



Aalto University  
School of Electrical  
Engineering  
Lighting Unit

# Correlation between subjective preferences and colour quality descriptors for LED lighting

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30.10.2012

# Outline

- Introduction
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- Conclusion

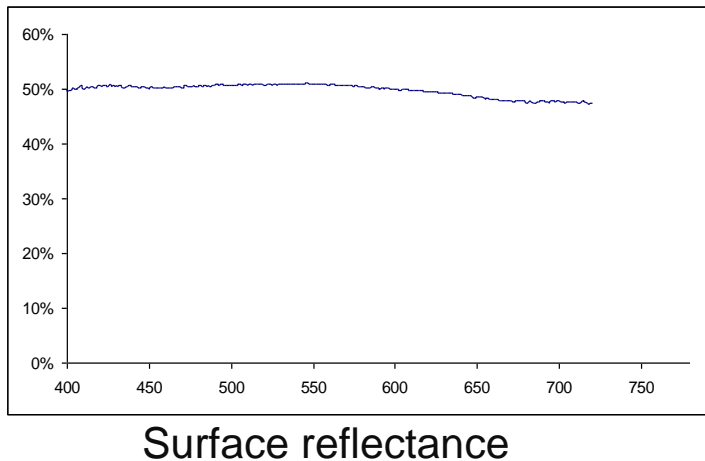
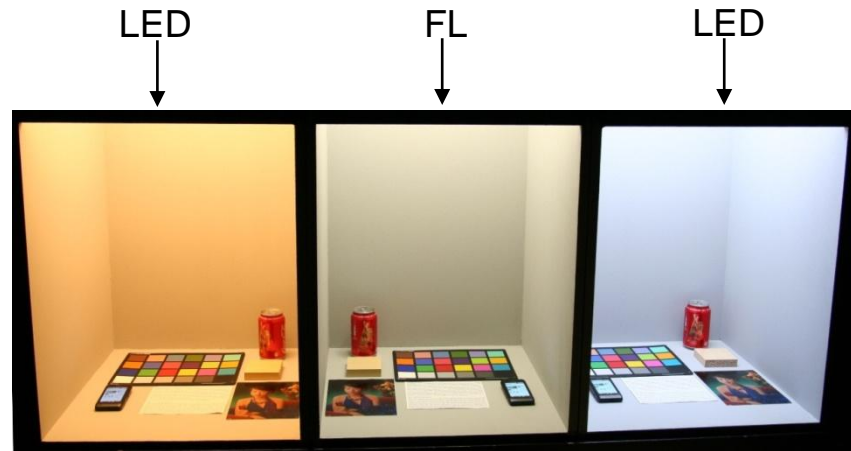
# Introduction

- CIE Colour Rendering Index (CRI)
- The CIE technical committee (TC) 1-62 concluded that the current CIE CRI cannot generally be applied to predict the colour rendering rank order of a set of light sources when white LED light sources are involved in the set.
- The CIE TC 1-69: Colour Rendition by White light sources is currently working on finding a new metric or metrics
  - 1) Rank- order based colour rendering index (RCRI) [6],
  - 2) **Feeling of contrast index (FCI)** [7],
  - 3) *CRI-CAM02UCS* [8],
  - 4) **Colour quality scale (CQS)** [3],
  - 5) Harmony rendering index (HRI) [9],
  - 6) *Memory CRI (MCRI)* [10],
  - 7) Categorical colour rendering index (CCRI) [11],
  - 8) *Gamut Area Index (GAI) and CIE CRI* [12], and
  - 9) Monte Carlo method of assessment [13].

- Jost-Boissard et al. [15] conducted a user acceptance studies by considering three metrics (CQS, full-spectrum colour index (FSCI) and the GAI) along with CIE CRI.
- Guo et al. [14] investigated the cross-comparison of several metrics based on simulation. However, they did not conduct a user acceptance study.
- Smet et al. [16] studied the performance of 13 colour quality metrics by calculating the average correlation of the metric predictions with visual scaling of the perceived colour quality obtained in several psychophysical studies.
- Smet et al. [17] optimized the LED module based on the MCRI and studied the psychophysical rating experiment at 2700 K along with an incandescent lamp with 18 observers.
- To investigate the subjective preference in terms of naturalness of objects, colourfulness of Macbeth Colour Checker (MCC) chart and visual appearance (brightness and pleasantness) of the lit environment under different light sources, lighting booth experiments were conducted in Lighting Unit, Aalto University.
- Six different LED SPDs at CCT 2700 K, were optimized for high CIE CRI, high Colour Quality Scale (CQS) colour preference scale ( $Q_p$ ) [3] keeping  $R_a=80$ , high Feeling of Contrast Index (FCI) keeping  $R_a=80$ , high CQS Relative Gamut area scale ( $Q_g$ ) [3] keeping  $R_a=80$ , low FCI keeping  $R_a=80$ , and low  $Q_p$  keeping  $R_a=80$ .
- The results were then compared with the performance of GAI, MCRI, and CRI-CAM02UCS (nCRI). The other metrics, like HRI, CCRI and the Monte Carlo method of assessment, were not considered because no software was available for their calculation.

# Experiment Setup

- Number of booths : 3
- Dimension of each booth:  
1 m x 0.5 m x 0.5 m
- Distance between observer  
and centre of booth 55 -60 cm
- Average illuminance 460 – 470 lx
- Surface reflectance: 50%



# Objects

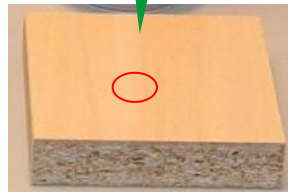
Hand



Colour Checker Chart



Sample of Table (wood)



Mobile phone



Coloured picture



Coke can



Black and white text

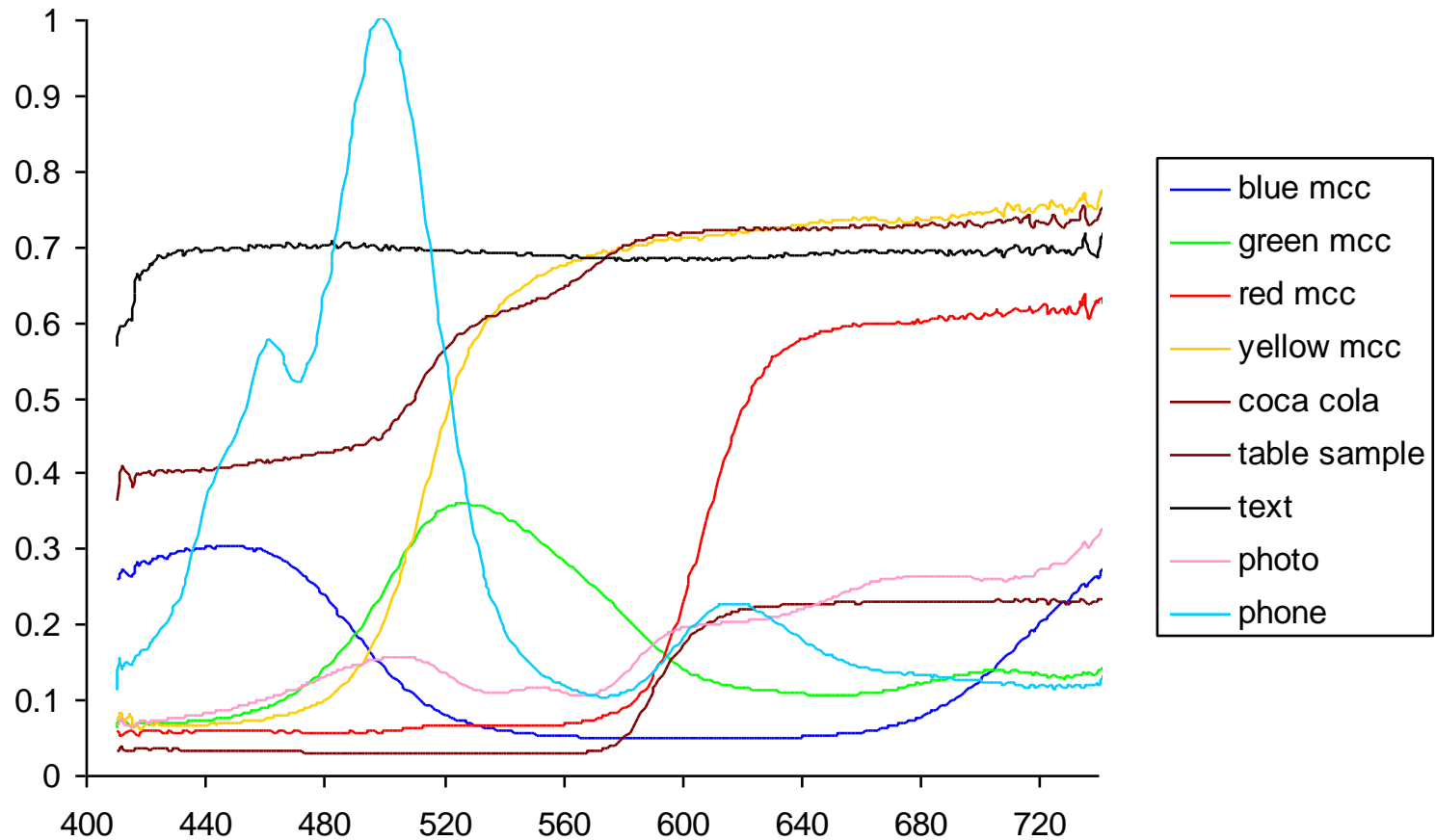
## THE BOY WHO LIVED

Mr and Mrs Dursley, of number four, Privet Drive, were proud to say that they were perfectly normal, thank you very much. They were the last people you'd expect to be involved in anything strange or suspicious, because they just didn't hold with such nonsense. Mr Dursley was the director of a firm called Grunnings, which made drills. He was a big, beefy man with hardly any neck, although he did have a very large mustache. Mrs Dursley was thin and blonde and had nearly twice the usual amount of neck, which came in very useful as she spent so much of her time craning over garden fences, spying on the neighbours. The Dursleys had a small son called Dudley and in their opinion there was no finer boy anywhere.

## Johnson's six blows England away

Mitchell Johnson revived his Test career and sparked Australia's Ashes hopes into life with a brutal six-wicket haul on the second day at the WACA as England subsided to 187 all out. Johnson claimed four during the morning session and returned to mop up the tail as the visitors lost all ten wickets for 109 following a solid opening partnership. He was well supported by Ryan Harris, who claimed three key victims, but this was the Johnson show. His hours in the nets since being dropped have clearly worked and he also rode on the confidence of his batting effort to produce a wonderful spell of 9-3-20-4 which included a spell of three wickets in 12 balls to crash through England's previously formidable top order. Harris's performance was also important, as he removed the key scalps of Andrew Strauss and Ian Bell who had both made impressive half-centuries.

# Spectral reflectance of objects:



# Light sources

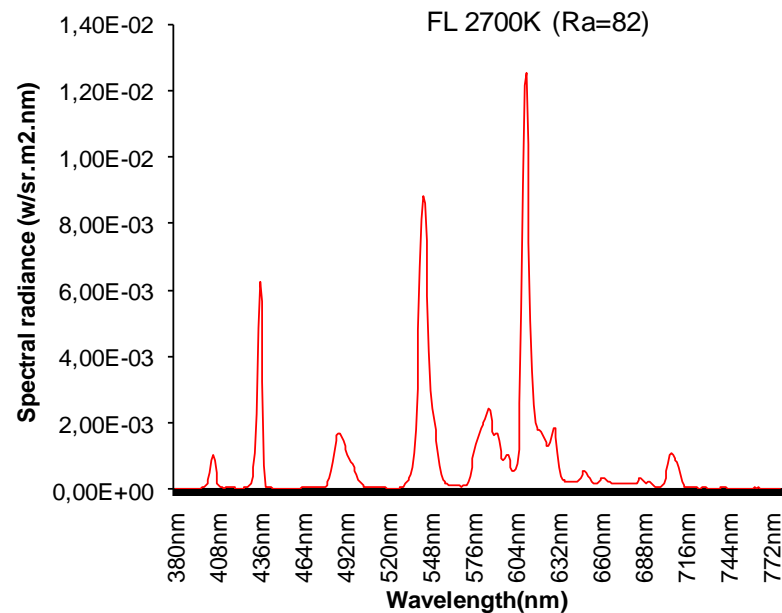
- Six LED Spectra
- One Fluorescent Lamp



# Fluorescent Lamp

**FL 2700K**

Osram FC 40W/ 827

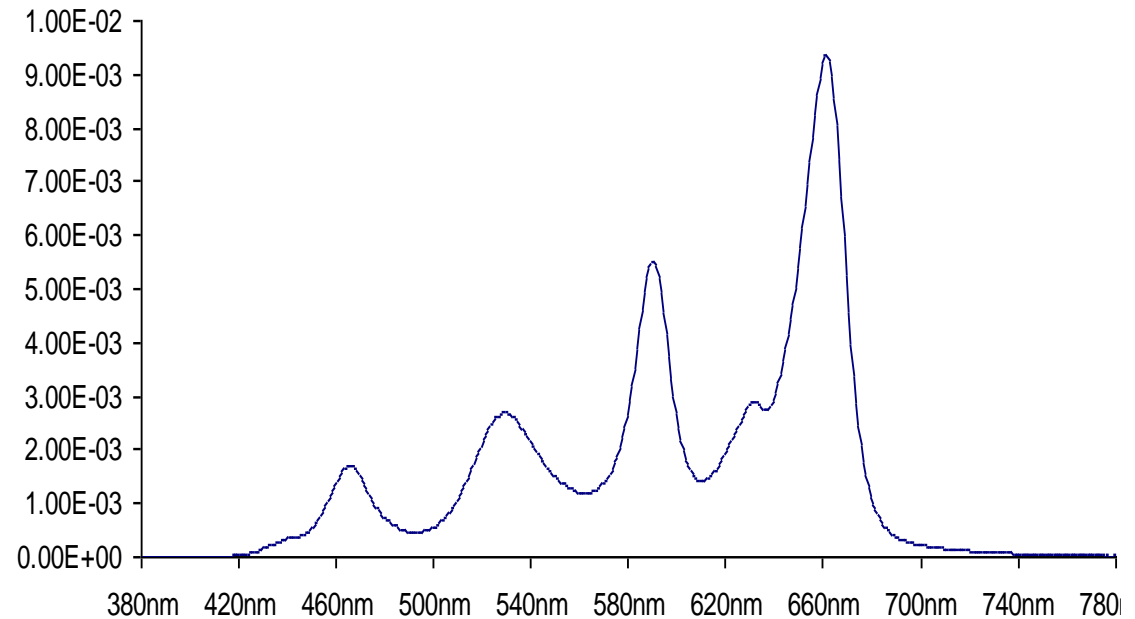


KONICA MINOLTA  
CS 2000  
Spectroradiometer

# LED spectra

Criteria 1: High value of colour rendering index (Ra)

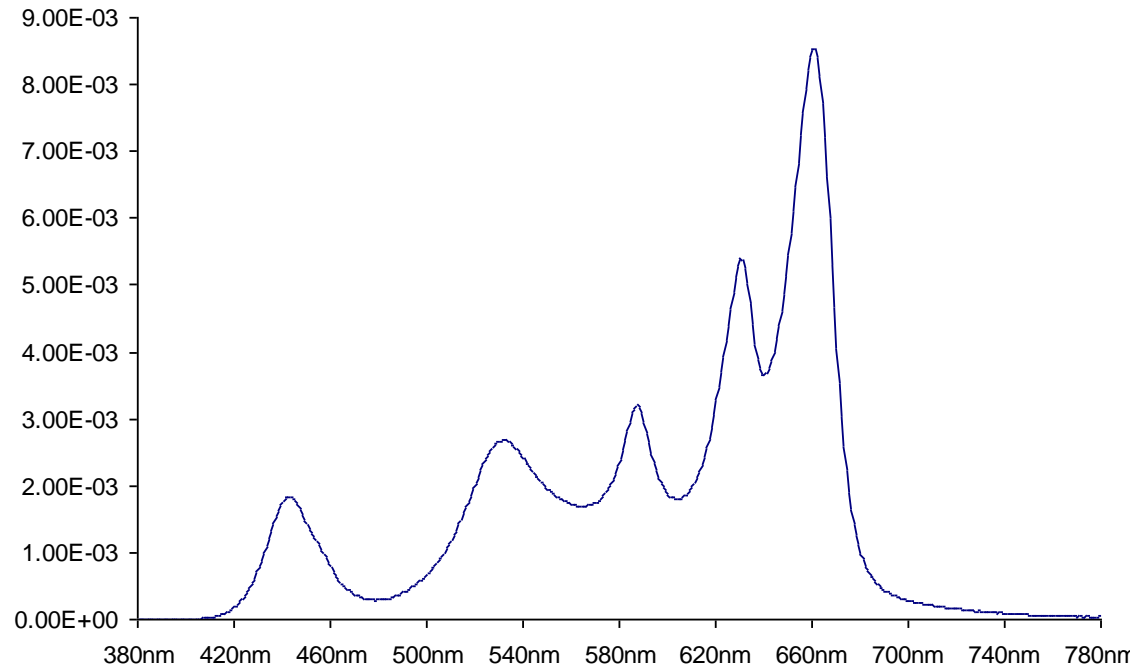
**2700K**  
Ra = 98



# LED spectra

Criteria 2: High value of CQS Gamut Area scale (Qg) keeping Ra at 80

**2700K**  
Qg = 119



# LED spectra

Criteria 3: High value of FCI (Feeling of Contrast Index) keeping Ra at 80

**2700K**

FCI = 135

Criteria 4: Lower value of FCI keeping Ra at 80

**2700K**

FCI = 93

Criteria 5: High value of CQS Colour Preference scale (Qp) keeping Ra at 80

**2700K**

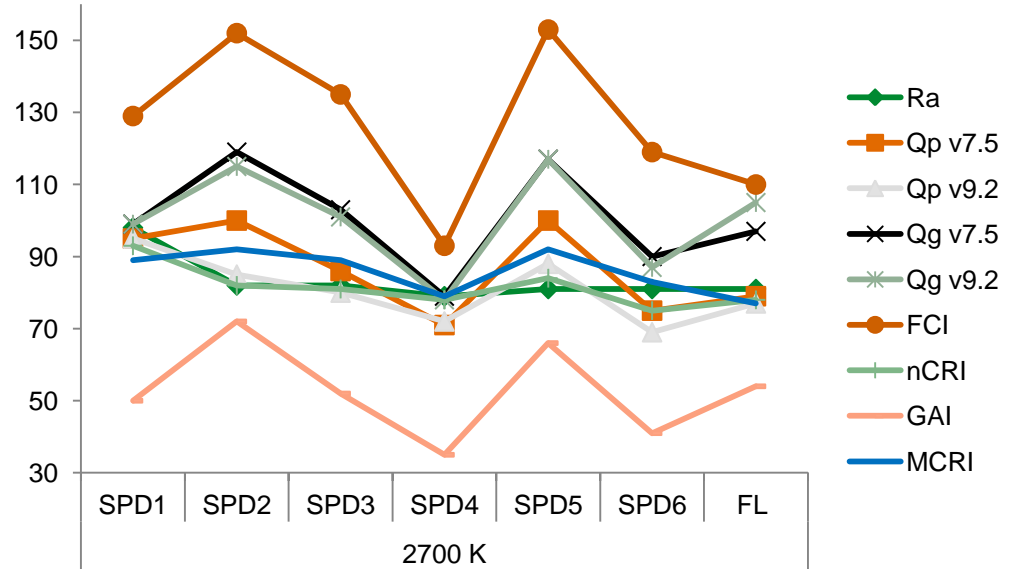
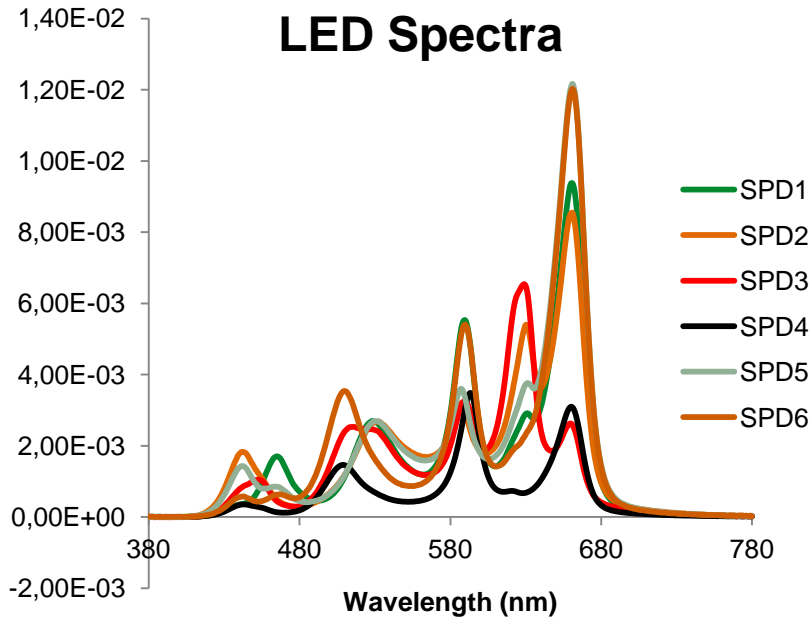
Qp = 100

Criteria 6: Lower value of Qp keeping Ra constant at 80

**2700K**

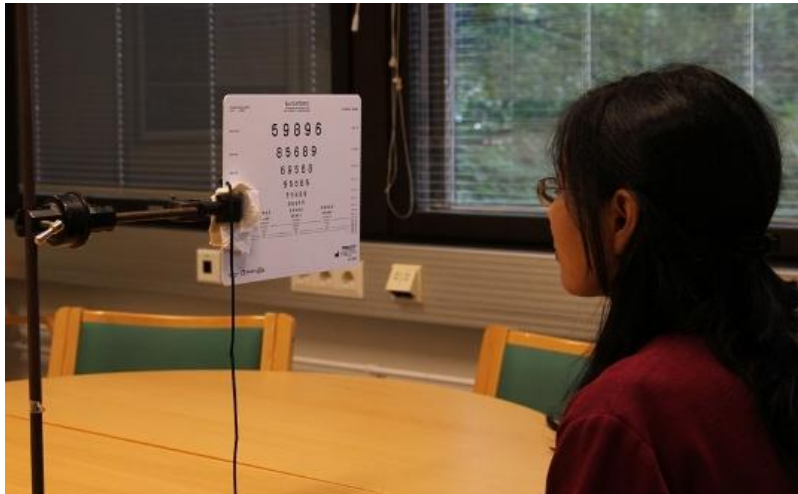
Qp = 75

# LED Spectra



# Observers

- Alltogether 60 Observers
  - 30 males and 30 females



Visual acuity test



Ishihara test for colour blindness

# Questionnaires

## Booth 1 evaluation

1) How would you rate the naturalness of the all objects shown?

very unnatural \_\_\_\_\_ very natural

2) How would you rate the naturalness of the following objects?

**Hand**      very unnatural \_\_\_\_\_ very natural

**Mobile phone** \_\_\_\_\_

**Coloured picture** \_\_\_\_\_

**Coke can** \_\_\_\_\_

**Sample of wood** \_\_\_\_\_

**Printed text** \_\_\_\_\_

3) How do you feel about the viewing/visual condition in this booth when you observe the objects?

Dim \_\_\_\_\_ Bright

Uncomfortable \_\_\_\_\_ Comfortable

Unpleasant \_\_\_\_\_ Pleasant

Boring \_\_\_\_\_ Interesting

# Questionnaires

4) How would you rate the colourfulness of the Colour checker Chart?

dark \_\_\_\_\_

bright

discoloured \_\_\_\_\_

colourful

## Comparison with booth 2

5) Under which lighting do the following objects look natural?

Hand	left booth	<input type="radio"/>	right booth
Mobile phone	left booth	<input type="radio"/>	right booth
Coloured picture	left booth	<input type="radio"/>	right booth
Coke can	left booth	<input type="radio"/>	right booth
Sample of wood	left booth	<input type="radio"/>	right booth
Printed text	left booth	<input type="radio"/>	right booth
Colour Checker Chart	left booth	<input type="radio"/>	right booth

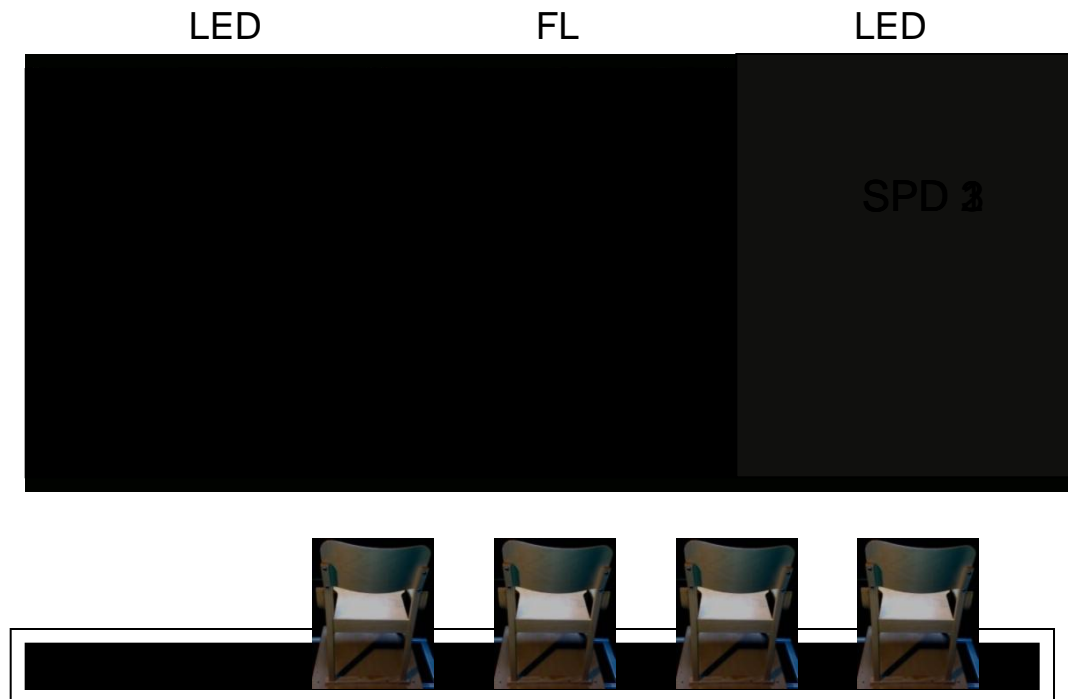
6) Which lighting environment do you prefer?

left booth  right booth



# Test procedure

Example of one session



## Comparison with booth 2

5) Under which lighting do the following objects look natural?

Hand	left booth <input type="radio"/>	<input type="radio"/>	right booth
Mobile phone	left booth <input type="radio"/>	<input type="radio"/>	right booth
Coloured picture	left booth <input type="radio"/>	<input type="radio"/>	right booth
Coke can	left booth <input type="radio"/>	<input type="radio"/>	right booth
Sample of wood	left booth <input type="radio"/>	<input type="radio"/>	right booth
Printed text	left booth <input type="radio"/>	<input type="radio"/>	right booth
Colour Checker Chart	left booth <input type="radio"/>	<input type="radio"/>	right booth

6) Which lighting environment do you prefer?

left booth   right booth

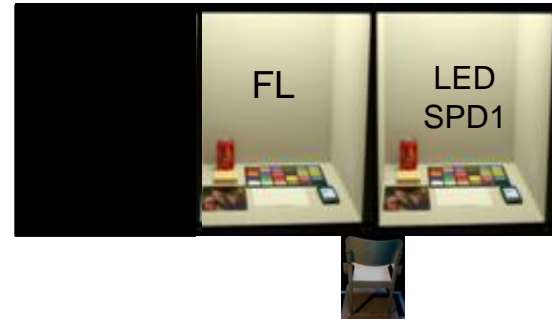


Fig. Comparison Evaluation



Fig. Reverse Comparison Evaluation

# Results

## • Symmetry testing

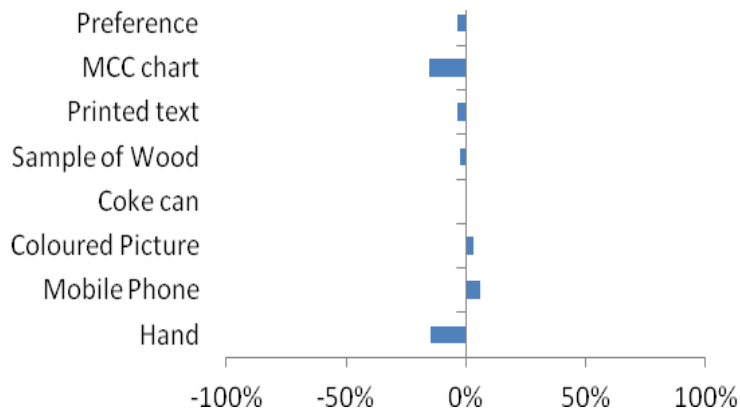
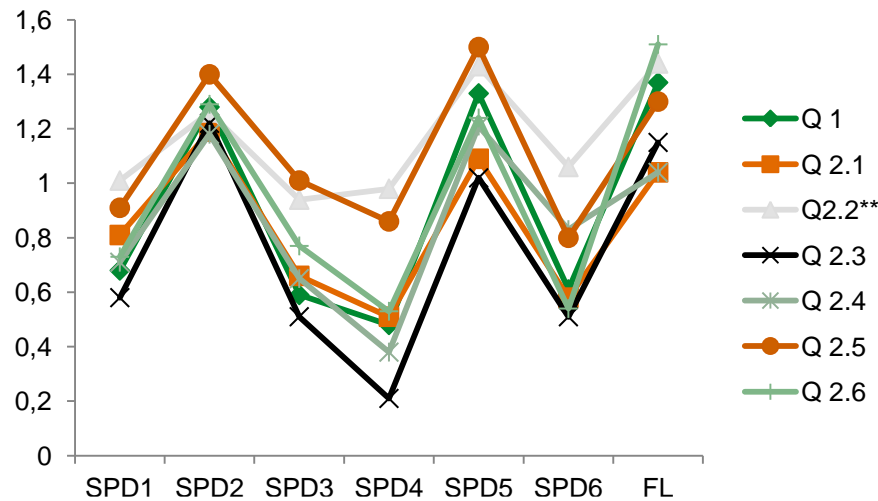


Fig. The difference in percentage between the comparison and the reverse comparison evaluations between the LED SPD1 and FL.

# Results:



Mean ratings for question about naturalness of objects

SPD 1: Ra maximum

SPD 2: Qg high, Ra 80

SPD 3: FCI high, Ra 80

SPD 4: FCI low, Ra 80

SPD 5: Qp high, Ra 80

SPD 6: Qp low, Ra 80

Q1: How would you rate the naturalness of the all the objects shown ?

Q2: How would you rate the naturalness of the following objects ?

Q2.1: Hand

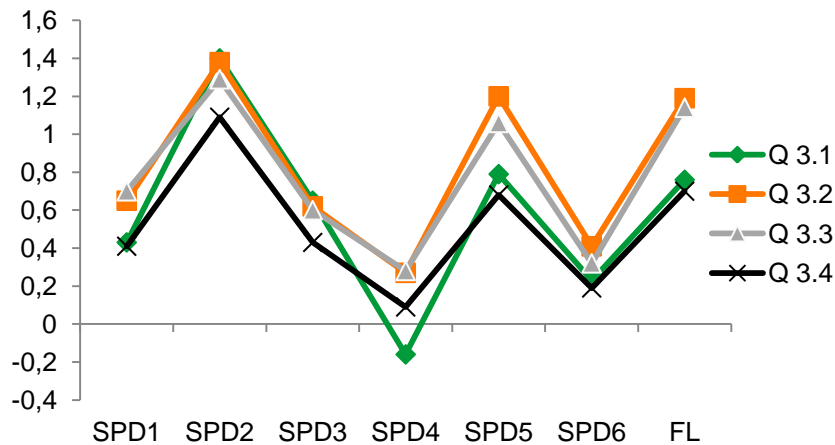
Q2.2: Mobile phone

Q2.3: Coloured picture

Q2.4: Coke can

Q2.5: Sample of table

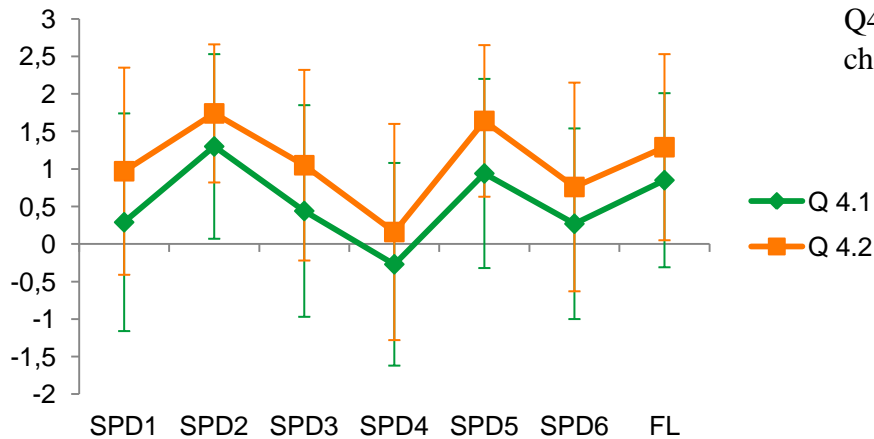
Q2.6: Printed text



Q 3: How do you feel about the viewing/visual condition in this booth ?

- Q3.1: bright \_\_\_\_\_ dim
- Q3.2: comfortable \_\_\_\_\_ uncomfortable
- Q3.3: pleasant \_\_\_\_\_ unpleasant
- Q3.4: interesting \_\_\_\_\_ boring

Mean ratings for questions about visual appearance of the lit environment



Q4: How would you rate the colourfulness of the colour checker chart ?

- Q4.1: dark \_\_\_\_\_ bright
- Q4.2: discoloured \_\_\_\_\_ colourful

Mean ratings for questions about colourfulness of MCC

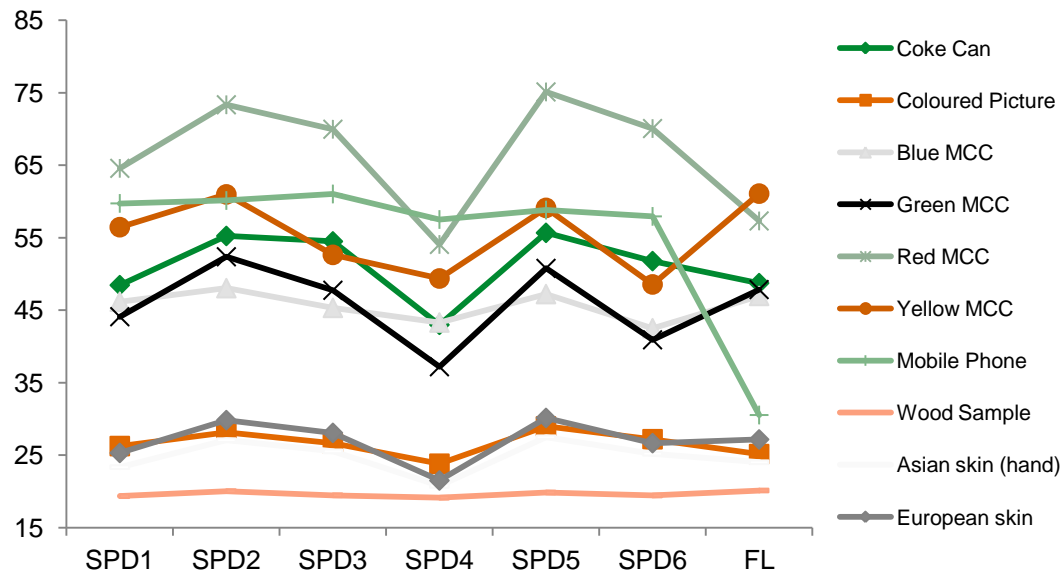
- SPD 1: Ra maximum
- SPD 2: Qg high, Ra 80
- SPD 3: FCI high, Ra 80
- SPD 4: FCI low, Ra 80
- SPD 5: Qp high, Ra 80
- SPD 6: Qp low, Ra 80

## Summary of the ANOVA test with the significance level of 0.05 at 2700 K

	p-value
<b>Q1 (Naturalness of all objects)</b>	<0,0001
<b>Naturalness of</b>	
Q2#1 Hand	0,043
Q2#2 Mobile phone	<b>0,109</b>
Q2#3 Coloured picture	<0,0001
Q2#4 Coke can	0,012
Q2#5 Sample of wood	0,015
Q2#6 Printed Text	<0,0001
<b>Visual appearance of the lit environment</b>	
Q3#1 (Dim/Bright)	<0,0001
Q3#2 (Uncomfortable/Comfortable)	<0,0001
Q3#3 (Unpleasant/Pleasant)	<0,0001
Q3#4 (Boring/Interesting)	<0,0001
<b>Colourfulness of MCC chart</b>	
Q4#1 (dark/bright)	<0,0001
Q4#2 (discoloured/colourful)	<0,0001

A Post hoc analysis (Duncan procedure) was performed to investigate which SPDs observers preferred. It was found that the observers preferred SPD2, SPD5 and FL in most cases . The SPD4 and SPD6 were least preferred.

# Chroma of different objects and colours, calculated in CAM02UCS, under different light sources at 2700 K



# Spearman correlation coefficient between the indices and the mean rating of observers in favour of different SPDs.

	Naturalness							Visual appearance				Colourfulness of MCC Chart											
	Q1	Q2.1	Q2.2	Q2.3	Q2.4	Q2.5	Q2.6	Q3.1	Q3.2	Q3.3	Q3.4	Q4.1	Q4.2	Ra	CQsv7.5	CQsv9.2	Qpv7.5	Qpv9.2	Qgv7.5	Qgv9.2	FCI	nCRI	GAI
Q1	1.000																						
Q2.1	.821*	1.000																					
Q2.2	.929**	.679	1.000																				
Q2.3	.883**	.955**	.775*	1.000																			
Q2.4	.857*	.857*	.857*	.829*	1.000																		
Q2.5	.714	.893**	.571	.775*	.750	1.000																	
Q2.6	.857*	.857*	.714	.901**	.714	.821*	1.000																
Q3.1	.750	.964**	.607	.901**	.821*	.929**	.893**	1.000															
Q3.2	.821*	1.000**	.679	.955**	.857*	.893**	.857*	.964**	1.000														
Q3.3	.857*	.964**	.714	.991**	.786*	.821*	.929**	.929**	.964**	1.000													
Q3.4	.786*	.929**	.643	.937**	.750	.857*	.964**	.964**	.929**	.964**	1.000												
Q4.1	.750	.964**	.607	.901**	.821*	.929**	.893**	1.000**	.964**	.929**	.964**	1.000											
Q4.2	.750	.964**	.607	.901**	.821*	.929**	.893**	1.000**	.964**	.929**	.964**	1.000**	1.000										
Ra	.131	.412	-.187	.368	.075	.187	.262	.356	.412	.412	.356	.356	.356	1.000									
CQsv7.5	.393	.643	.107	.487	.357	.607	.357	.536	.643	.536	.429	.536	.536	.692	1.000								
CQsv9.2	.393	.643	.107	.487	.357	.607	.357	.536	.643	.536	.429	.536	.536	.692	1.000**	1.000							
Qpv7.5	.559	.883**	.342	.727	.703	.811*	.595	.847*	.883**	.757*	.721	.847*	.847*	.614	.847*	.847*	1.000						
Qpv9.2	.393	.643	.107	.487	.357	.607	.357	.536	.643	.536	.429	.536	.536	.692	1.000**	1.000**	.847*	1.000					
Qgv7.5	.464	.857*	.250	.703	.643	.821*	.643	.893**	.857*	.750	.786*	.893**	.893**	.599	.714	.714	.955**	.714	1.000				
Qgv9.2	.786*	.929**	.643	.829*	.857*	.964**	.857*	.964**	.929**	.857*	.893**	.964**	.964**	.262	.571	.571	.847*	.571	.857*	1.000			
FCI	.357	.714	.179	.505	.643	.714	.429	.750	.714	.536	.571	.750	.750	.505	.679	.679	.919**	.679	.929**	.786*	1.000		
nCRI	.288	.577	.018	.400	.288	.559	.252	.468	.577	.450	.342	.468	.468	.661	.991**	.991**	.818*	.991**	.685	.505	.667	1.000	
GAI	.750	.964**	.607	.901**	.821*	.929**	.893**	1.000**	.964**	.929**	.964**	1.000**	1.000**	.356	.536	.536	.847*	.536	.893**	.964**	.750	.468	1.000
MCRI	.164	.618	.018	.395	.509	.582	.218	.618	.618	.418	.418	.618	.618	.514	.691	.691	.881**	.691	.873*	.618	.946**	.716	.618

\*. Correlation is significant at the 0.05 level.

\*\* . Correlation is significant at the 0.01 level.

# Conclusion

- The observers preferred the SPDs under which the chroma and colourfulness values of the object colours were higher.
- As expected, the CIE Colour Rendering Index (CRI) was not good indicator of the observers' preference for LED SPDs.
- The experiment results showed that the light sources with higher CQS Gamut Area Scale (Qg) and CQS Colour Preference Scale (Qp) values were preferred by the observers as far as LED spectra were concerned.
- The metric Qg v9.2 (CQS Qg version 9.2) and Gamut Area Index (GAI) correlates highly with naturalness of objects, visual appearance of lit environment and colourfulness of MCC chart, and were also suitable indicators of observers' preference for both the LEDs and fluorescent lamp spectra.



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**Thank you for your attention !!**