Vision Experiment on the effects of chroma saturation on general color preference of lighting

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Problem of CRI

CRI Ra=94

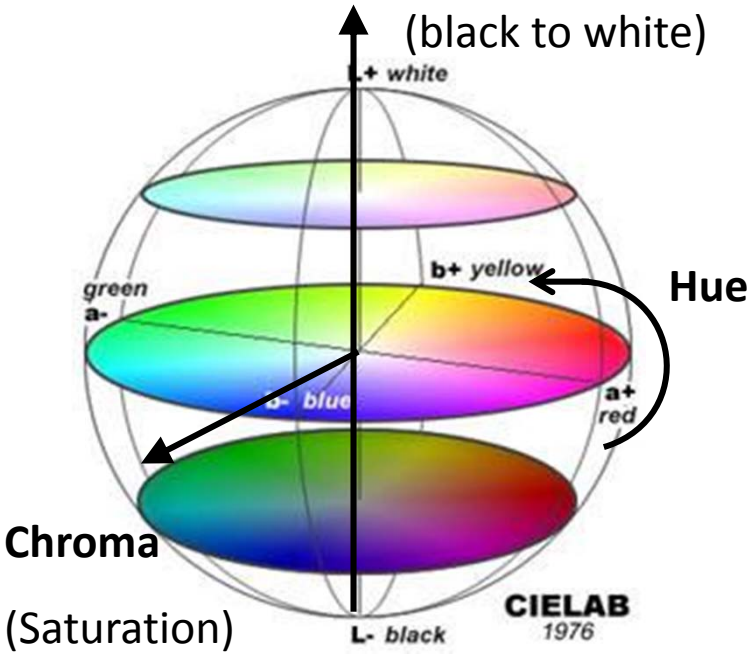
CRI Ra=78

This looks better
(for most people)

Object Color Space

15 saturated color samples

Lightness
(black to white)

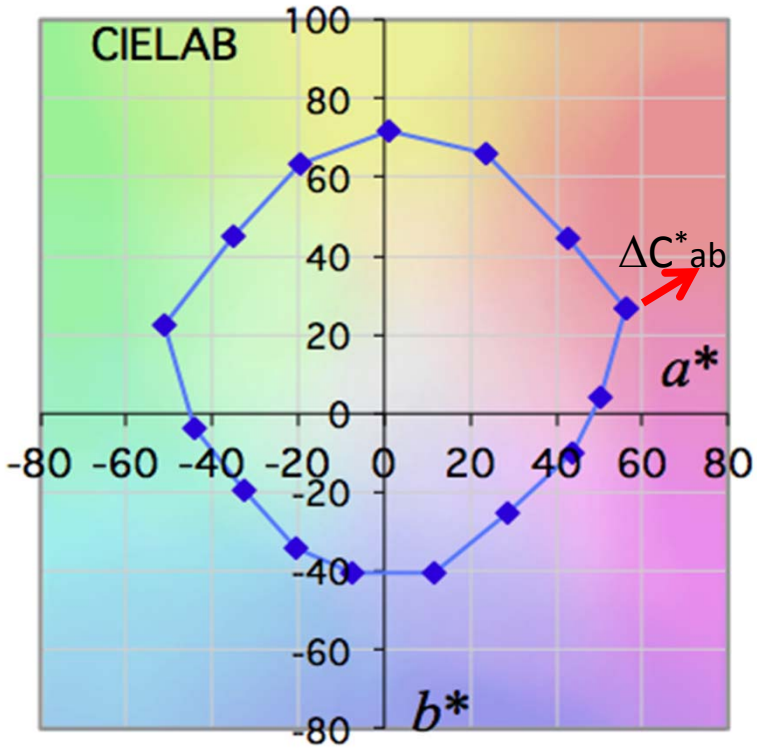


Hue

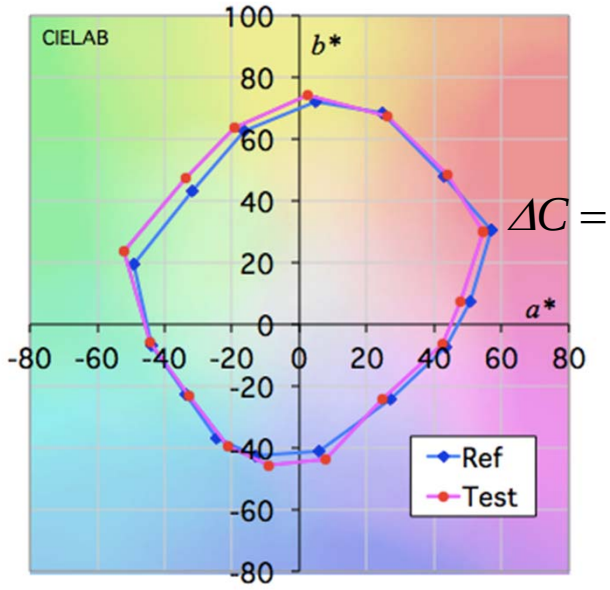
Chroma

(Saturation)

Illuminated by D65



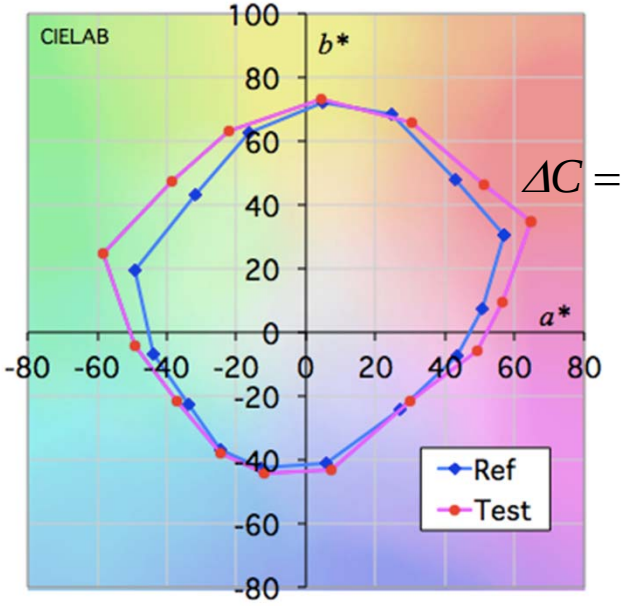
CRI Ra=94



4000 K
Duv=0

$\Delta C = -2$

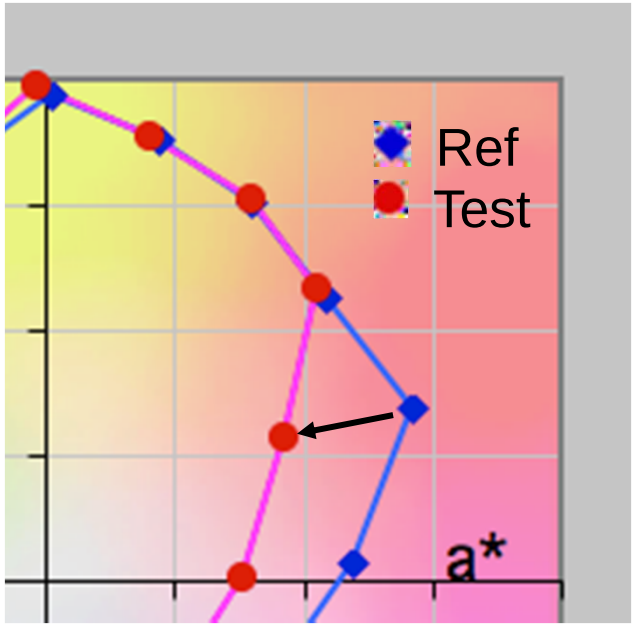
CRI Ra=78

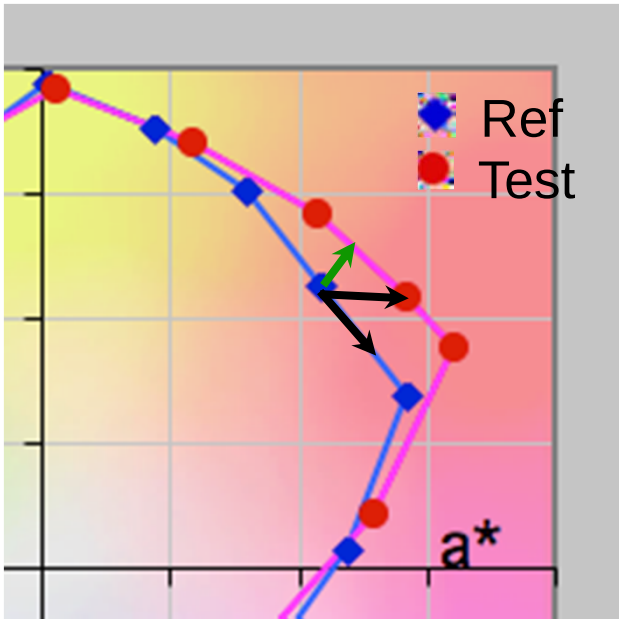


$\Delta C = 8$

Color Quality Scale (CQS)

- Saturation factor





Score is decreased for the full color difference (same as CRI)

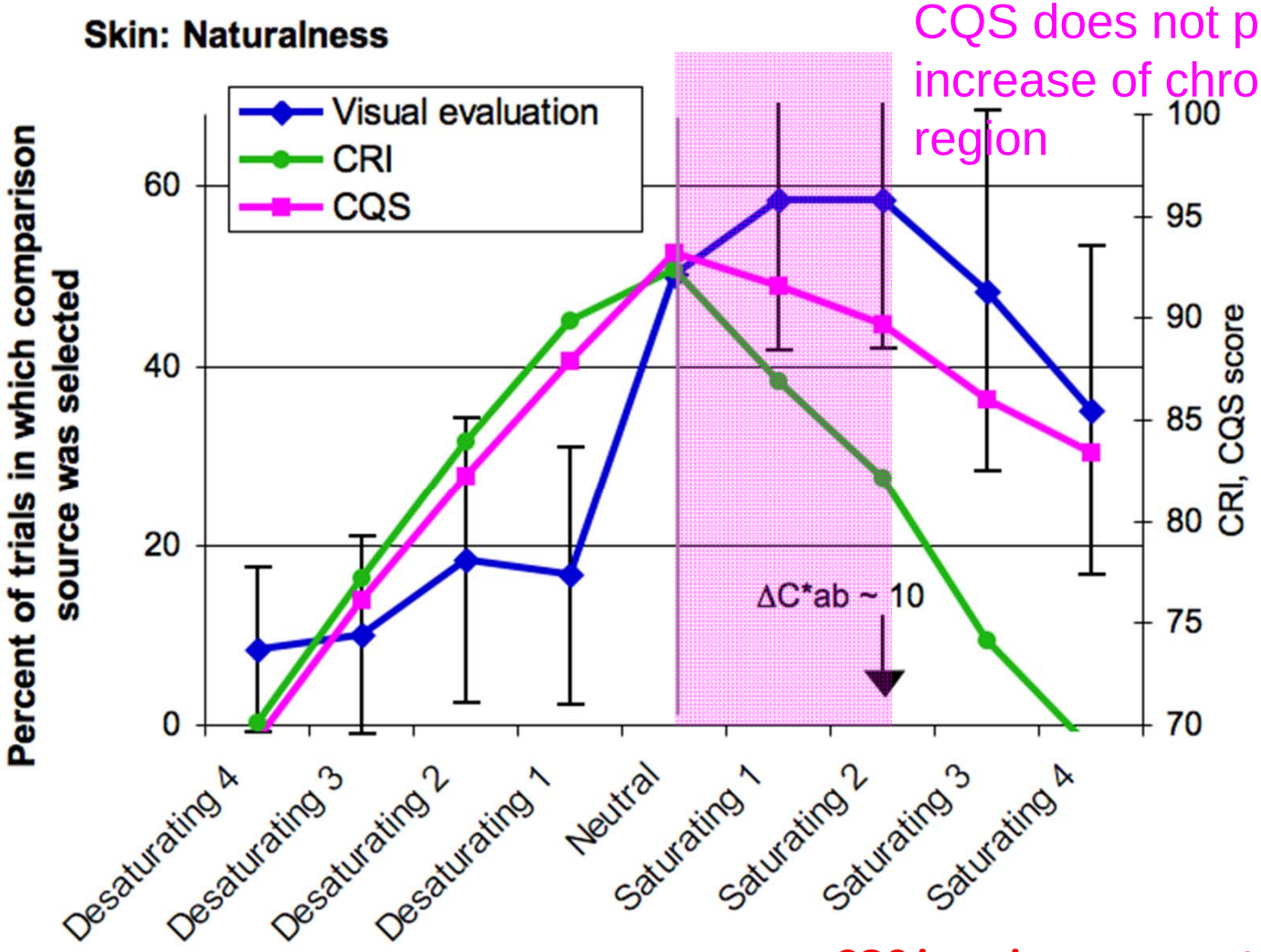
$$\Delta c_{ab} = c^*_{ab,test} - c^*_{ab,ref}$$

$$\Delta E^*_{ab,sat} = \sqrt{(\Delta E^*_{ab})^2 - (\Delta c_{ab})^2} \quad ; \Delta c_{ab} > 0$$

$$\Delta E^*_{ab,sat} = \Delta E^*_{ab} \quad ; \Delta c_{ab} \le 0$$

Score is not penalized for increase of chroma.
(Score is decreased for hue and lightness shifts)
With limit of ΔC^*_{ab}<10

How CQS works (ver. 9.0)



CQS does not penalize the increase of chroma in this region

CQS is an improvement of CRI.
CQS is not a color preference metric.

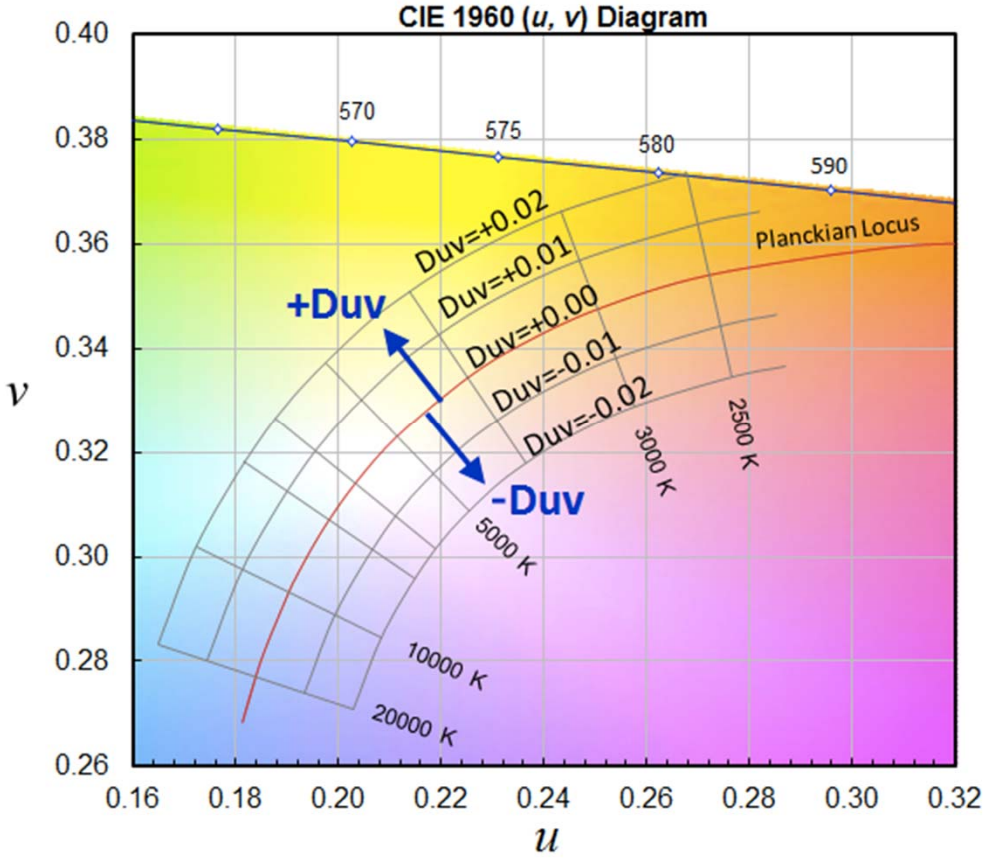
2014 Experiment on the effects of chroma saturation level on general color preference

- Purpose: develop **a color preference metric** (NST Color Preference Scale)
- Use 20 subjects
- 2700 K, 3500 K, 5000 K (D_{uv}=0) and 3500 K (D_{uv}=-0.015)
- Use Spectrally Tunable Lighting Facility

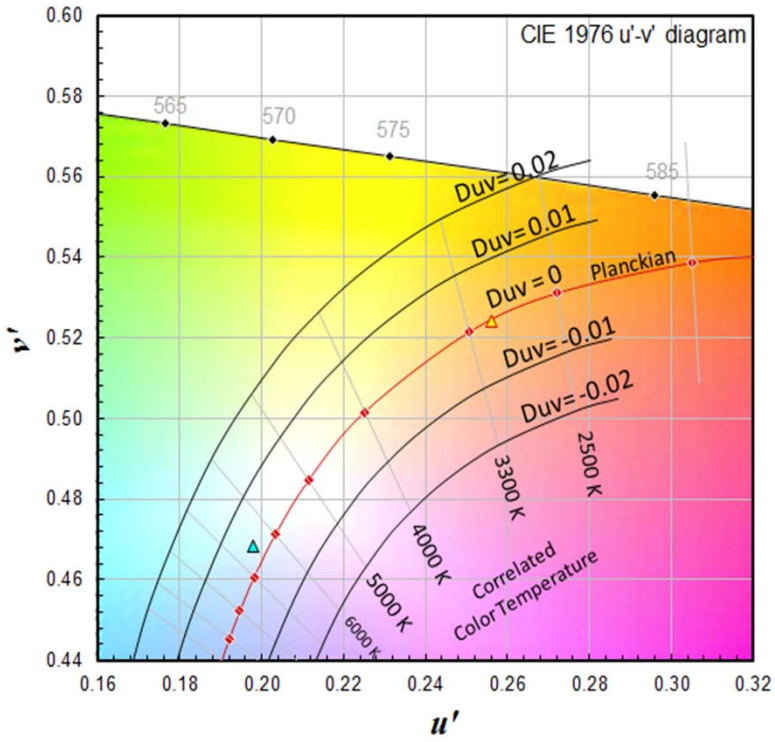
1) fruits/vegetable (mix) and room
2) skin tone (face and hands)
3) fruits/vegetable (red only)
4) fruits/vegetable (green only)

- More different colors were not possible
- 3500 K condition was repeated.

Duv



Duv scale on (*u', v'*) diagram

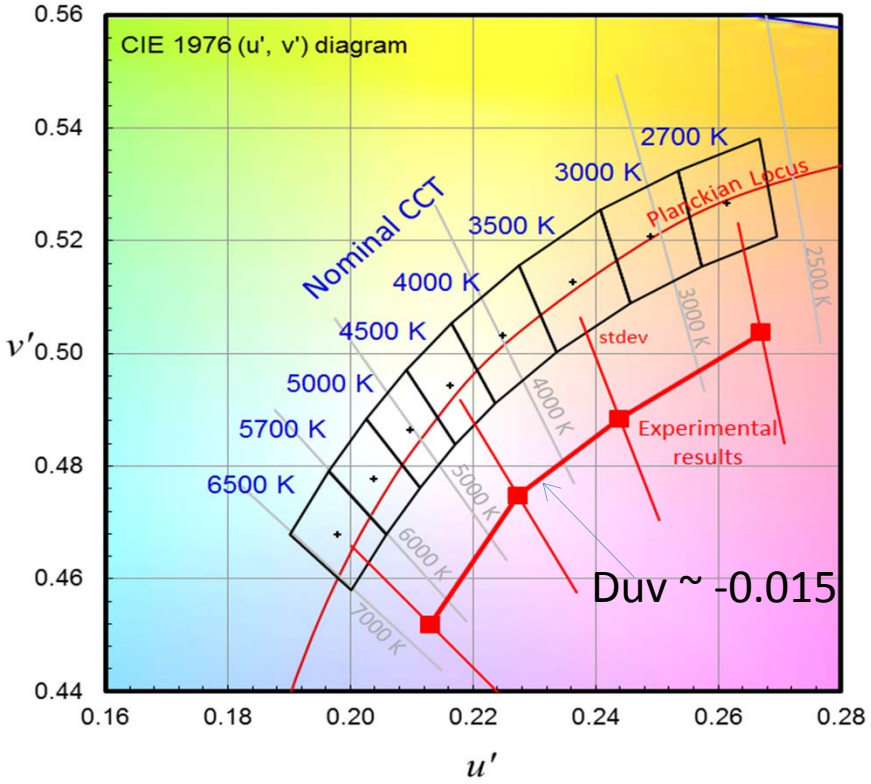


Defined in ANSI C78.377

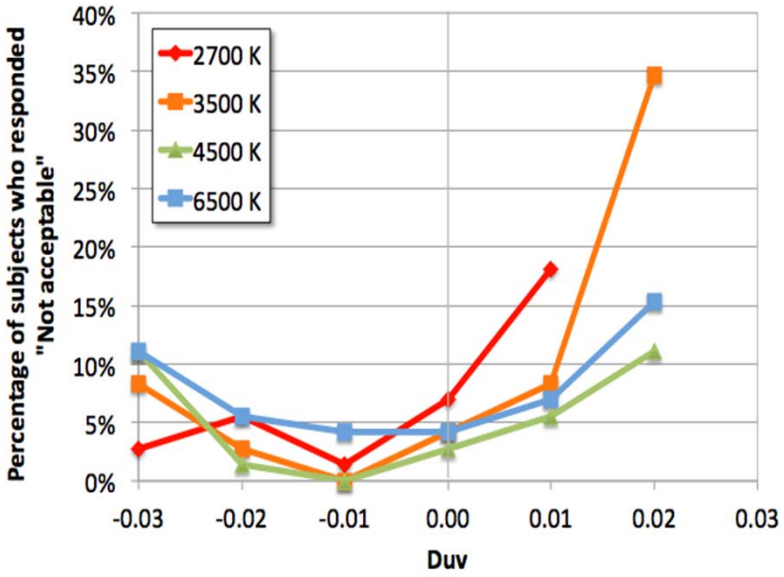
Closest distance from the Planckian locus on the (*u'*, 2/3 *v'*) diagram, with + sign for above and - sign for below the Planckian locus.

2013 Vision Experiment on Preferred and Acceptable level of Duv

Results



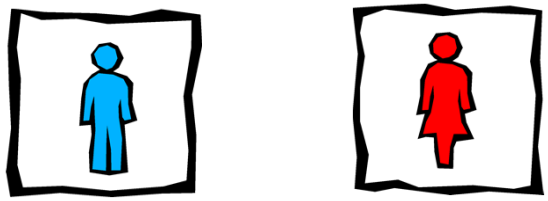
Results of "Is this light acceptable?"



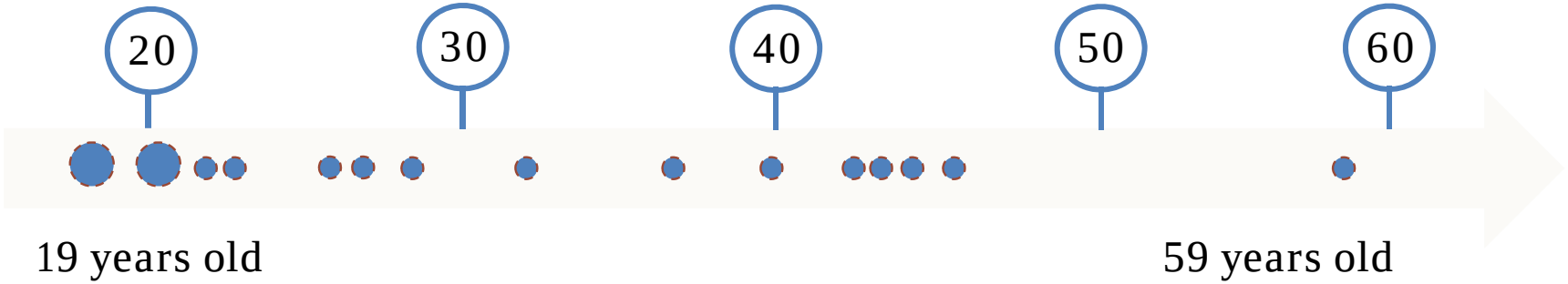
Y. Ohno and M. Fein, Vision Experiment on Acceptable and Preferred White Light Chromaticity for Lighting, CIE x029:2014, pp. 192 – 199 (2014)

Subjects

20 subjects

10  10

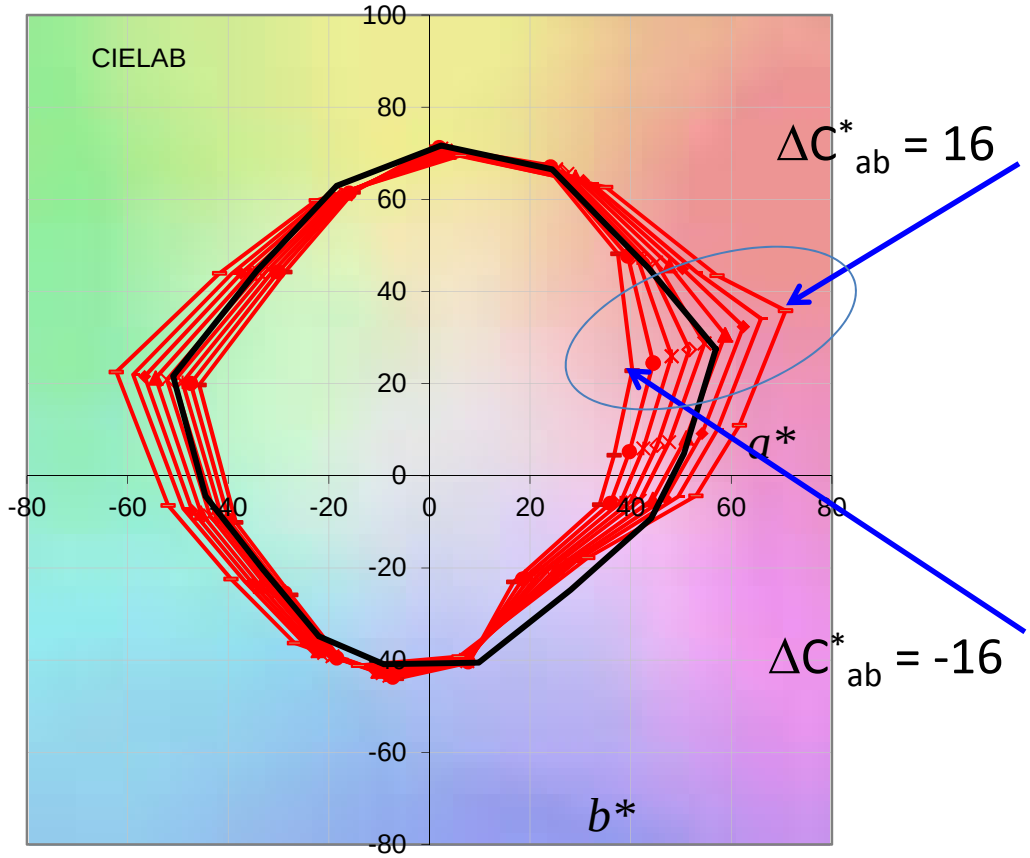
With ages ranging from…



Illumination: 9 levels of chroma differences

for each condition

ΔC^*_{ab} = -16, -12, -8, -4, 0, 4, 8, 12, 16



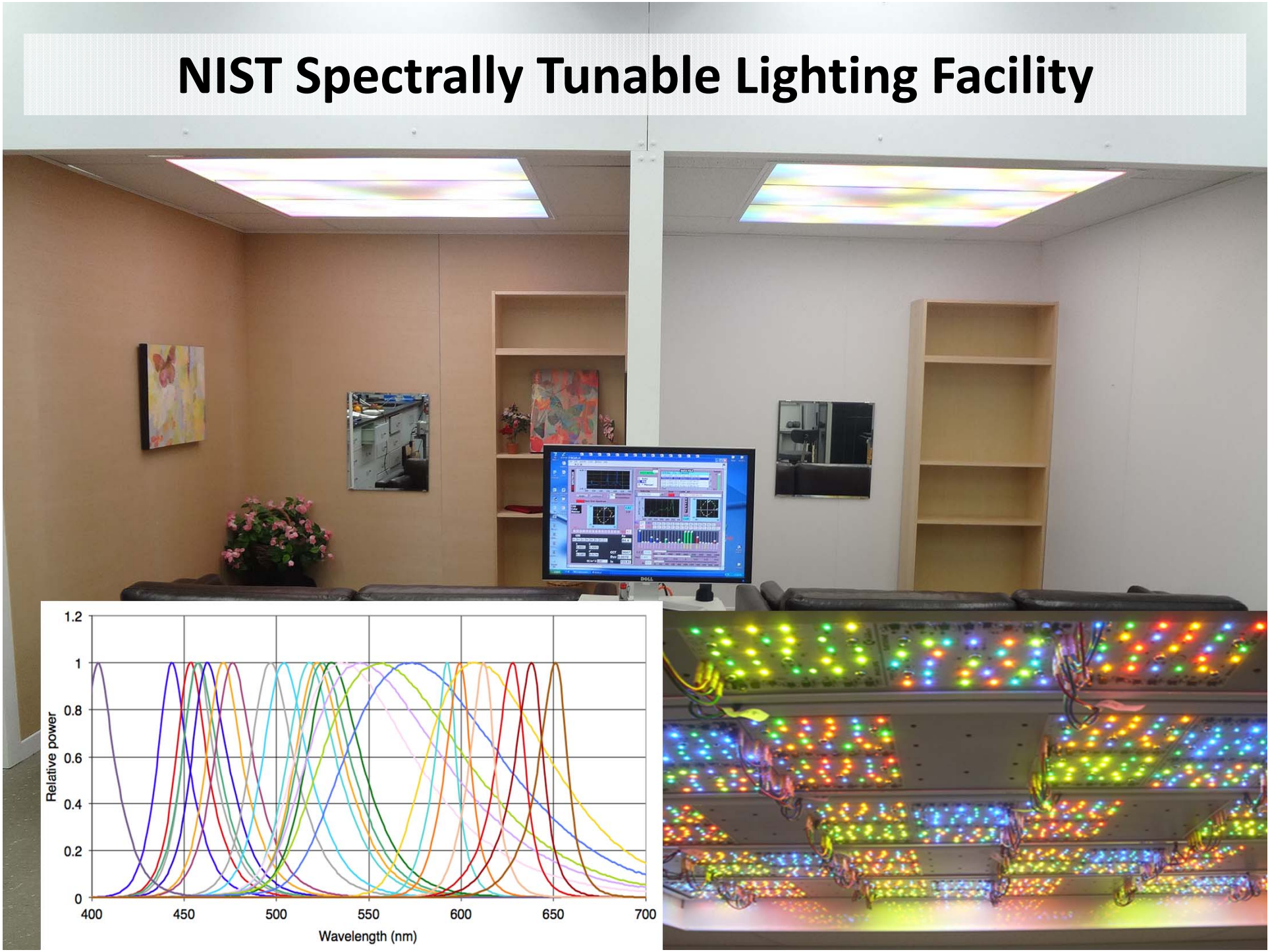
ΔC^*_{ab} = 16

Most saturated

ΔC^*_{ab} = -16

Most de-saturated

NIST Spectrally Tunable Lighting Facility




LCAS1.vi
File Edit Operate Tools Window Help
CAS SPECTRUM
8.0E-3
-2.0E-3
400 450 500 550 600 650 700
Single
Continous
100 IntegrationTime
5 Accumulations
Save 5nm-Spectrum
STLS MODE
1. Auto
2. File
3. * Manual
DATA FILE
CCT Duv Lx Comment
3595 -0.0038 401.1 B) Duv=-0.005 Ra=96
3580 0.0010 401.6 4. Duv=0.000 3500K
3595 -0.0038 401.1 A) Duv=-0.005 Ra=96
3580 0.0067 401.9 B) Duv=+0.005 Ra=97
3580 0.0118 402.2 5. Duv=+0.010 Ra=95
Output
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Data File
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Comment
4. Duv=0.000 3500K
CAS Color Metrics
80
-60
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b*
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1.67
S/P
mW/(m^2 nm)
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2
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400 450 500 550 600 650 nm
OUTPUT
LER
309
lm/W
S/P
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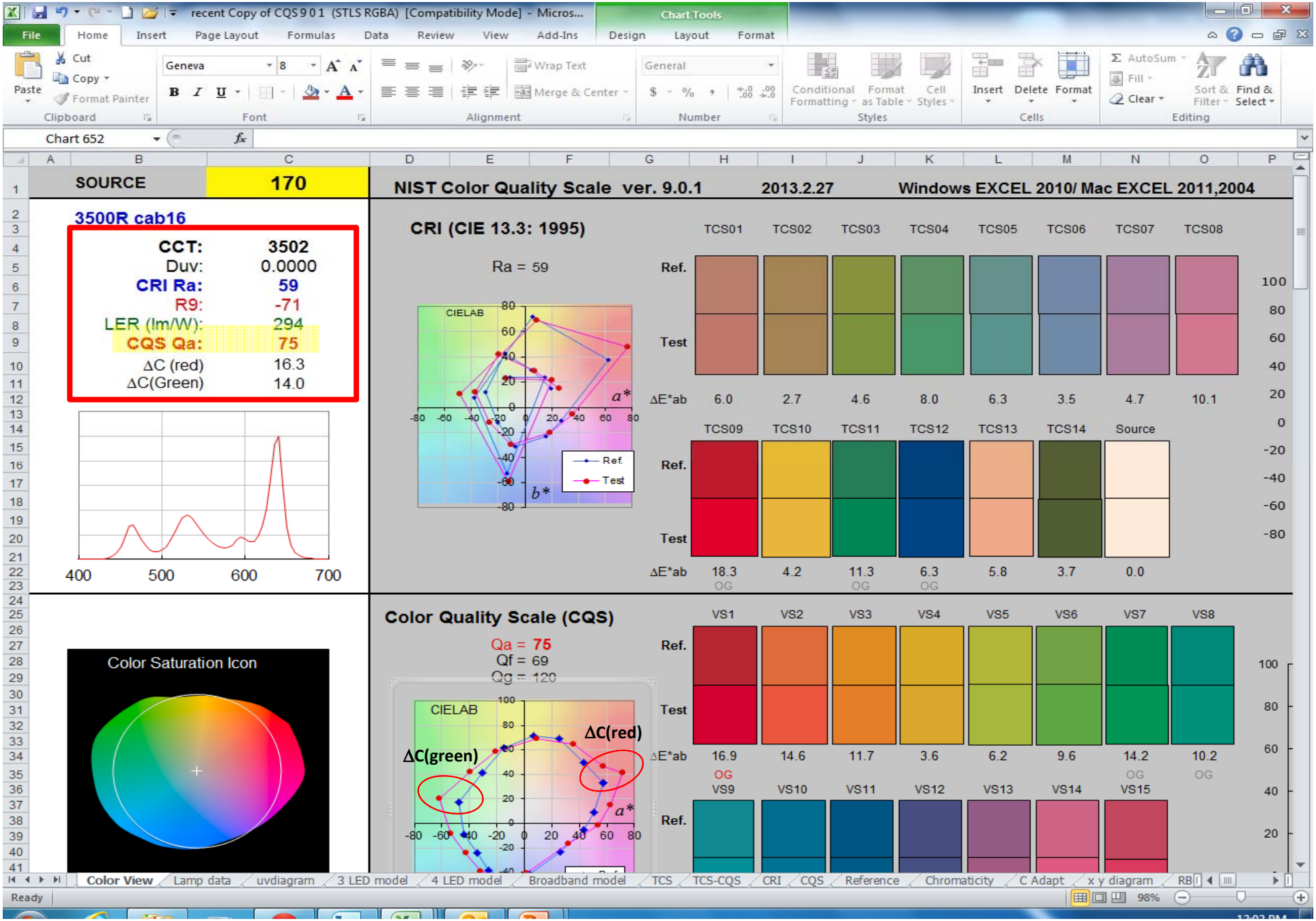
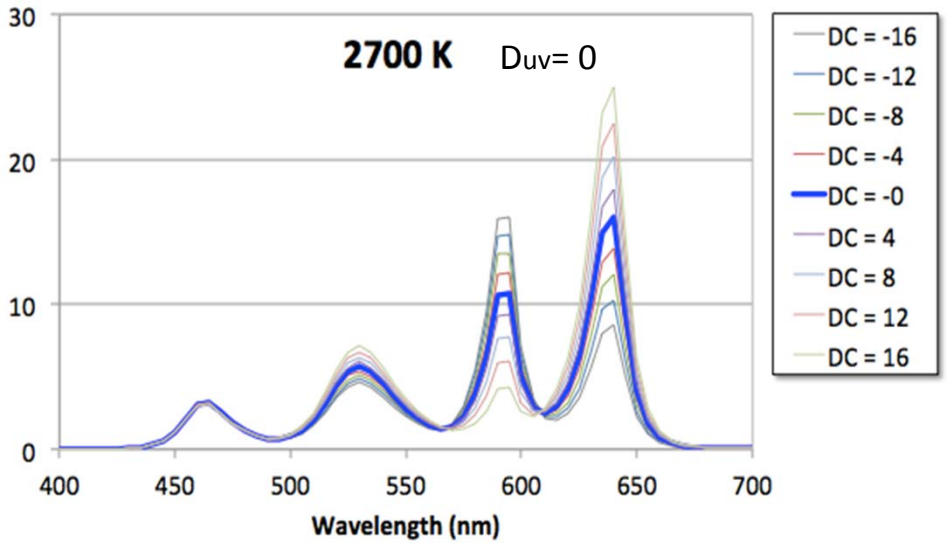
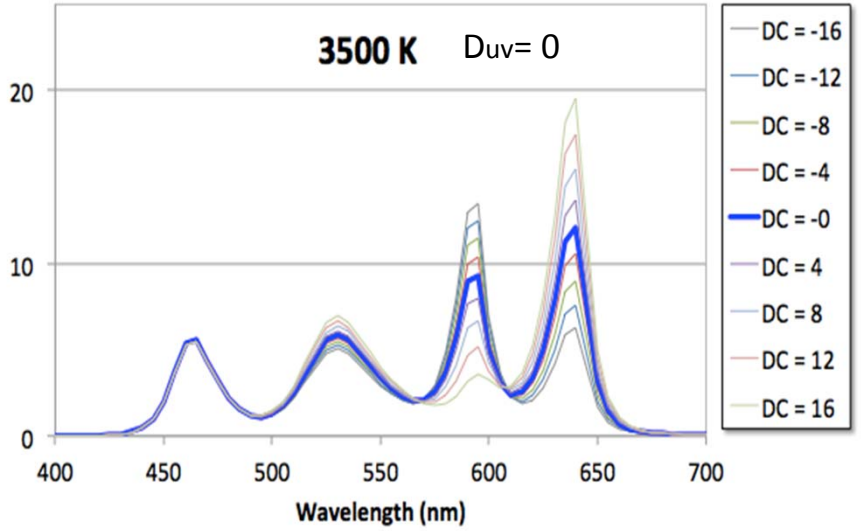
Ra 98 CRI 97 10(93 95 98 98 99 99 95 97 92 85 98 95
Qa 97 CQS 97 99 94 98 98 96 98 99 98 99 98 96 97 99 98
CQS 2
97 99 93 96 99 96 97 10 98 98 10 98 98 98 97
Qa 97
CRI
99 99 95 96 99 98 98 97
Ra
97.7
x
0.4043
y
0.3903
u'
0.2352
v'
0.5109
CCT 3519
Duv -0.0000
W/m^2 1.09
lx 339.91
CCT 3520
2000 3000 4000 5000 6000 7000 8000 9000 10000
Duv 0.0004
-0.03 -0.02 -0.01 0 0.01 0.02 0.03
lx 325
200 400 600 800 1000 1200 1400 1600 1800 2000

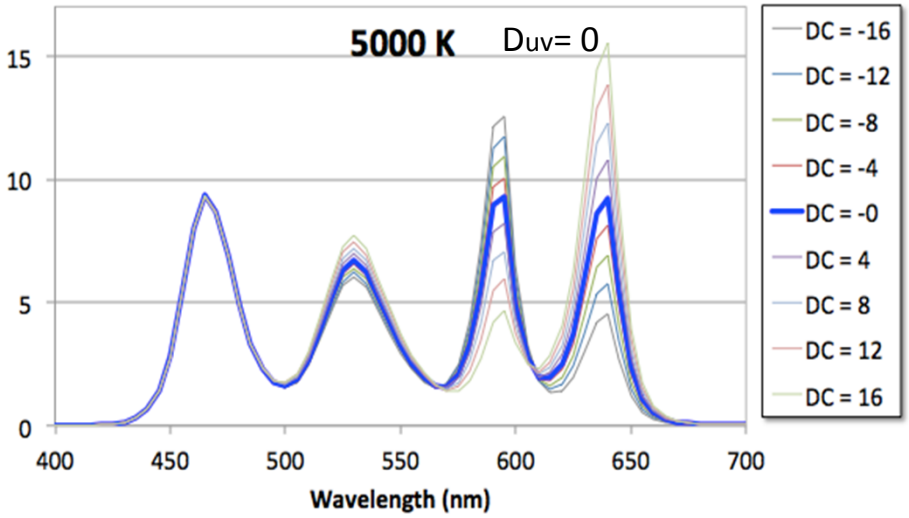
STLF spectroradiometer linked to CQS spreadsheet

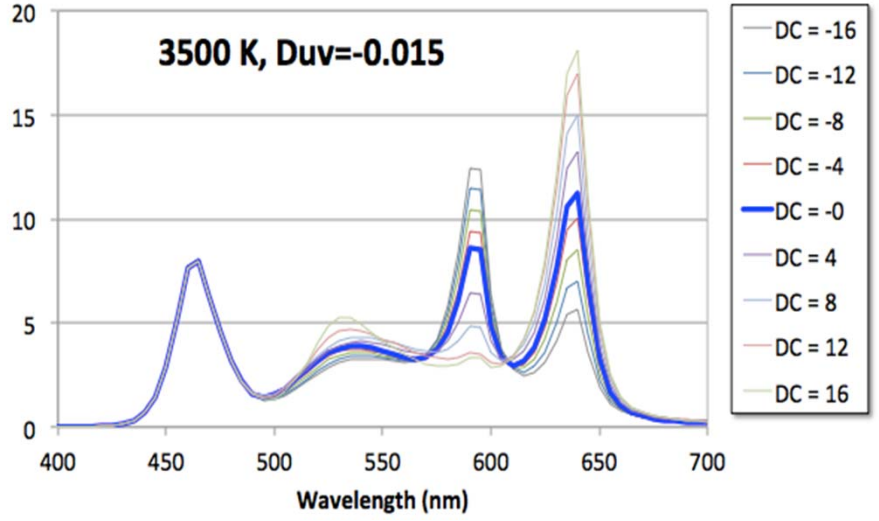


Spectra of light

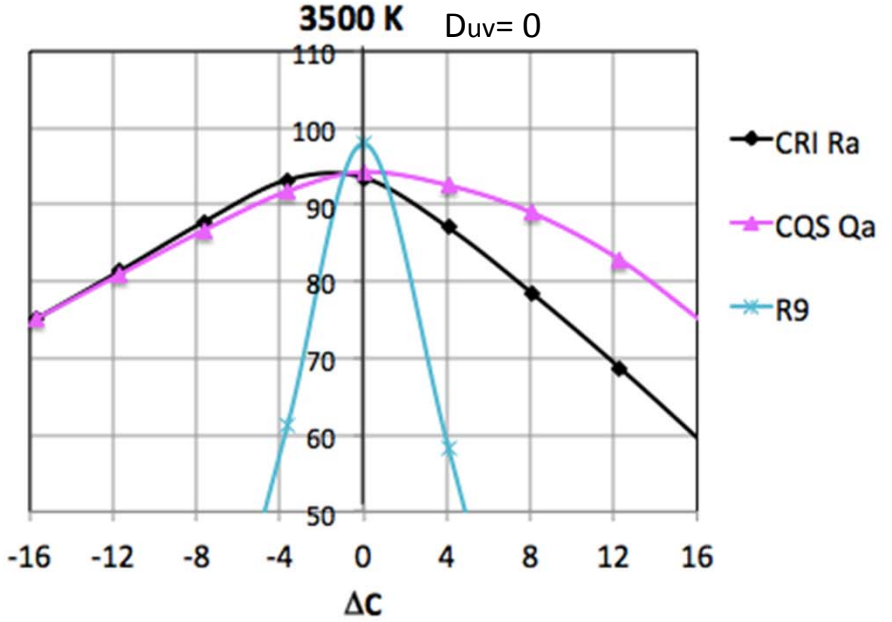


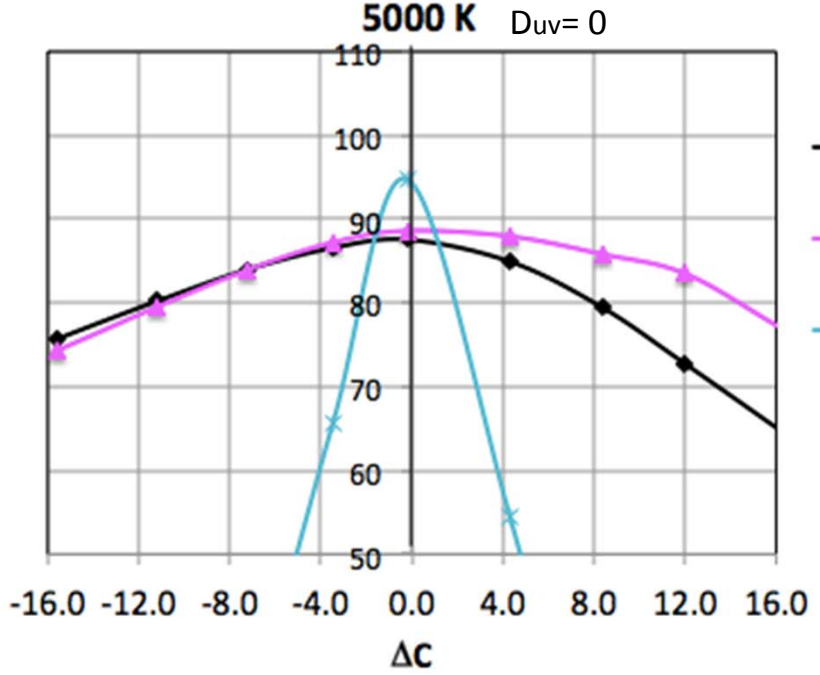


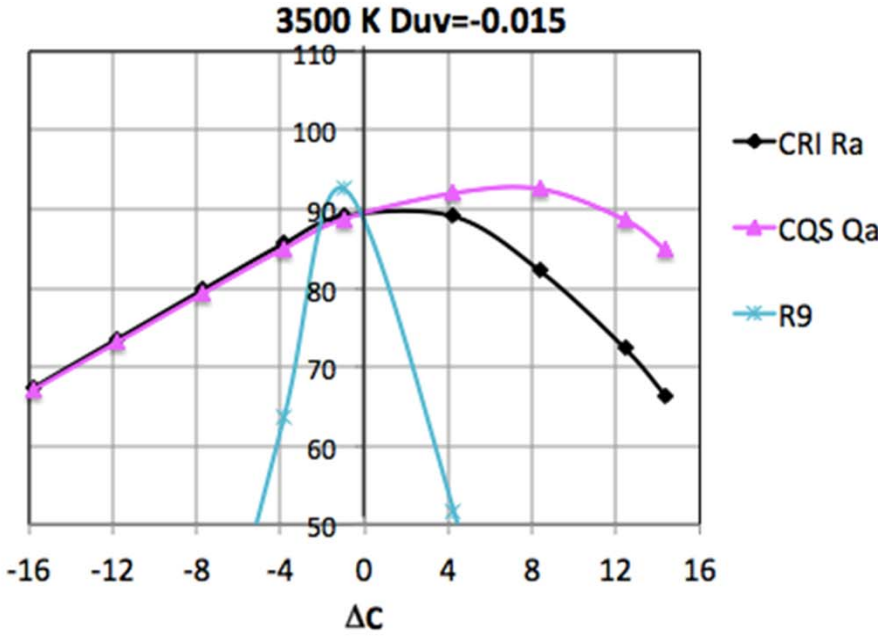




CRI and CQS values



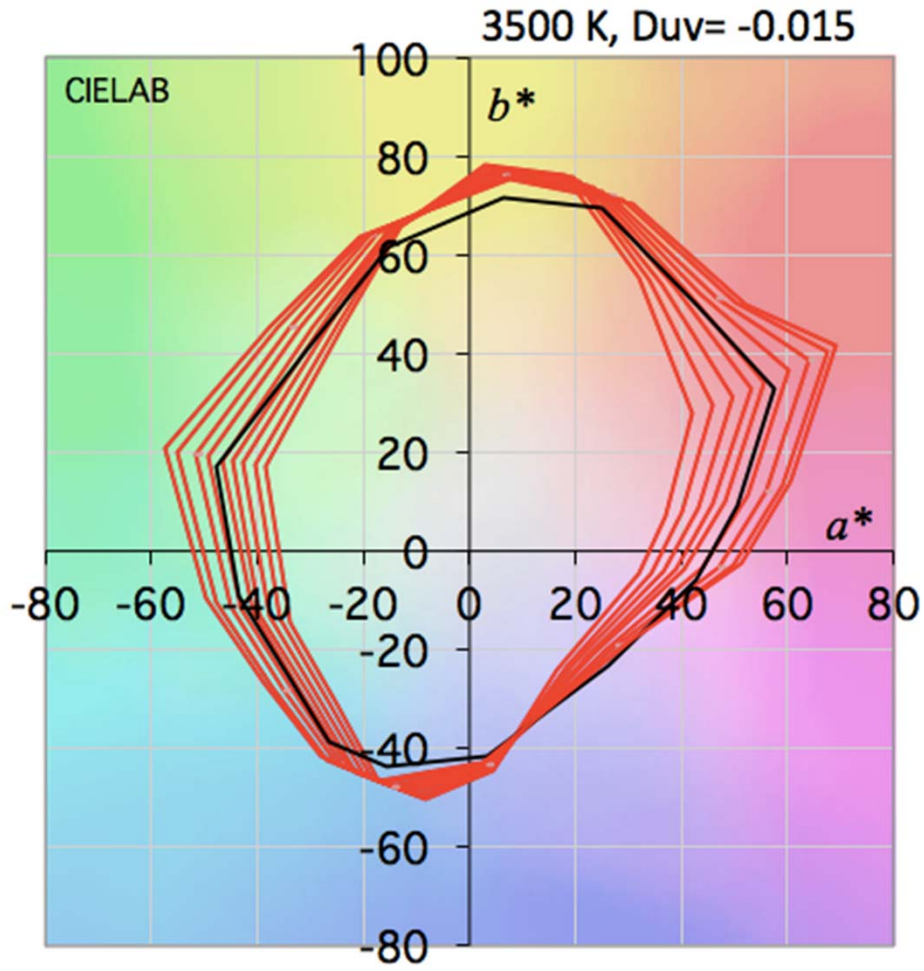


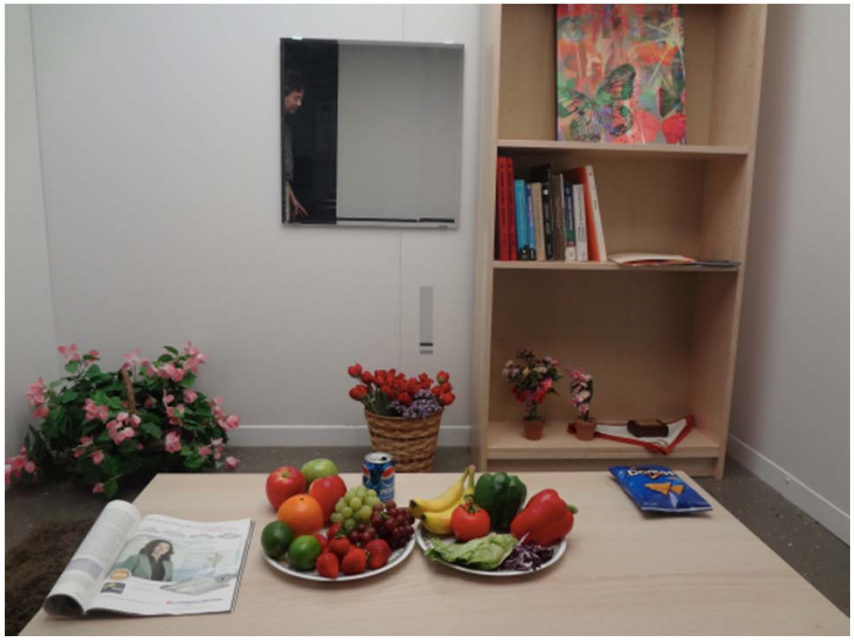


Condition 1: mixed fruits/vegetable and room

2700 K, 3500 K, 5000 K (D_{uv}=0), 3500 K (D_{uv}= -0.015)

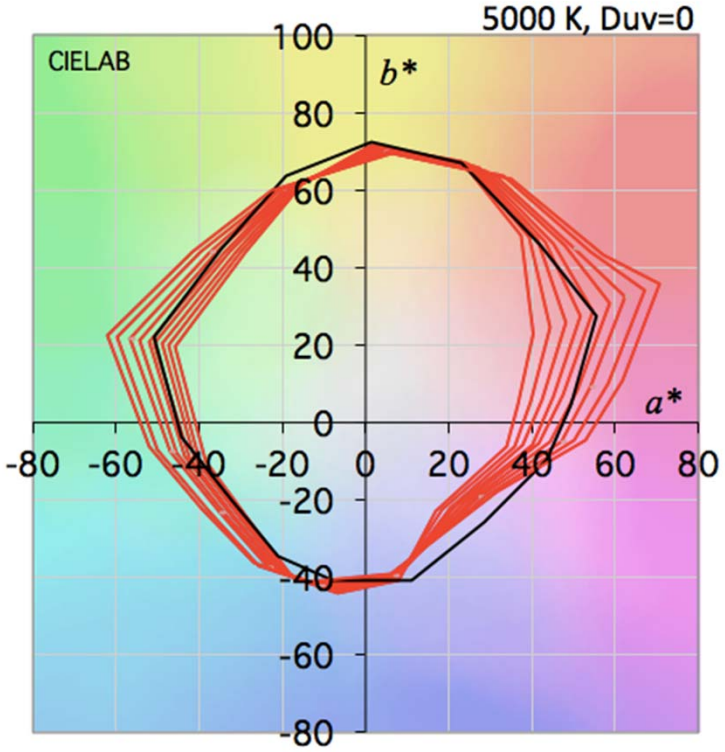
ΔC^*_{ab} = -16, -12, -8, -4, 0, 4, 8, 12, 16





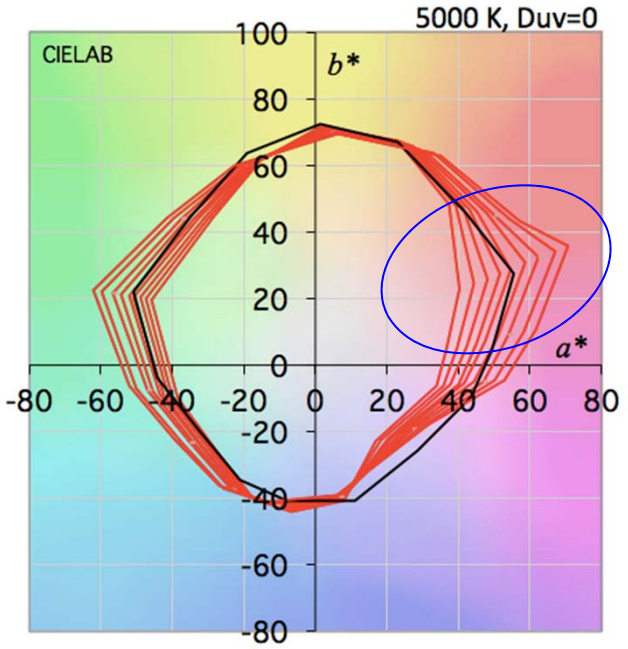
Condition 2: Skin tone

2700 K, 3500 K, 5000 K (D_{uv}=0), 3500 K (D_{uv}= -0.015)
ΔC^*_{ab} = -16, -12, -8, -4, 0, 4, 8, 12, 16



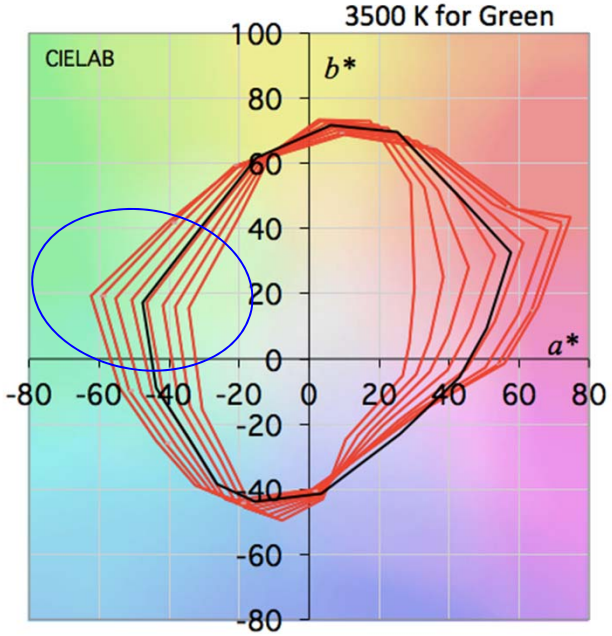
Condition 3) Red Fruits/Vegetables

2700 K
3500 K
5000 K
Duv= 0
3500 K
Duv= -0.015



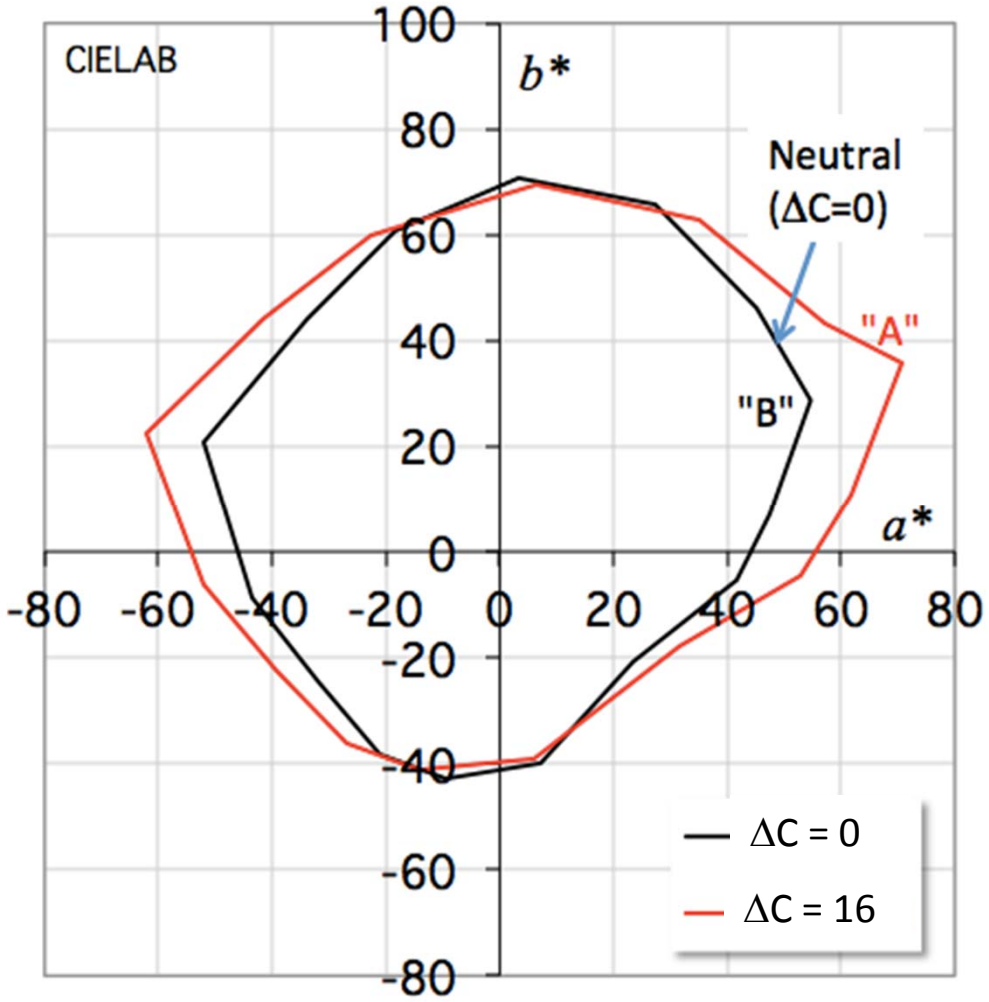
Condition 4) Green Fruits/Vegetables

2700 K
3500 K
5000 K
Duv= 0
3500 K
Duv= -0.015



A Pair of Light

was presented sequentially



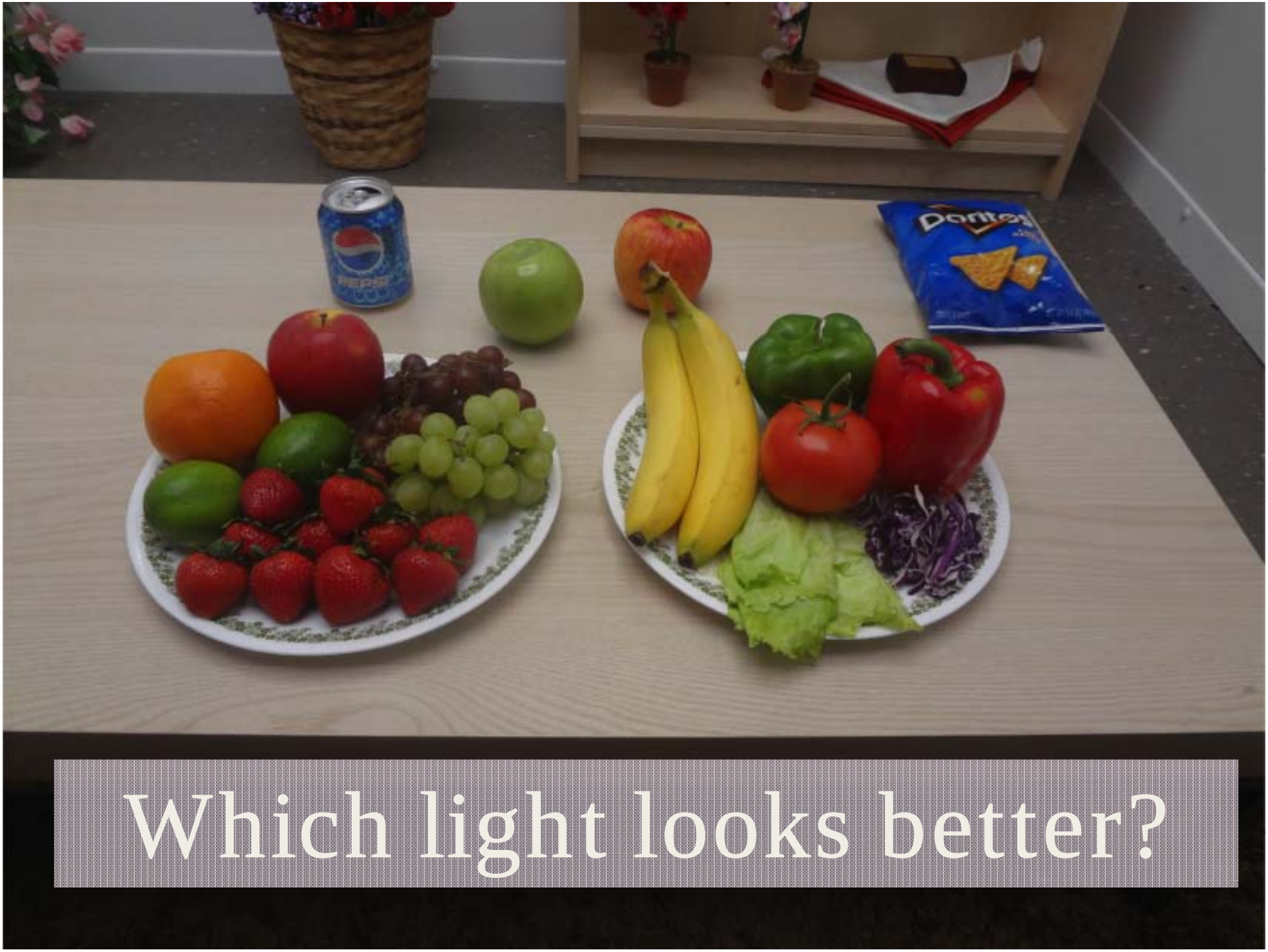
One was always neutral one ($\Delta C=0$).

Each light was called “A” and “B”

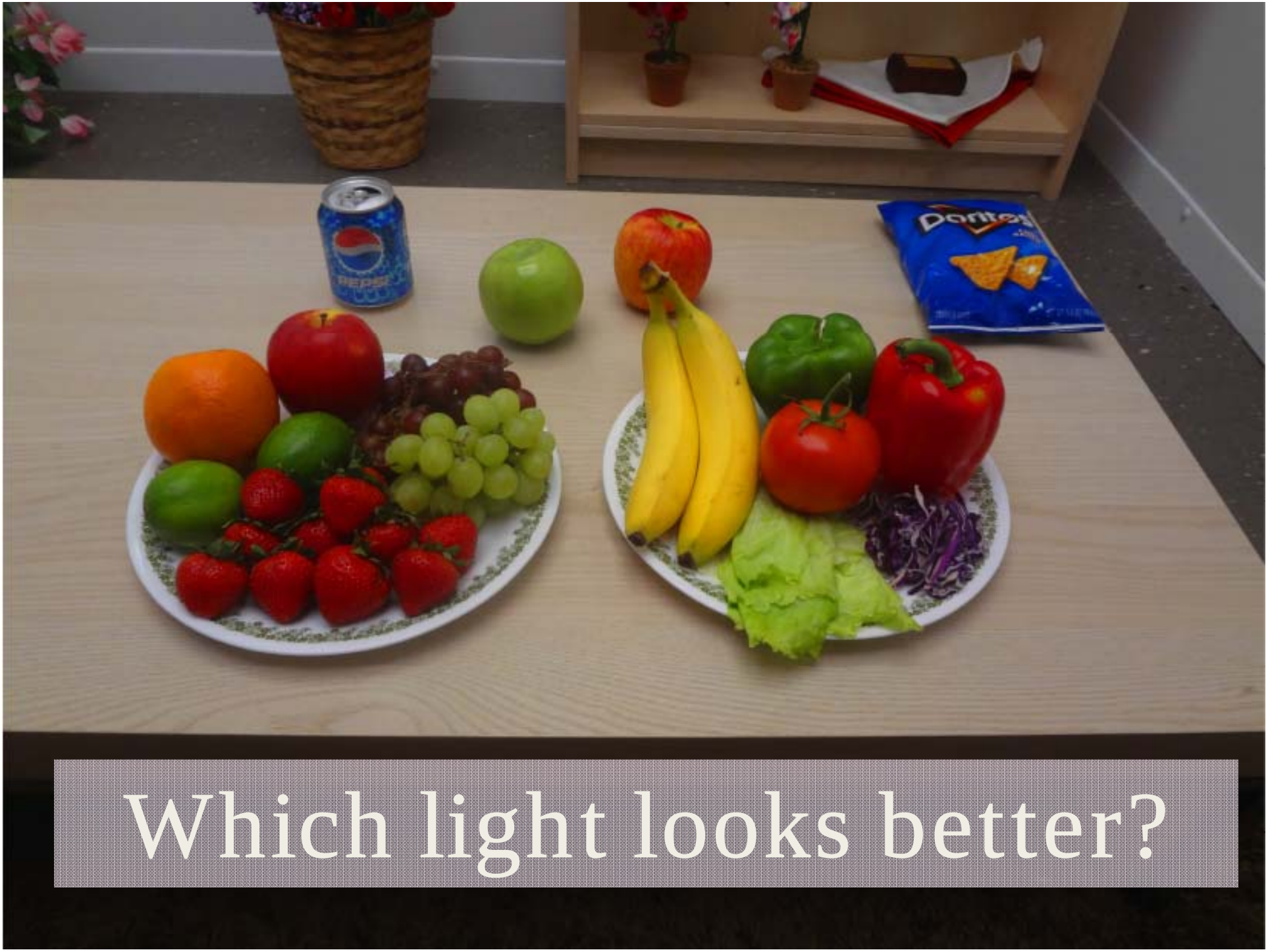
“A” and “B” assigned randomly.

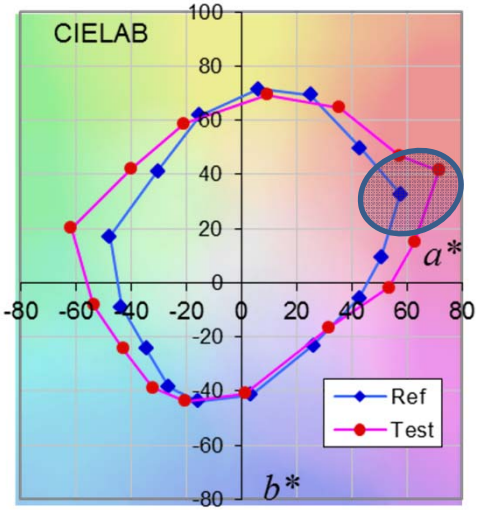
Each light presented for a few seconds.

Light was switched back and forth for a few times as necessary.

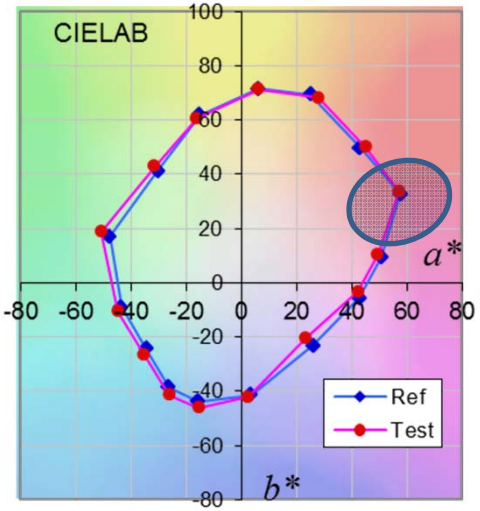


Which light looks better?


Which light looks better?



"Which light looks better?"



Raw data

Basically, forced choice.

Marked if subject said it was difficult to choose.

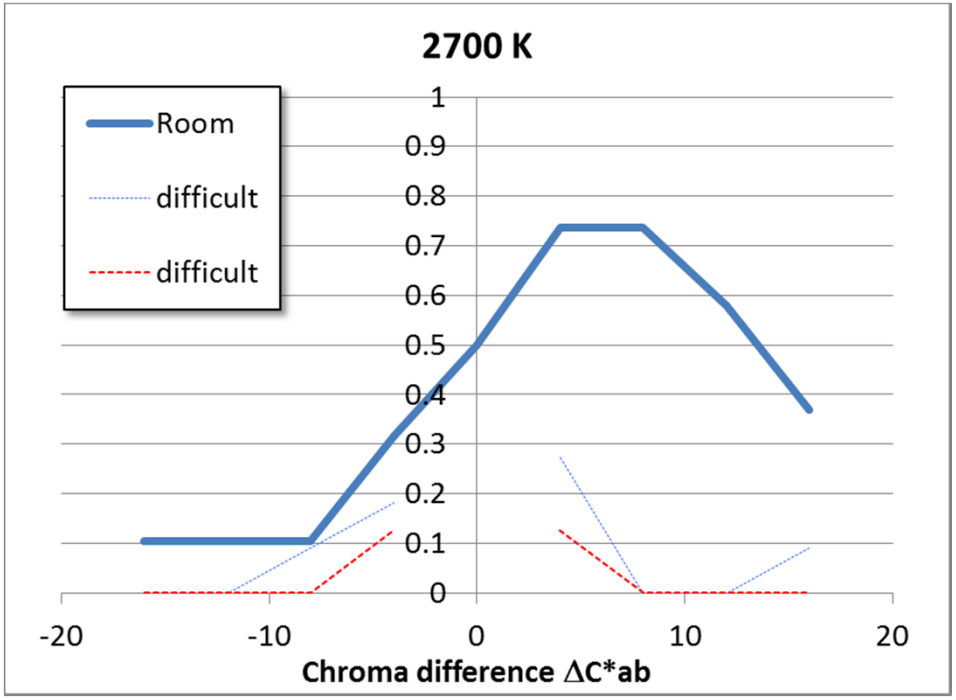
3500 K Room, Red	A	B	Don't know	ΔC	
Pair 1		1		-8	0
Pair 2	1			8	1
Pair 3		1		16	1
Pair 4		1		-12	0
Pair 5		1		-4	0
Pair 6	1			4	1
Pair 7		1		12	1
Pair 8	1			-16	0

Summary Raw Data

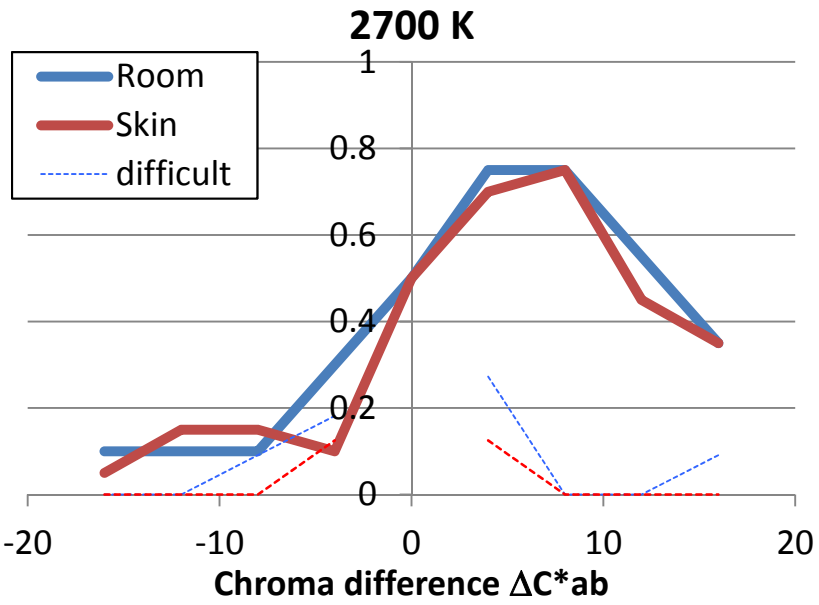
All subjects for each condition

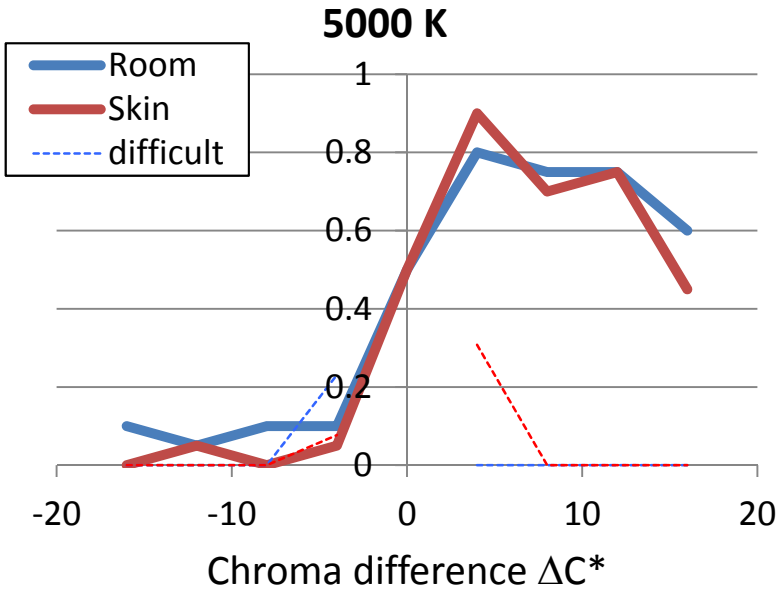
Room 2700 K ΔC	-16	-12	-8	-4	0	4	8	12	16
2001	0	0	0	0	0.5	1	1	0	0
2002	0	0	0	0	0.5	0	0	0	0
2003	1	0	0	1	0.5	1	1	1	1
2004	0	0	0	0	0.5	1	1	1	1
2005	0	0	0	0	0.5	1	1	1	1
2006	0	0	0	0	0.5	1	1	1	0
2007	0	0	0	0	0.5	1	0	1	0
2008	0	0	0	0	0.5	1	1	1	1
2009	0	1	1	1	0.5	0	0	0	0
2010	0	0	0	0	0.5	1	1	1	0
2011	0	0	0	1	0.5	1	0	1	0
2012	0	0	0	1	0.5	0	1	0	0
2013	0	0	0	0	0.5	1	1	0	0
2014	0	0	0	1	0.5	0	1	0	1
2015	0	0	0	0	0.5	1	1	0	0
2016	0	0	0	0	0.5	1	1	1	0
2017	0	0	0	0	0.5	1	1	1	1
2018	0	0	0	0	0.5	1	1	1	1
2019	1	1	1	1	0.5	0	0	0	0
2020	0	0	0	0	0.5	1	1	0	0
Average	0.1	0.1	0.1	0.3	0.5	0.75	0.75	0.55	0.35
difficult	0	0	0.09	0.18		0.27	0	0	0.09

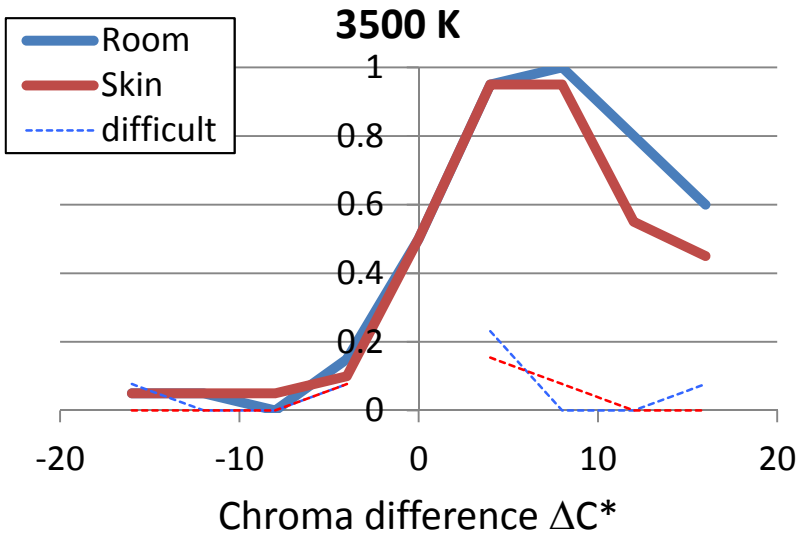
2700 K Mix/Room

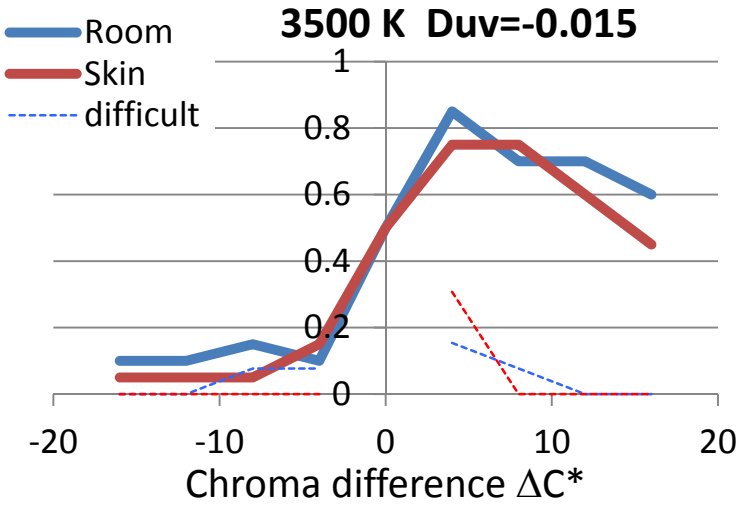


Results –Mixed_Fruits/Vegetables/Room and Skin tone

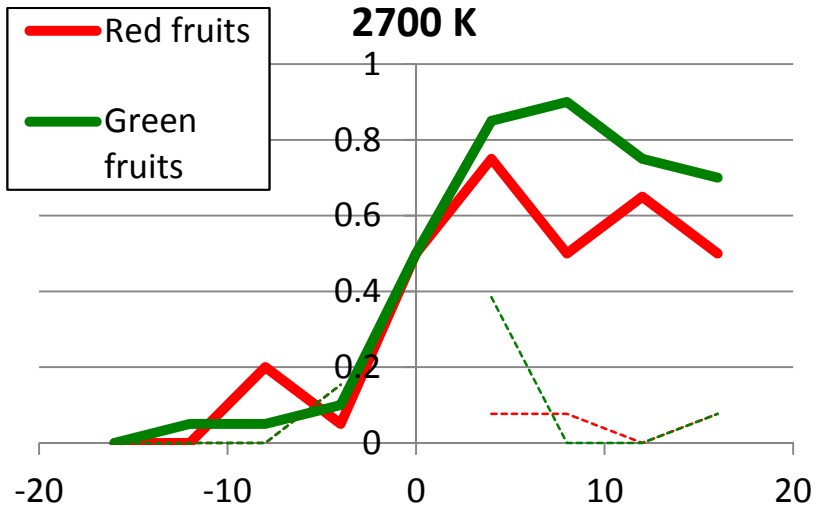


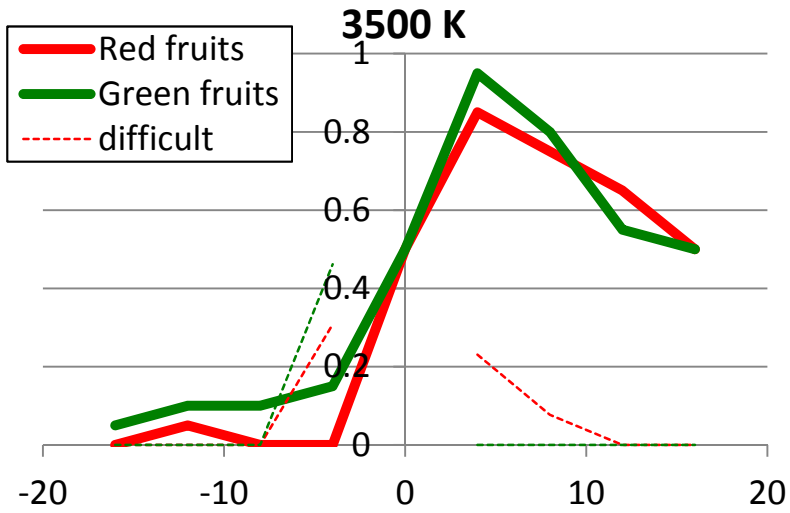


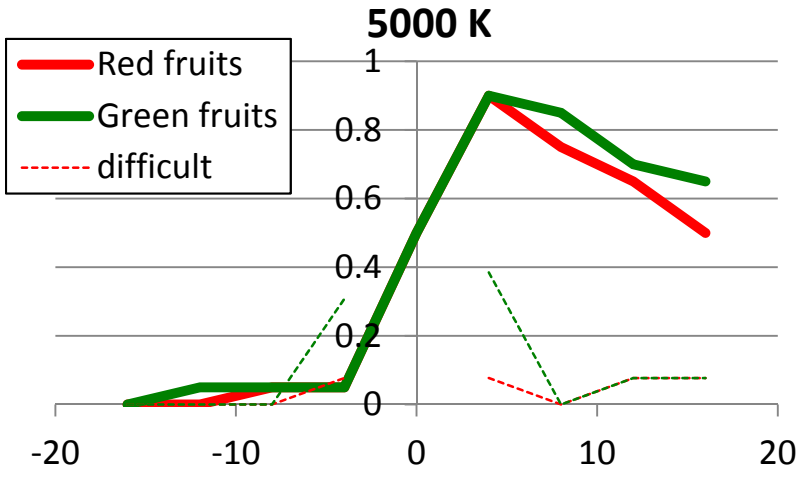


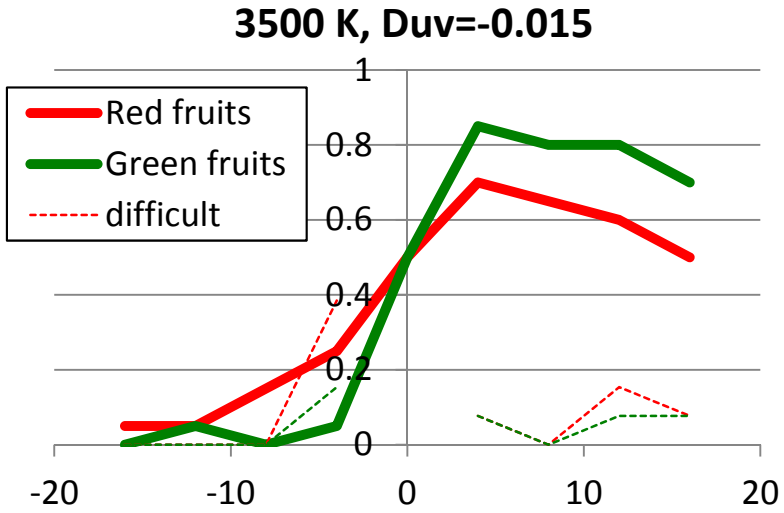


Results – Red or Green Fruits/vegetables

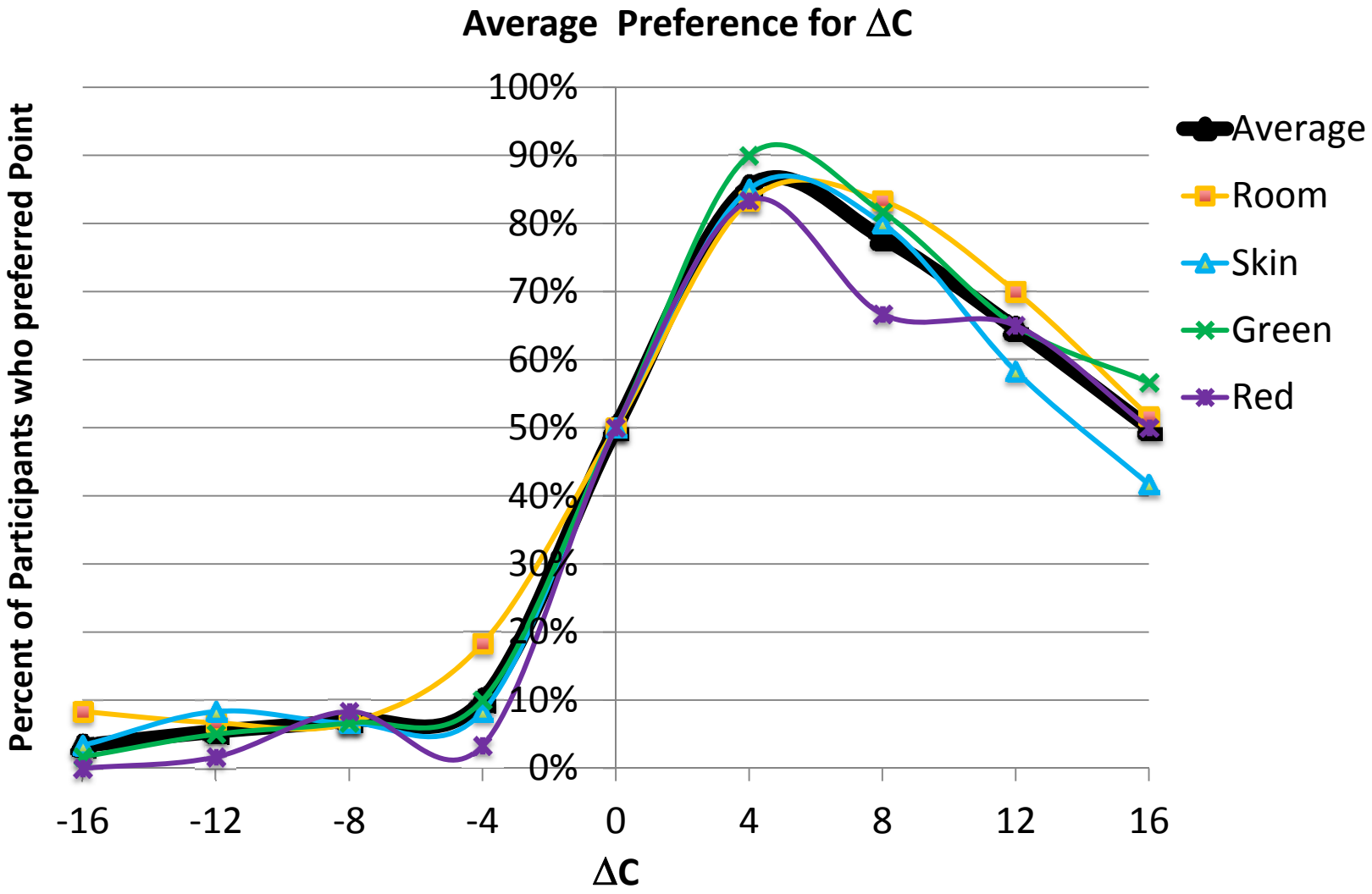




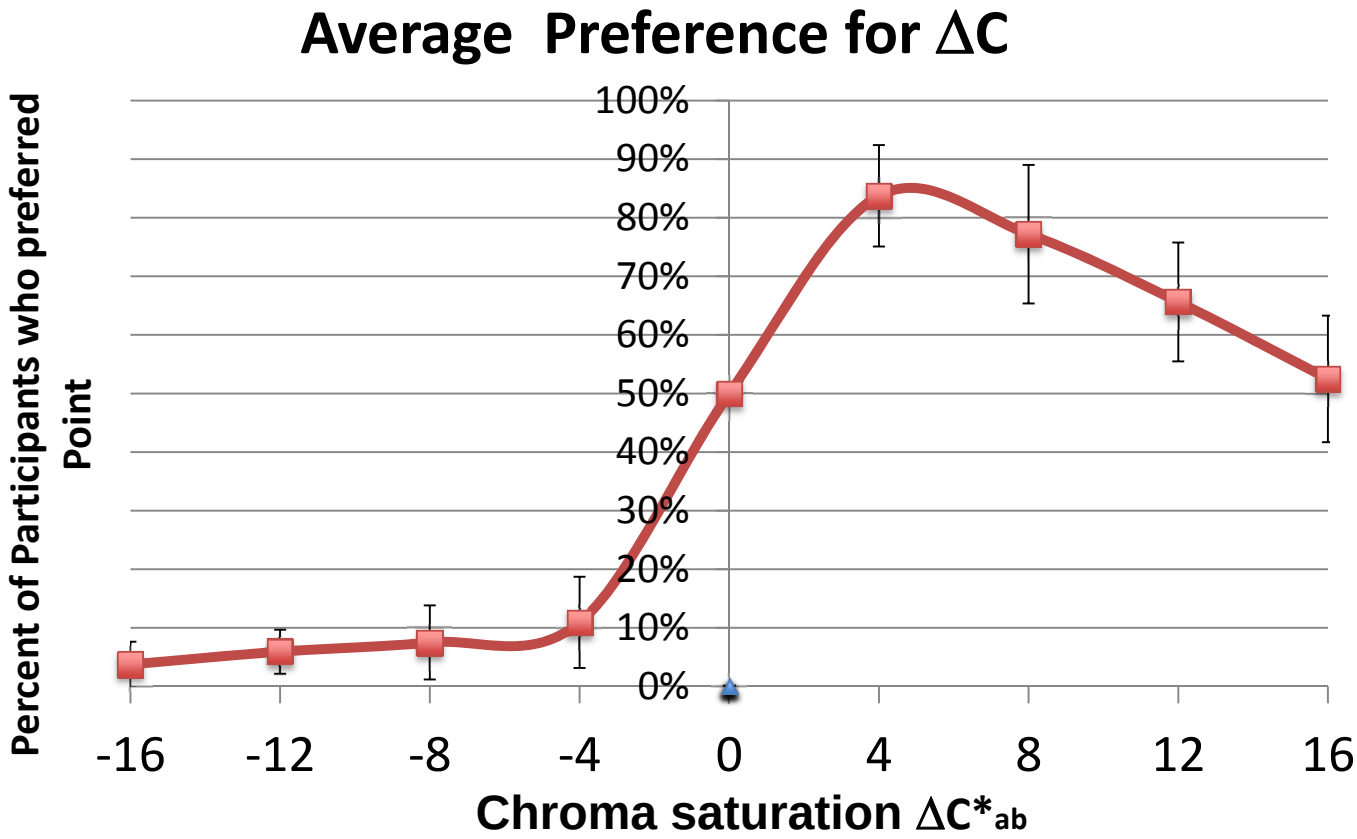




Average Results for all subjects, all CCTs



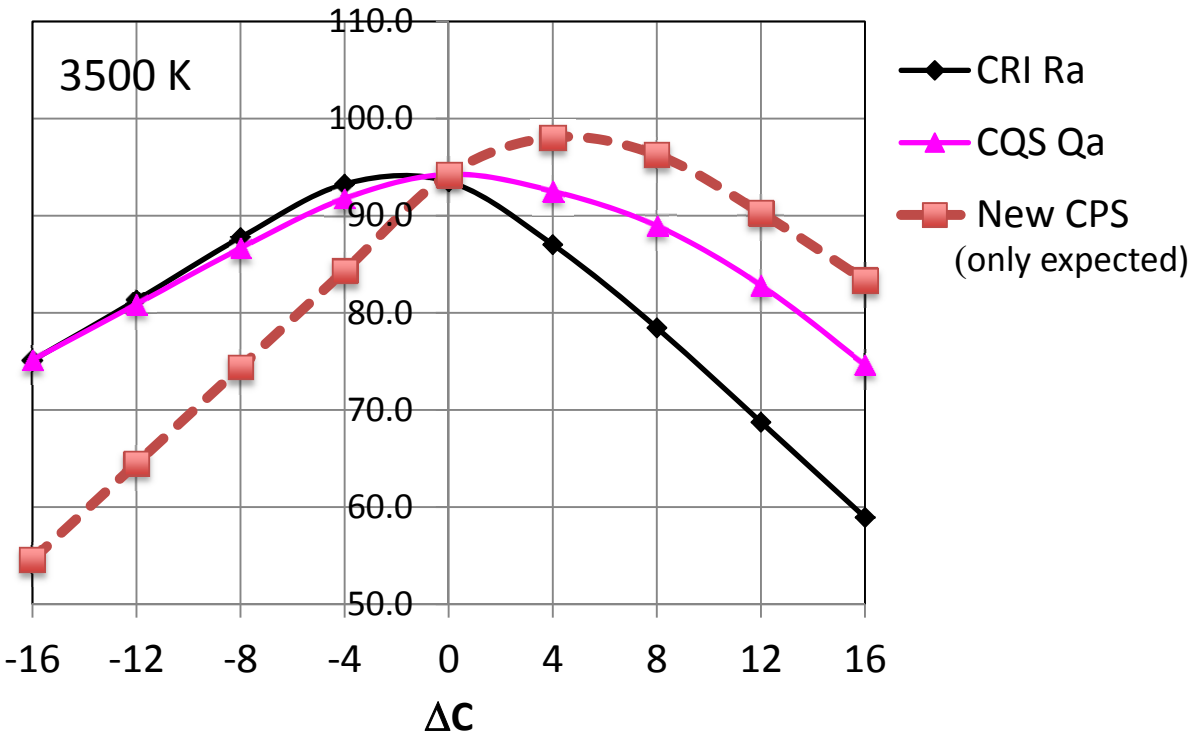
Average Results for all conditions



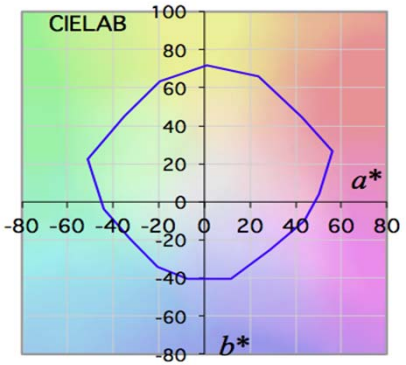
Error bars: standard deviation of 16 values at various conditions and CCTs.

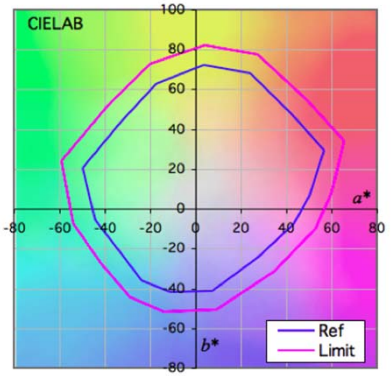
Expected Color Preference Scale

based on the results



Reference Chroma





Conclusions

- Vision experiments have been conducted on the effect of chroma of light on color rendering preference, in typical indoor lighting environment.
- The results showed consistently the most preferred chroma saturation at ΔC around 4 to 8
- De-saturalated lights were clearly not preferred in all cases.
- Almost no differences with CCT in all results.
- A new Color Preference Scale will be developed based on the results.

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THANK YOU FOR YOUR ATTENTION. Contact: ohno@nist.gov