
A Study about Colour-Difference Thresholds

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Properties of Dynamic Illumination Concept:

Temporal Variation of:

- illuminance
- spectral distribution of light
- spatial distribution of light



Effects on:

- visual perception
- photobiological processes
- emotional effects of light

Availability of Technical Equipment:

- light sources
- control units
- detectors for feedback control



Design of Control Strategy

Conditions:

knowledge of quantitativ and qualitativ light effects:

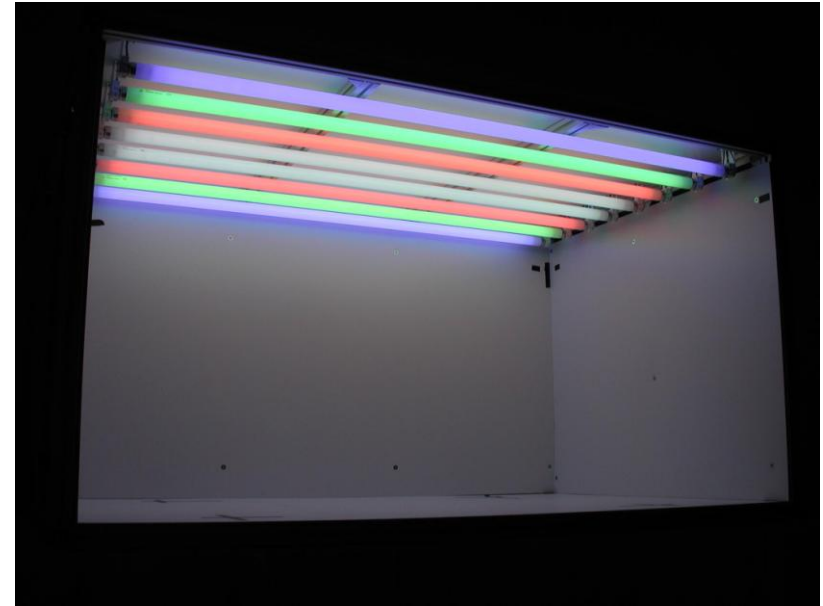
- ***visual perception***
- emotional light effects
- biological light effects

Main Topic:

Visual Perception of Colour Differences when the Chromaticity Coordinates varied

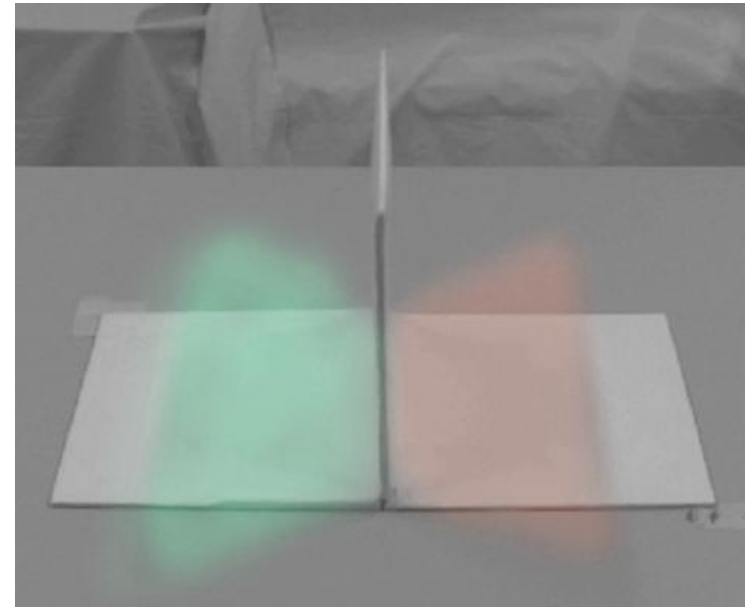
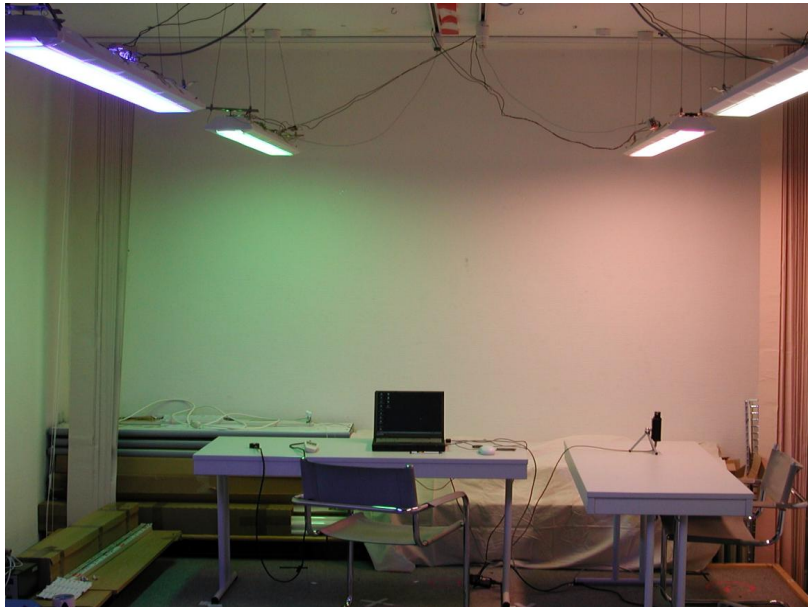
1. Experimental Design and Methodology
2. Preferred Luminous Colour
3. Visual Threshold and Tolerance Limits of Luminous Colour Variation
4. Limits of Colour Differences between Luminaires
5. Combination of Different Luminous Colours
6. Conclusion and Prospect

Realisation of predefined light scenarios (E, CCT, x,y) by digital tunable white and coloured fluorescent lamps with DALI-Protokoll



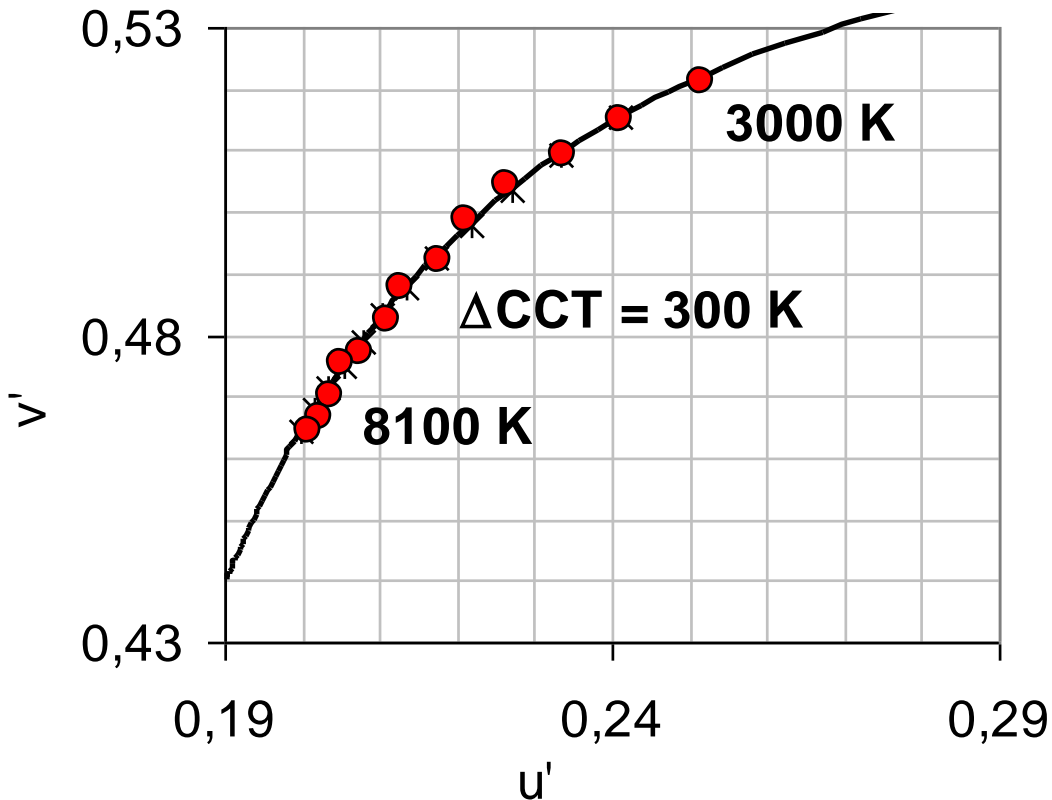
Lightsimulator

Realisation of predefined light scenarios (E, CCT, x,y) by digital tunable white and coloured fluorescent lamps with DALI-Protokoll

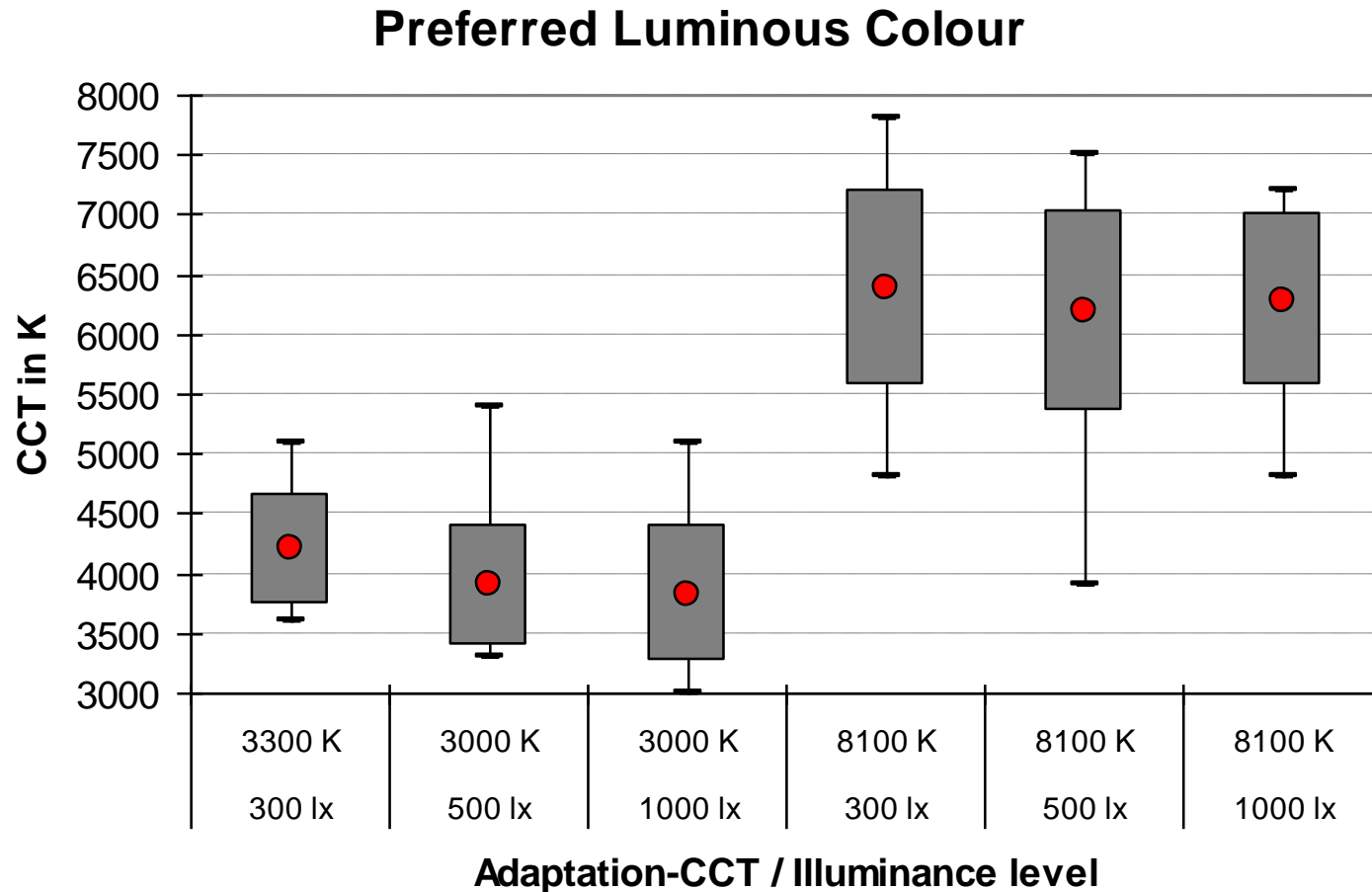


Experimental Laboratory

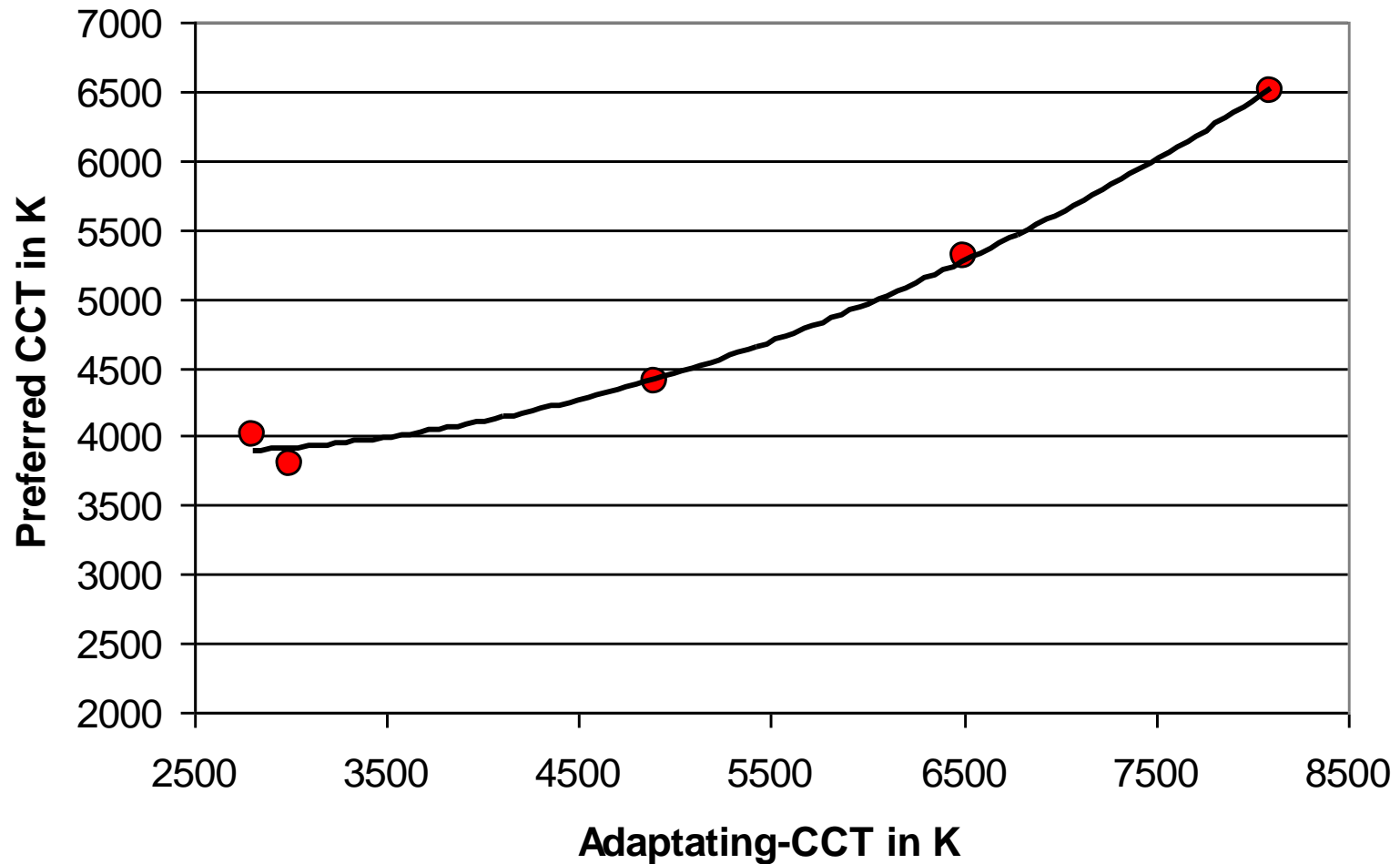
Control Values



- > 5 min adaptation to 3000 K and 8100 K
- Selection of the most pleasant luminous colour
- $E = 300 \text{ lx}; 500 \text{ lx}; 1000 \text{ lx}$
- 21 subjects (23-73 y.)
- 2 repetitions



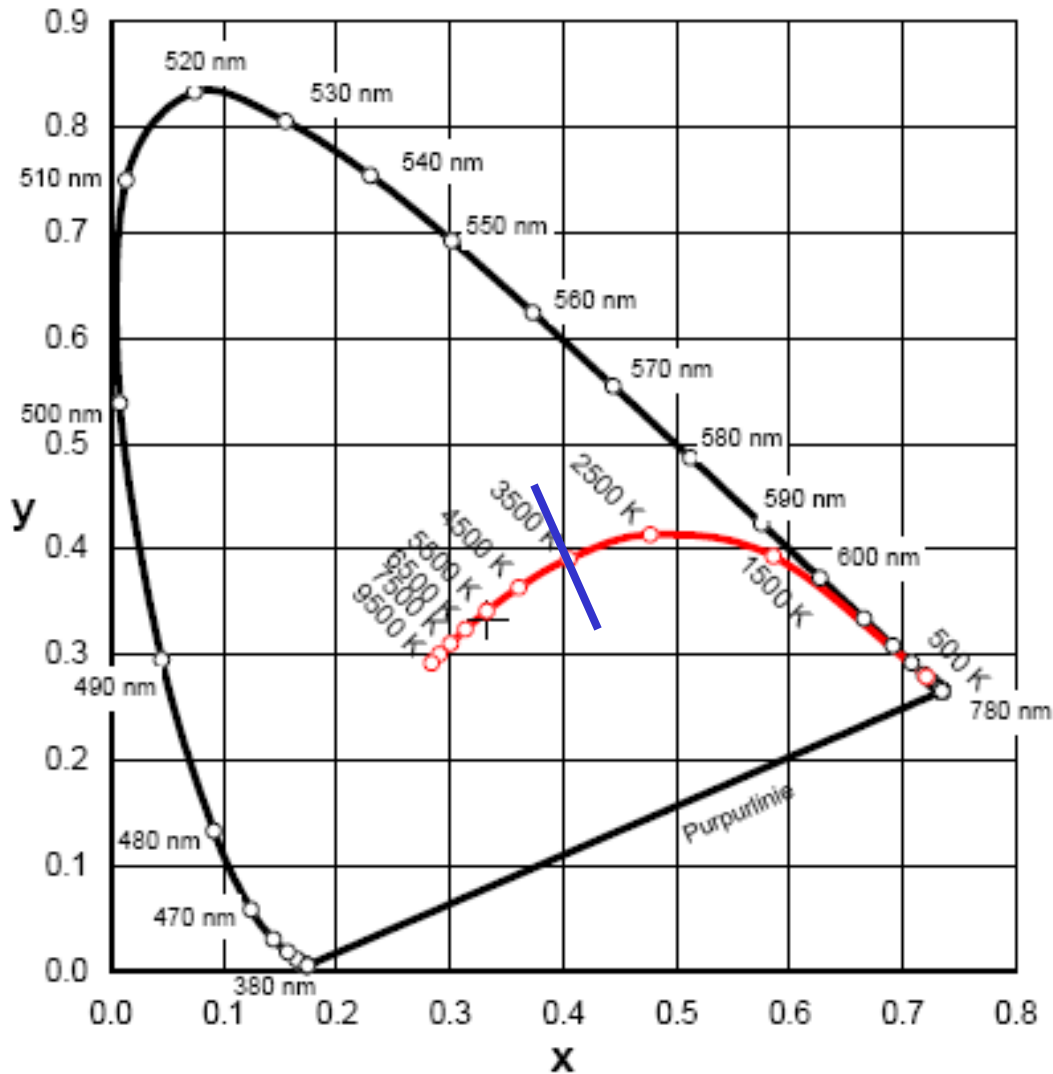
- no dependance on the illuminance
- influenced of adapting conditions



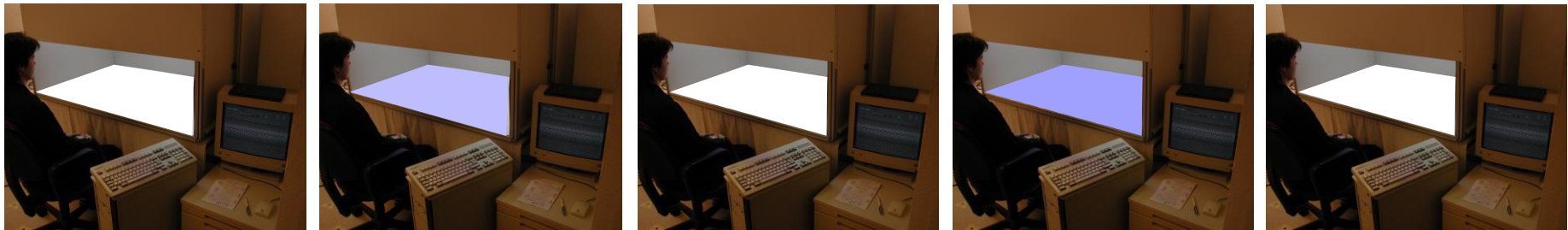
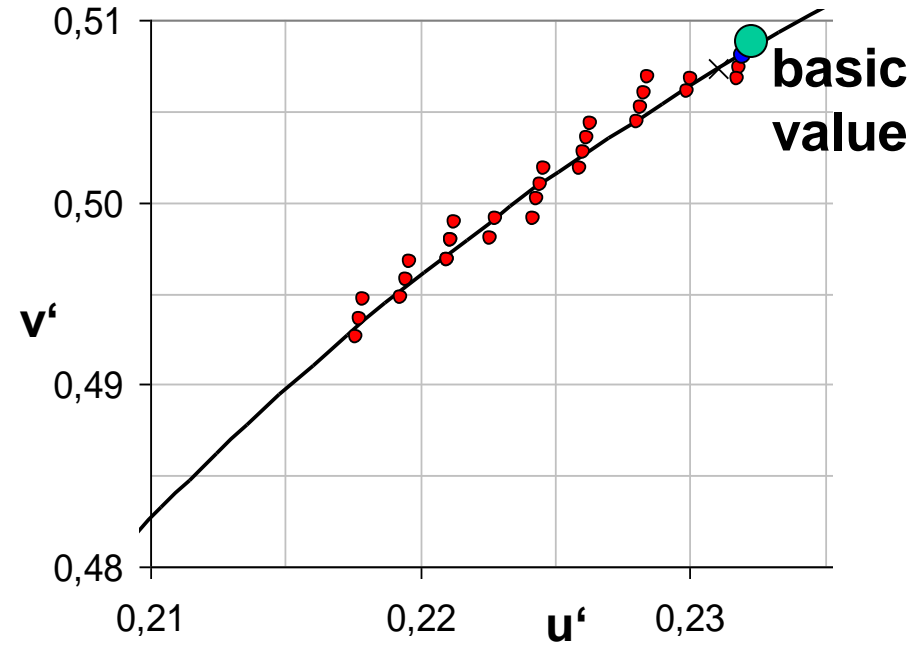
$$CCT_{pref} \approx 8 \cdot 10^{-5} \cdot CCT_{adapt}^2 - 0,3474 \cdot CCT_{adapt} + 4260 \text{ K}$$

- no fixed value of the preferred luminous colour
- Necessary range of luminous colour at least:
3000 K to 8000 K
- Control of luminous colour independent of the illumination level

3. Visual Threshold and Limits of Luminous Colour Variation ¹¹



- Variation along Planckian Locus and Iso-temperature Lines
- Adaptation at basic value
- Colour Temperature: 3000 K, 3300 K, 3700 K, 4200 K, 4700 K, 5200 K, 5700 K, 6700 K
- Illumination levels: 300 lx, 500 lx, 1000 lx
- 21 subjects (22 – 73 y.)



- Increasing colour differences
rating: - *just noticeable*, - *distinctively perceptible*, - *disturbing*

Determination of Colour Differences:

UCS-Difference:

$$\Delta u'v' = \sqrt{(u'_2 - u'_1)^2 + (v'_2 - v'_1)^2}$$

u'_1, v'_1 Reference

u'_2, v'_2 Test

CIE-Lab-Colour Difference:

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

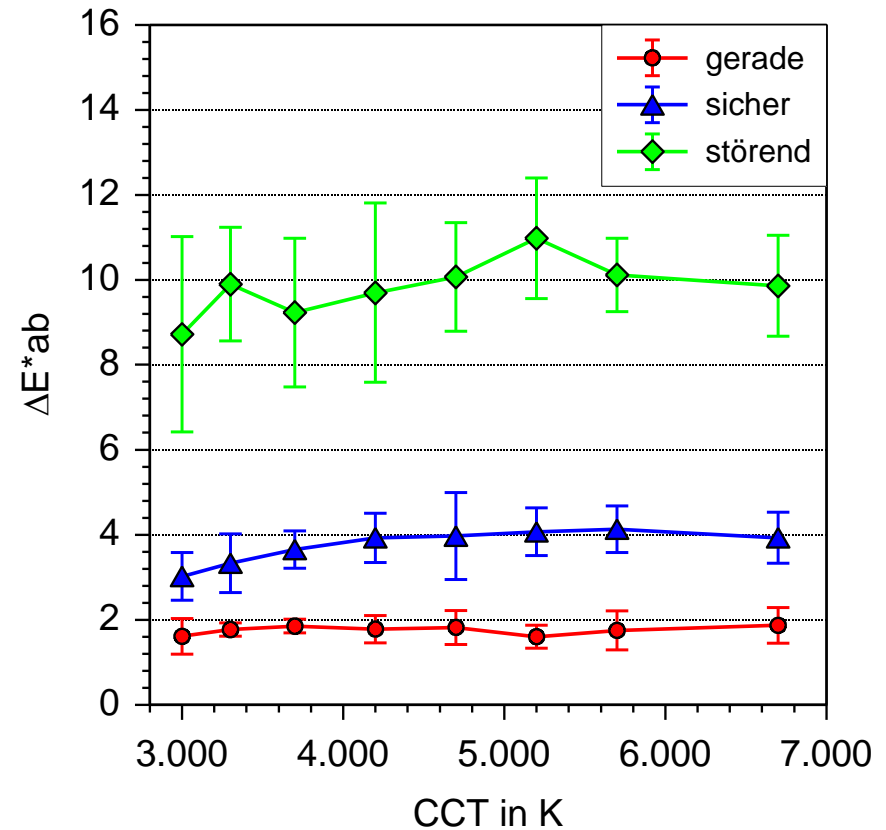
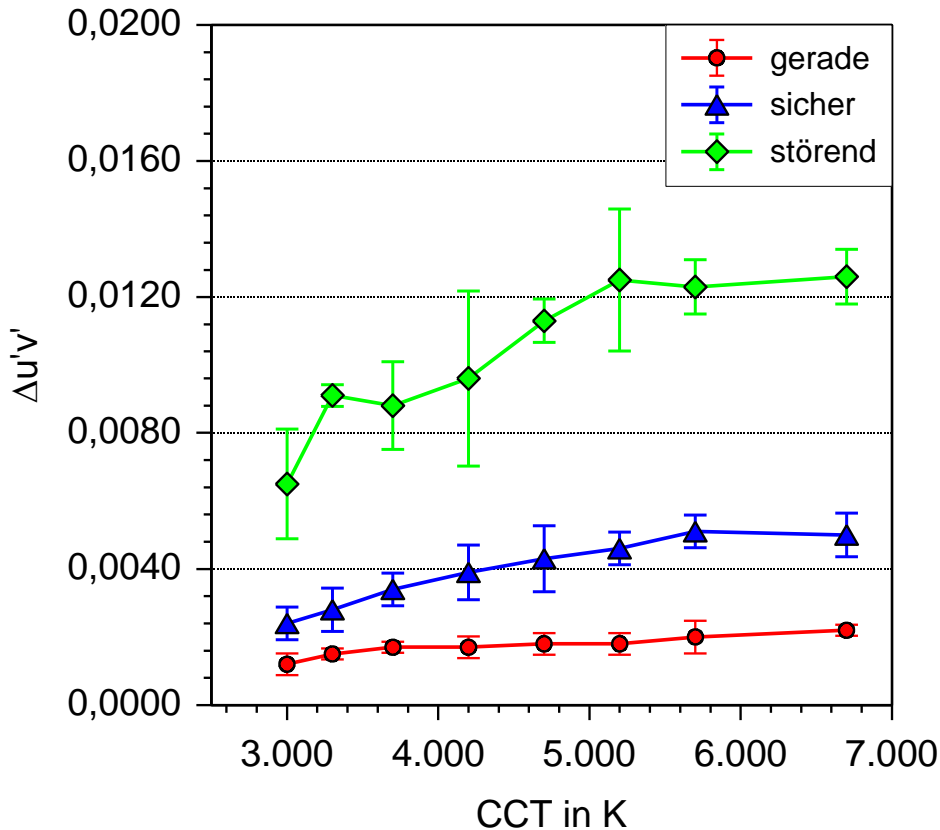
a^*_1, b^*_1, L^*_1 Reference

a^*_2, b^*_2, L^*_2 Test

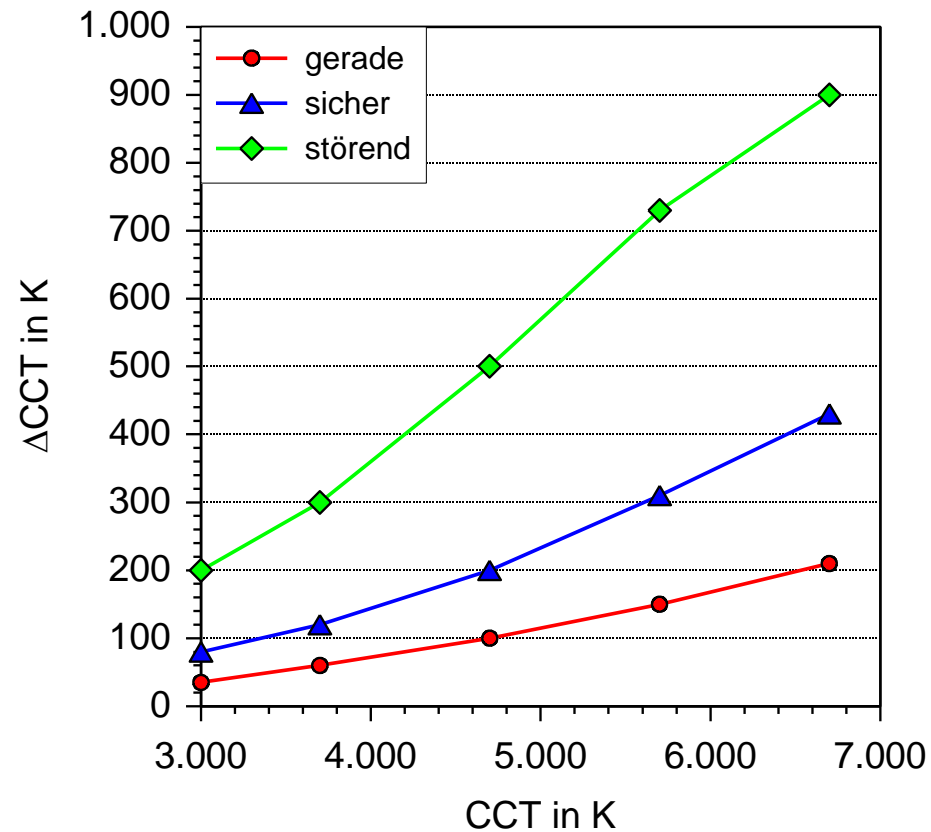
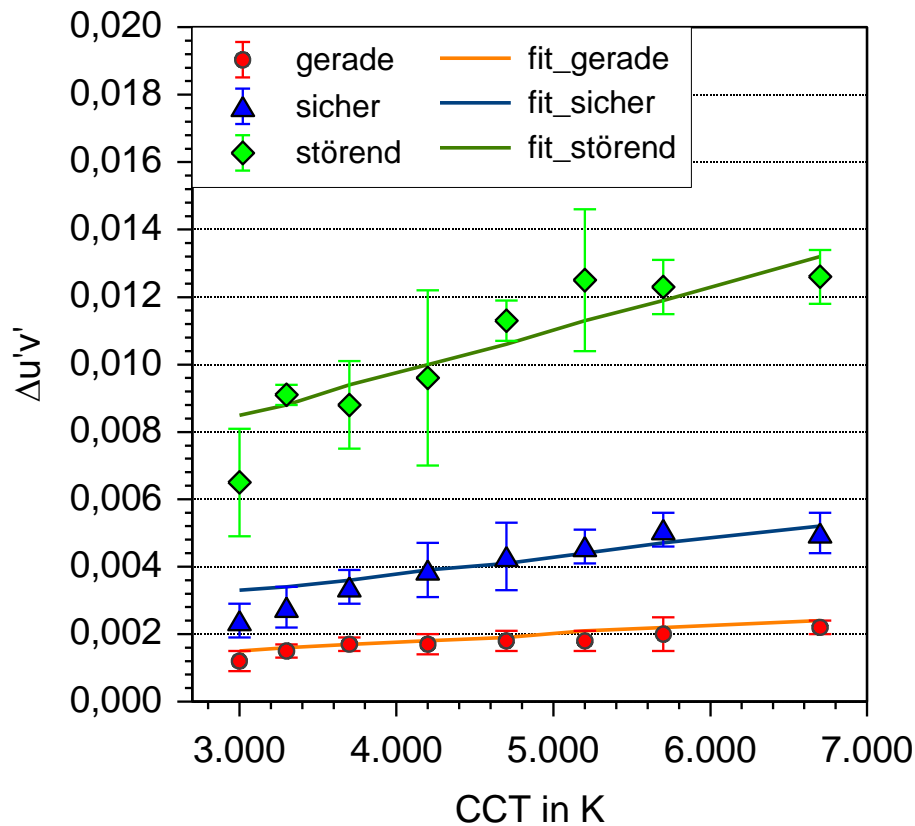
Reference: basic value

Condition: $L^*_1 = L^*_2$

Variation along Planckian Locus



Criteria	<i>just noticeable</i>	<i>distinctively perceptible</i>	<i>disturbing</i>
ΔE^*ab	1,8	3,8	9,8



$\Delta u'v' = 0,0046 + CCT \cdot 1,28 \cdot 10^{-6}$ **disturbing** $\Delta CCT = CCT \cdot 0,0195 - 403$

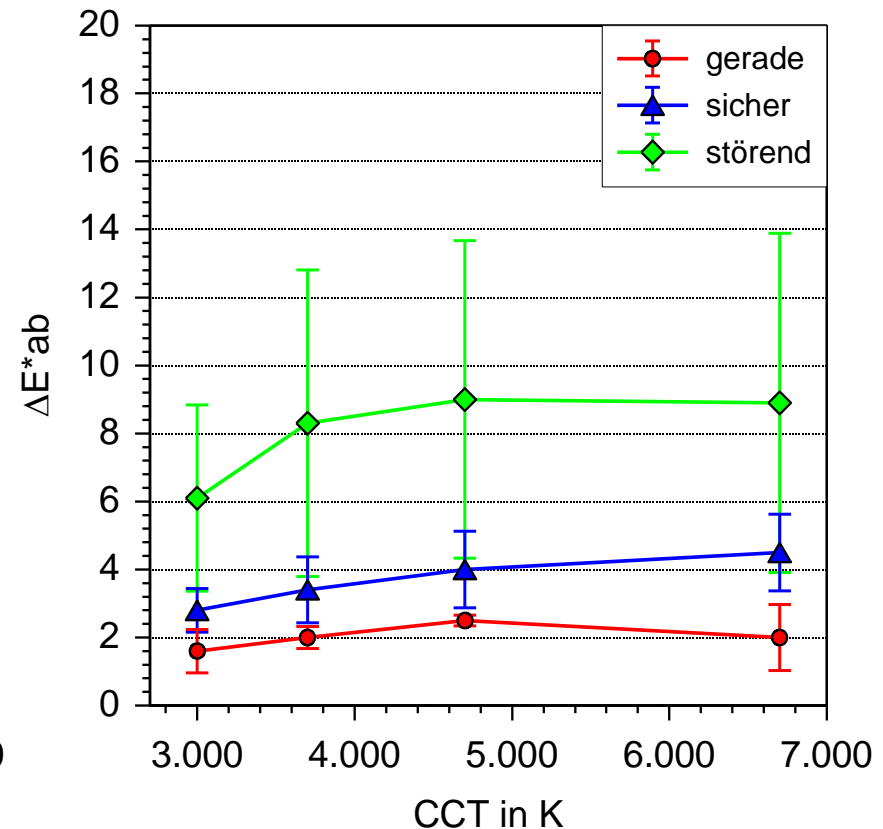
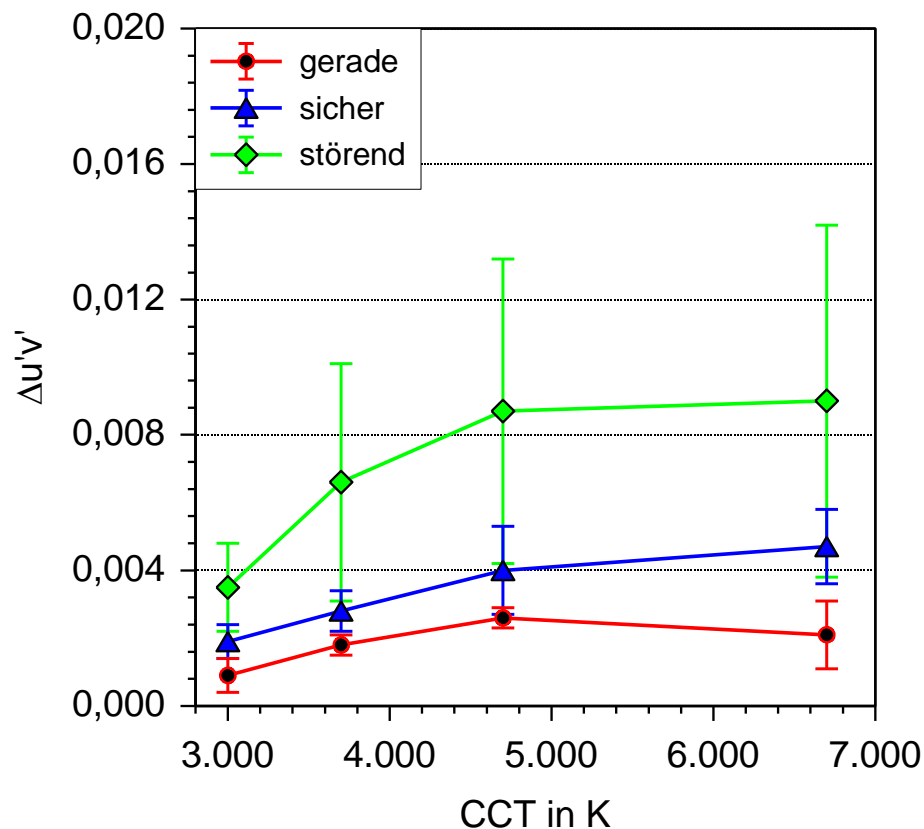
$\Delta u'v' = 0,0017 + CCT \cdot 5,20 \cdot 10^{-7}$ **perceptible** $\Delta CCT = CCT \cdot 0,0953 - 226$

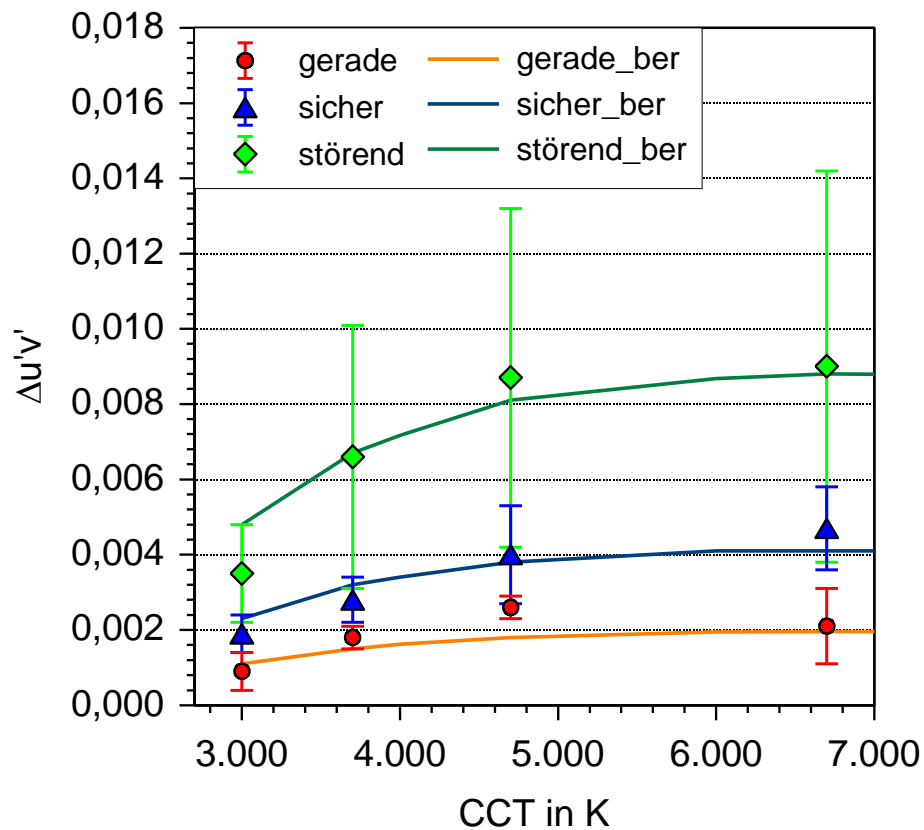
$\Delta u'v' = 0,0008 + CCT \cdot 2,44 \cdot 10^{-7}$ **just noticeable** $\Delta CCT = CCT \cdot 0,047 - 113$

Permitted CCT Deviations

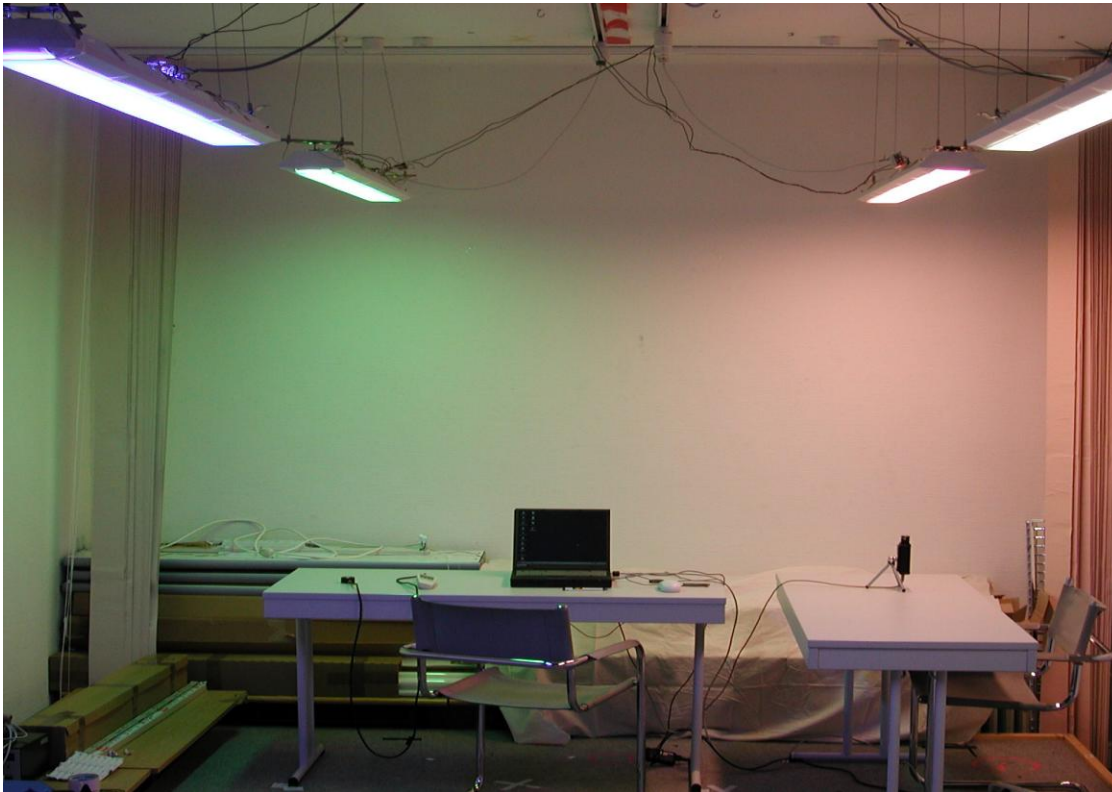
CCT in K	<i>just noticeable</i>	<i>distinctively perceptible</i>	<i>disturbing</i>
3000	+/- 28 K	+/- 60 K	+/- 182 K
4000	+/- 75 K	+/- 155 K	+/- 377 K
5000	+/- 122 K	+/- 250 K	+/- 572 K
6500	+/- 192 K	+/- 393 K	+/- 865 K

- Illuminance level: 500 lx
- Colour temperature: 3000 K, 3700 K, 4700 K, 6700 K
- 21 subjects (21 - 59 years)

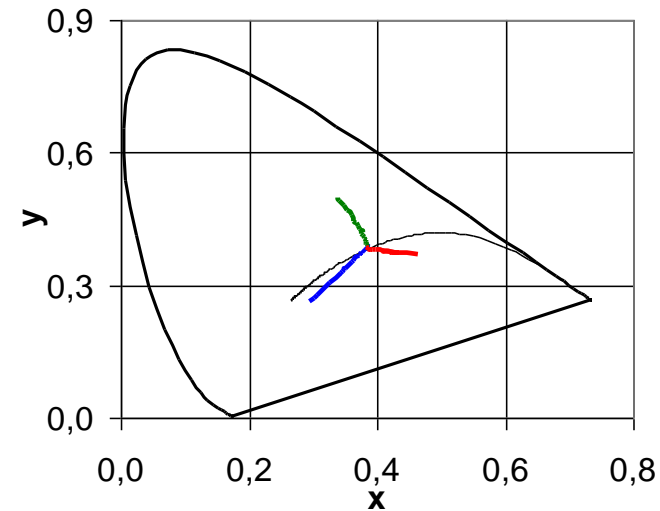




Criteria	<i>just noticeable</i>	<i>distinctively perceptible</i>	<i>disturbing</i>
ΔE^*_{ab}	1,8	3,5	7,8

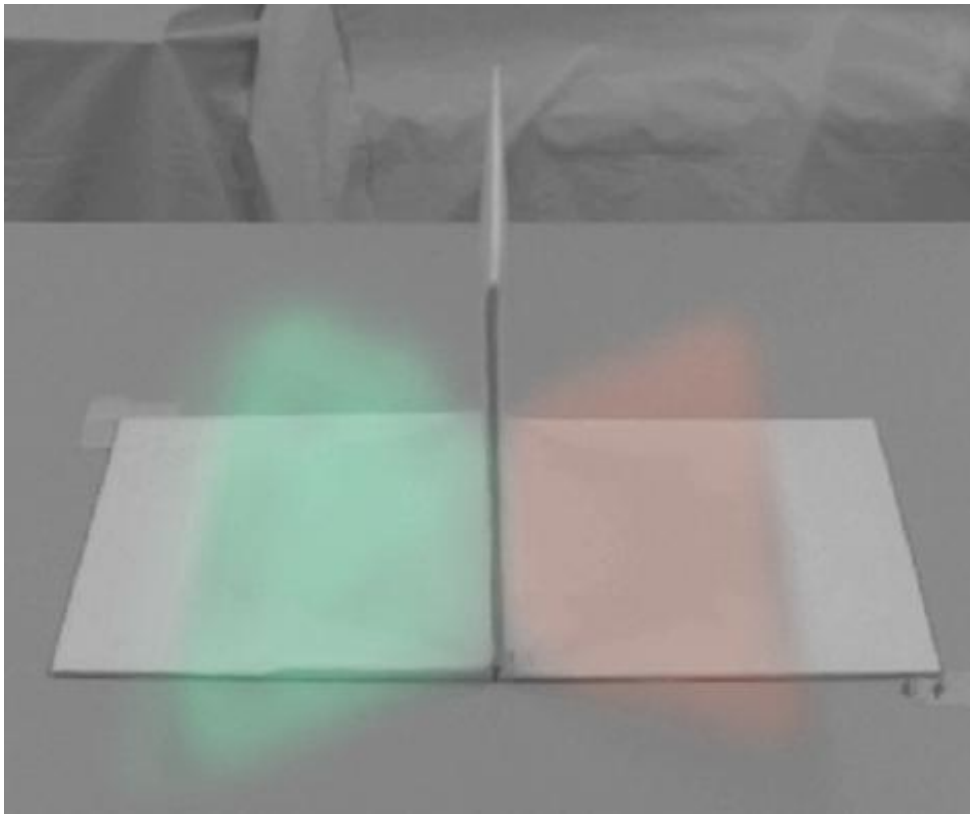


- CCT: 4000 K
- L_{Luminair} : 9300 cd/m²
- 25 subjects



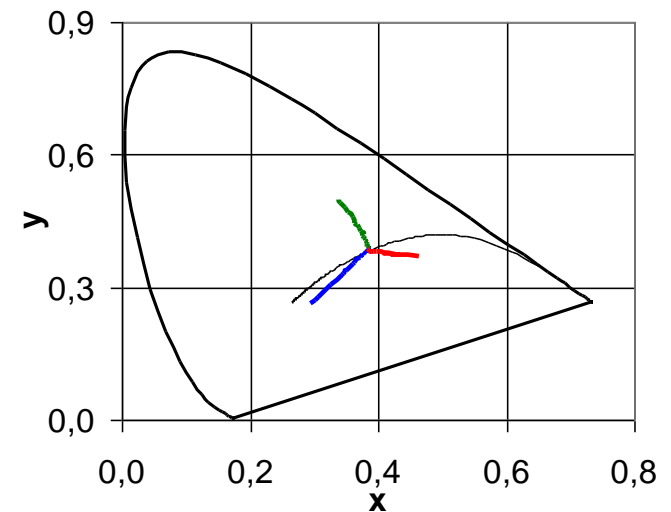
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Criteria	<i>just noticeable</i>	<i>distinctively perceptible</i>	<i>disturbing</i>
ΔE^*_{ab}	1,8	5,7	10,7



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- CCT: 4000 K
- E_{Desk} : 500 lx
- 25 subjects



Criteria	<i>just noticeable</i>	<i>distinctively perceptible</i>	<i>disturbing</i>
ΔE^*_{ab}	1,6	2,4	8,5

Thresholds and Limits

Criteria/ Situation	<i>just noticeable</i>	<i>distinctively perceptible</i>	<i>disturbing</i>
ΔE^*_{ab} Colour Shadows	1,6	2,4	8,5
ΔE^*_{ab} between Luminaires	1,8	5,7	10,7
ΔE^*_{ab} Planckian Locus	1,8	3,8	9,8
ΔE^*_{ab} Iso-temperature Lines	1,8	3,5	7,8

- Preferred luminous colour is describable as a function of the adapting colour temperature.
- The preferred luminous colour depends not on the illumination level.
- Illumination level and colour temperature should be independently adjustable.
- Necessary range of luminous colour at least: 3000 K to 8000 K
- Up to the thresholds the change of luminous colour can be implemented in steps.
- Use similar luminous colours within illumination area
- In order to stabilize the colour coordinates in luminaires feedback control is beneficial.

Future projects should be directed to:

- colour rendering properties
- disagreements between the traditional calculation of CRI and the subjective colour perception of LEDs
- daytime dependent control of luminous colour
- speed of changes in luminous colour

Thank you for your attention!