Colorimetria: tra fisica e psicofisica

Speaker:

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Alcune domande

- Cosa è il bianco?
- Vediamo tutti i colori allo stesso modo?
- Nello spettro elettromagnetico dove sta il marrone?
- I daltonici possono guarire?

Da cosa dipende il colore di un oggetto?

- L’oggetto stesso
- Il meccanismo visuale dell’osservatore
- Le qualità spettrali della sorgente luminosa
- Le dimensioni dell’oggetto
- Lo sfondo

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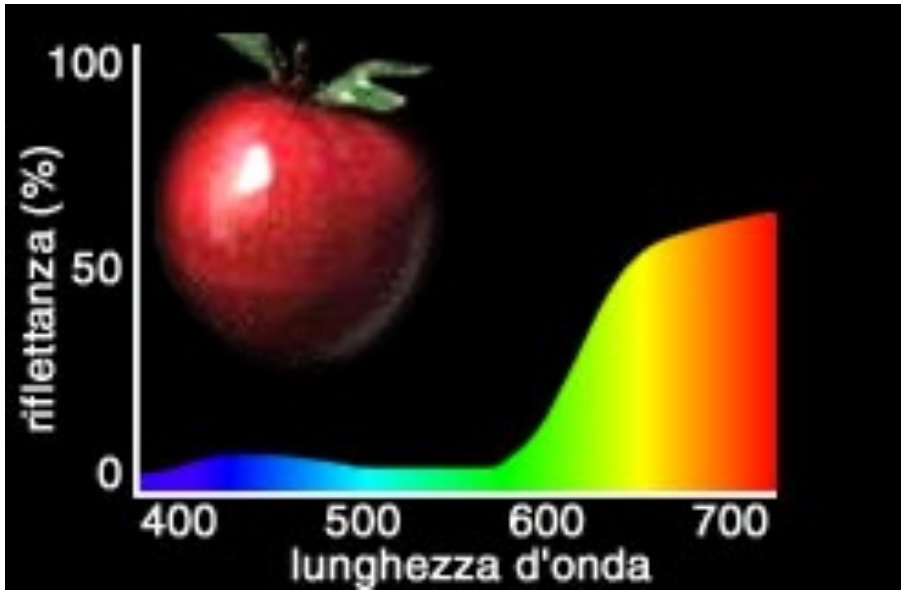
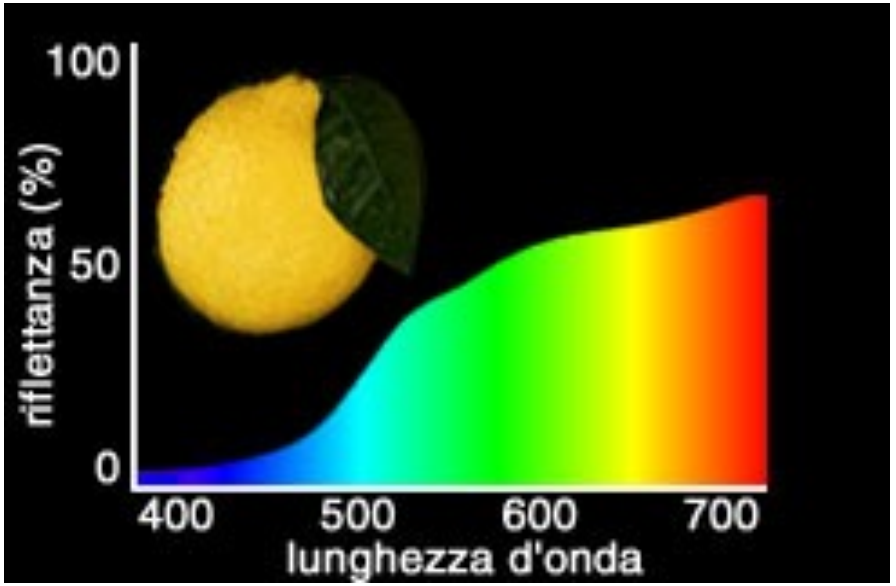
L’oggetto stesso!





Ma noi non “vediamo” mai questo spettro!

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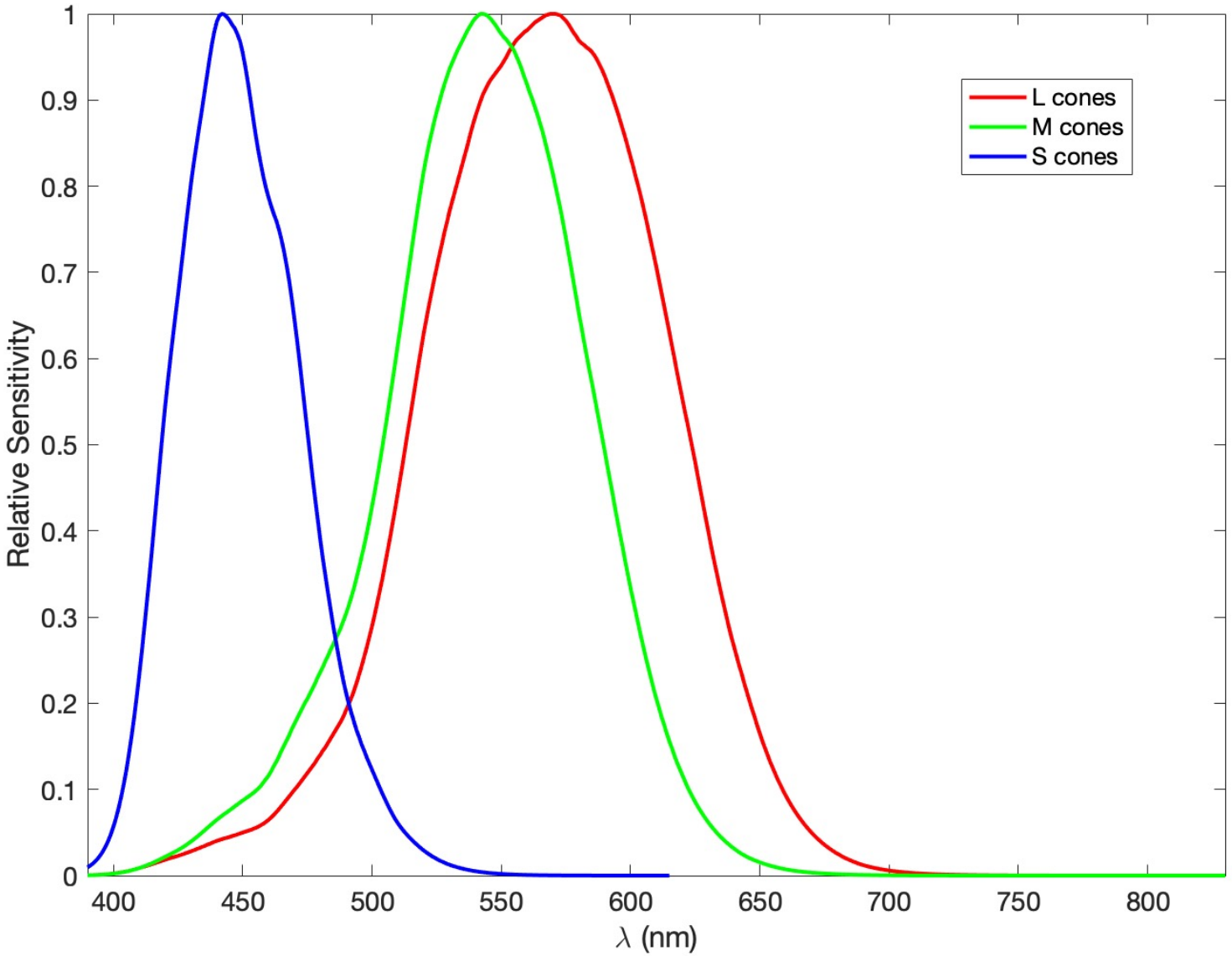
Sensibilità dei coni



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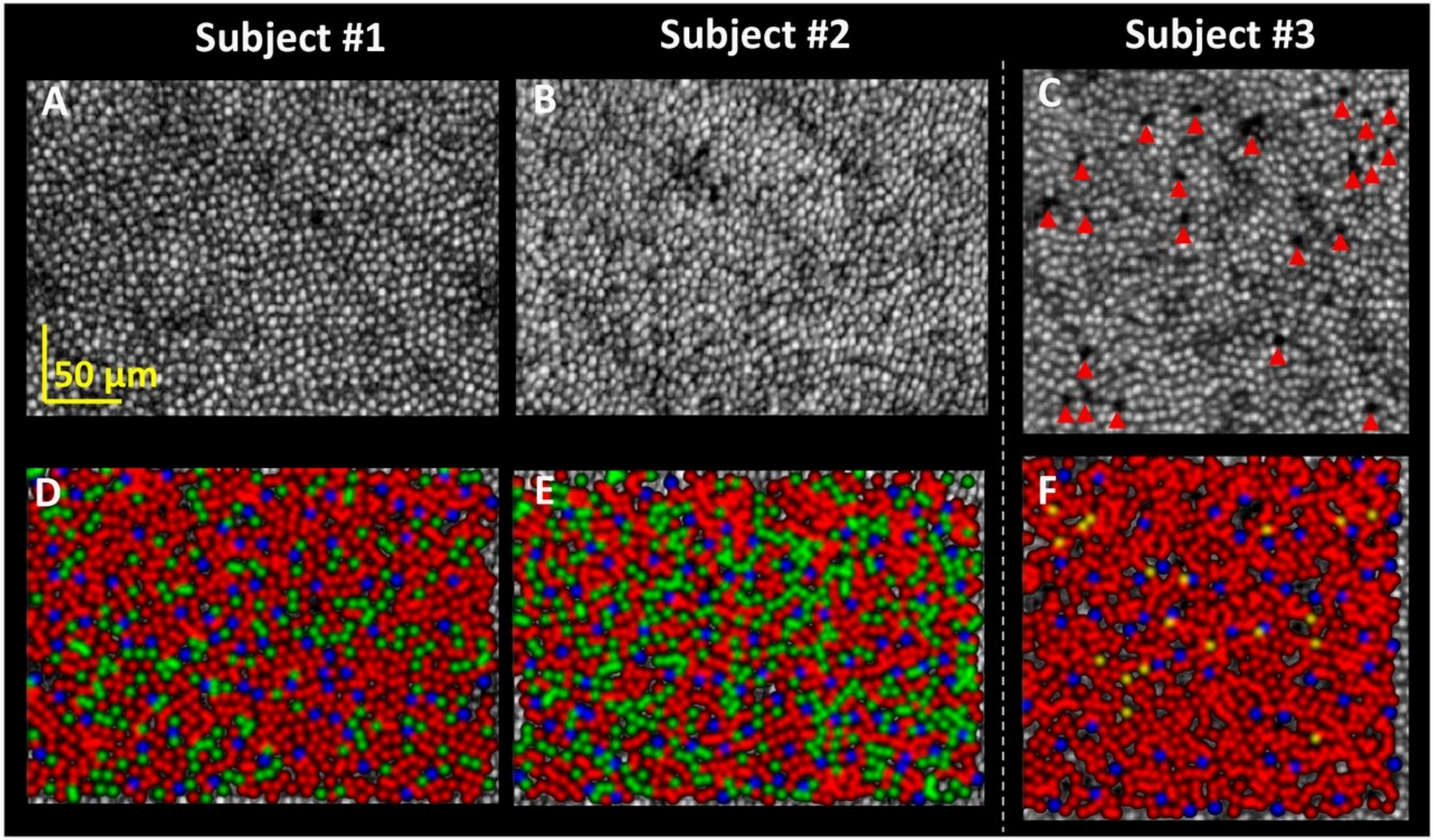
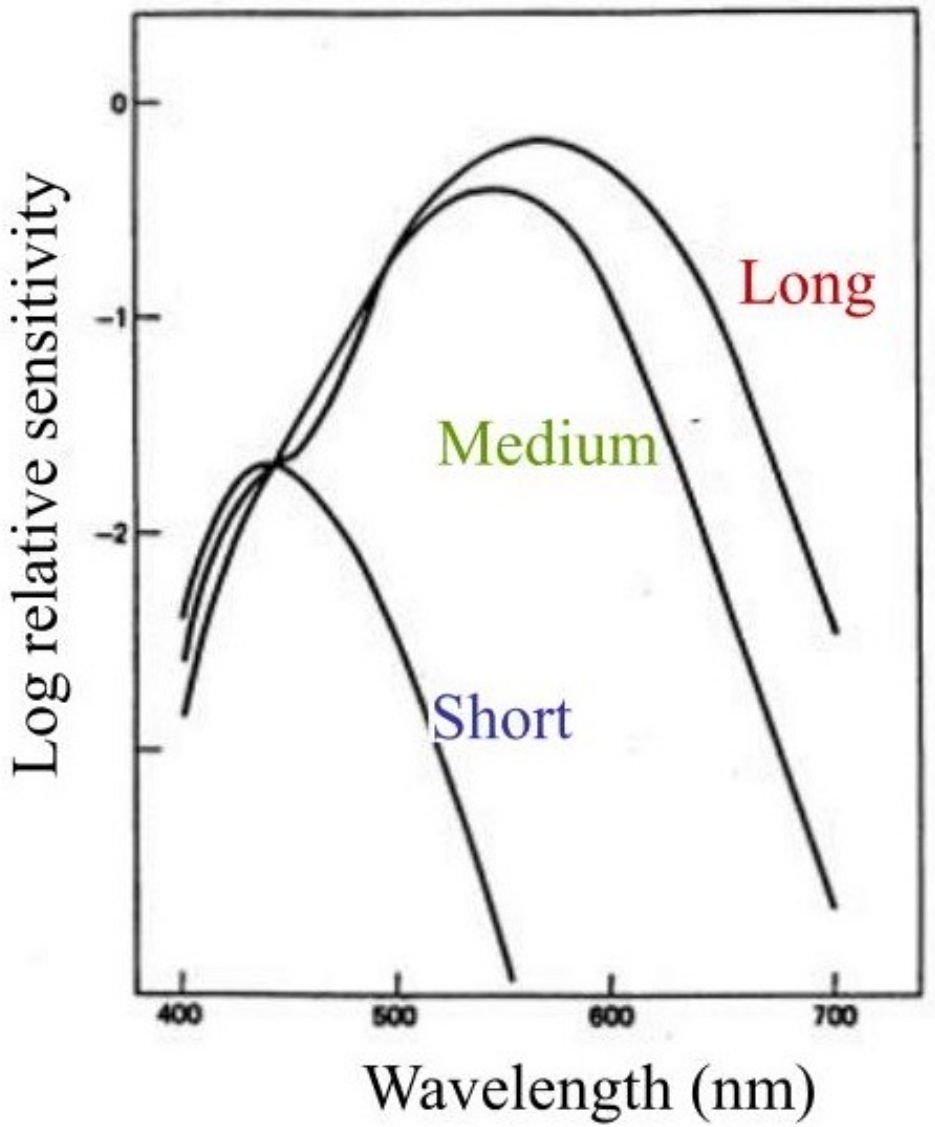
Mapping the trichromatic cone mosaic of the three subjects.



Furu Zhang et al. PNAS 2019;116:16:7951-7956

PNAS

Sensibilità reale



Sensibilità dell'occhio

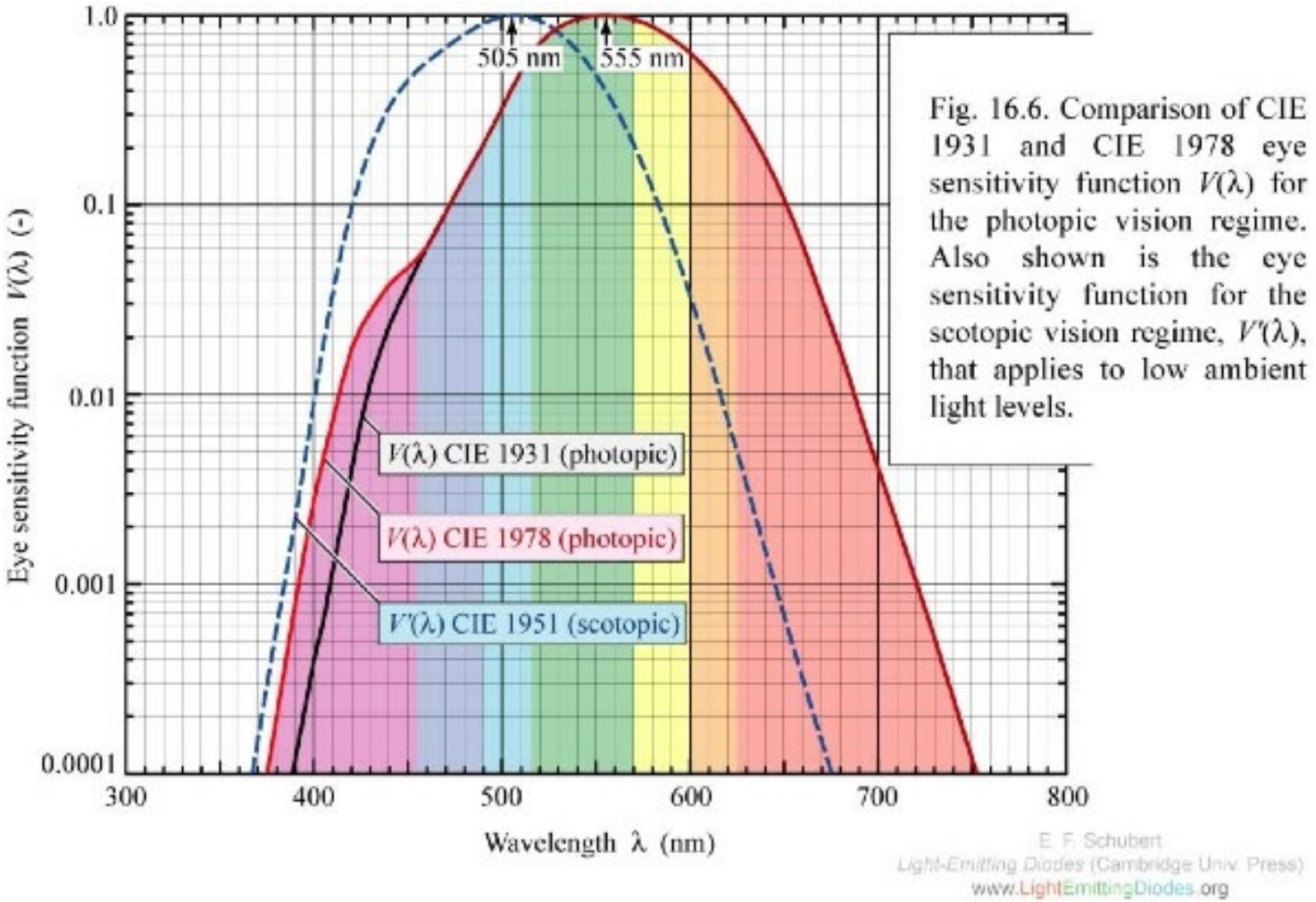


Fig. 16.6. Comparison of CIE 1931 and CIE 1978 eye sensitivity function $V(\lambda)$ for the photopic vision regime. Also shown is the eye sensitivity function for the scotopic vision regime, $V'(\lambda)$, that applies to low ambient light levels.

REGIONE FOTOPICA >3 Cd m^{-2} (CIE 1924)

3 Cd m^{-2} > REGIONE MESOPICA >10^{-3} Cd m^{-2}

10^{-3} Cd m^{-2} > REGIONE SCOTOPICA (CIE 1951)

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Due colori “uguali”

In questo approccio quando due colori X e Y sono indistinguibili li chiameremo uguali: X=Y (è l’eguaglianza metamerica)

Se due distribuzioni spettrali sono indistinguibili, e se sommiamo a ciascuna una certa luce, le nuove misture sono indistinguibili: X+Z=Y+Z

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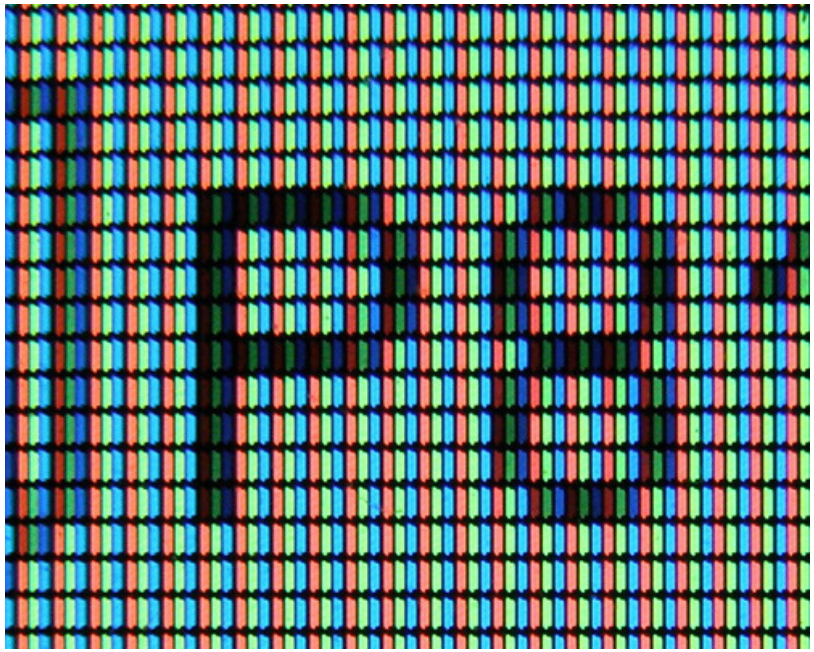
Ancora tre colori!

Tre differenti luci colorate qualsiasi (purché nessuno dei tre colori possa essere ottenuto per mescolanza degli altri due) possono essere mischiate per ottenere qualunque colore

$$X = aA + bB + cC$$

(A patto che la somma sia vista in maniera **algebrica**)



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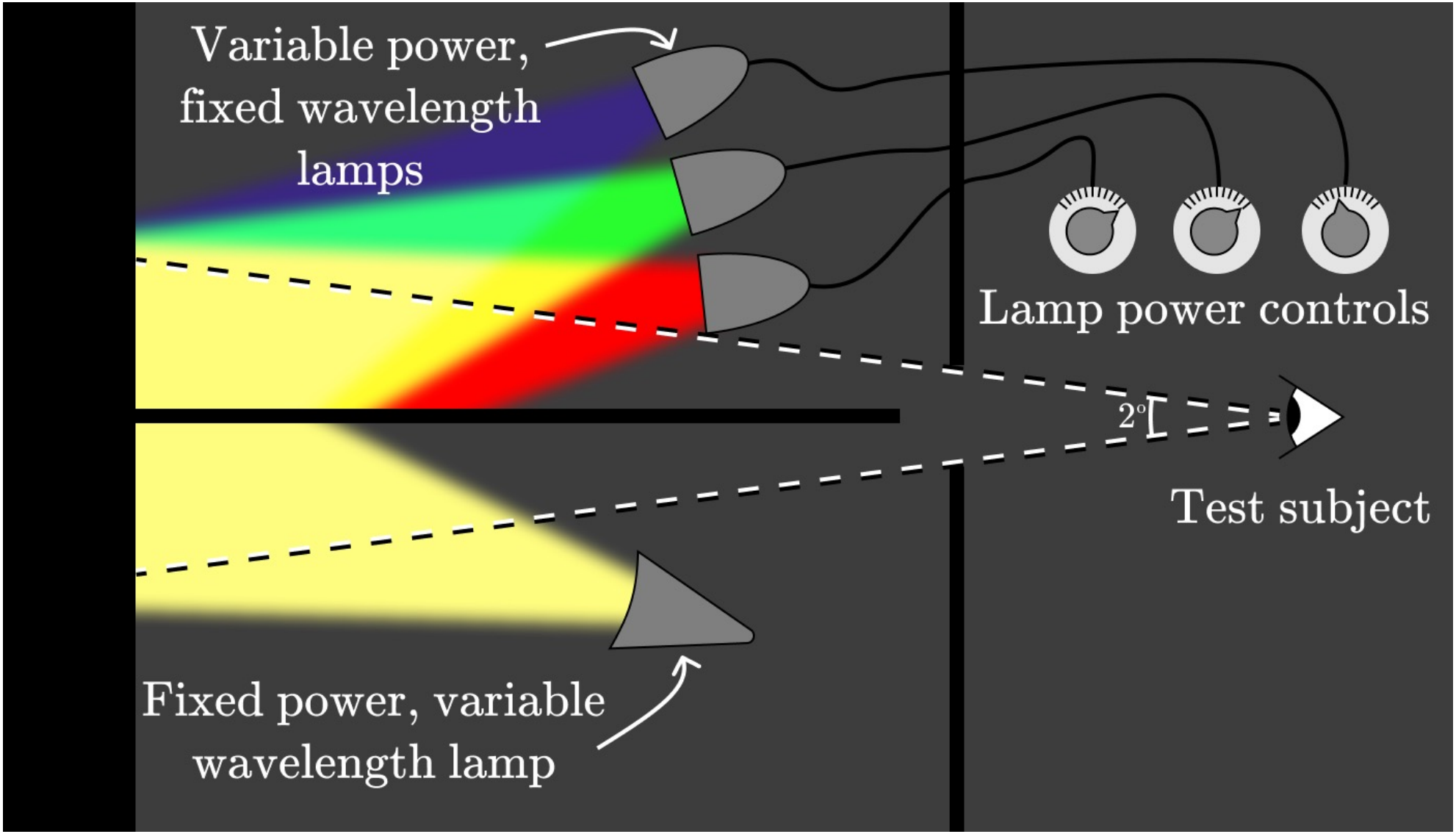
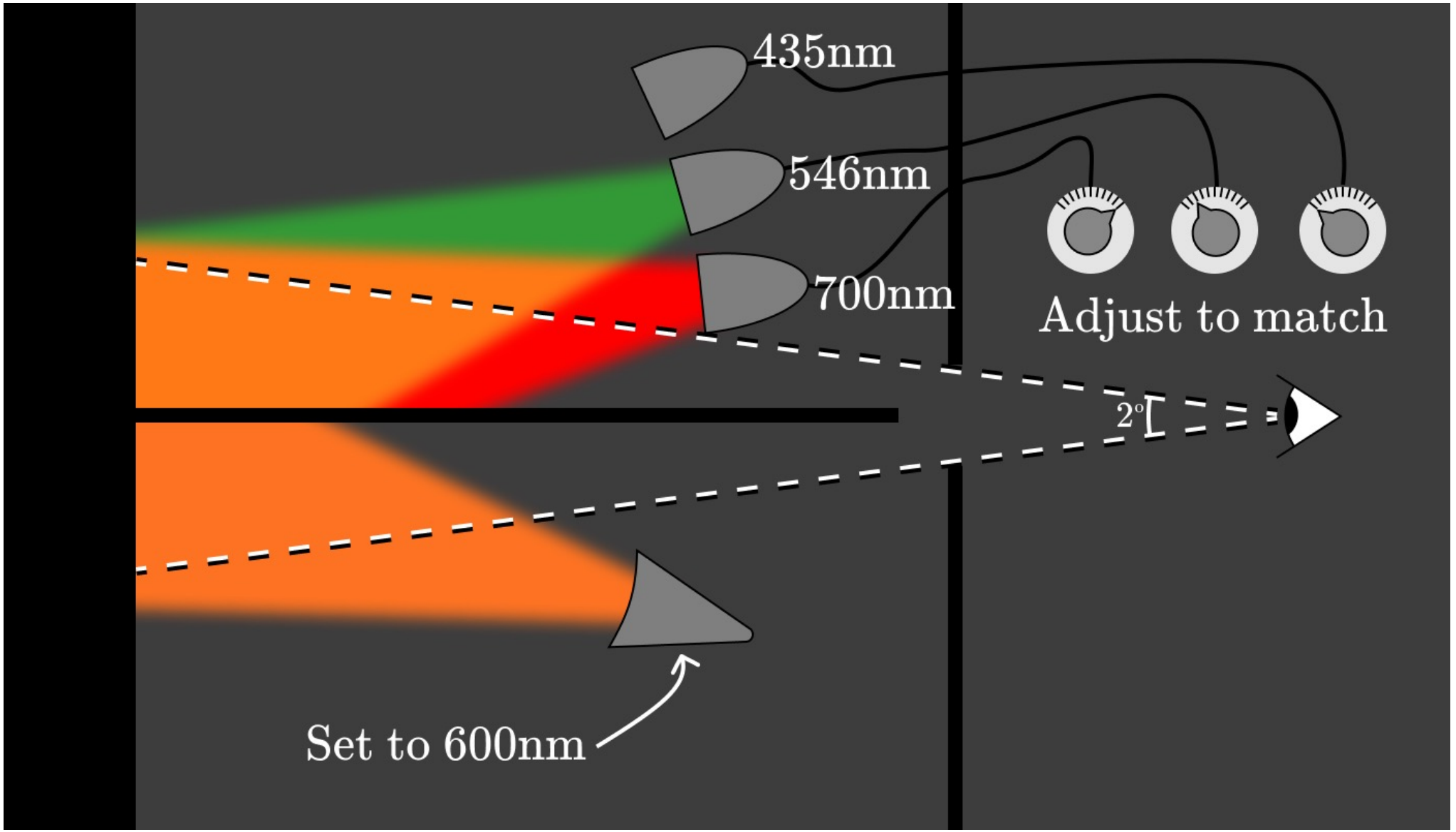
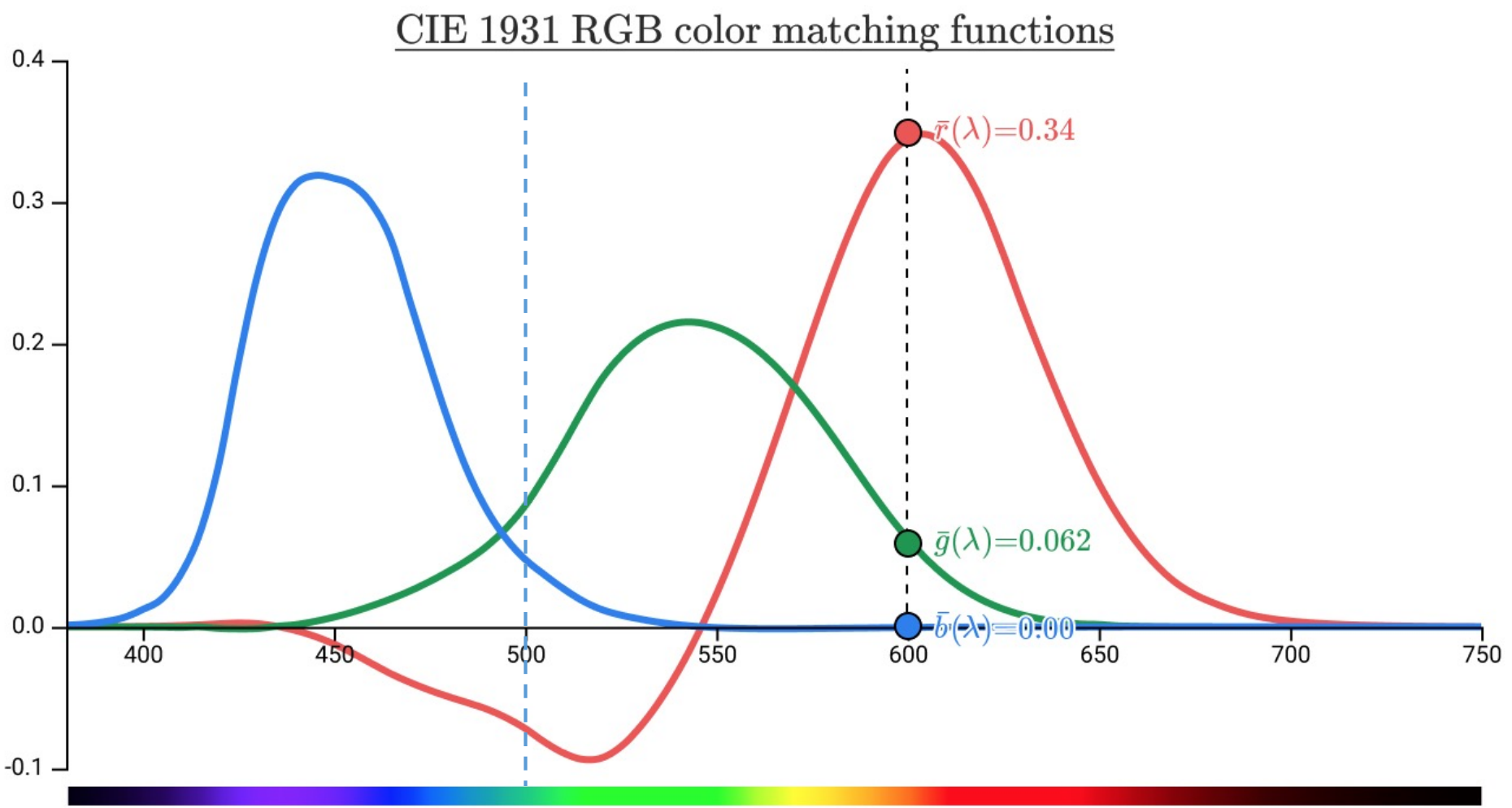
Esperimento di color matching

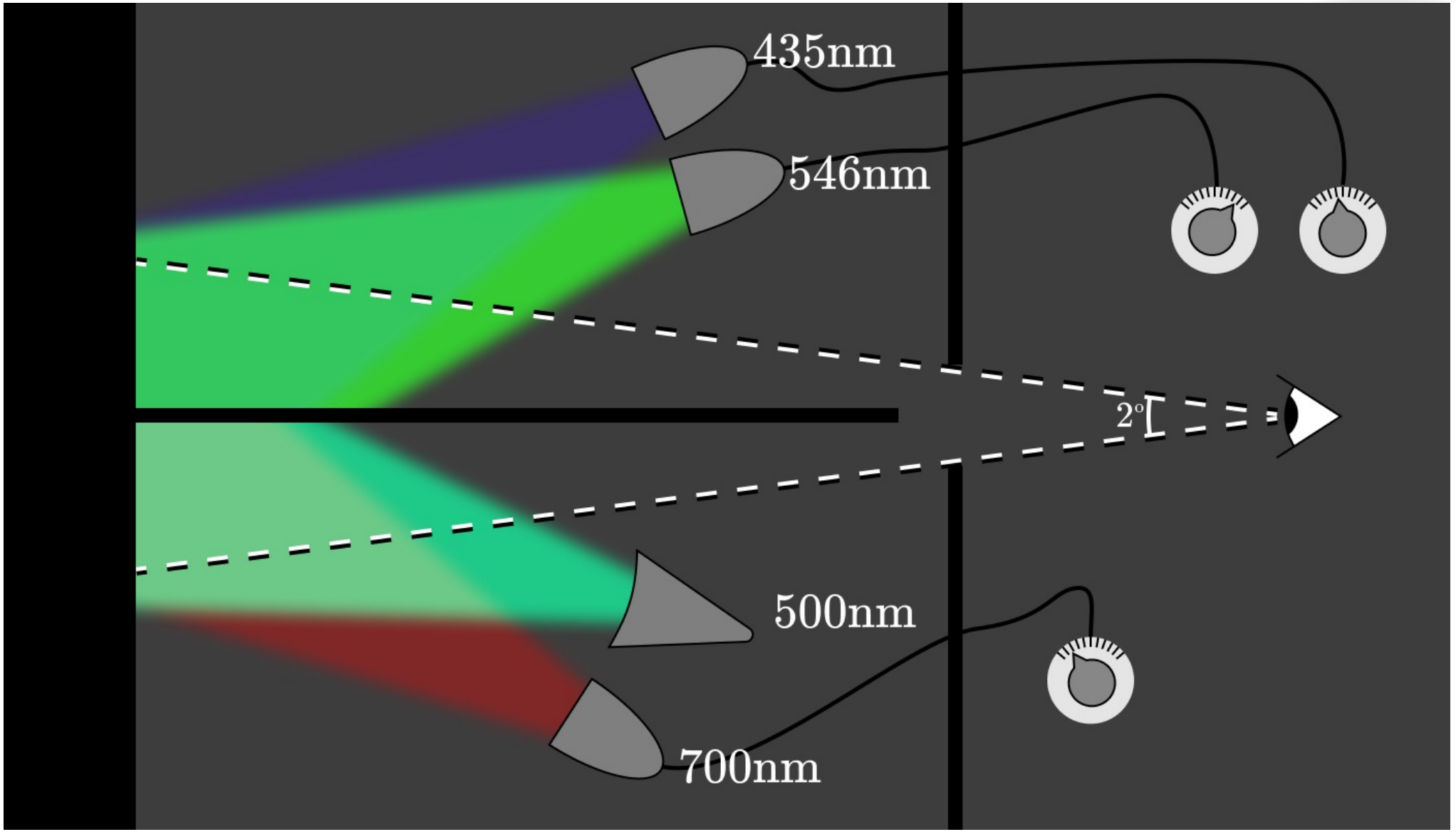


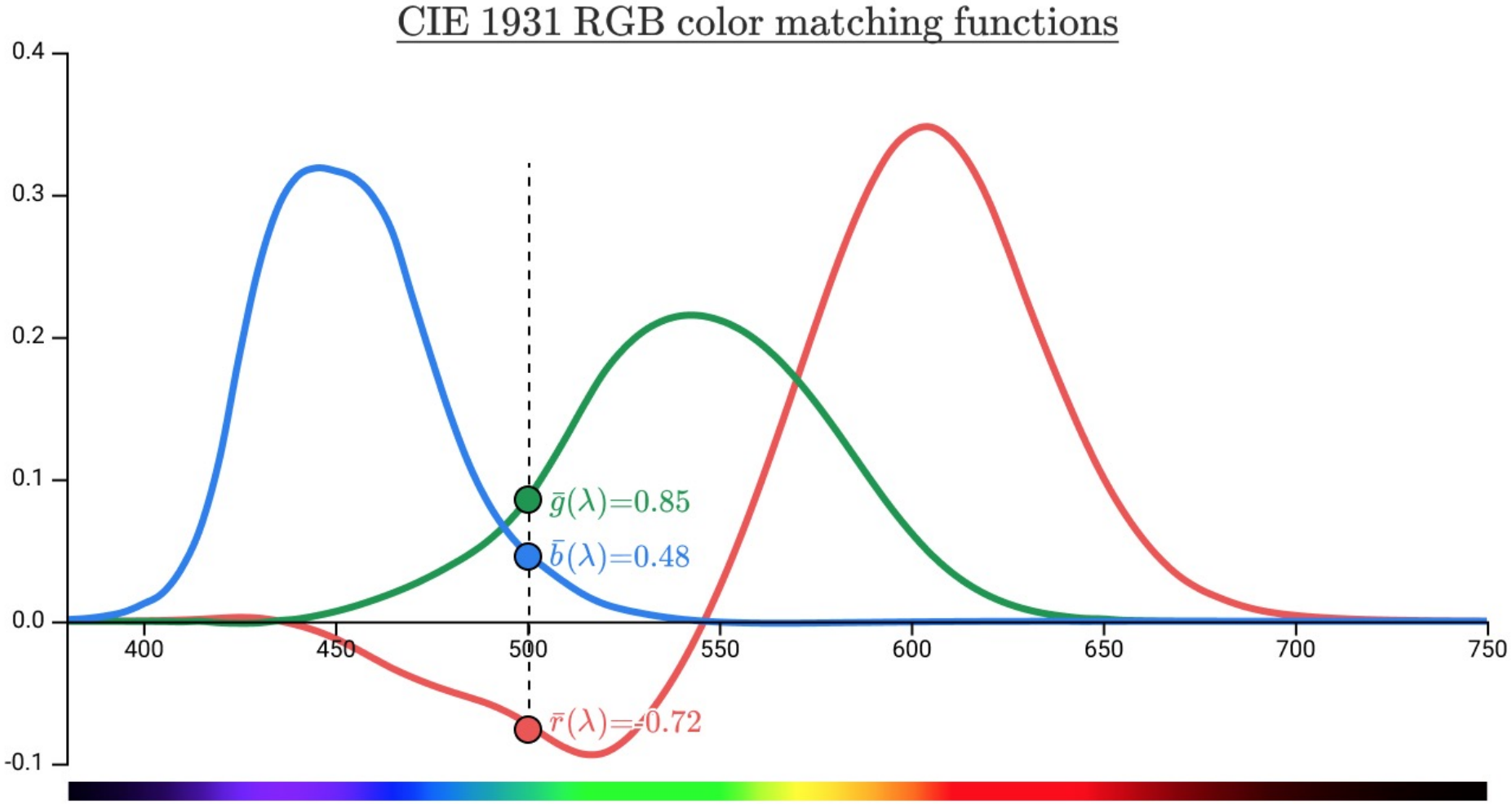
http://jamie-wong.com/post/color/



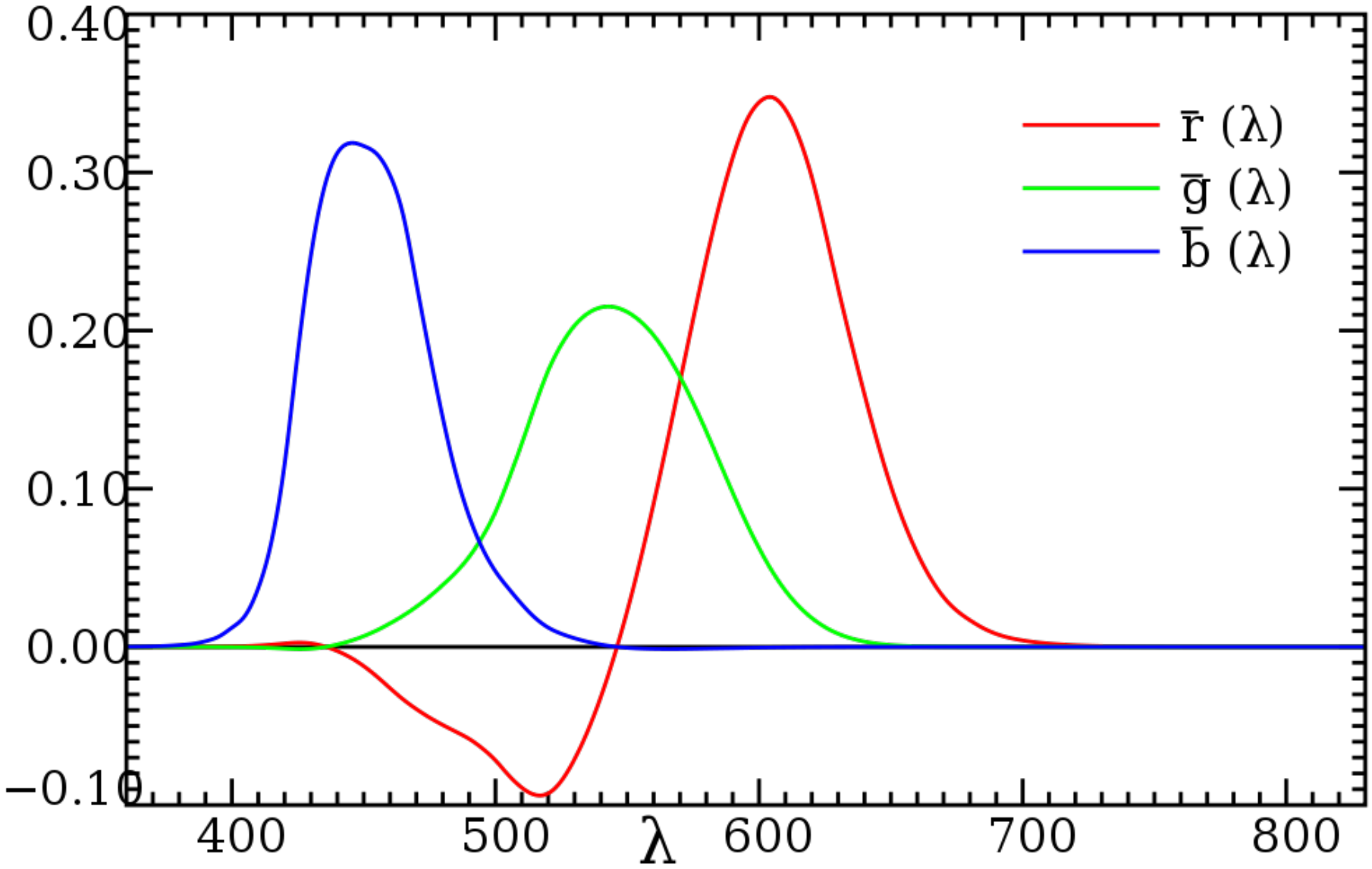
http://jamie-wong.com/post/color/


CIE 1931 RGB color matching functions
0.4
0.3
0.2
0.1
0.0
-0.1
400
450
500
550
600
650
700
750
$\bar{r}(\lambda)=0.34$
$\bar{g}(\lambda)=0.062$
$\bar{b}(\lambda)=0.00$


435nm
546nm
2°
500nm
700nm


CIE 1931 RGB color matching functions
0.4
0.3
0.2
0.1
0.0
-0.1
400
450
500
550
600
650
700
750
$\bar{g}(\lambda)$=0.85
$\bar{b}(\lambda)$=0.48
$\bar{r}(\lambda)$=-0.72

Risultato dell’esperimento di matching



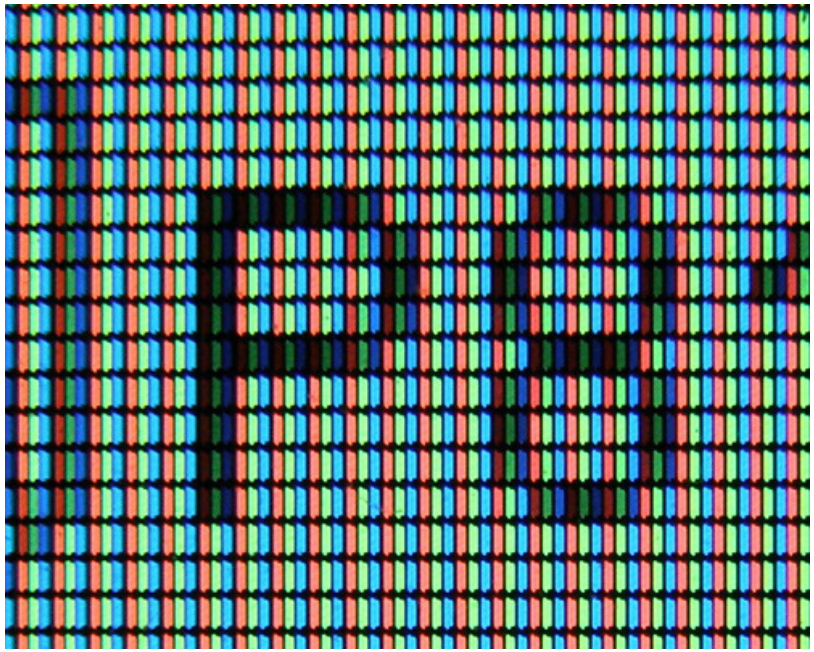
CNRINO

Ancora tre colori!

Tre differenti luci colorate qualsiasi (purché nessuno dei tre colori possa essere ottenuto per mescolanza degli altri due) possono essere mischiate per ottenere qualunque colore

$$X = aA + bB + cC$$

(A patto che la somma sia vista in maniera algebrica)



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Nessuna soluzione

Non esiste nessuna terna di colore che possa riprodurre tutti i colori dello spettro (e men che meno tutti i colori, dato che i colori puri dello spettro ne sono un sottoinsieme)

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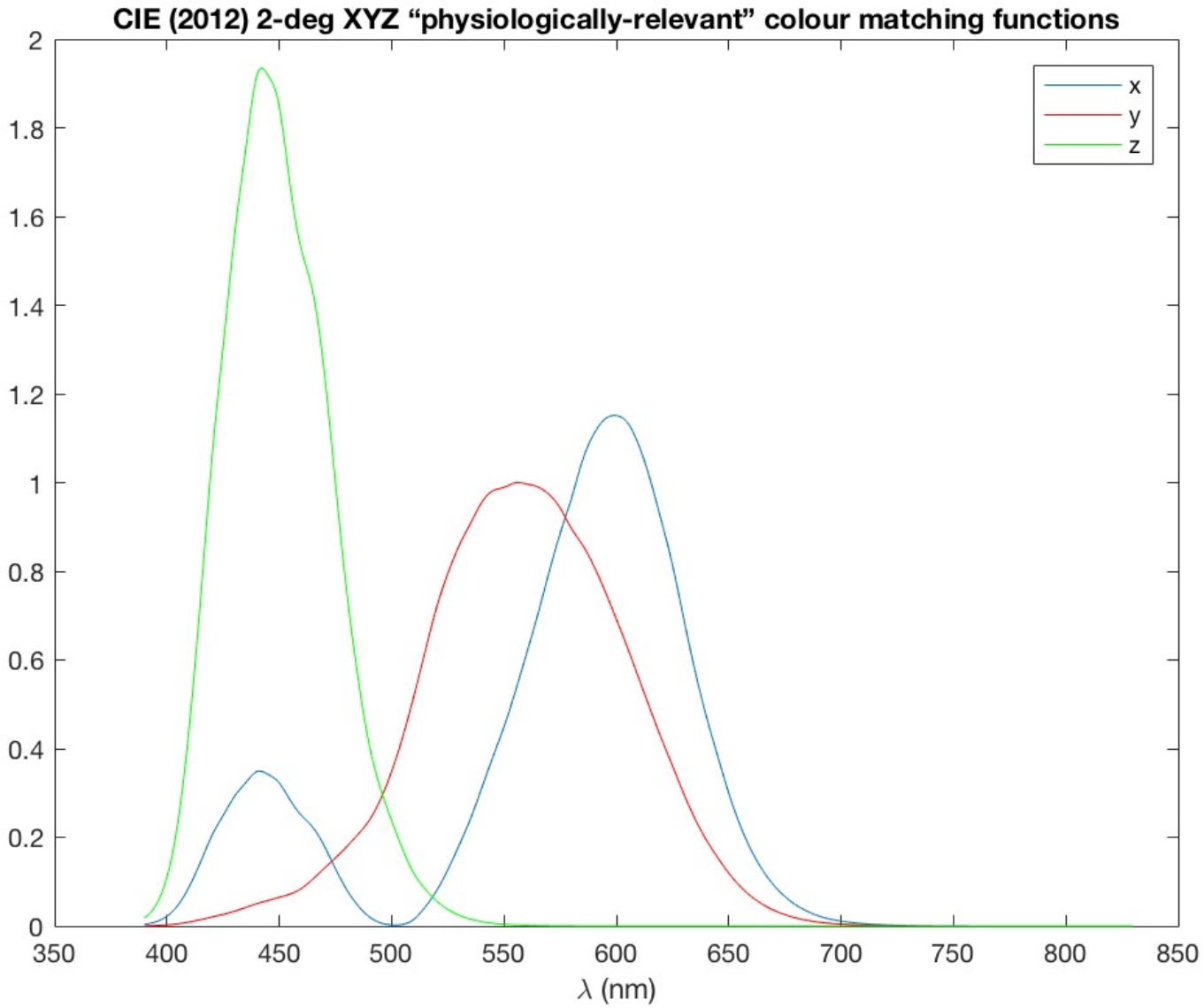
CIE (2012) 2-deg XYZ “physiologically-relevant” colour matching functions



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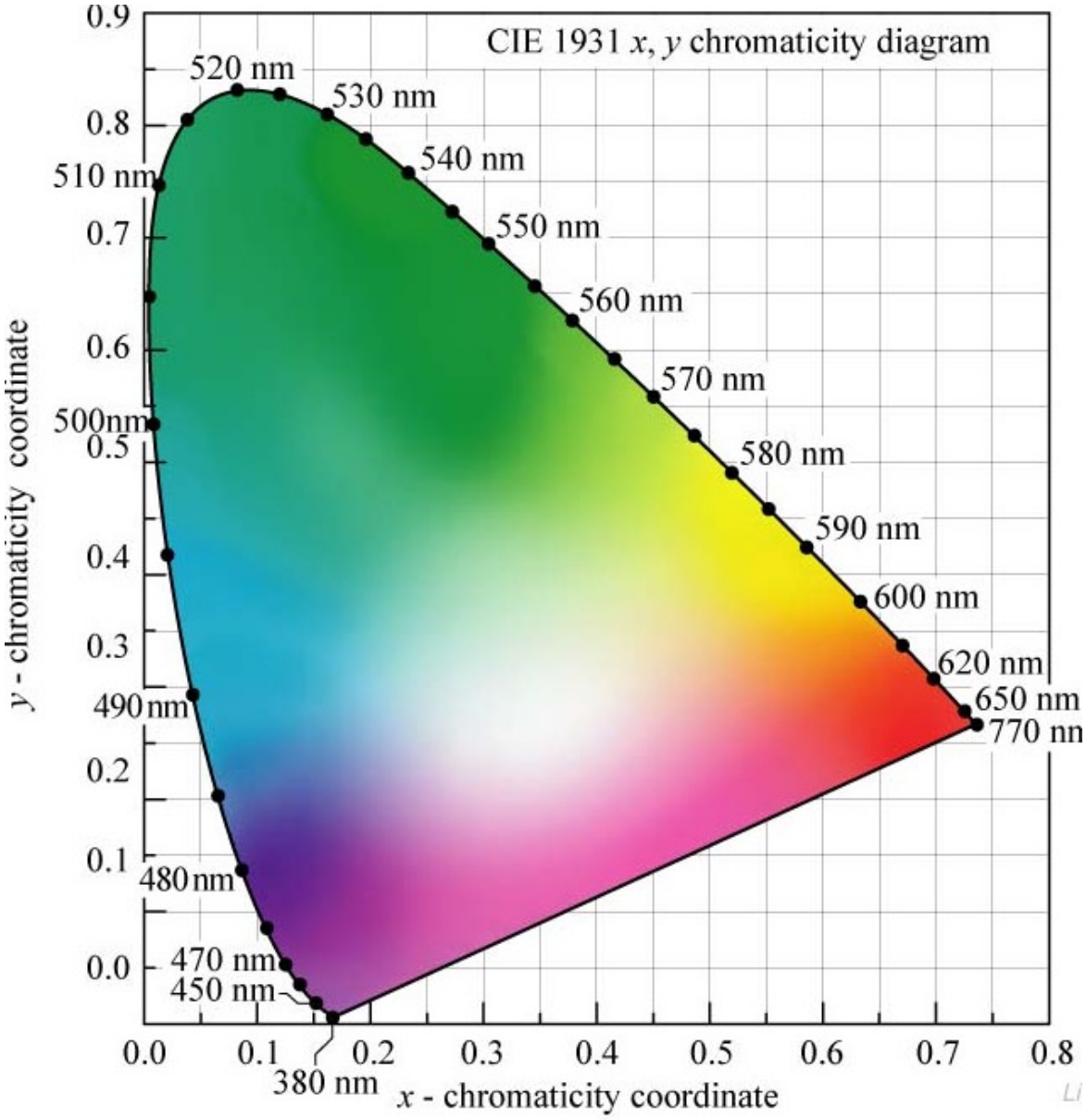
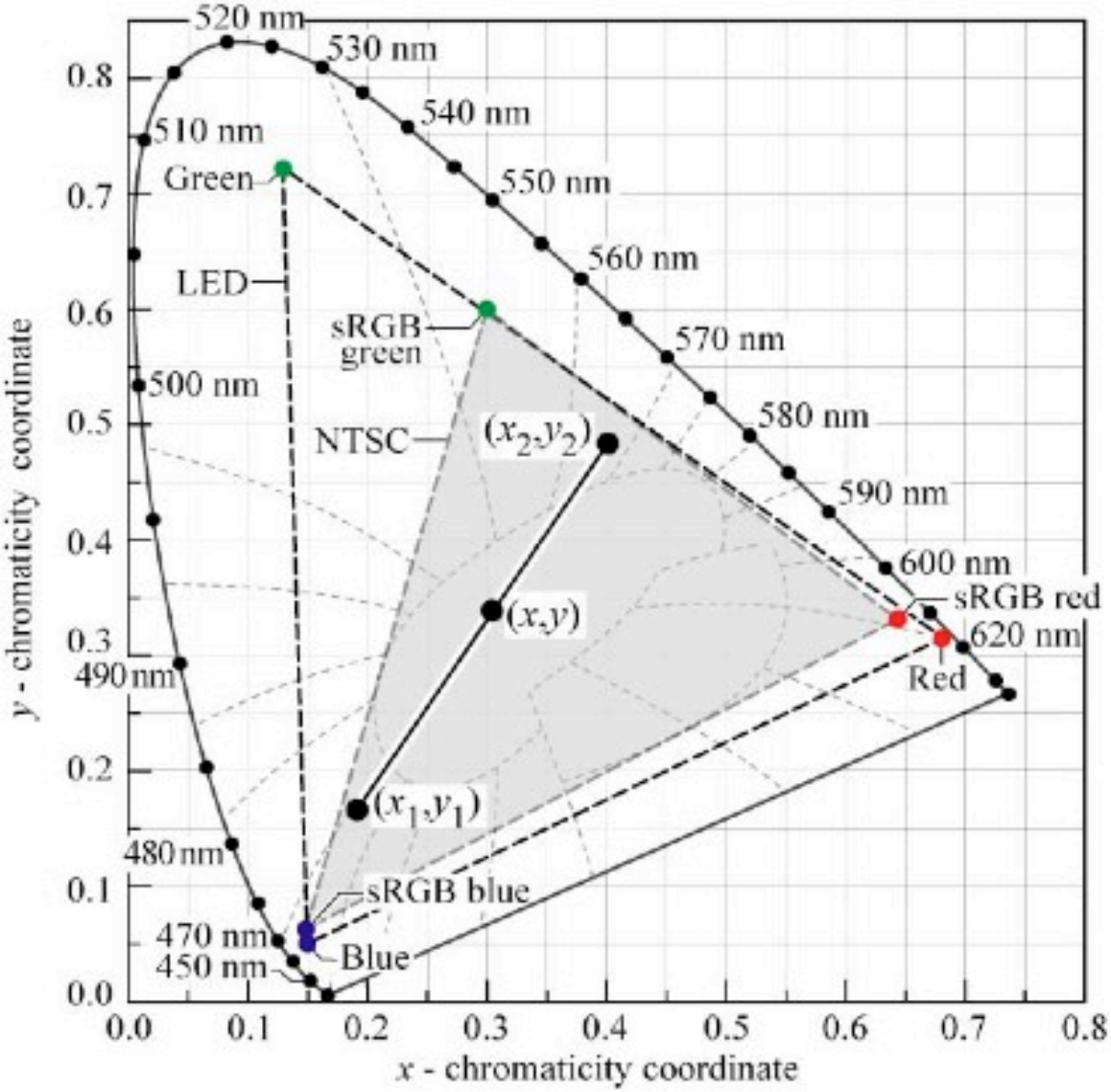
CIE 1931


CIE 1931 x, y chromaticity diagram
520 nm
530 nm
540 nm
550 nm
560 nm
570 nm
580 nm
590 nm
600 nm
620 nm
650 nm
770 nn
510 nm
500nm
490 nm
480 nm
470 nm
450 nm
380 nm
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
y - chromaticity coordinate
x - chromaticity coordinate

Quali colori si ottengono?



Anche usando 5, 6, 7 colori di base non è possible ottenerli tutti

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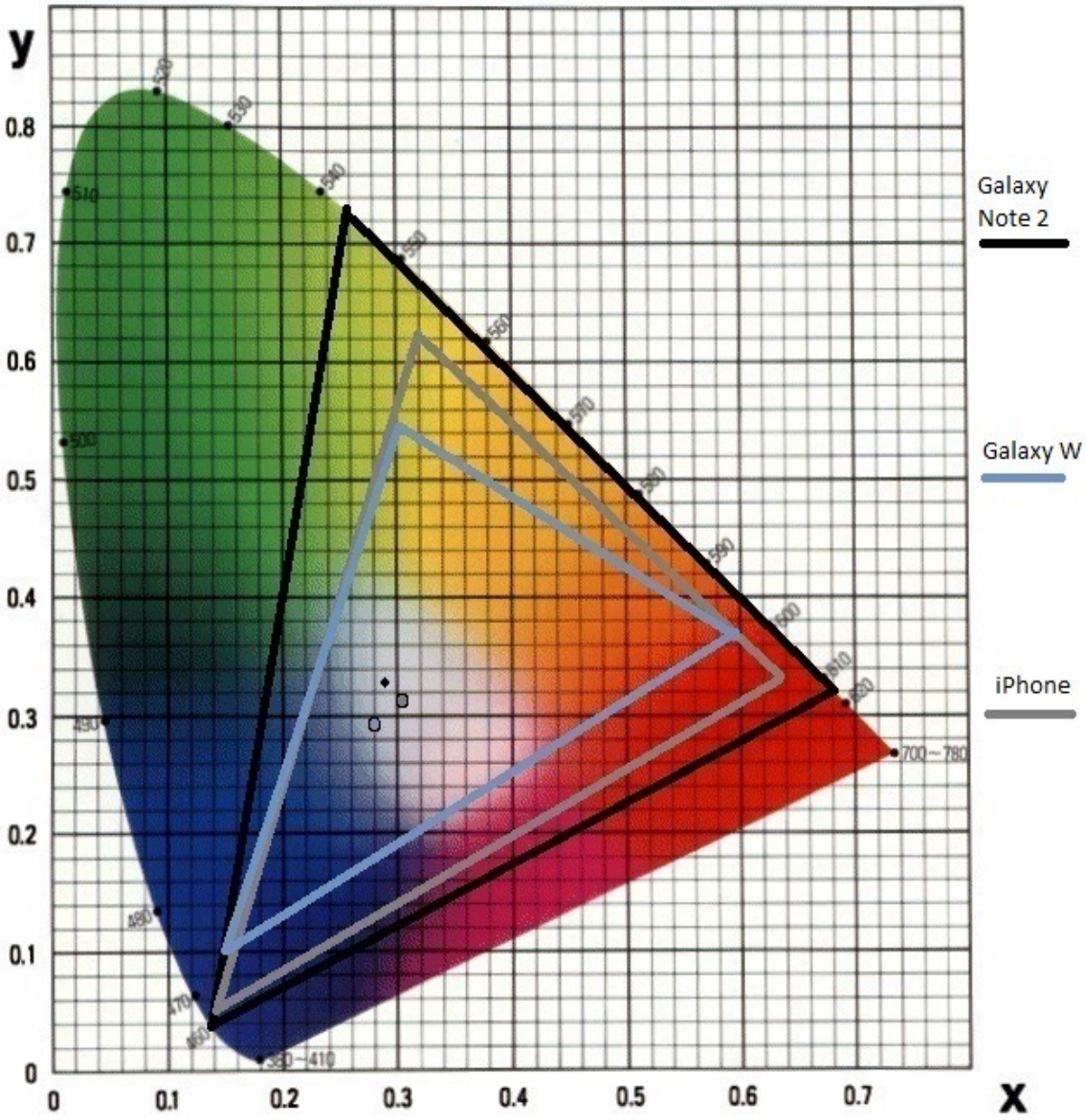
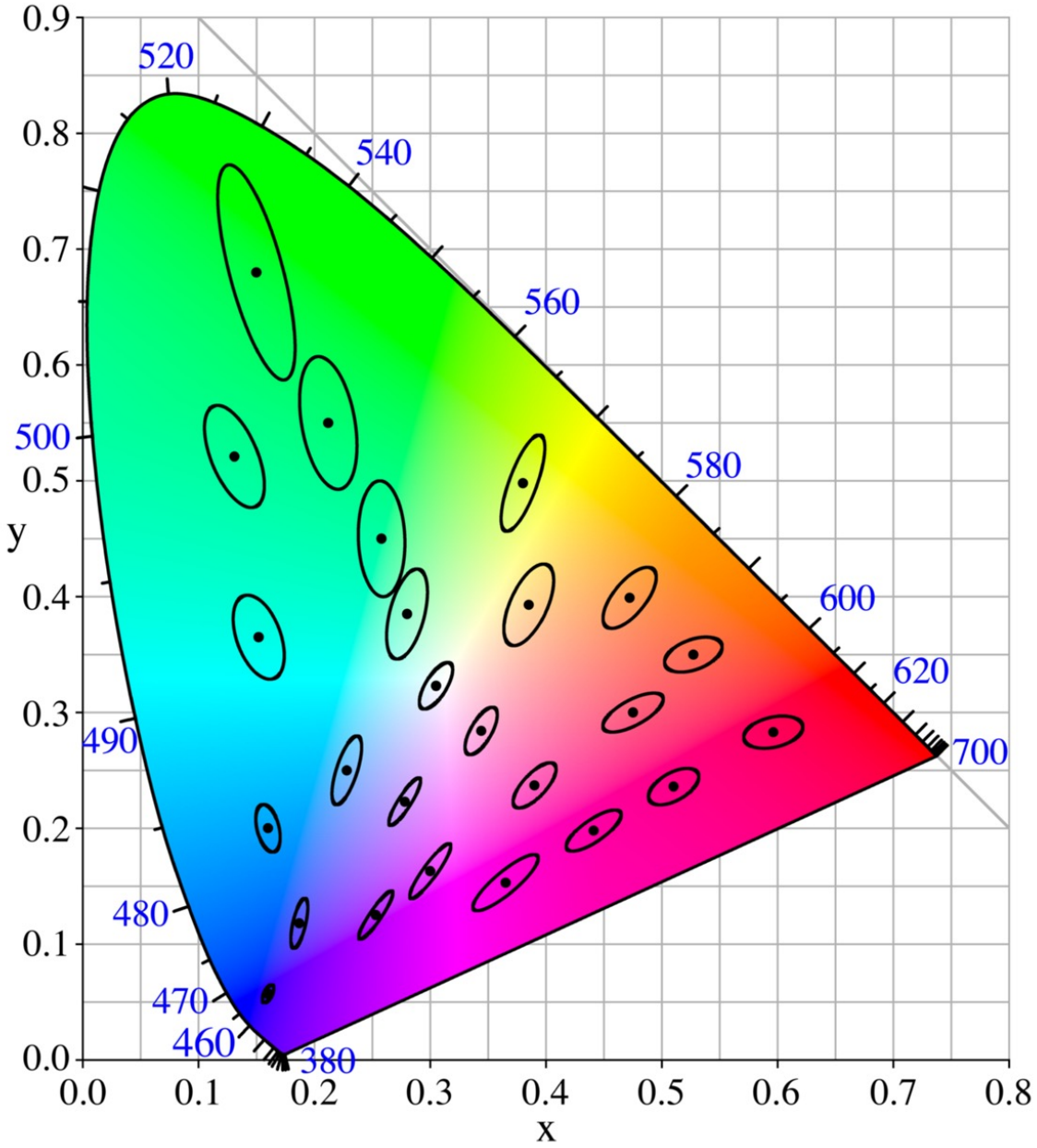
Colour gamut



Ellissi di Mac Adam e non linearità



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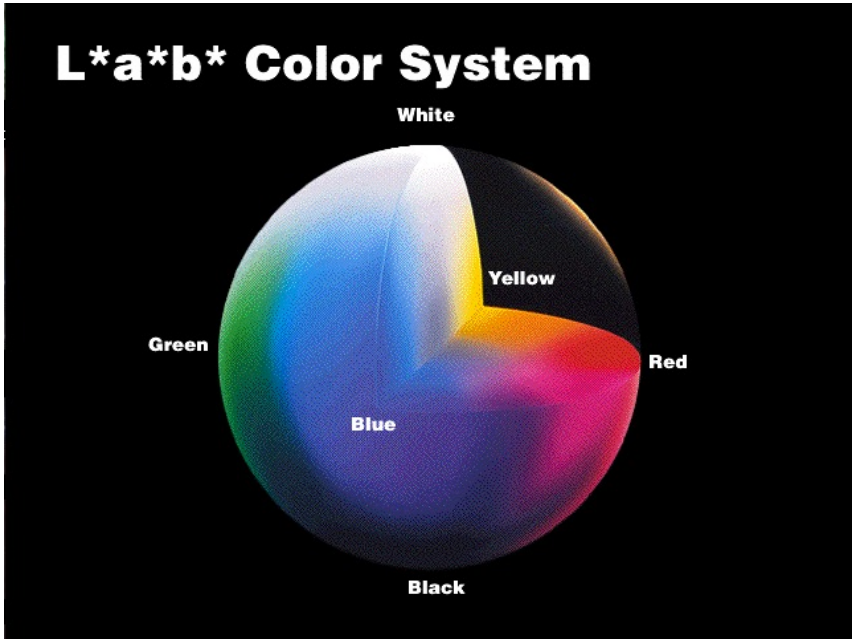
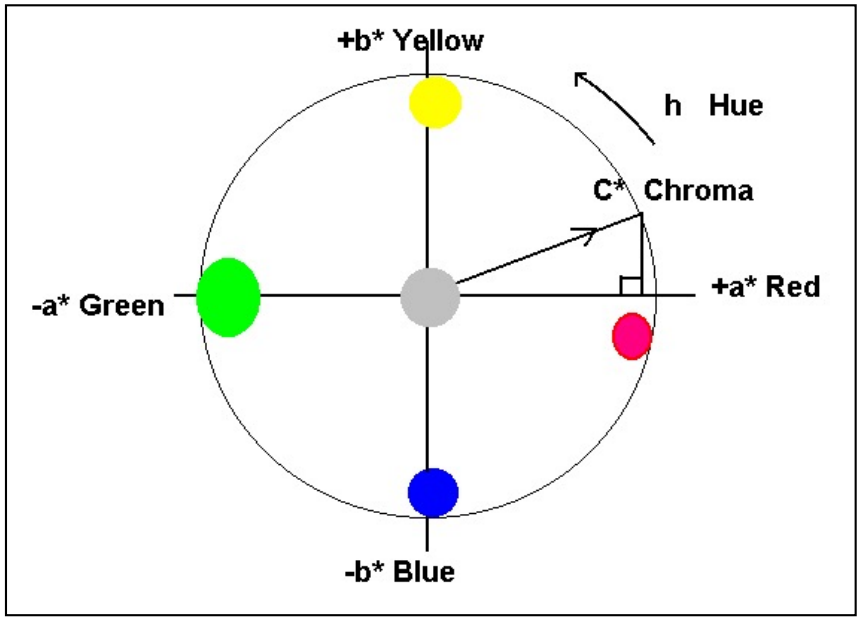
Miglioramenti di CIE 1931

- **Lab**
- **LCh**
- **HLab**
- **CMC**





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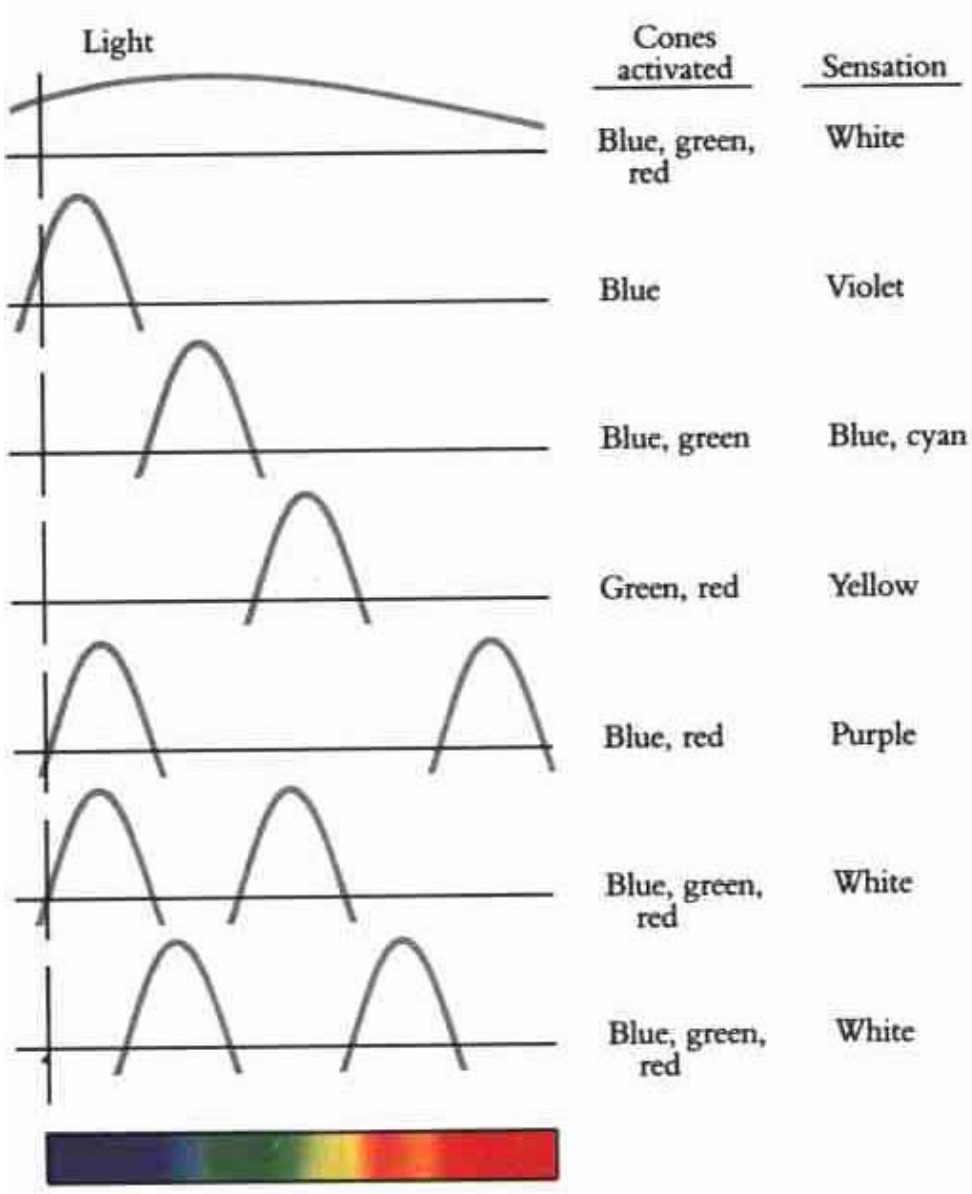
Tanti spazi colore (and counting)

		Historical steps/stages of vision/systems		
		First stage of vision: transduction	Second stage of vision: colour difference and illuminant discounting	Third stage of vision: colour appearance and adaptation
		Psychophysics (Chapter 9)	Psychometrics (Chapter 11)	Colour appearance
visual	Visual field < 4°	CIE 1931 standard observer (X, Y, Z),	CIELUV system (L^*, u^*, v^*) CIELAB system (L^*, a^*, b^*)	CIECAM97 CIECAM02 Retinex
		Vos observer 2° CIE fundamental observer		
field	10° visual field	CIE 1964 supplementary standard observer (X_{10}, Y_{10}, Z_{10})	CIELUV system (L^*_{10}, u^*_{10}, v^*_{10}) CIELAB system (L^*_{10}, a^*_{10}, b^*_{10})	
		10° CIE fundamental observer		

Stessa percezione, diverso spettro



La sensazione di bianco può essere dovuta a uno spettro continuo, ma anche addirittura a due radiazioni colorate

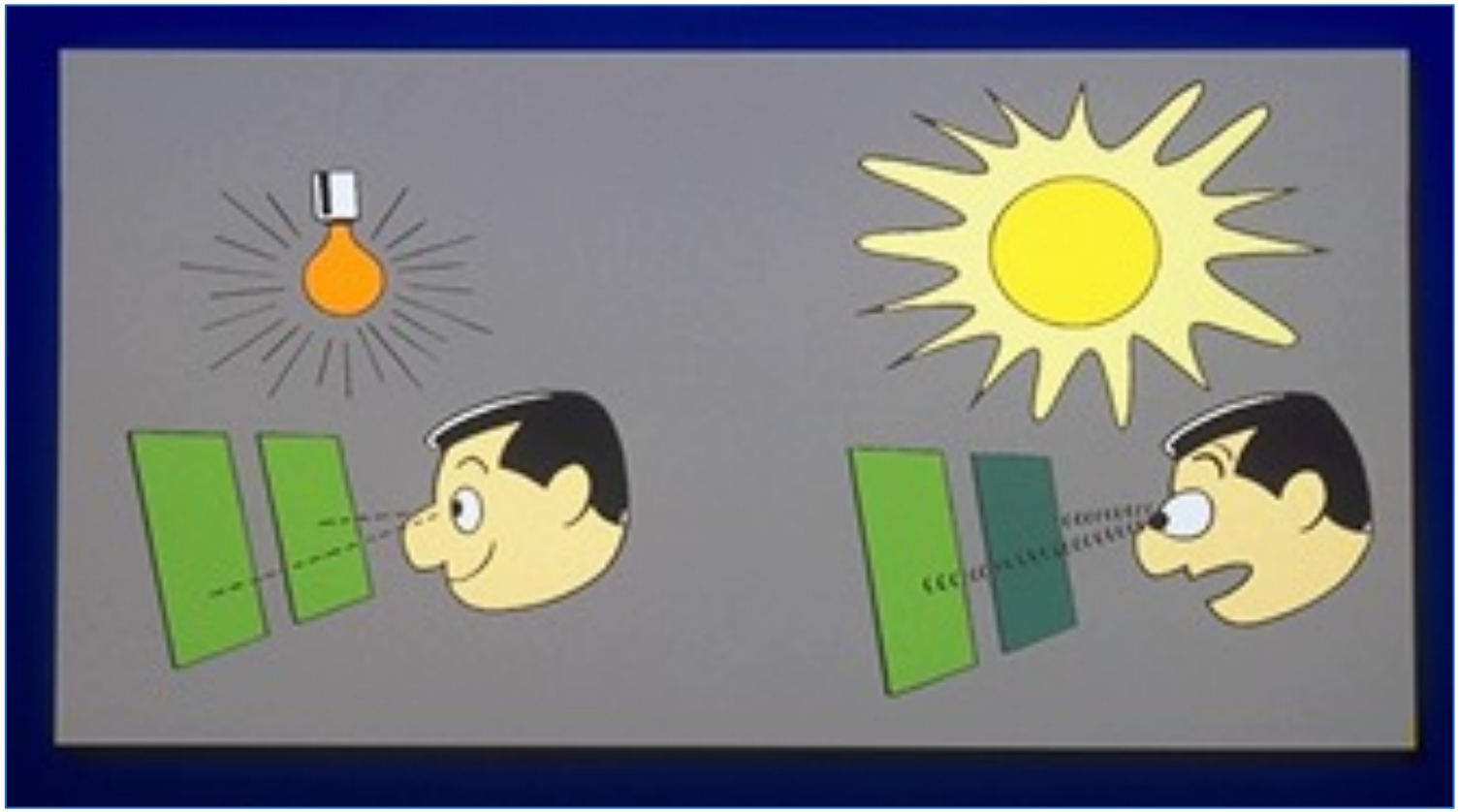
Non è vero che il bianco è la somma di tutti i colori

E' vero che la somma di tutti i colori è bianco

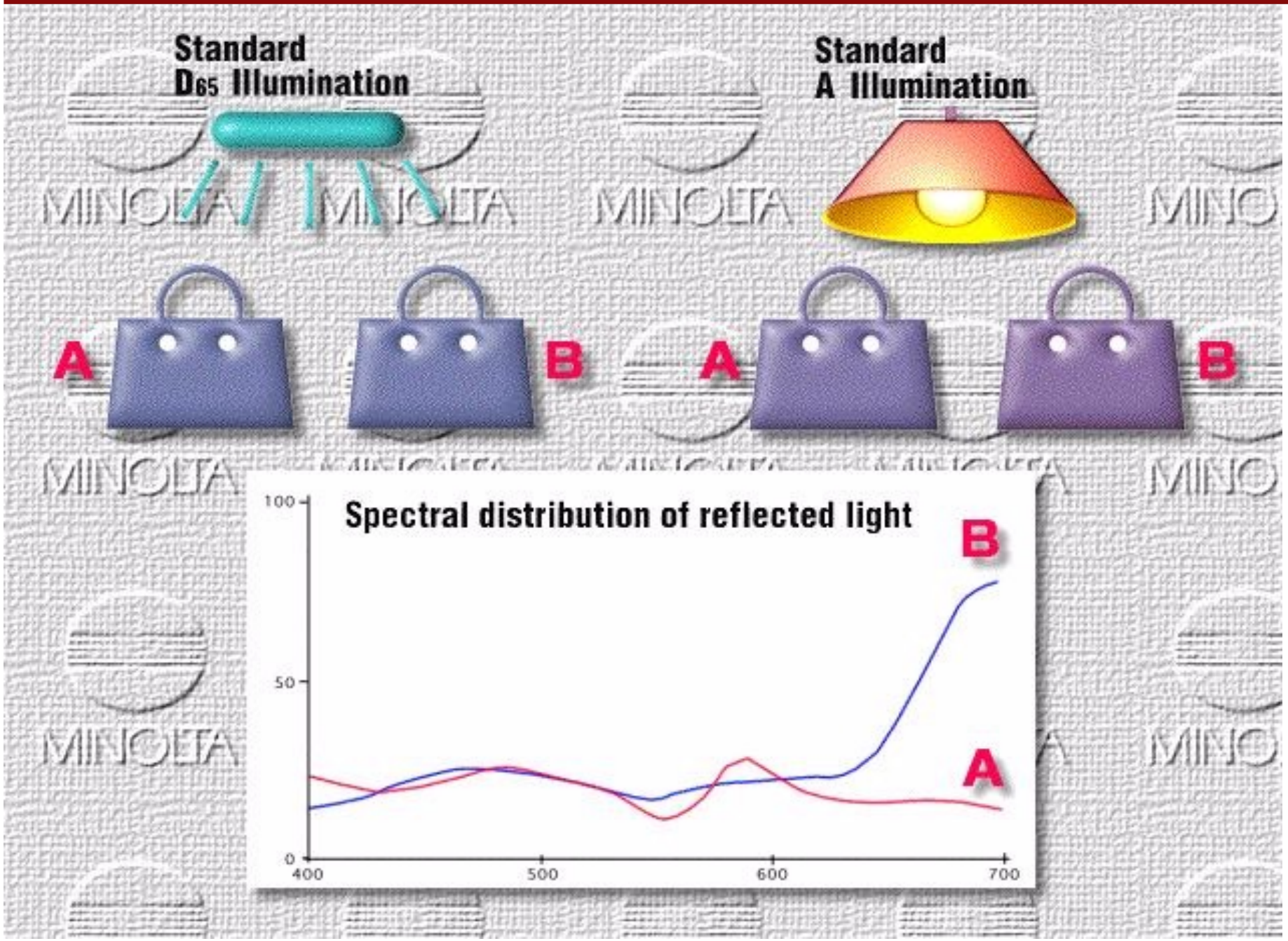
Ma il bianco di uno spettro continuo è come l'altro bianco?

Il metamerismo

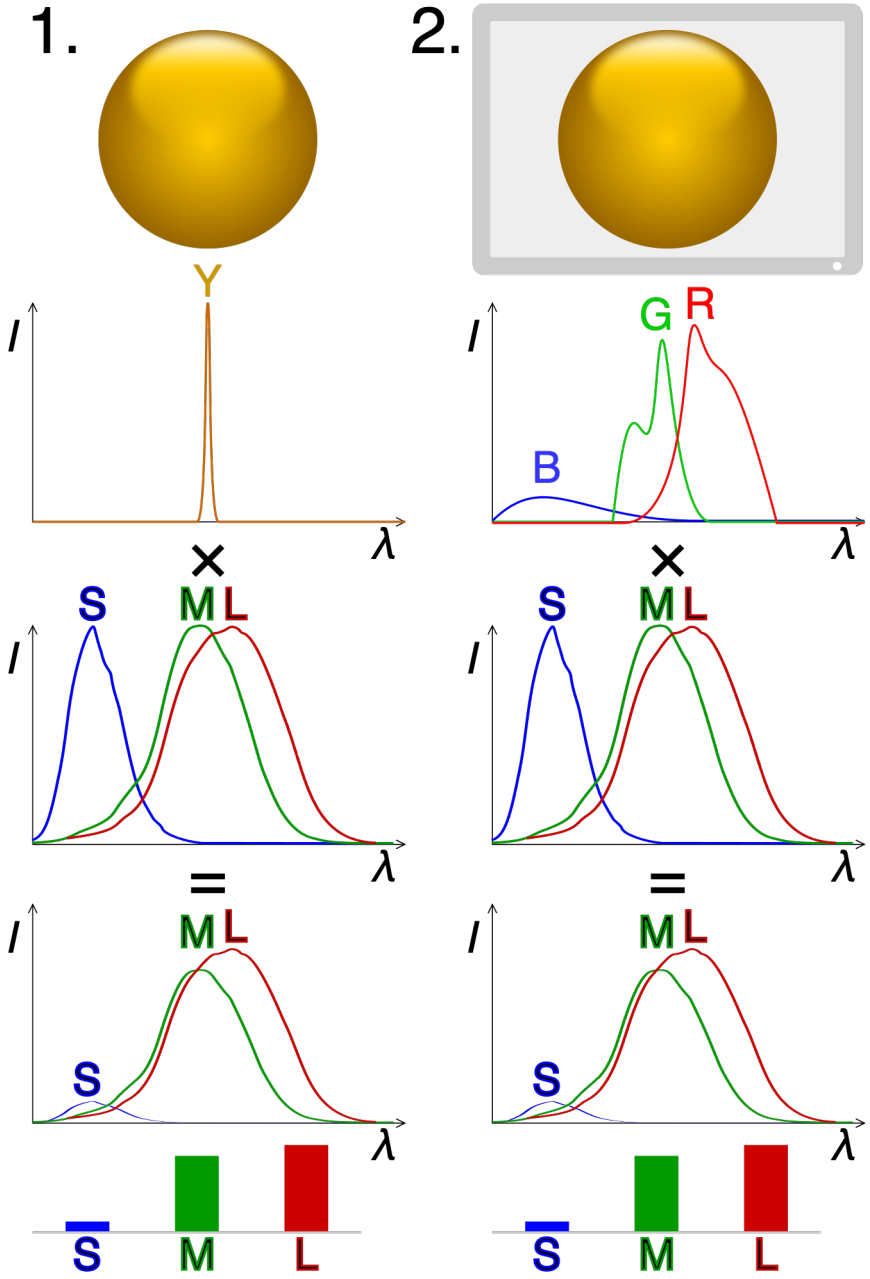
- Due colori che sembrano gli stessi ma che hanno differenti energie in funzione della lunghezza d'onda si chiamano metamerici



Un esempio

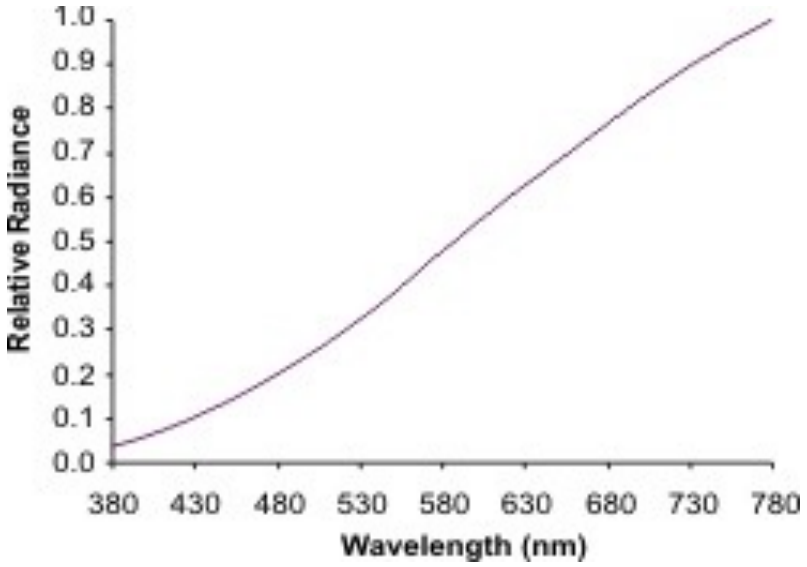

Standard
D65 Illumination
Standard
A Illumination
A
B
A
B
Spectral distribution of reflected light
100
50
0
400
500
600
700
B
A

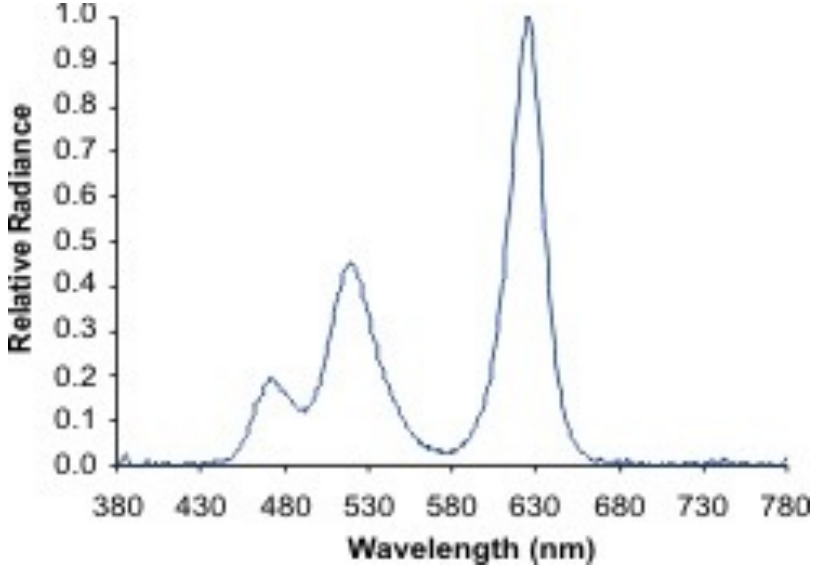
Spettri diversi, colori uguali



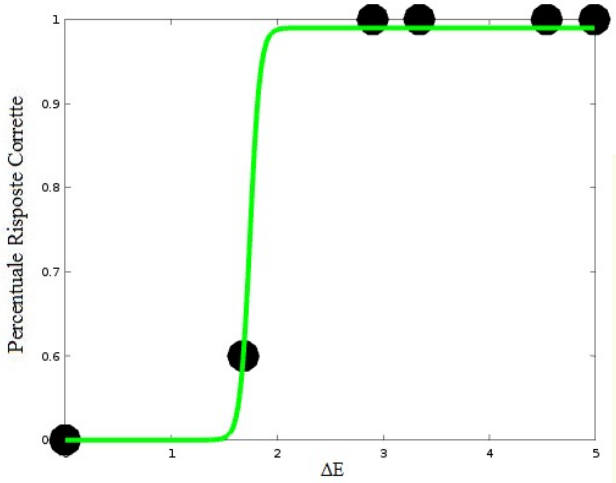
Differenze in riflessione

- Due bianchi identici come colore "di sorgente" possono dare riflessioni molto diverse su oggetti colorati

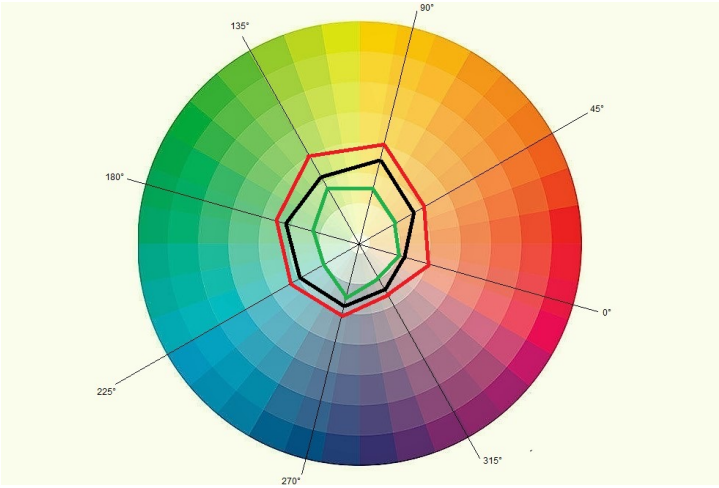




Obiettivi dell'esperimento

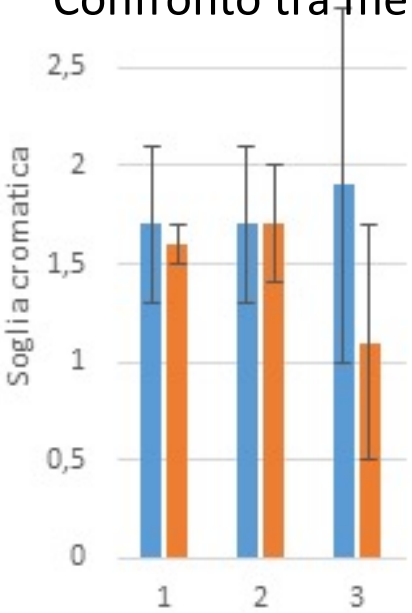


Soglia cromatica

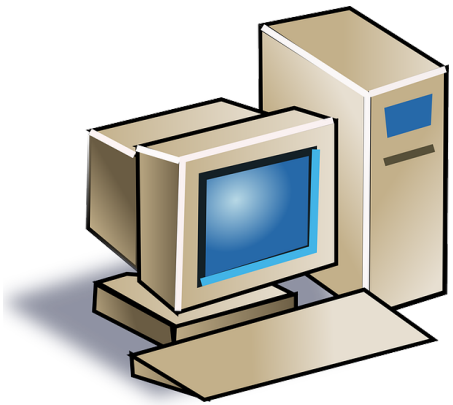


Area cromatica

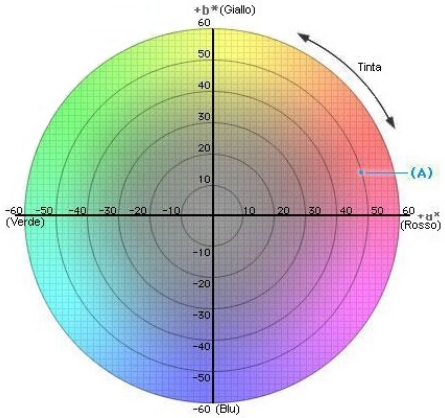
Confronto tra metodi



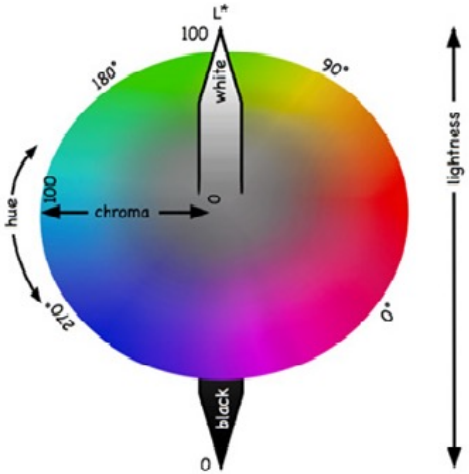
Calibrazione e definizione dello spazio cromatico



Monitor

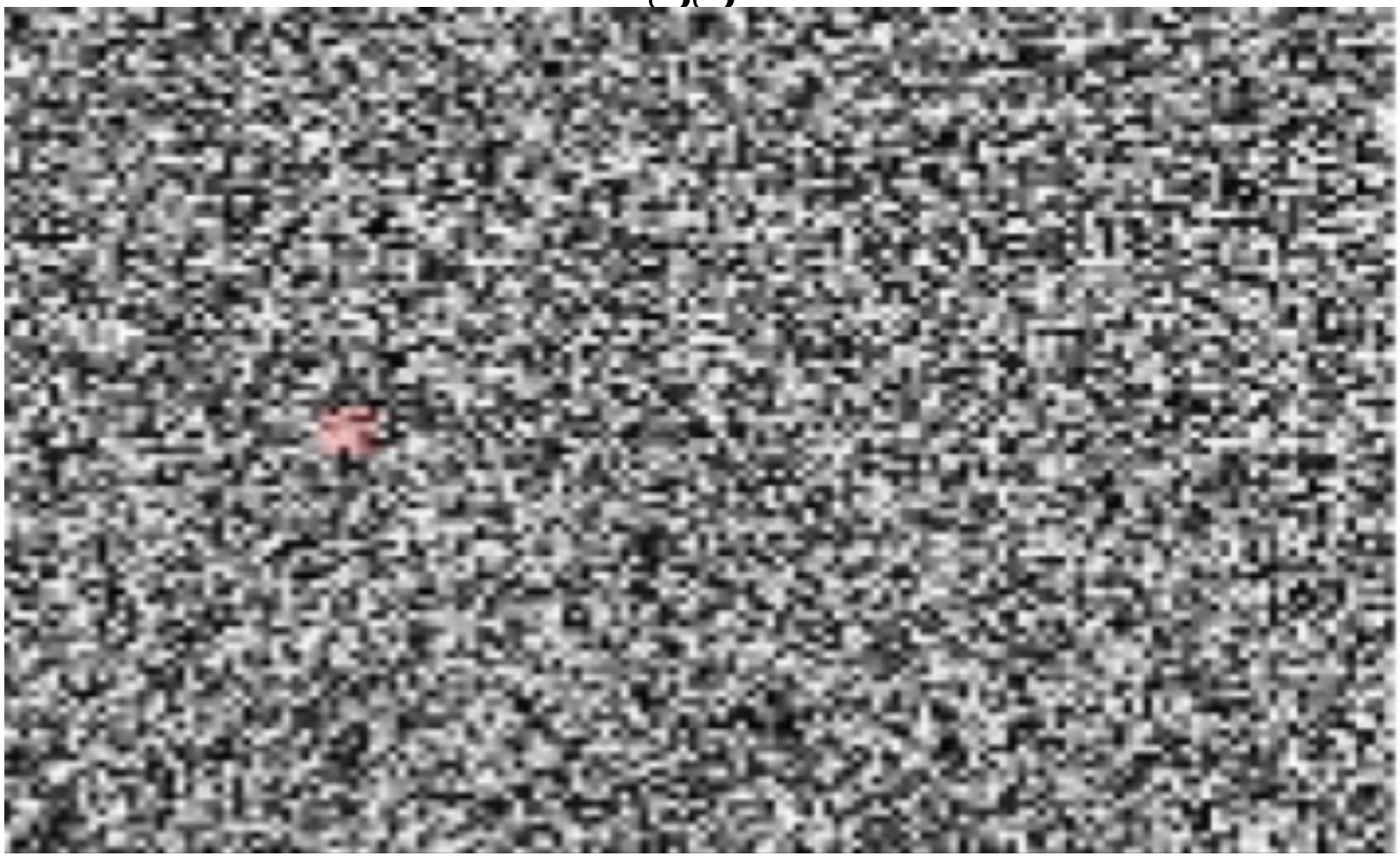


CIELab

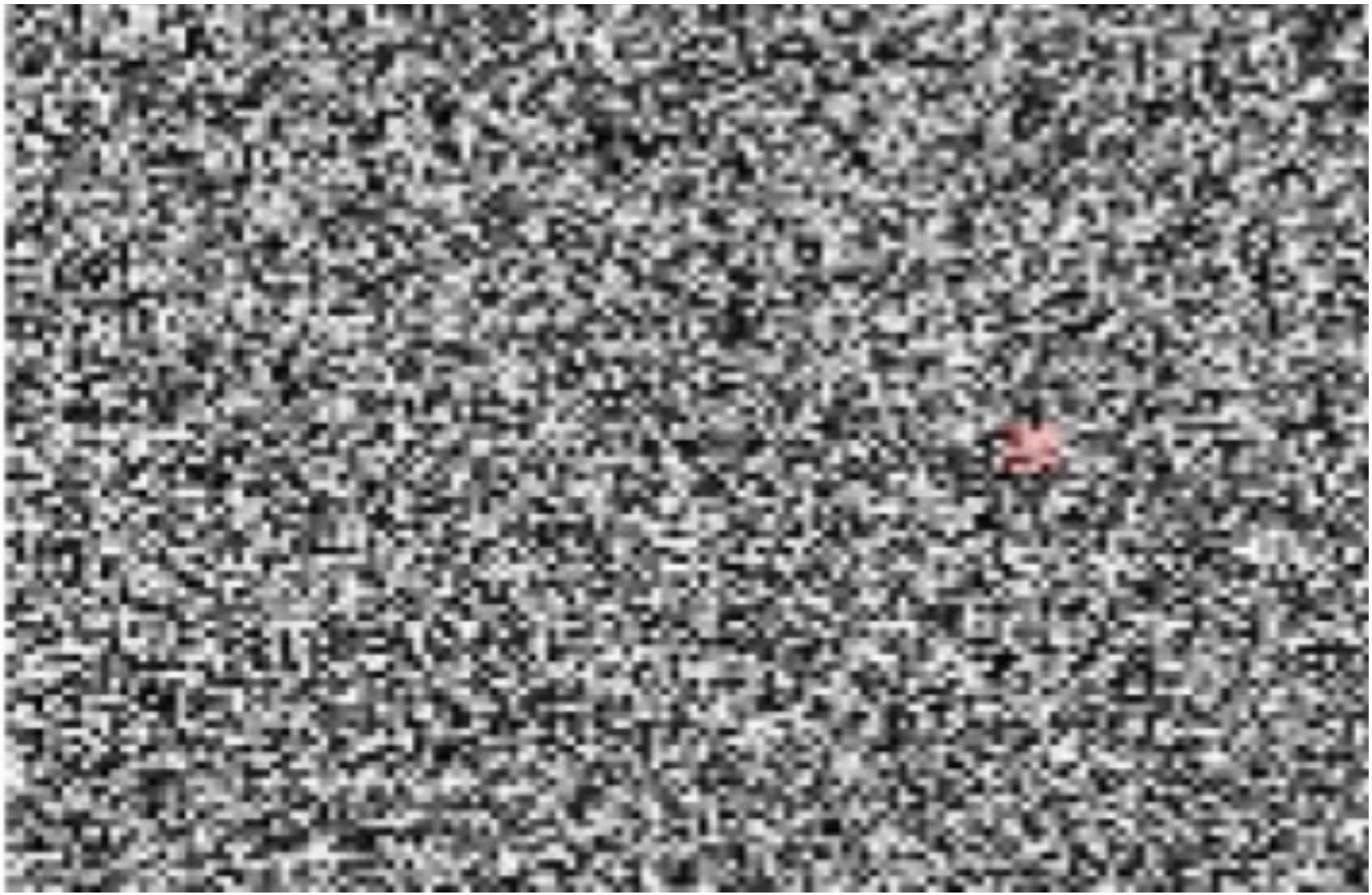


CIELch

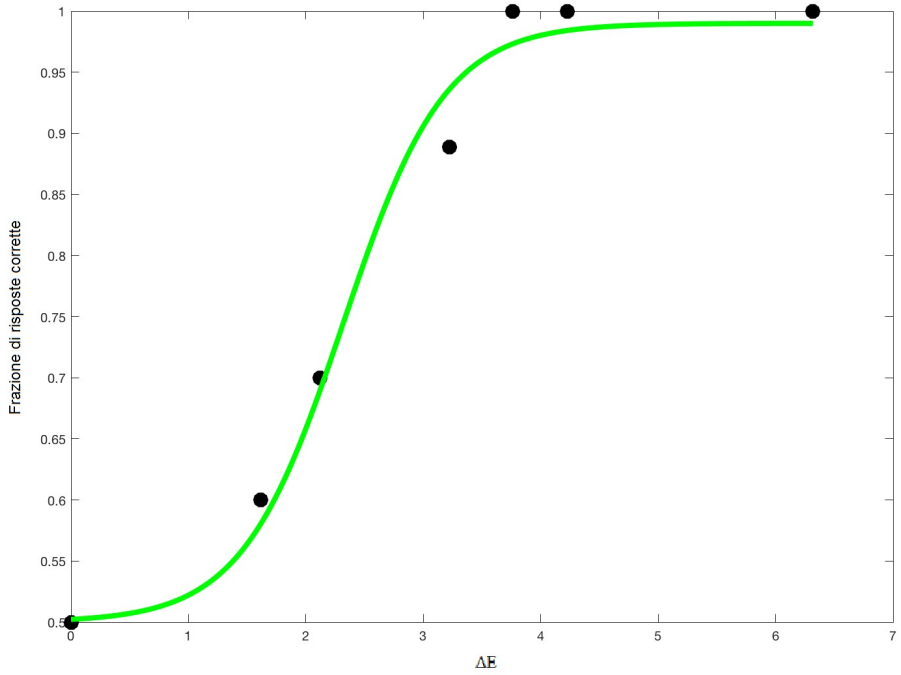
Esperimento e compito del soggetto

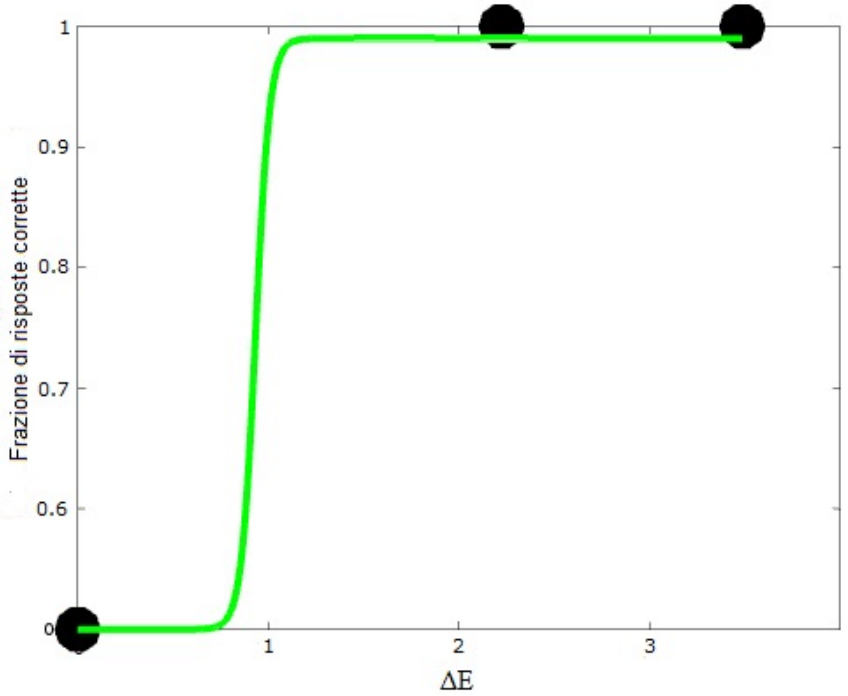


Esperimento e compito del soggetto

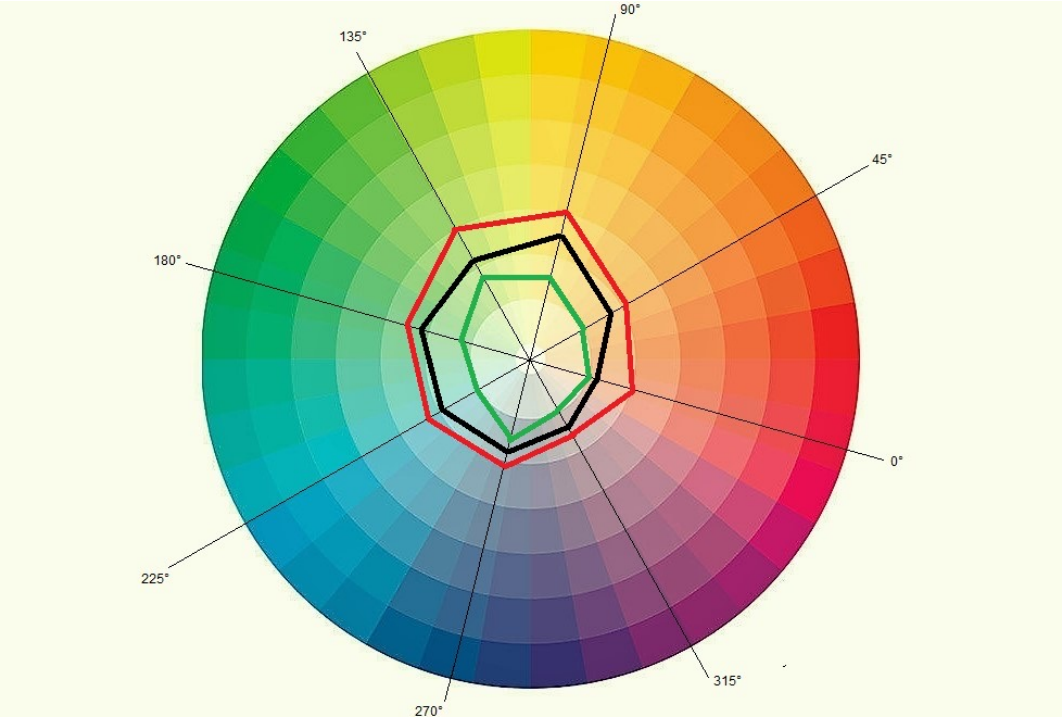


Curva psicometrica





Area cromatica

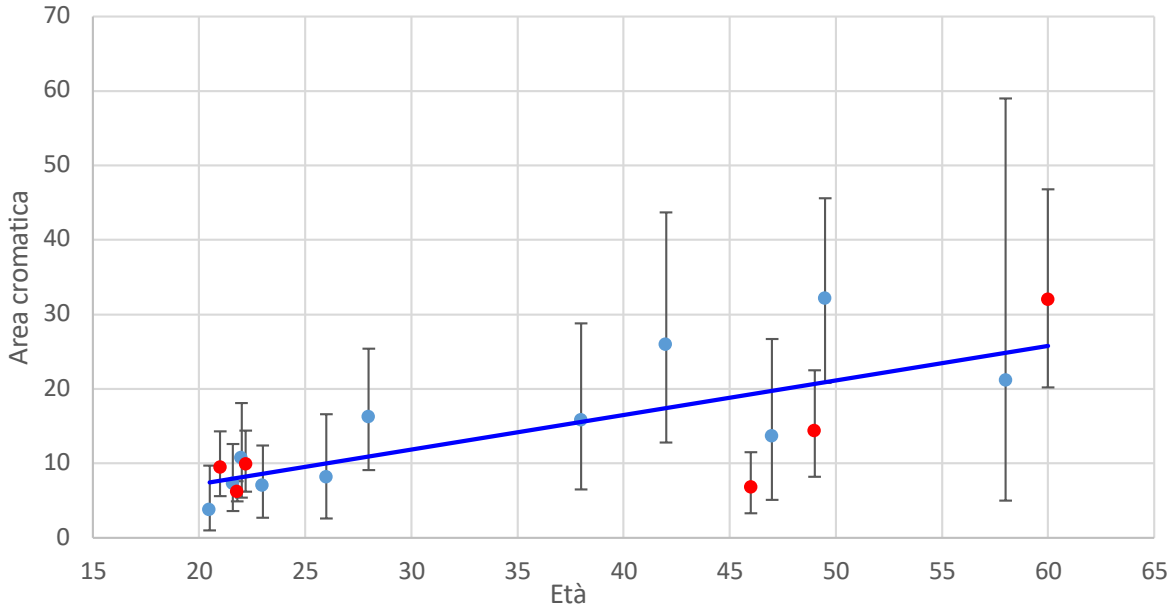


Area cromatica

Area Massima= Soglie + errore

Area minima= Soglie - errore

Area cromatica in funzione dell'età

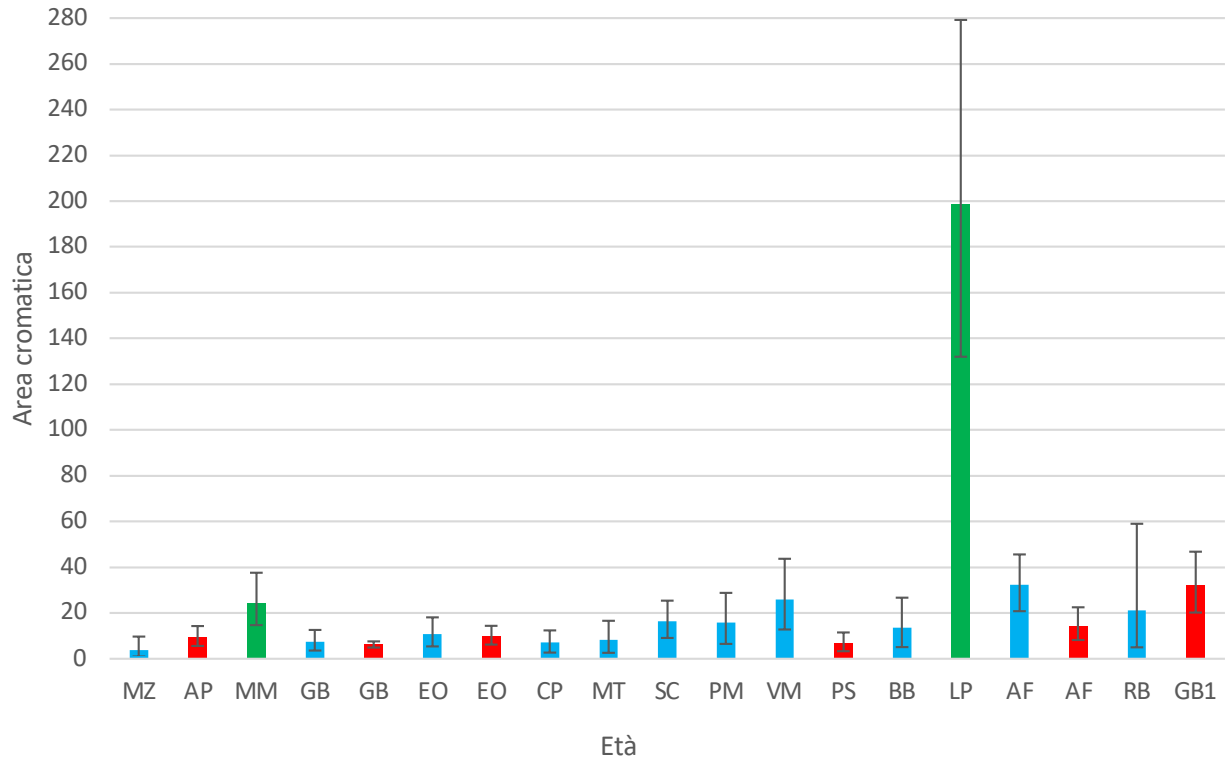


$y = (0.46 \pm 0.1)x - (2.1 \pm 4.0)$

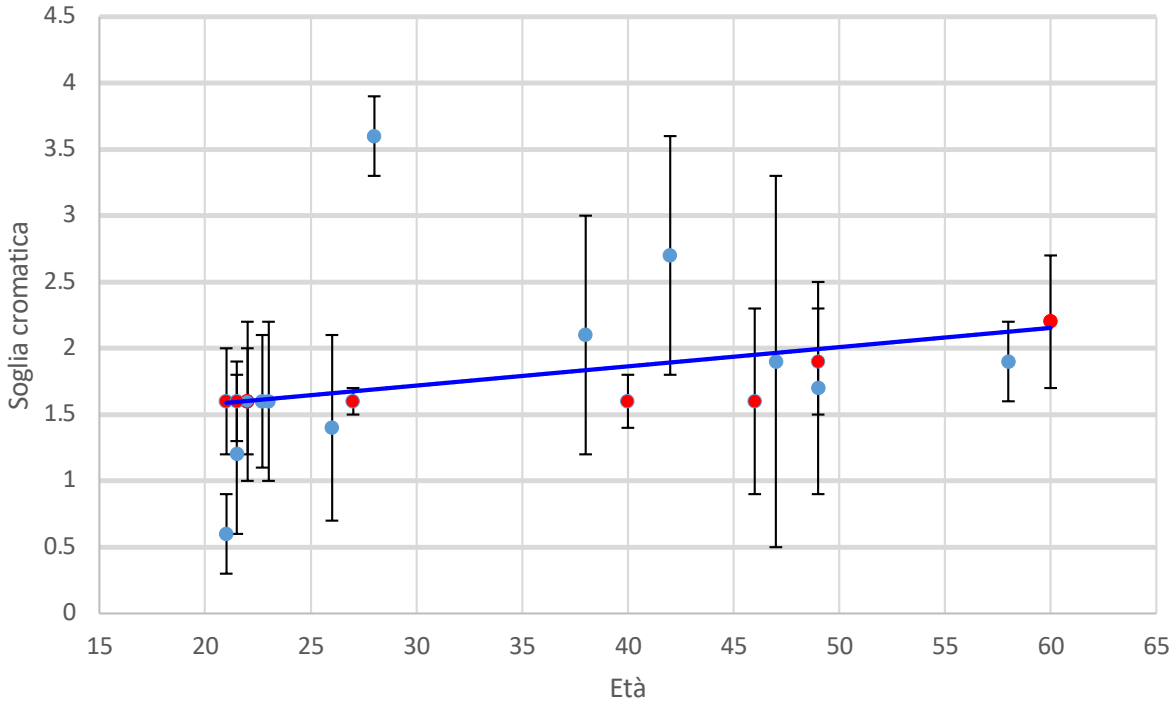
$R^2 = 0.56$

$p = 0.0005$

Confronto tra aree cromatiche dei soggetti



Soglie cromatiche in funzione dell'età



Metodo degli stimoli costanti

Metodo staircase

Fit lineare

Angolo 0°, 45°, 180°: no correlazione con età

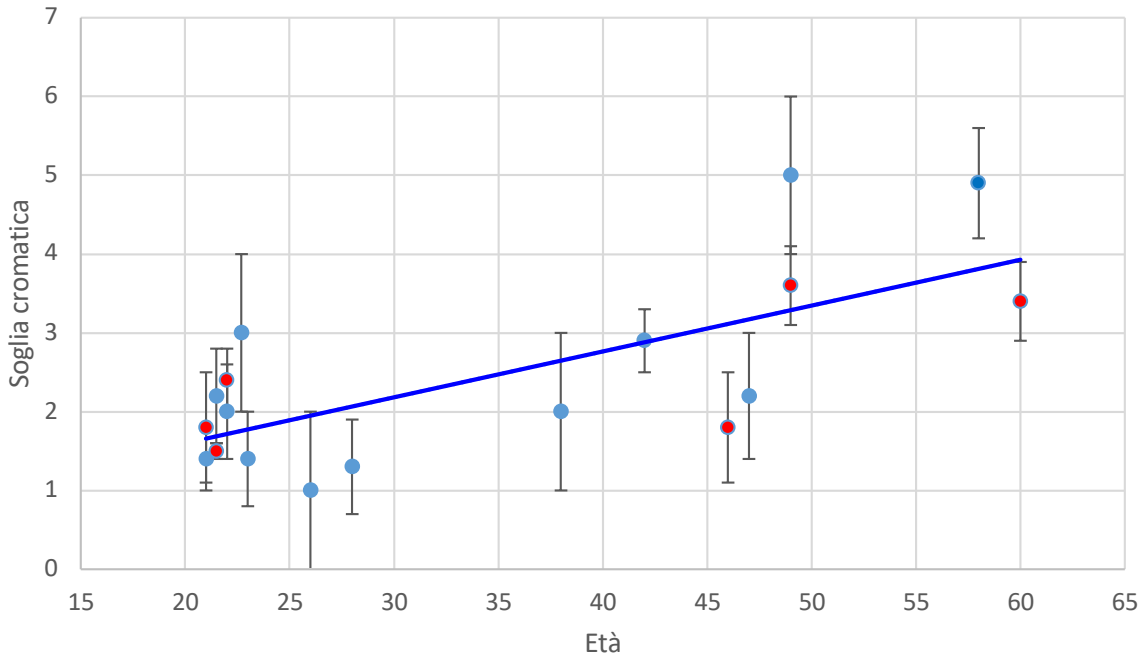
Angolo 0° (rosso):

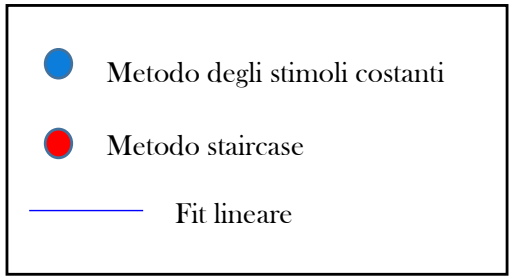
$y=(0.014\pm0.009)x+(1.3\pm0.3)$

$R^2=0.11$

$p = 0.15$

Soglie cromatiche in funzione dell'età





90°, 225°, 270° e 315°: correlazione con età

Angolo 270° (blu):

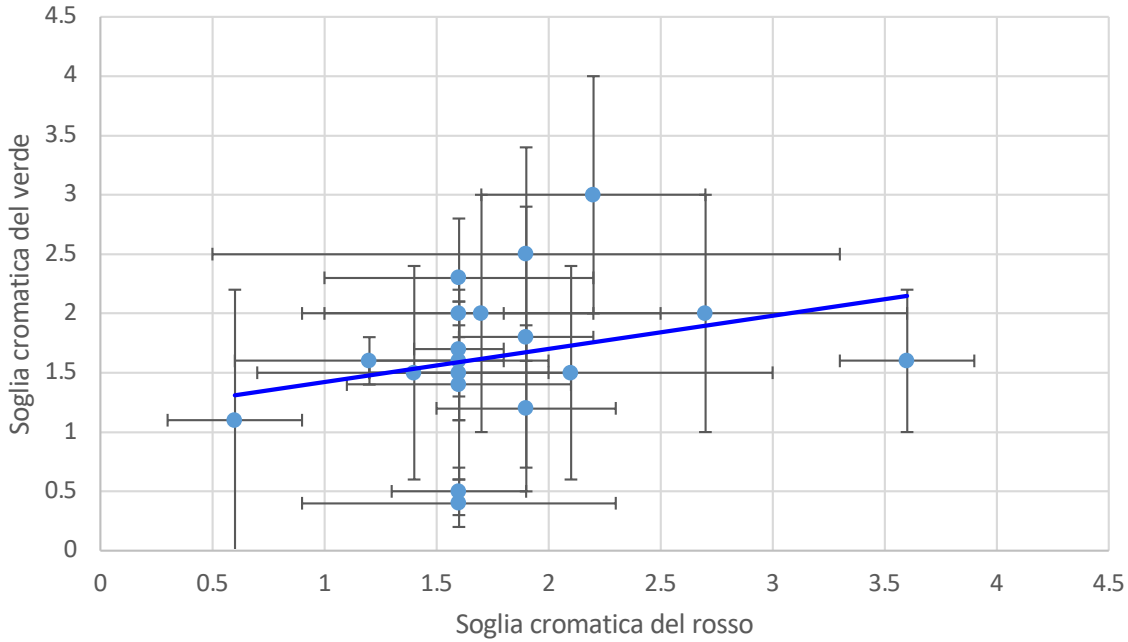
$y=(0.06\pm0.01)x+(0.4\pm0.5)$

$R^2 = 0.49$

$p = 0.01$

Correlazione tra soglie cromatiche

Correlazione tra soglie cromatiche del **rosso** e soglie del **verde**



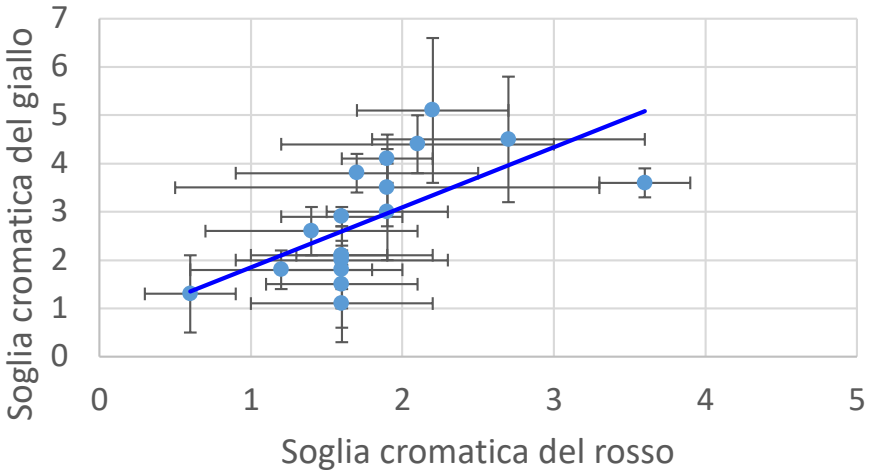
$y=(0.3\pm0.2)x+(1.1\pm0.4)$

$R^2=0.075.$

$p= 0.26$

Correlazione tra soglie cromatiche

Rosso - Giallo

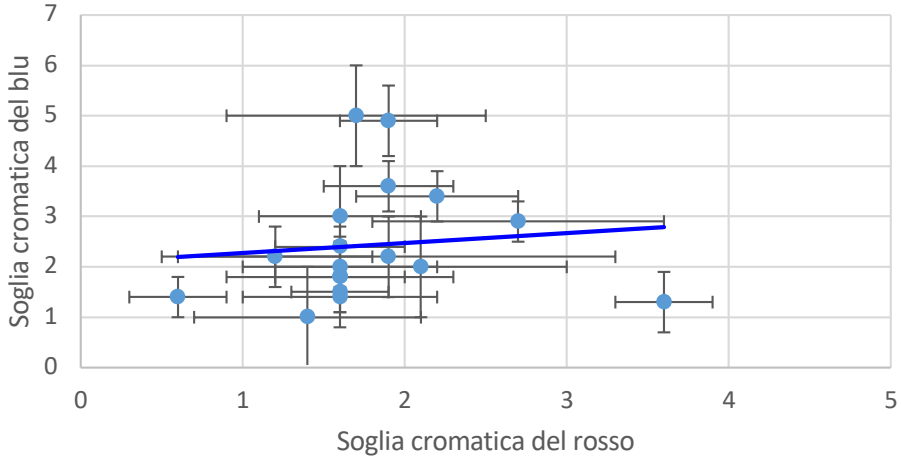


$y=(1.2\pm0.4)x+(0.6\pm0.7)$

$R^2=0.4067$

$p = 0.004$

Rosso - Blu

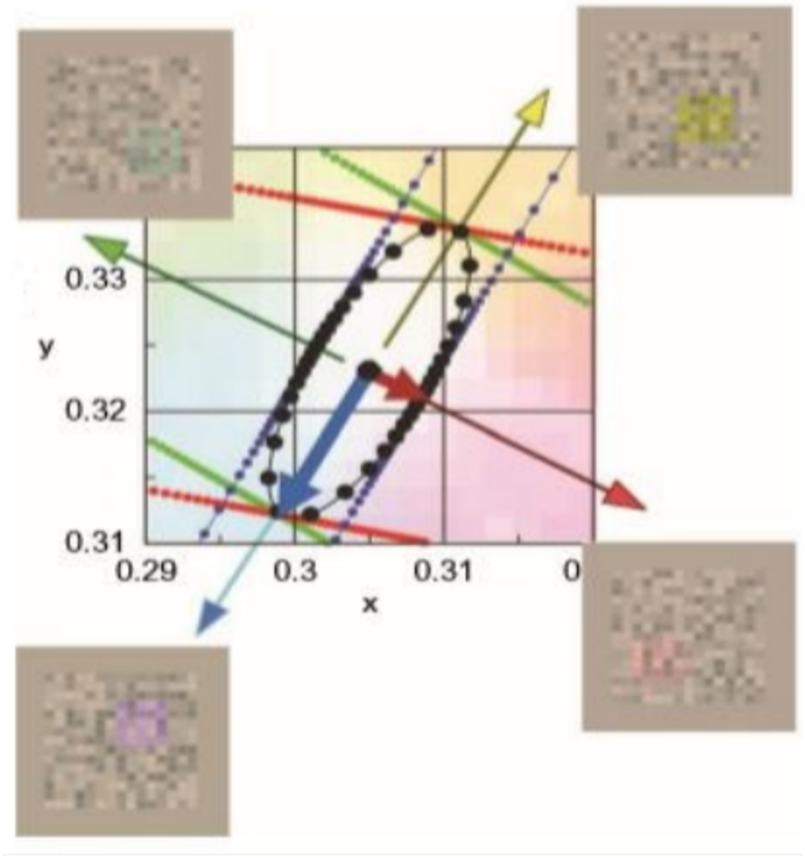


$y=(0.6\pm0.2)x+(0.9\pm0.3)$

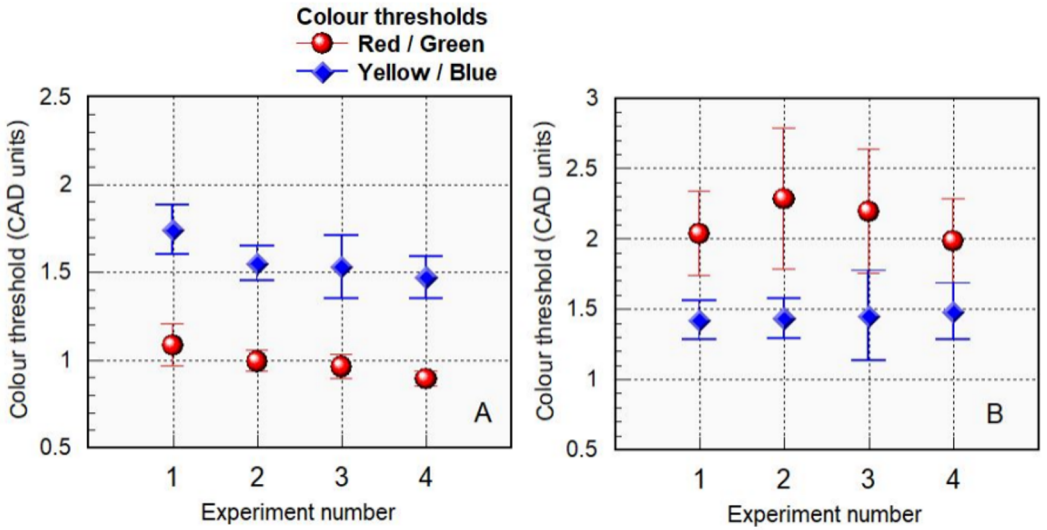
$R^2=0,48$

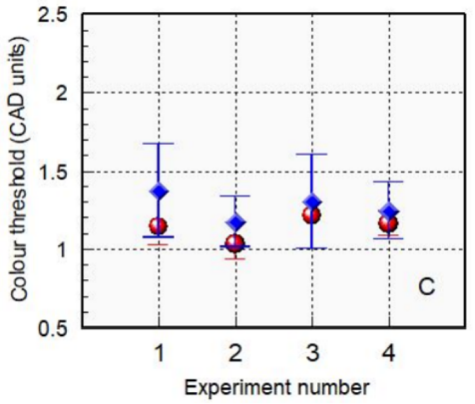
$p < 0.001$

Cad test



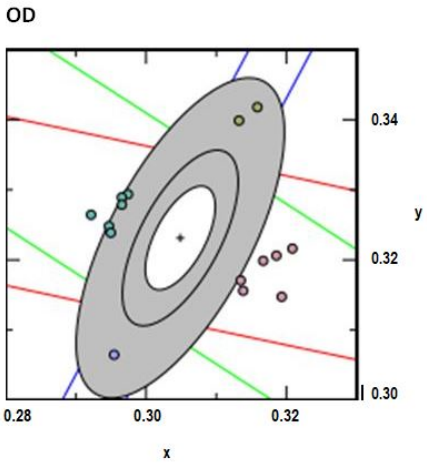
Results



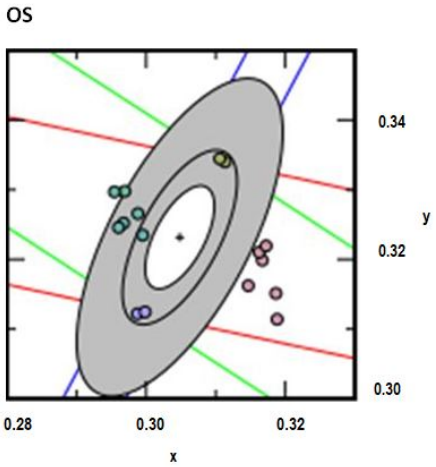


1. With display set as D65 illuminants
2. With display simulating lens 1
3. With display simulating lens 4
4. With display set as D65 illuminants and subjets wearing lens 1.

An interesting subject

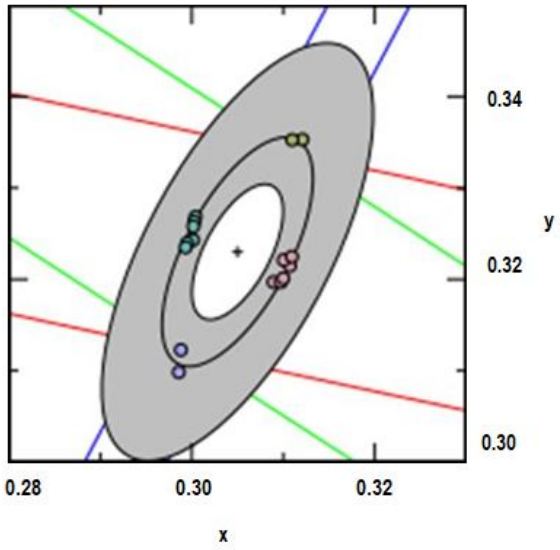


Right eye



Left eye

Binocular

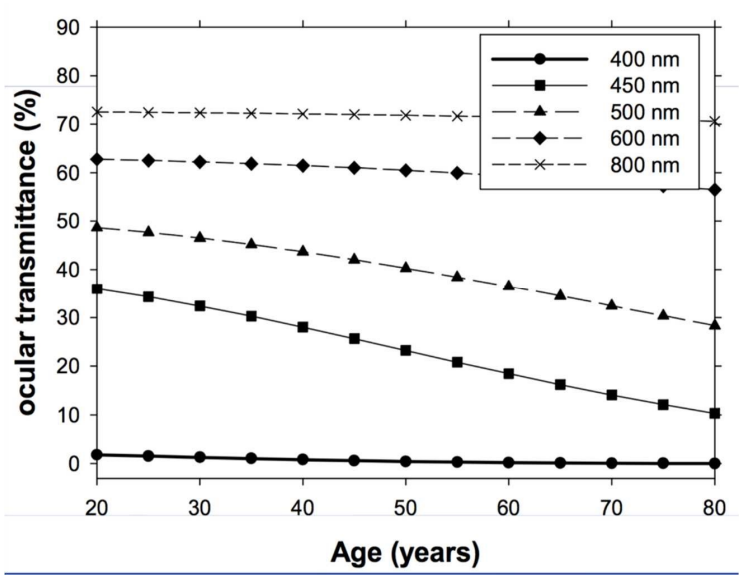


	Binoculare	*Monoculare*
RG	1.34 ± 0.02	2.6 ± 0.1
YB	1.20 ± 0.08	1.47 ± 0.04

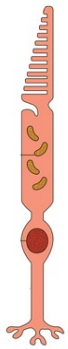
Binocular summation index=1.94 (normal: less than 1.3)

Fattori che causano l'aumento delle soglie

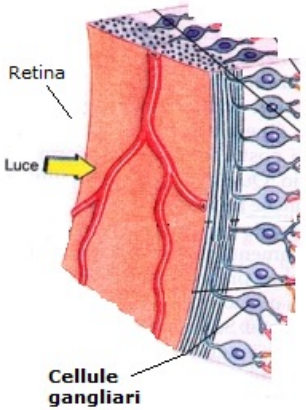
Ingiallimento del cristallino



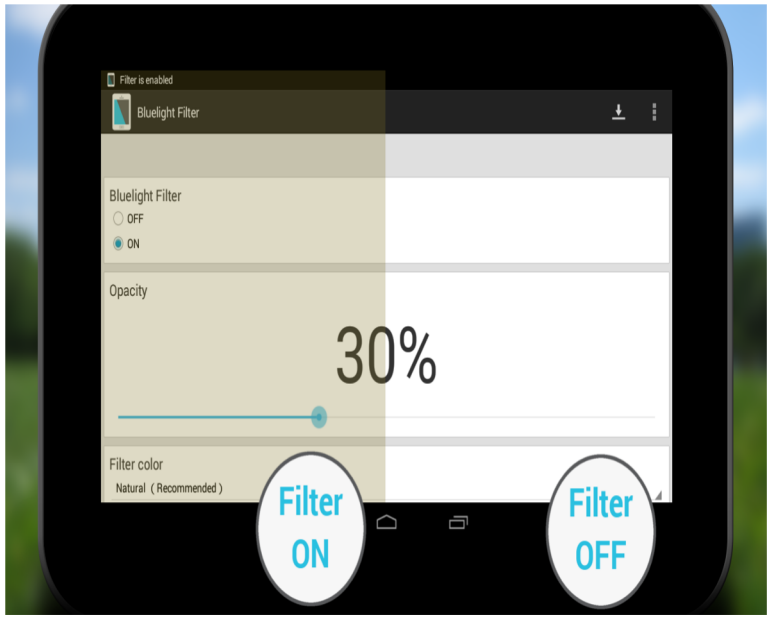
Riduzione della sensibilità dei coni

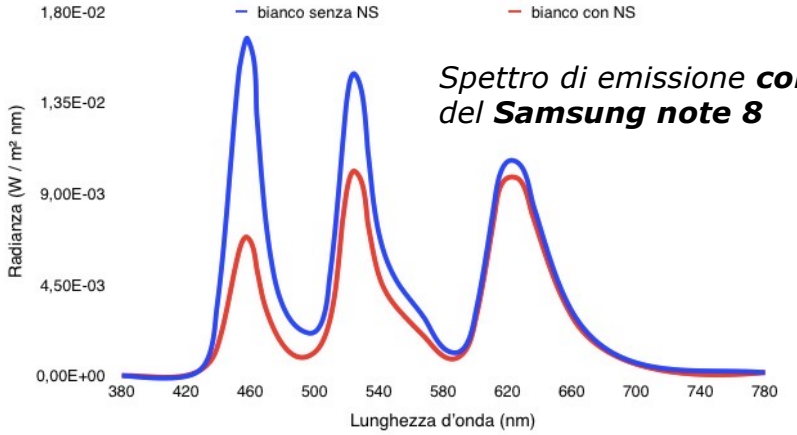


Perdita degli assoni delle cellule gangliari

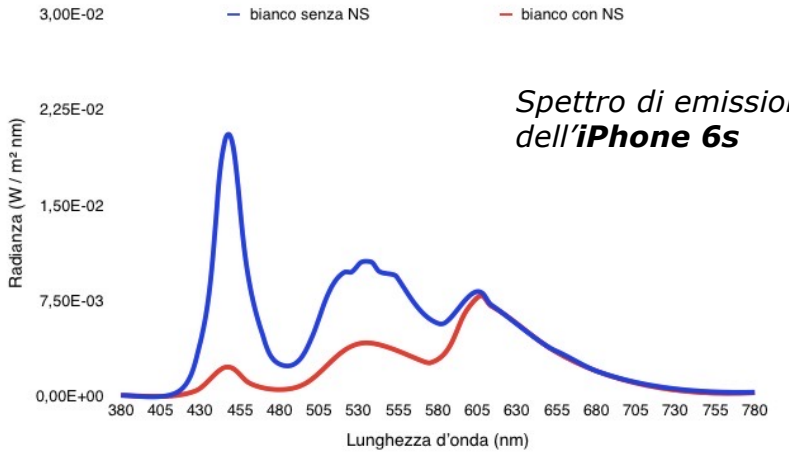


Night shift



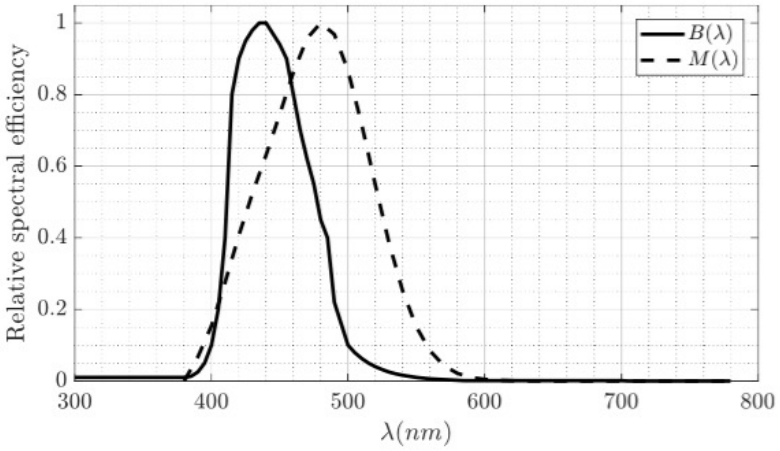


*Spettro di emissione **con e senza NS** del **Samsung note 8***



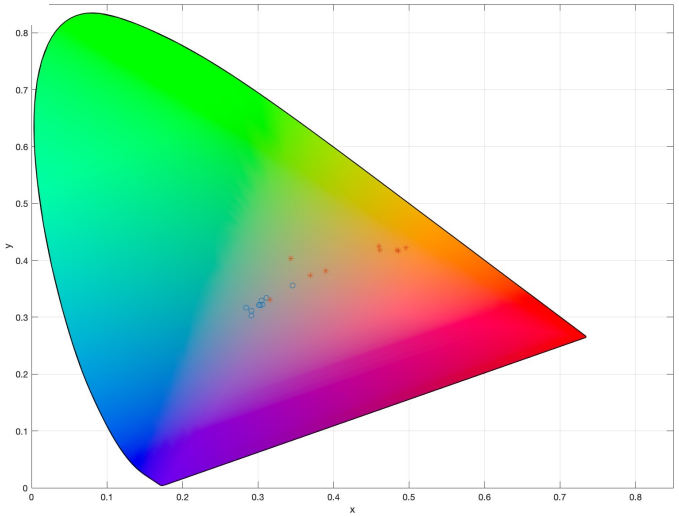
*Spettro di emissione **con e senza NS** dell'**iPhone 6s***

Stima dell'efficacia del **Night Shift** sul ciclo circadiano



La curva tratteggiata M(λ) rappresenta l'efficienza della radiazione nel bloccare la produzione di melatonina

Tipo cellulare	EM senza NS	EM_{con} NS
Redmi	0.84	0.66
Huawei	0.90	0.51
Samsung Note 8	0.90	0.45
Iphone 6s	1.00	0.21
Samsung 8	0.64	0.18
Lg5	0.99	0.07
Samsung a7	0.73	0.17
Iphone xs	0.94	0.28
Ipad	0.67	0.15



Aim of the experiment

Evaluating subjective preferences regarding lighting in front of a painting



Svolgimento dell’esperimento

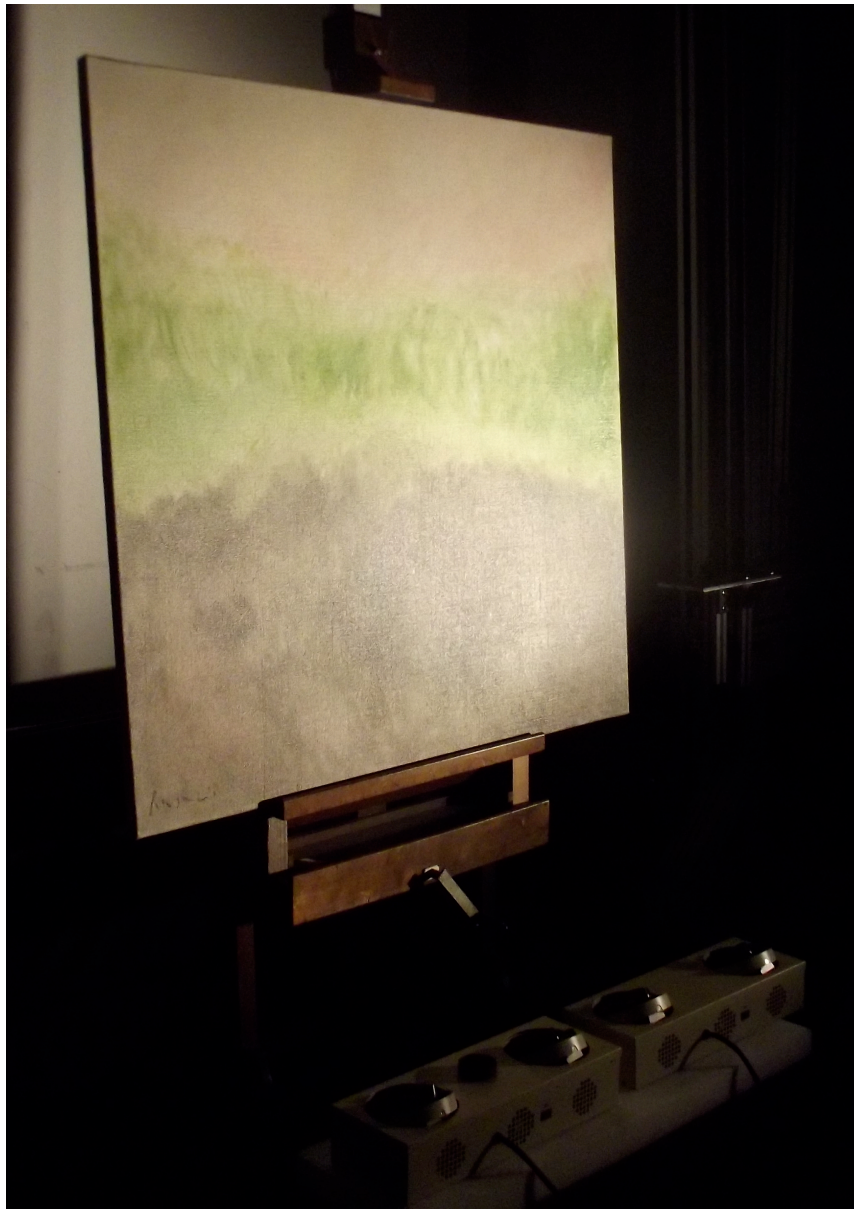
Paintings selected for the experiment

"*Madonna del Granduca*"
Raffaello (1504)
Olio su tavola 84,4 X 55,9 cm

Paintings selected for the experiment

"*Madonna del velo*"
Anonimo (1500)
Olio su tavola 120 X 90 cm

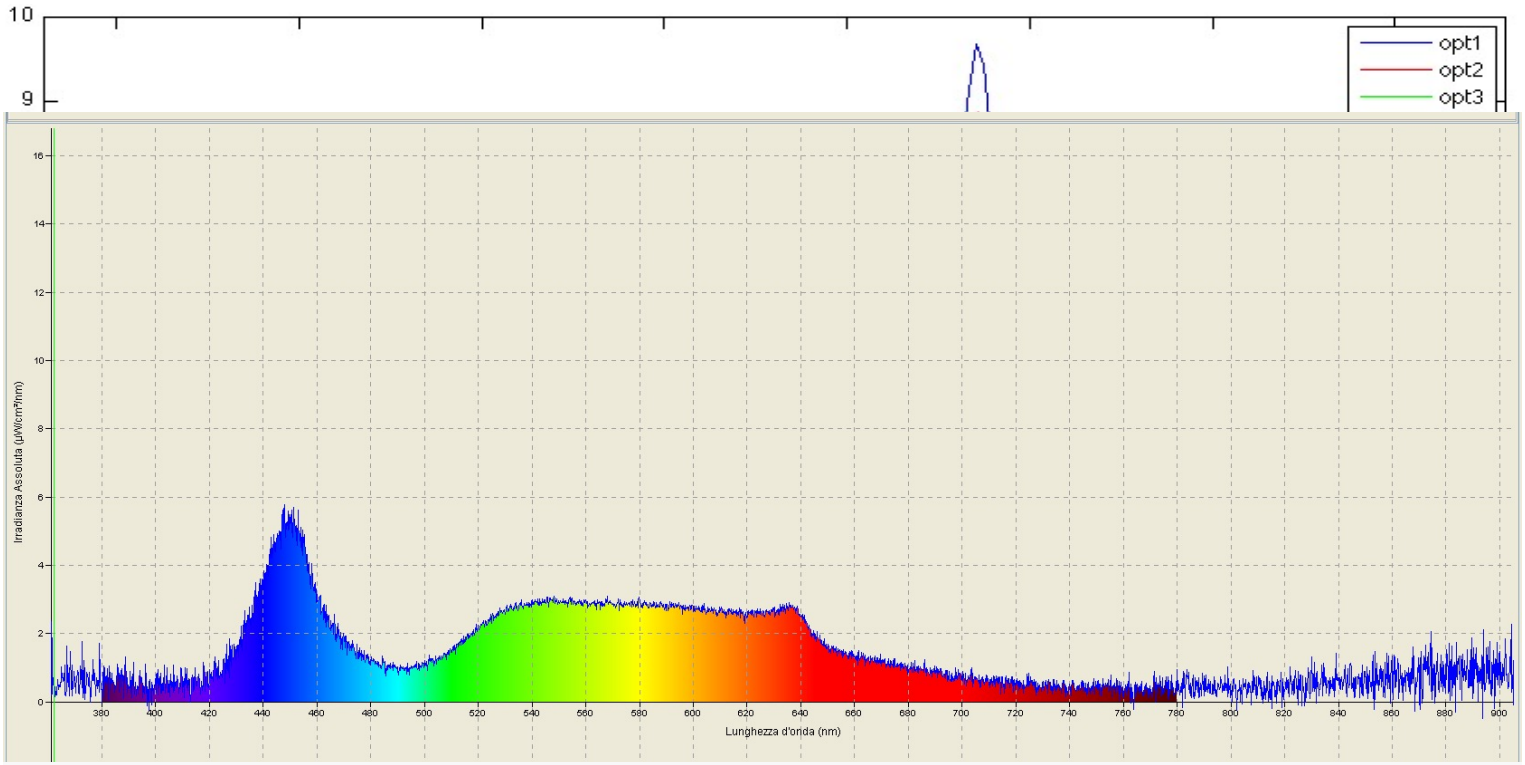
Paintings selected for the experiment



"*L'Assoluto della luce*"
di Giovanna Rasario (2010)

Lighting

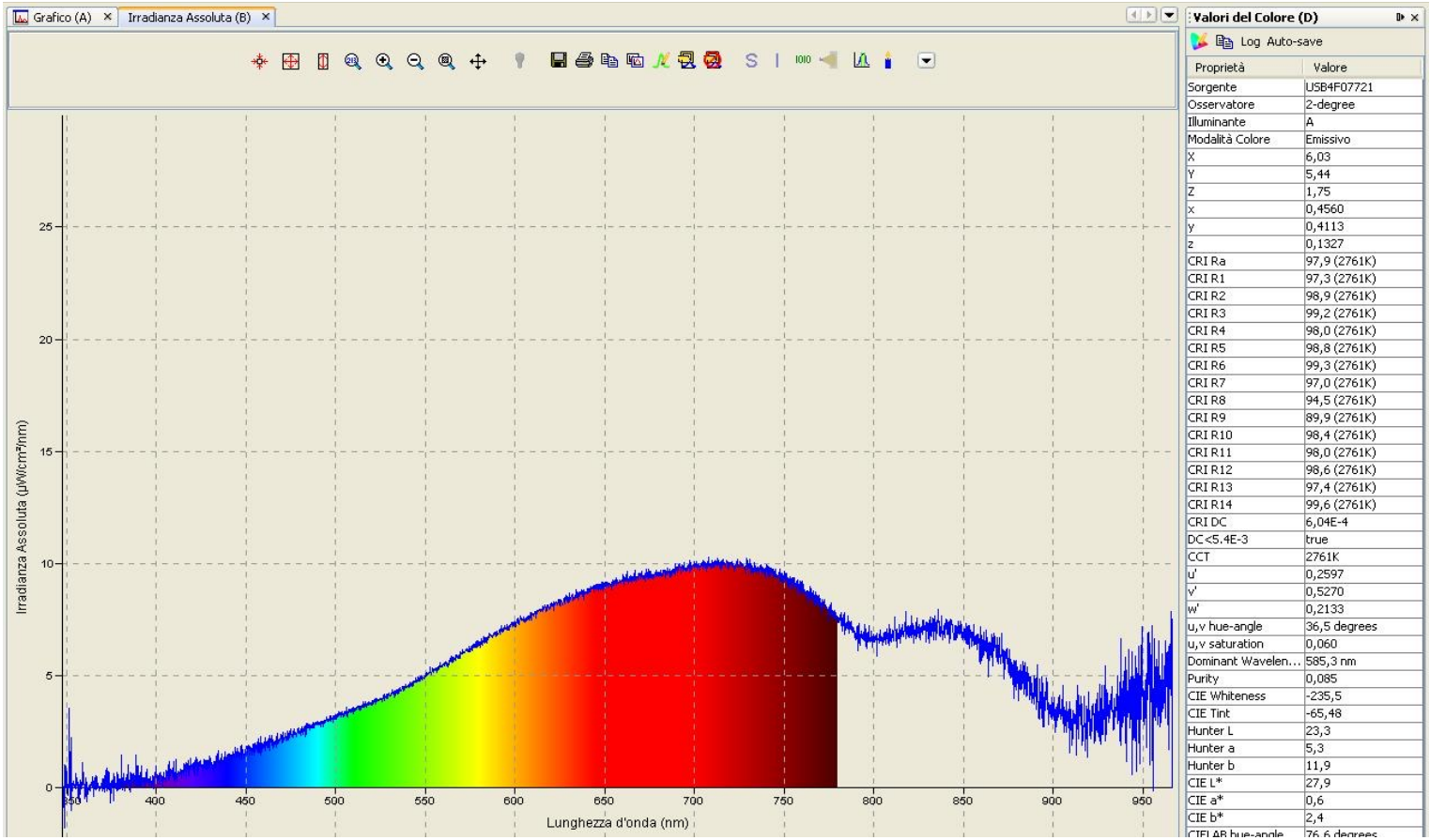
Optagon – Targetti: Tunable LED source



Full Spectrum Modulated Light

Lighting

Halogen lamp



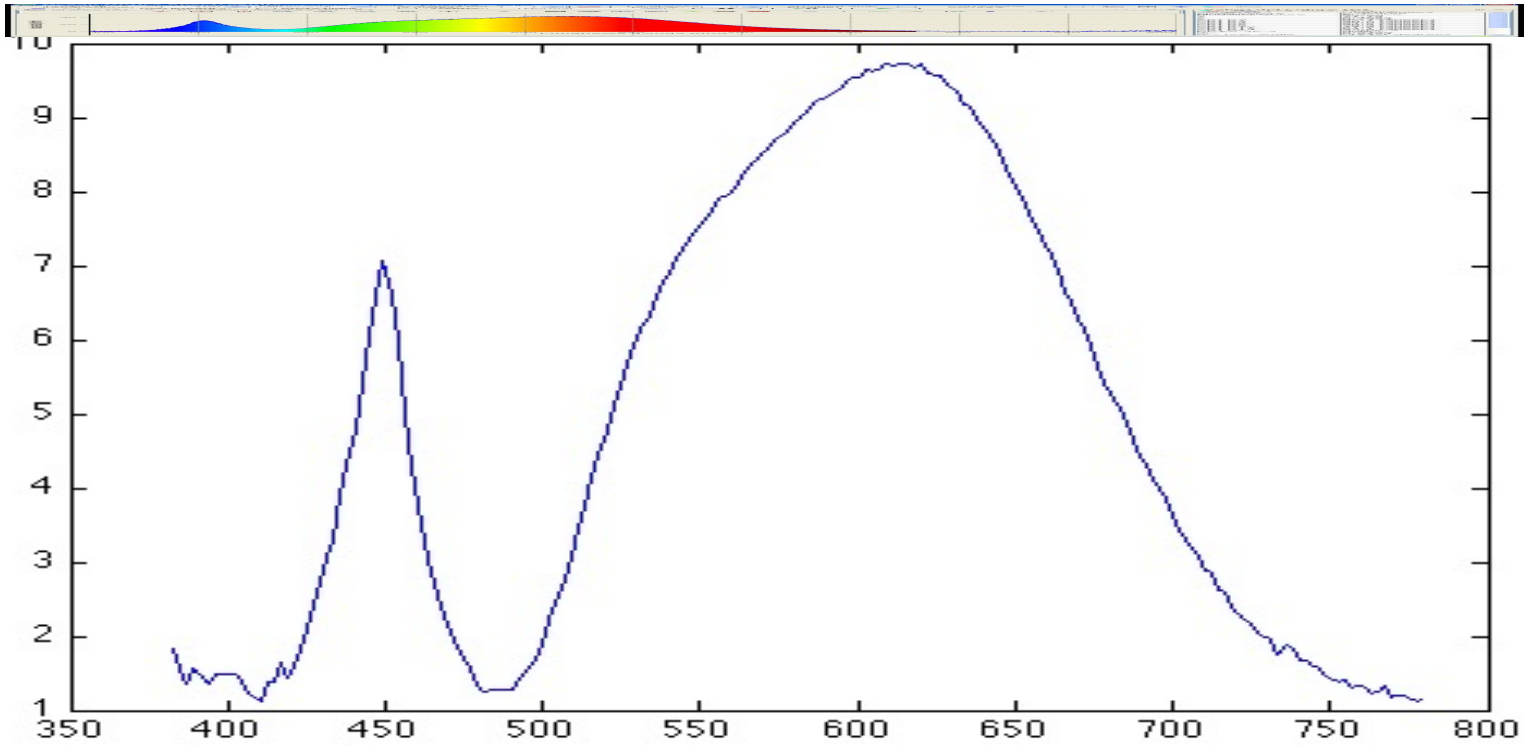
Valori del Colore (D)

Log Auto-save

Proprietà	Valore
Sorgente	USB4F07721
Osservatore	2-degree
Illuminante	A
Modalità Colore	Emissivo
X	6,03
Y	5,44
Z	1,75
x	0,4560
y	0,4113
z	0,1327
CRI Ra	97,9 (2761K)
CRI R1	97,3 (2761K)
CRI R2	98,9 (2761K)
CRI R3	99,2 (2761K)
CRI R4	98,0 (2761K)
CRI R5	98,8 (2761K)
CRI R6	99,3 (2761K)
CRI R7	97,0 (2761K)
CRI R8	94,5 (2761K)
CRI R9	89,9 (2761K)
CRI R10	98,4 (2761K)
CRI R11	98,0 (2761K)
CRI R12	98,6 (2761K)
CRI R13	97,4 (2761K)
CRI R14	99,6 (2761K)
CRI DC	6,04E-4
DC<5.4E-3	true
CCT	2761K
u'	0,2597
v'	0,5270
w'	0,2133
u,v hue-angle	36,5 degrees
u,v saturation	0,060
Dominant Wavelen...	585,3 nm
Purity	0,085
CIE Whiteness	-235,5
CIE Tint	-65,48
Hunter L	23,3
Hunter a	5,3
Hunter b	11,9
CIE L*	27,9
CIE a*	0,6
CIE b*	2,4
CIELAB hue-angle	76,6 degrees

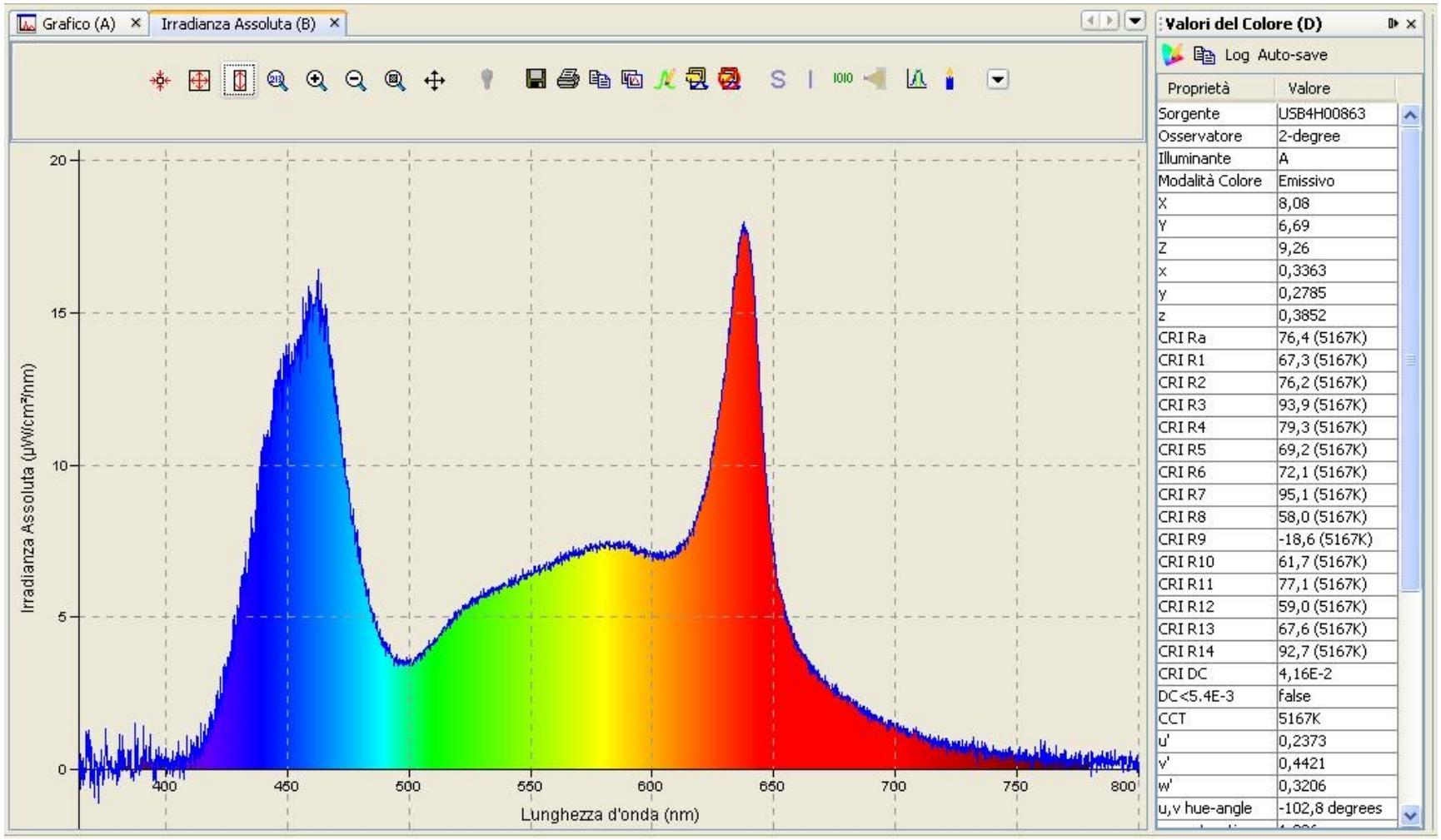
Lighting

LED 3200 K

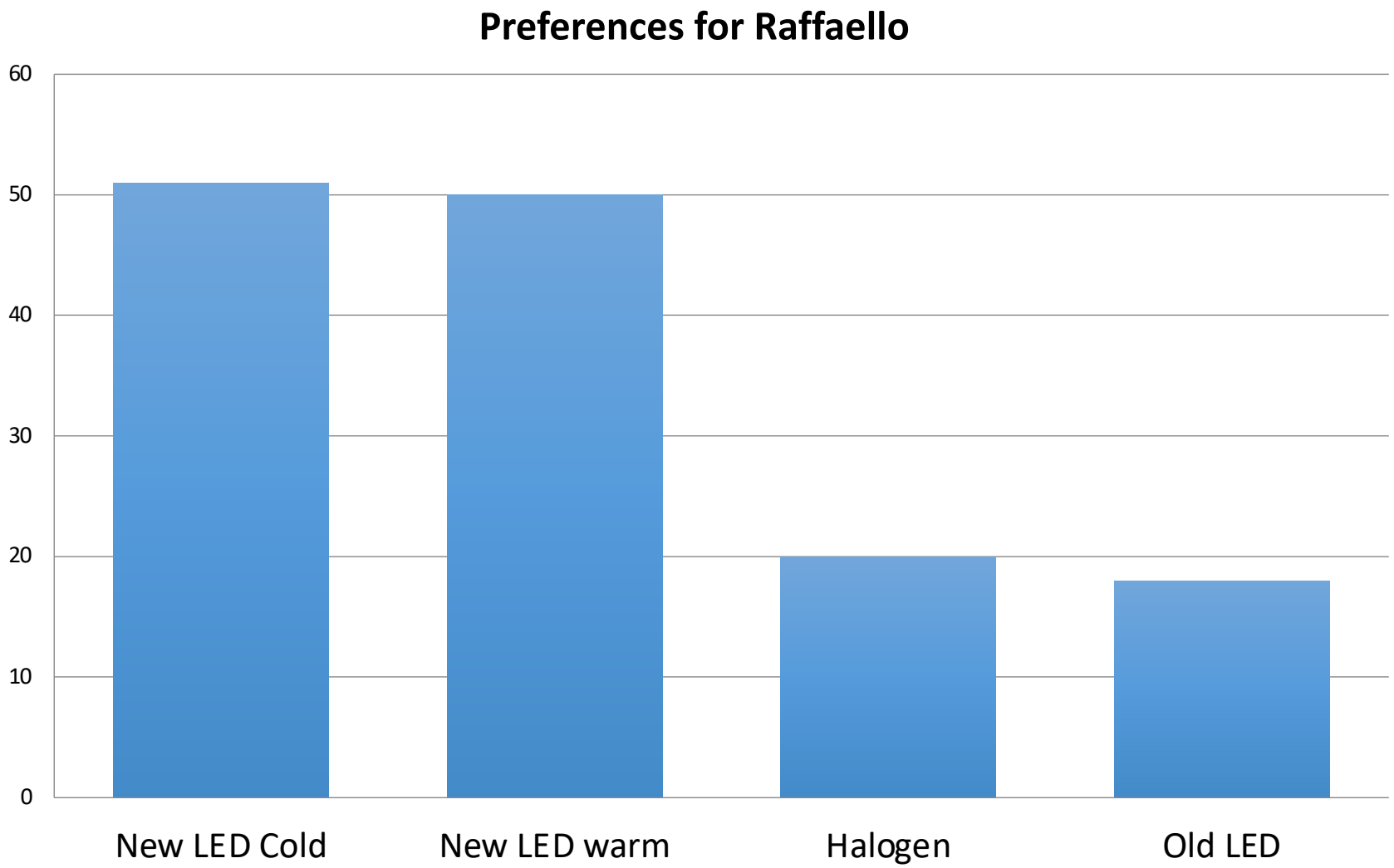


Lighting

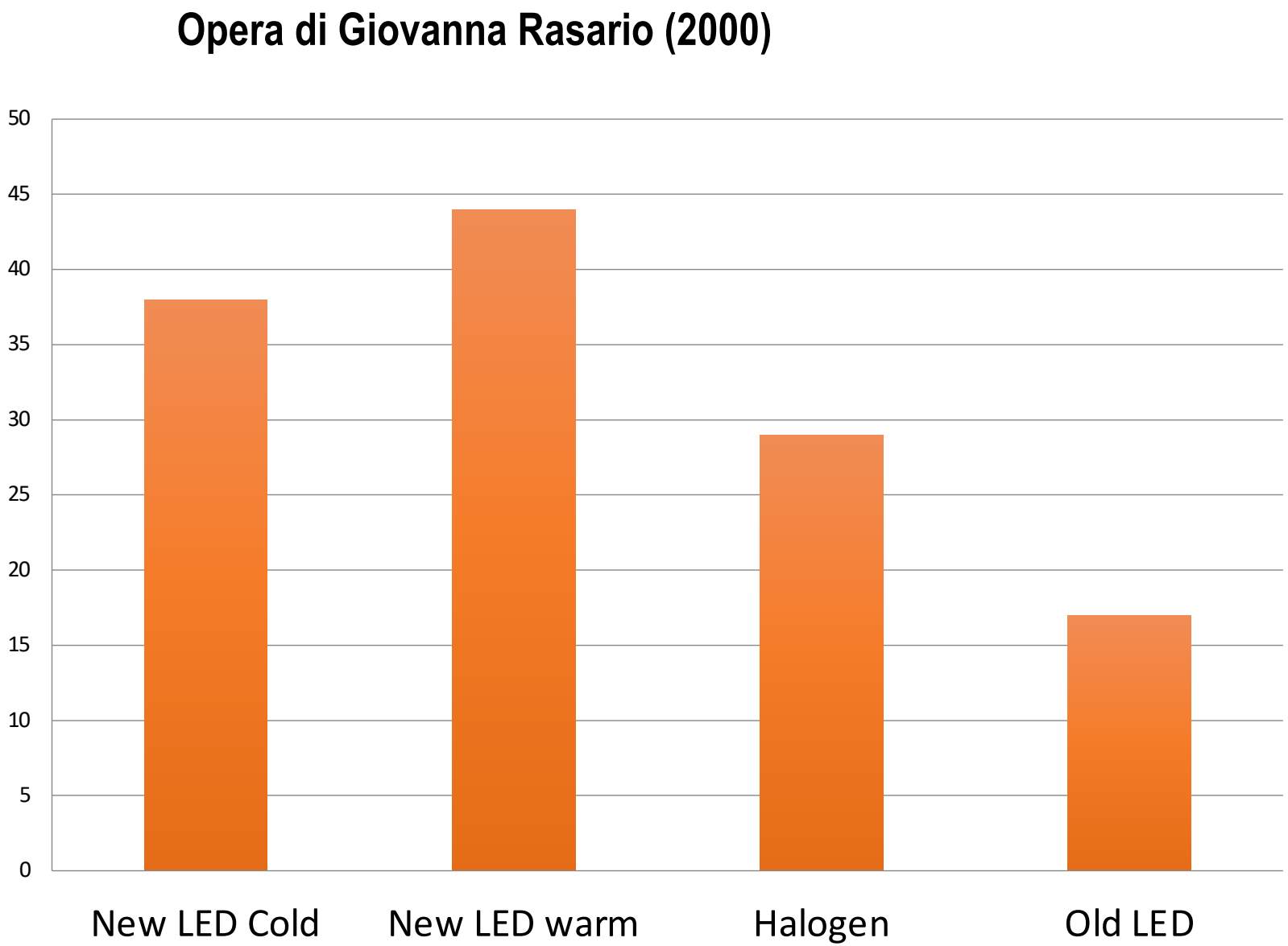
Targetti RUTA



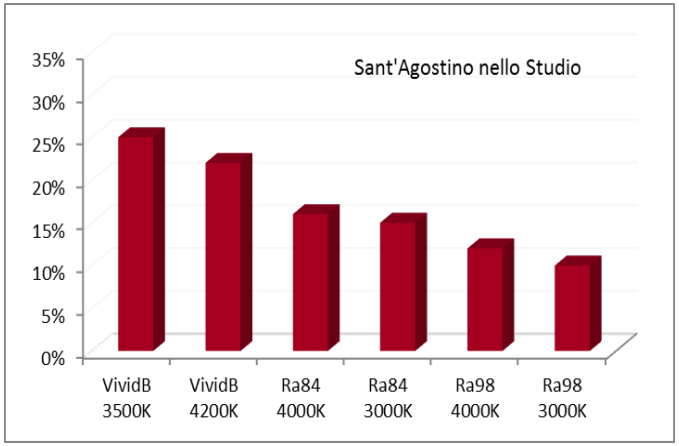
Preferences

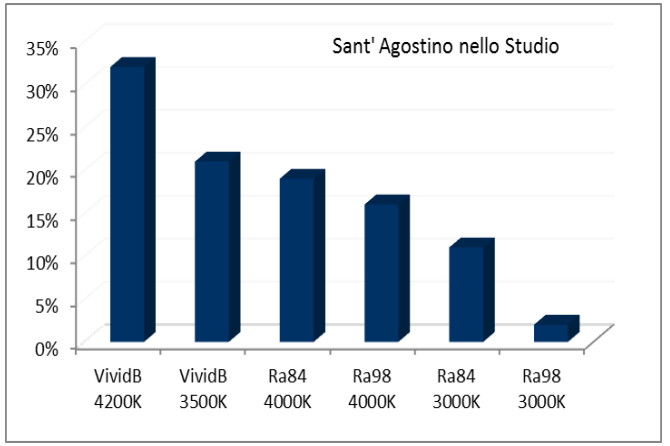


Lighting preferences



Color rendering index is not good nowaday





Alcune domande

- Cosa è il bianco?
- Vediamo tutti i colori allo stesso modo?
- Nello spettro elettromagnetico dove sta il marrone?
- I daltonici possono guarire?

Contacts

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