HSD

α= 0.050   Q= 2.88174

Level					Least Sq Mean
GB Y-B	A				4.13
GB M-G	A	B			4.07
GB C-R		B	C		3.43
S			C		3.23
TVI				D	2.53
Control					E	1.70

Levels not connected by same letter are significantly different.

Results: Comparison of Color Appearance Ratings for Sets of Images

NOVICES ONLY (6 participants)

LSMeans Differences Tukey HSD

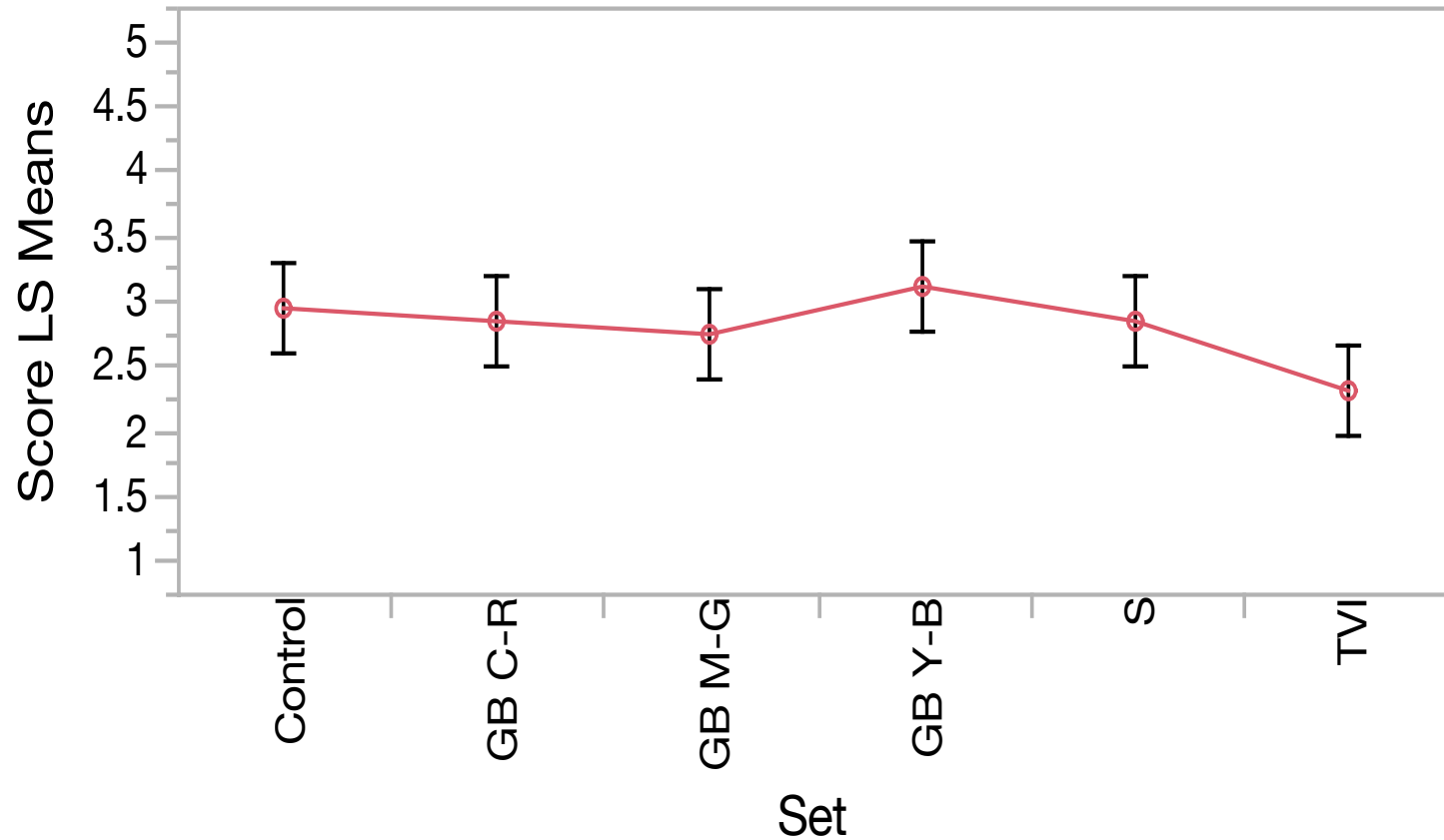α= 0.050   Q= 2.88174

Level		Least Sq Mean
GB Y-B	A	3.10
Control	A B	2.93
GB C-R	A B	2.83
S	A B	2.83
GB M-G	A B	2.73
TVI	B	2.30

Levels not connected by same letter are significantly different.

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F

Conclusions

- A methodology for studying Consistent Color Appearance for a set of printed images was developed.

- Psychometric tests showed that CCA of image set with chroma changes appear to be more consistent than due to other attribute (+/- TR, +/- GB) change.

- There is a discrepancy between experts and novices when judging CCA which may be attributed to the CCA versus image quality perceptions.

- Large range of image variations within a set can be problematic for judging CCA.

- Device-based 95th percentile ΔE_{00} is shown to be a good predictor for Consistent Color Appearance in the present experiment. The 95th percentile ΔE_{00} ~ 3 were perceptible in terms of CCA evaluations.

- Additional experiments are needed to evaluate the effects of pictorial scene on CCA.