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Threshold Experiment

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- Introduction
- Colour threshold experiment
- Conclusion

Introduction

- Colour assessment experiment
- Surface colours → CIELAB colour space
- 2° standard observer
- Standard illuminant D65
- 45°/0° standard viewing condition

Statistic

- **40 person participated in the experiments**
- **None of the test persons had experience in colorimetric assessment**
- **All test persons had normal colour vision according to the *Nagel* anomaloskop test**
- **17 women and 23 men have taken part**
- **The average age was about 25 years. Only six person which were older than 30 participated**

Colour Threshold Experiment

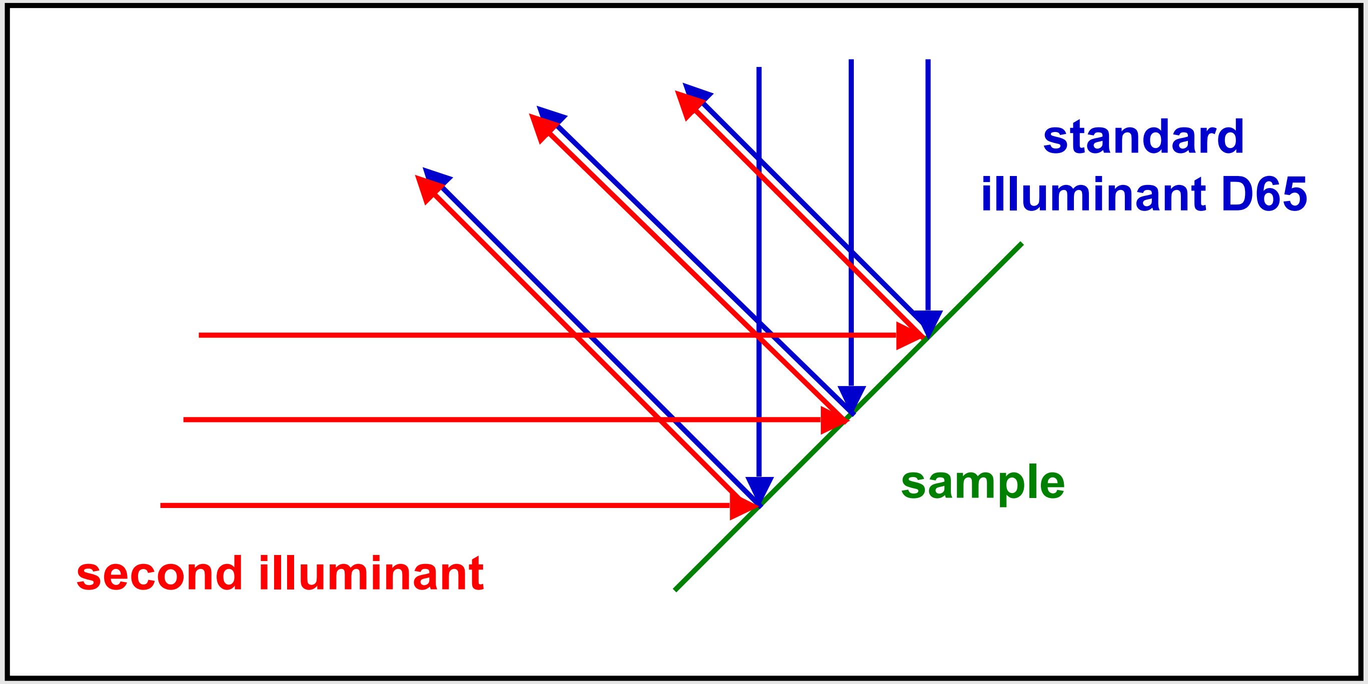
- **Yes/No decision**
  - **Test person can see a difference or not**

- **Direct contact of the samples**
  - **Between the areas was no gap → other colour threshold experiments have shown that 25 % of the test persons think to see a colour diffeence when they look at the same colour (hairline, gloss difference effect)**

- **Symmetric spread of the CIELAB colours**
  - **Consistent spread of the reference colours and colour change in four different directions in CIELAB space**

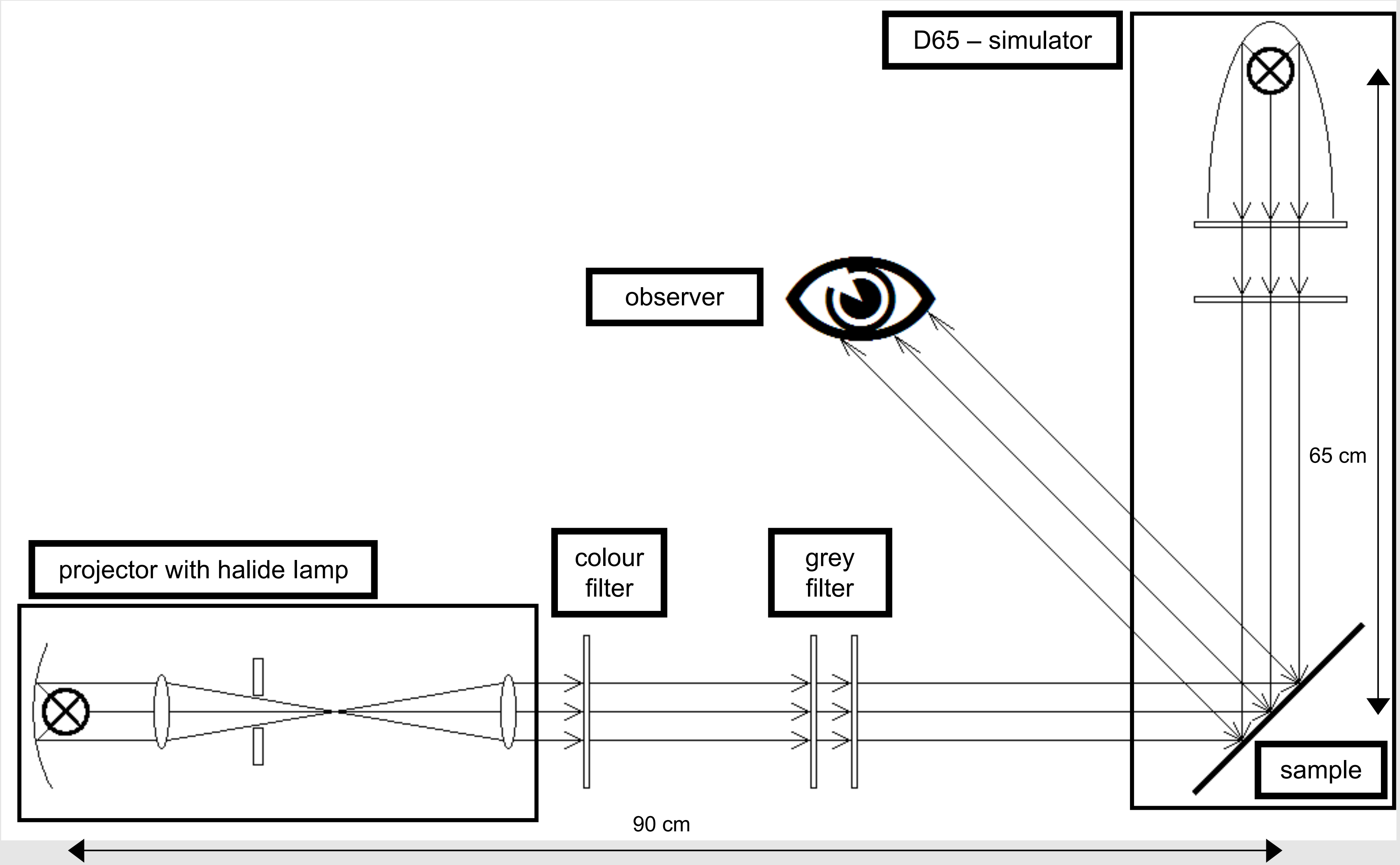
Princip of the Threshold Experiment

- **The colour differences are created over “addition” of a second illuminant to the standard illuminant D65**

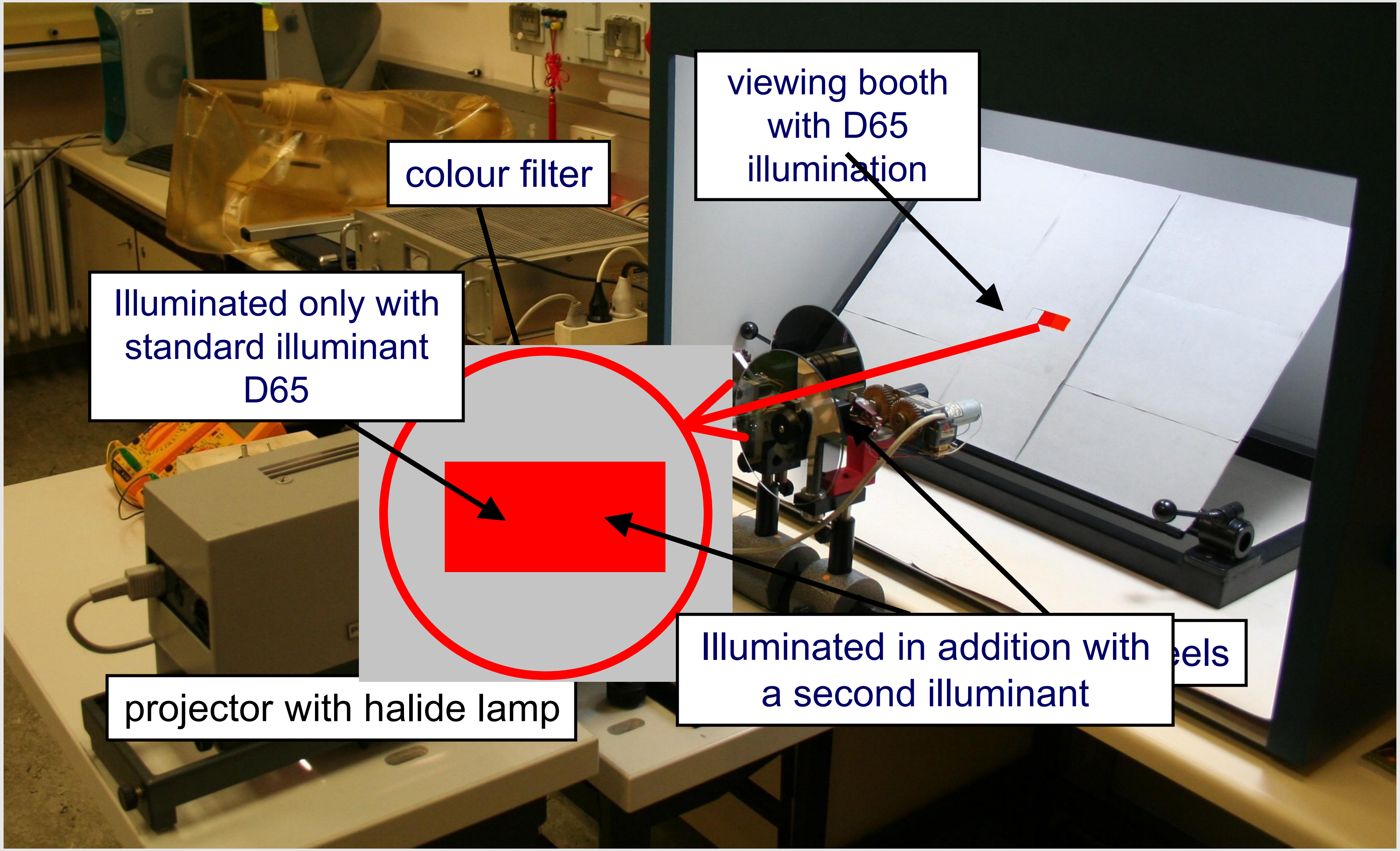


$$R_{neu}(\lambda) = \frac{S_{D65}(\lambda) + S_2(\lambda)}{S_{D65}(\lambda)} R_{alt}(\lambda)$$

Schematic Experiment Set-up

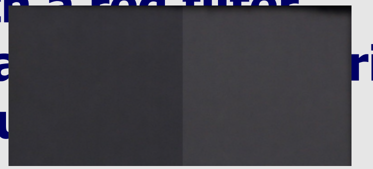


Picture of the Set-up



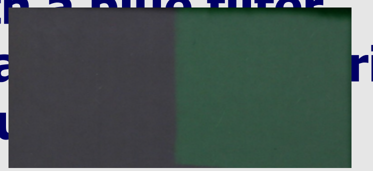
Colour Threshold Experiment

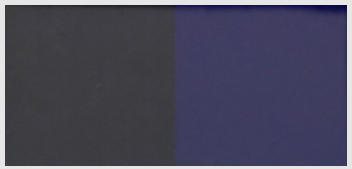
- **98 colour sample with four colour changes per sample**
  - **without filter (main change in luminance)**
  - **with a red filter (ma… ristimulus valu…**

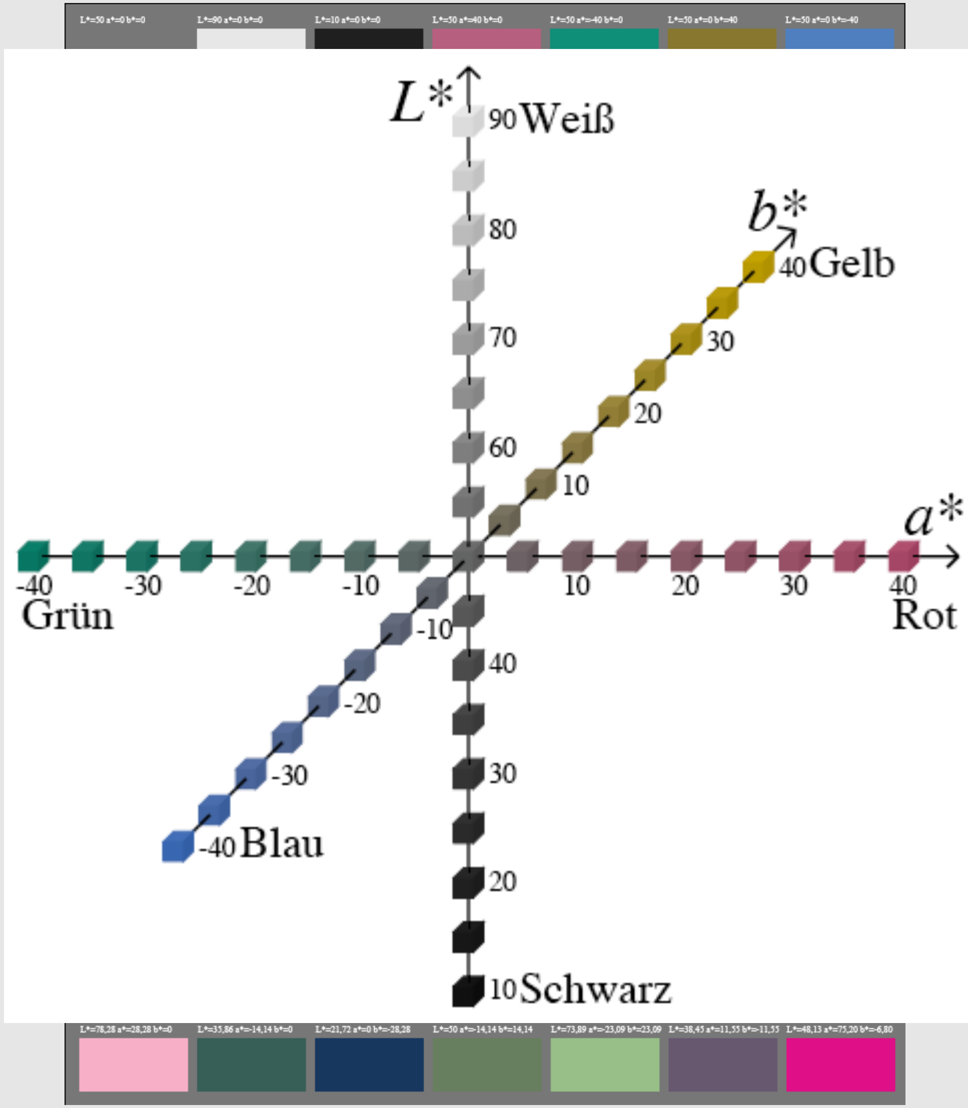


  - **with a green filter (ma… ristimulus valu…**

  - **with a blue filter (ma… ristimulus valu…**





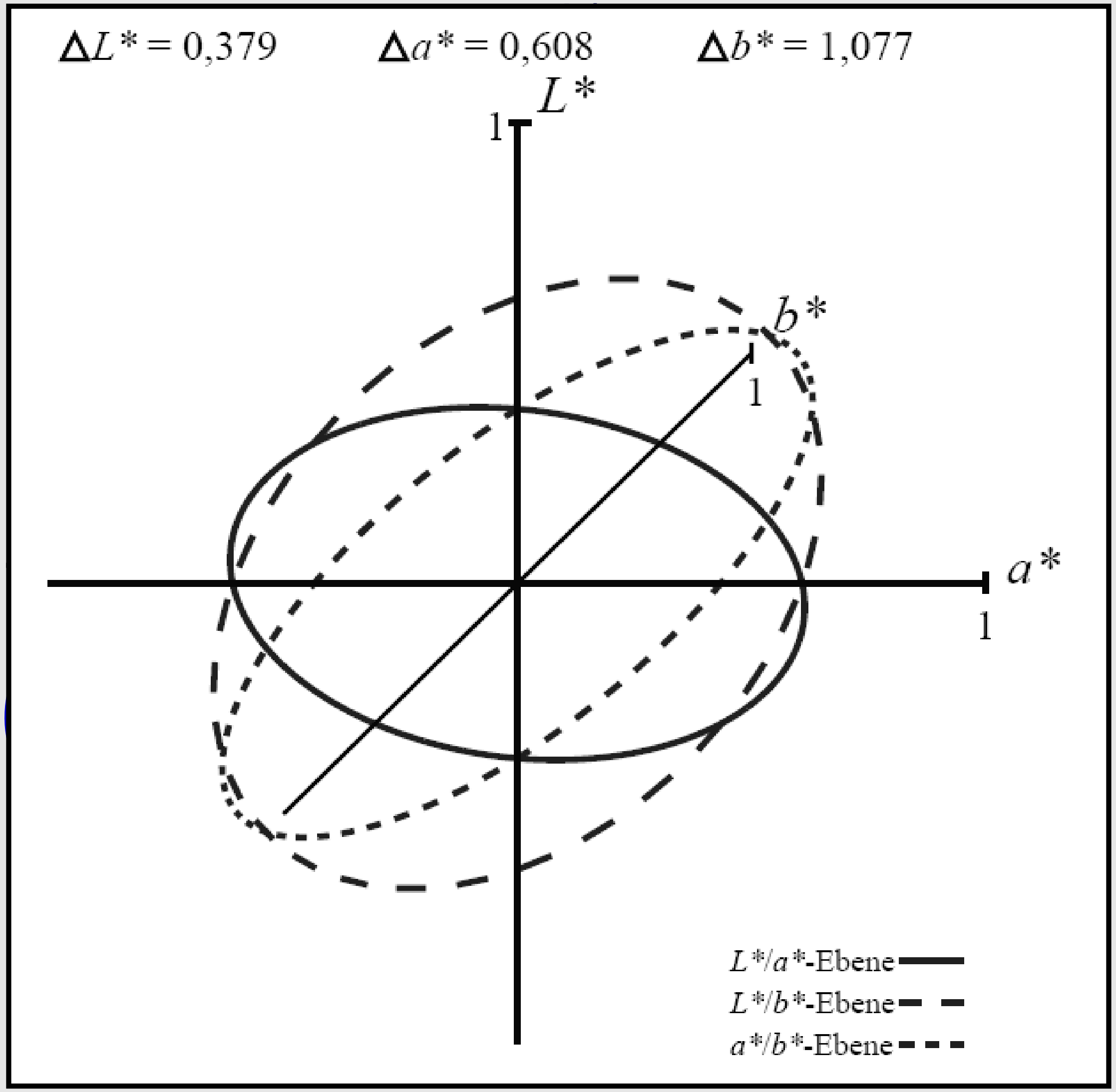


Analysis of the Threshold Experiment

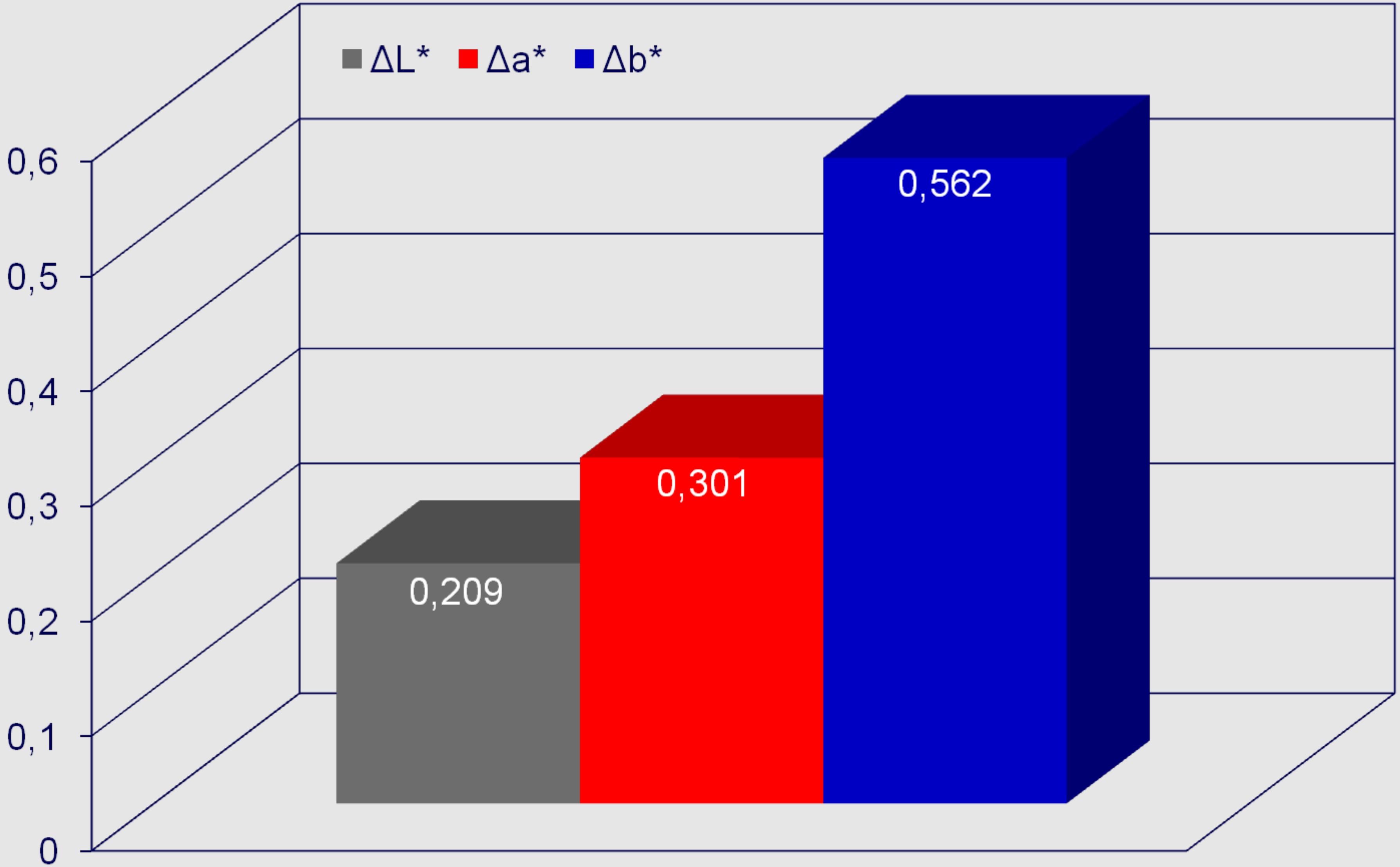
- **The analysis of the determined colour threshold is separated in two sections**
  1. **Calculation of threshold ellipsoids around the reference colours:**
     - analysis of the calculated colour differences ΔL^*, Δa^*, Δb^*
     - optimization in the CIELAB colour space
     - colour differences ΔL^*, Δa^*, Δb^* as function of CIELAB data L^*, a^* and b^* of the reference colours
  2. **Comparison of the colour differences calculated by several formulas for the colour threshold:**
     - analysis with the quotient Θ
     - analysis with the STRESS value S
     - parametric optimization in the colour difference formulas

Colour Threshold Ellipsoid

- an ellipsoid is calculated out of the four evaluated colour differences
- cut ellipses in the three planes
  - ***L*-a****-plane
  - ***L*-b****-plane
  - ***a*-b****-plane
- the distances of the ellipsoid are calculated in the directions L^*, a^* and b^*
  - ΔL^*
  - Δa^*
  - Δb^*



Colour Data Differences



Optimization of the CIELAB Colour Space

- **large discrepancy between the colour differences ΔL^*, Δa^*, Δb^* → next step: optimized in the CIELAB colour space (index o, ΔL^*_o, Δa^*_o, Δb^*_o)**

$$L^*_o = 116 \cdot f\left(Y/Y_n\right) - 16$$

$$a^*_o = \alpha \cdot 500 \cdot \left[f\left(X/X_n\right) - f\left(Y/Y_n\right)\right]$$

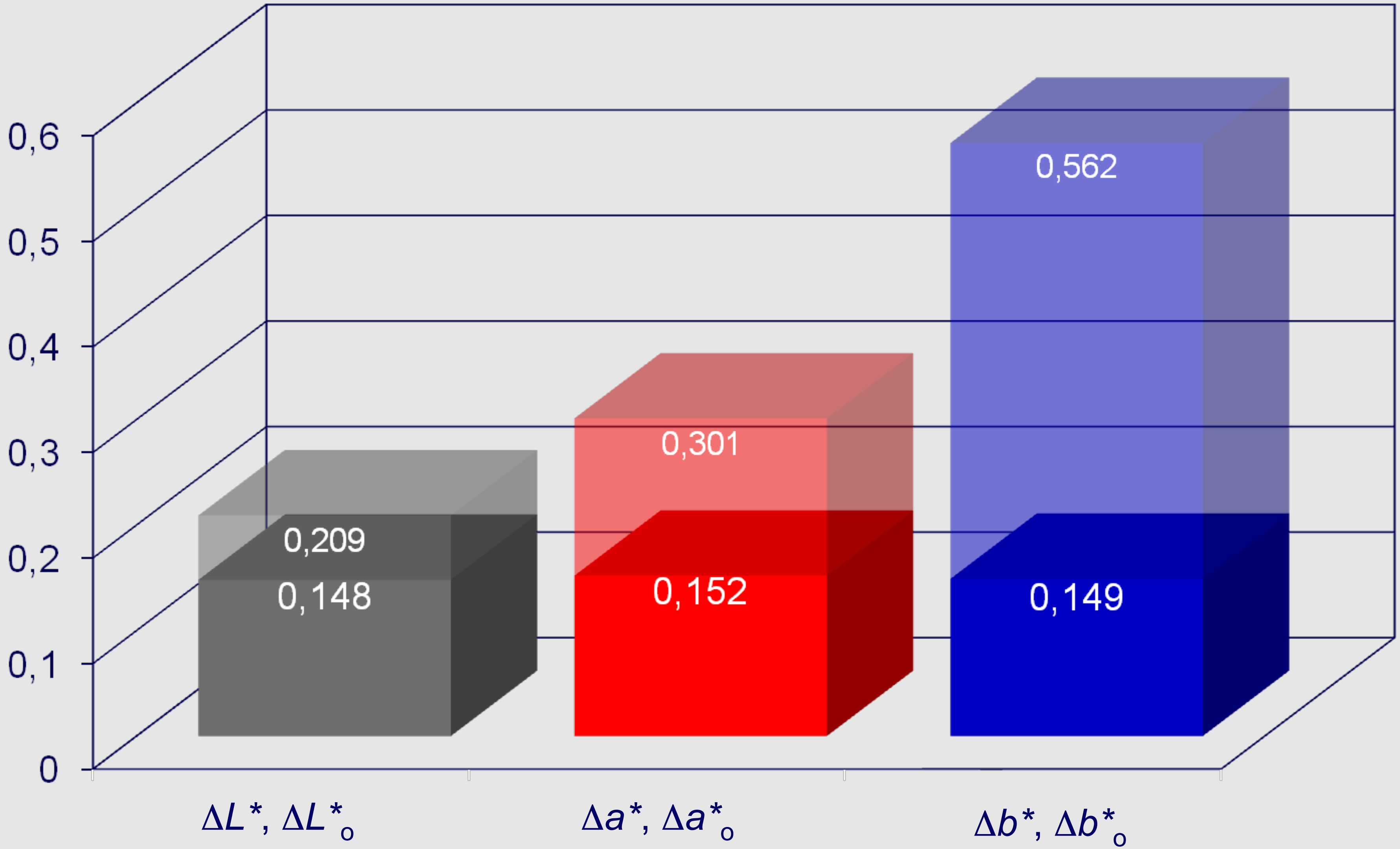
$$b^*_o = \beta \cdot 200 \cdot \left[f\left(Y/Y_n\right) - f\left(Z/Z_n\right)\right]$$

→

$$\alpha = 0{,}515$$

$$\beta = 0{,}153$$

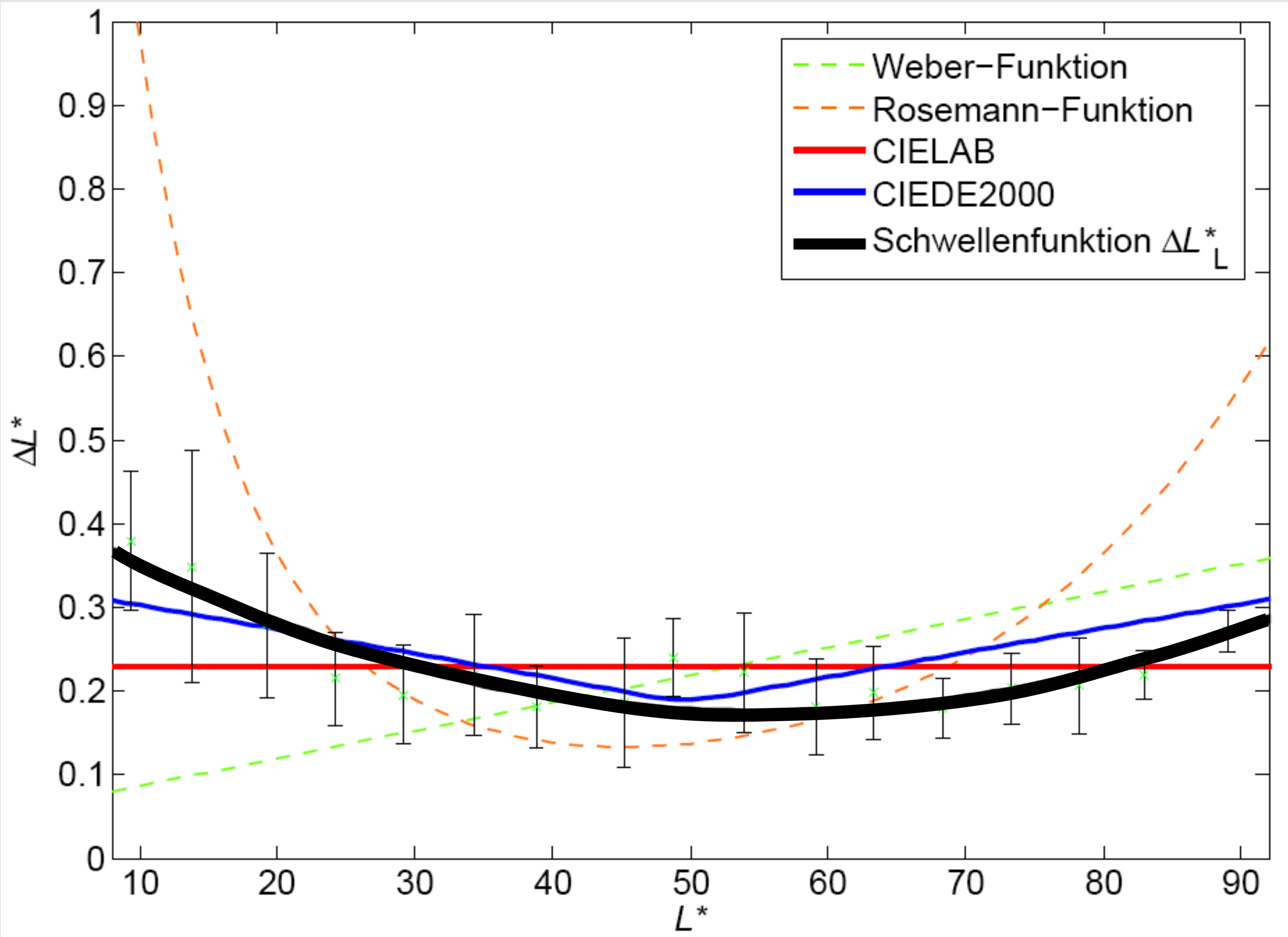
Differences of the optimizied Colour Datas



- **colour differences Δ*L*, Δa*, Δb** depend very much on the reference colour**
- **colour difference Δ*L**, Δ*a** and Δ*b** as separate function of the colour data *L**, *a** and *b***
- **the following function (polynomial) is used:**

$$f(x) = a_0 + a_1 \cdot x + a_2 \cdot x^2$$

Colour Data Difference ΔL^* as Function of L^*



- **Comparison of the colour differences ΔE^* calculated by several formulas for the colour threshold**
  - ➔ **the perfect formula leads to the same value for every colour threshold**
- **calculation of the quotient Θ und the STRESS value S**
- **optimization in the colour difference formulas by their adjustment parameters**

Quotient Θ

$$\Theta = \frac{\Delta E^*_{\min}}{\Delta E^*_{\max}}$$

- **ΔE^*_{min} is the smallest of four colour differences at colour threshold for one sample**
- **ΔE^*_{max} is the largest of four colour differences at colour threshold for one sample**
- **a good quotient is near to 1**

STRESS Value S

$$S = 100 \cdot \sqrt{\frac{\sum \left(\Delta E_i - F \cdot \Delta V_i\right)^2}{\sum \Delta E_i^2}} \qquad F = \frac{\sum \Delta E_i \cdot \Delta V_i}{\sum \Delta V_i^2}$$

developed at the university of Granada (Measurement of the relationship between perceived and computed color differences; P.A. Garcia, R. Huertas, M. Melgosa, G. Cui; 2007; J. Opt. Soc. Am. A, Vol. 24 Nr. 7, Seiten 1823-1829)

- **ΔE_i are the four colour differences at colour threshold for one sample**
- **ΔV_i is set 1 → four colour differences at colour threshold for one sample should have the same value**
- **a good STRESS value is near to 0**

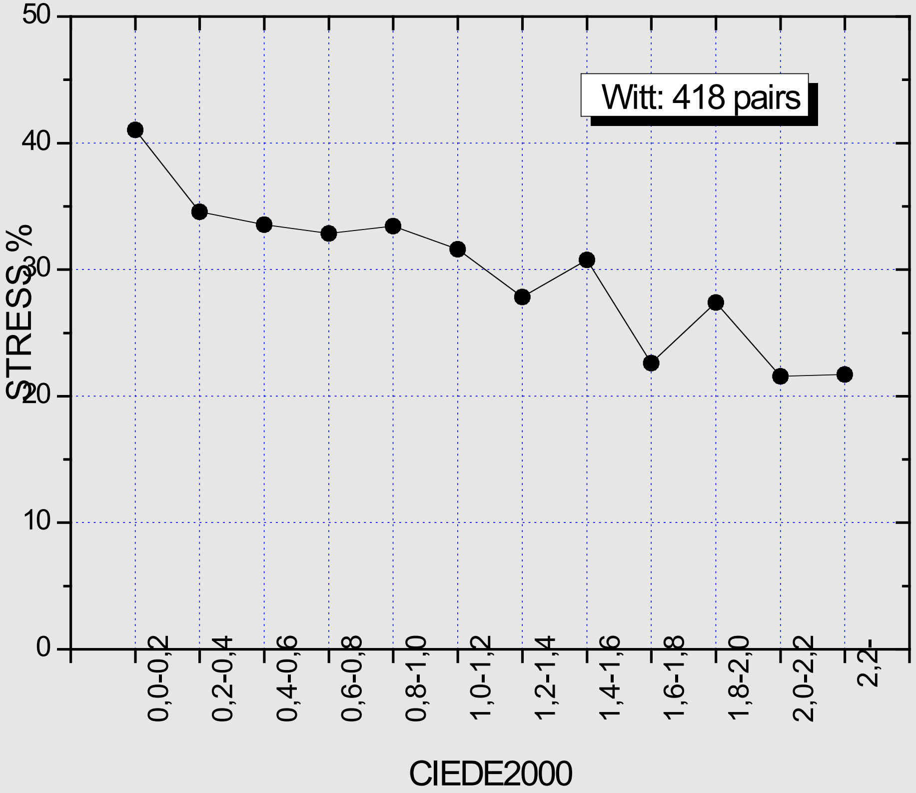
Comparison of some Colour Difference Formulas

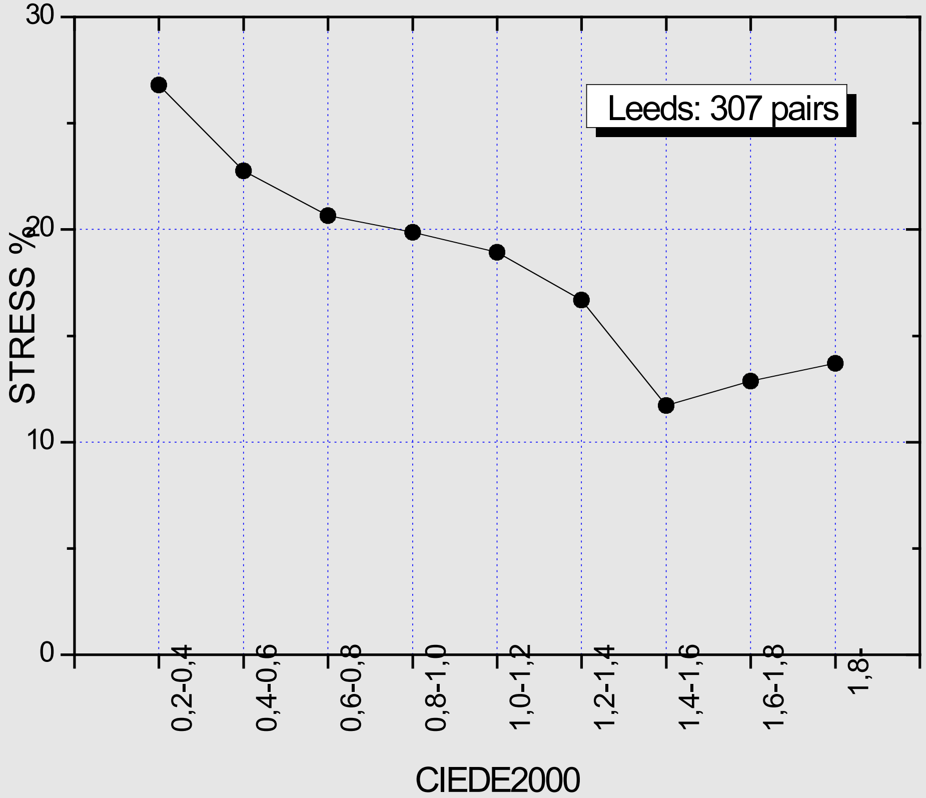
- values Θ_{100} and S_{100} are introduced for better comparability
- values near to 100 are better

$$\Theta_{100} = 100 \cdot \Theta \qquad S_{100} = 100 - S$$

	$\Theta_{100,s}$	$S_{100,s}$	optimized parameters				$\Theta_{100,p}$	$S_{100,p}$
CIELAB	29,800	54,587	α	0,515	β	0,153	60,100	80,200
CMC	32,600	56,937	l	0,418	c	2,417	46,200	71,436
CIE94	35,600	58,674	K_C	4,432	K_H	2,025	44,600	71,371
CIEDE2000	34,600	60,668	K_C	2,953	K_H	3,179	49,400	74,041
DIN99	44,500	67,674	k_E	1,756	k_{CH}	1,950	53,000	76,549
DIN99o	34,700	59,367	k_E	0,776	k_{CH}	3,439	48,400	74,559
LABJNDS	29,400	59,621	a_0	2,519	b_0	0,609	62,700	81,237

STRESS Value of other Experiment





Conclusions

- **The yellow-blue difference Δ*b** is by a factor 2 larger compared to the red-green difference Δ*a** and by a factor 3 larger compared to the lightness difference Δ*L** at colour threshold**

- **None of the existing colour difference formulas can be used to describe the colour threshold in agreement with *Melgosa (2007)***

- **For our experimental conditions the colour difference calculation can be optimized by using two parameters. Than a appropriate agreement is reached, but this is no general solution**

END

Thank you for your attention!