



UNIVERSITY OF LEEDS

**The Colour Group**  
(Great Britain)




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**INTERACTION OF  
COLOUR & LIGHT  
IN THE ARTS AND SCIENCES**

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# The impact of luminance level on the assessments of colour appearance and difference

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## Aims and Background



To develop a **model** for the evaluation of colour difference under different luminance levels

To reveal the **visual effect**

To evaluate the performance of **colour difference formulae** and **colour appearance models**

**Background:** related study with different methods by Guan and Luo (1999)

## Colour Difference Formulae



**CIELAB:** Published by CIE in 1976

- The most widely used uniform colour space ( $L^*a^*b^*$ )
- Based on perceived colour attributes (lightness, hue & chroma)

**CIEDE2000:** Recommended by CIE in 2000, based on CIELAB

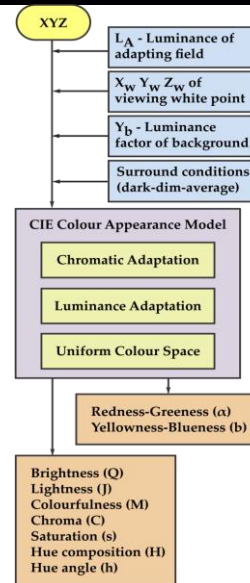
- Correction in lightness, chroma and hue directions
- Improved performance in blue and grey regions
- Inclusion of parametric factors

## Key features:

Predicted Colour Appearance Attributes  
Chromatic Adaptation  
Luminance Adaptation  
Uniform Colour Space

**CIECAM02:** Recommended by CIE for colour management

**CAM02-UCS:** Extended Uniform Colour Space of CIECAM02



## Experimental - 1

### Psychophysical Method & Experiment:

- 2 Viewing Cabinets with D65 – 20 Observers (Ishihara test)
- Short-term Memory Matching by using Grey Scale Method



Testing Field

Reference Field

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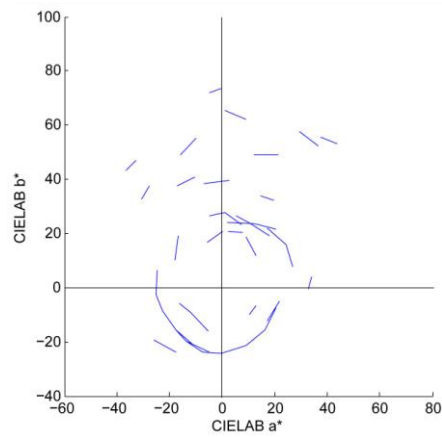
## Experimental - 2

### Samples Preparation:

- Measurement of samples with a CE7000A spectrophotometer
  - SPIN, UV included & large aperture size
- 40 pairs of hue difference:
  - mean  $\Delta E_{ab}^*$  of 7,8 units
  - $|\Delta H_{ab}^* / \Delta E_{ab}^*|$  greater than 0.8

### Grey Scale:

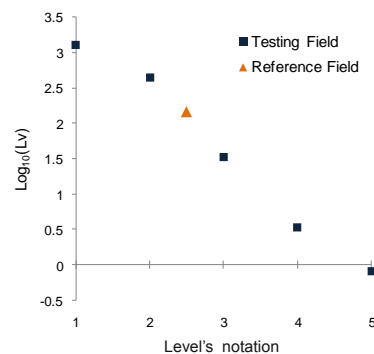
- According to ISO 105-A02:1993



## Experimental - 3

### Different Luminance Levels:

- Measurement of colours with a Konica Minolta CS1000S tele-spectroradiometer (TSR)
  - 0°: 45° geometry
- Adjustment of 5 luminance levels using different optical density filters
- Coverage from photopic to mesopic vision



	Lv (cd/m <sup>2</sup> )	Log(Lv)
Level 1	1230,0	3,09
Level 2	420,1	2,62
Level 3	32,4	1,51
Level 4	2,3	0,37
Level 5	0,7	-0,15

Percentage estimation of **error** by correlating 2 data sets

$\Delta V$  and  $\Delta E$  can be any data sets

Scaling Factor  $F$  (slope) can be set 1 or variable

STRESS equal to **zero** shows perfect agreement of data sets

$$STRESS = \sqrt{\frac{\sum (\Delta E_i - F_1 \Delta V_i)^2}{\sum F_1^2 \Delta V_i^2}}$$

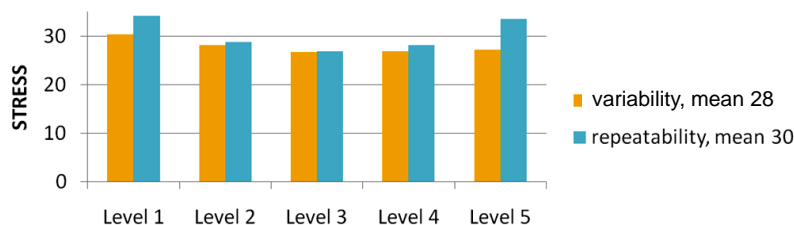
$$\text{where } F_1 = \frac{\sum \Delta E_i^2}{\sum \Delta E_i \Delta V_i}$$

## Observers' Variability and Repeatability

**Variability:** Inter-observer Variation

**Repeatability:** Intra-observer Variation

STRESS **values** were **low** for both of them (good observer performance)



### Perceived Colour Difference $\Delta V$

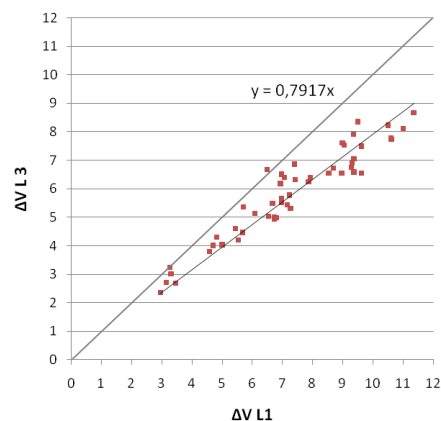
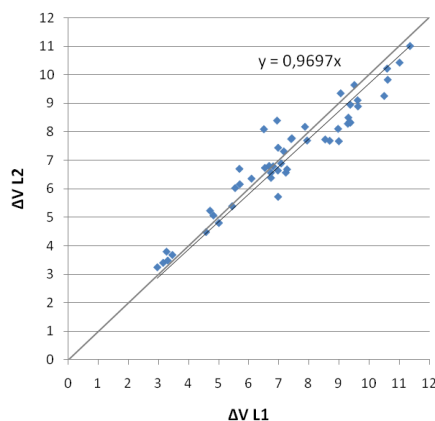
- Colour difference **decreases** as luminance becomes darker

Slope from plotting  $\Delta V$  of **Level 1** against the other levels gives us the percentage perceived colour difference decrease

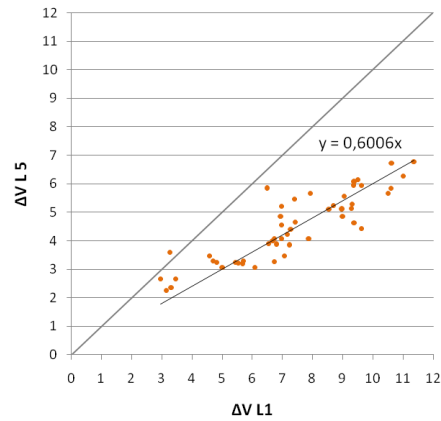
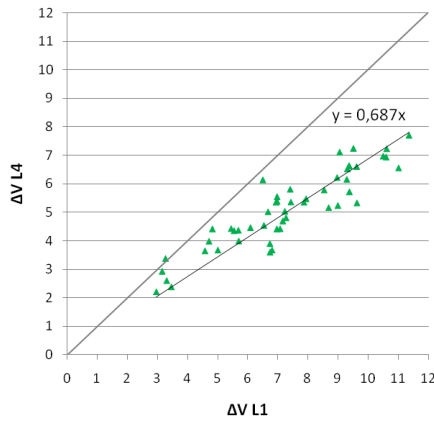
- $\Delta V1$  vs  $\Delta V2$  **3 %**
- $\Delta V1$  vs  $\Delta V3$  **21 %**
- $\Delta V1$  vs  $\Delta V4$  **31 %**
- $\Delta V1$  vs  $\Delta V5$  **40 %**

*See plots in next slides*

## Visual Effect - 2

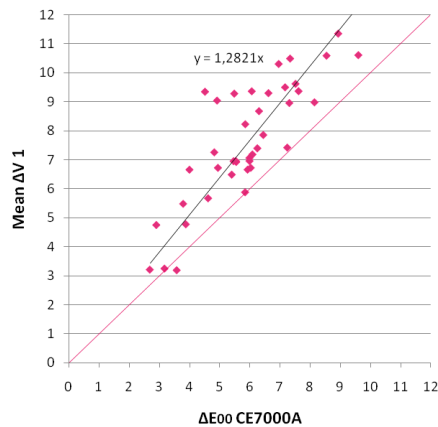
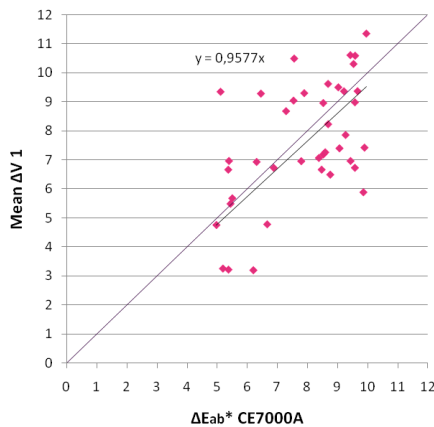


## Visual Effect - 3



## Modelling – Finding Slope - 1

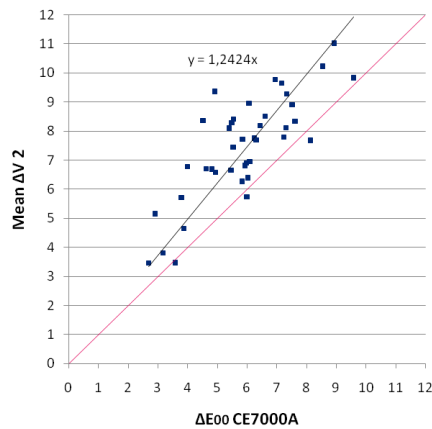
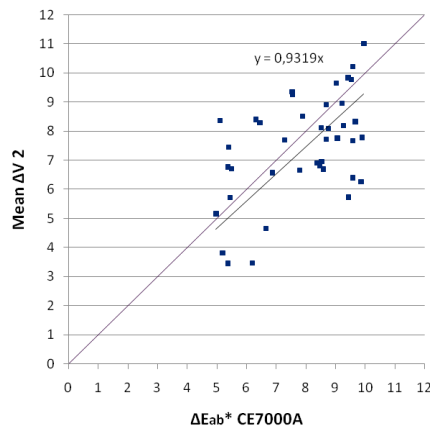
Visual difference ( $\Delta V$ ) against Measured difference ( $\Delta E$ ) for CIELAB and CIEDE2000 – Level 1



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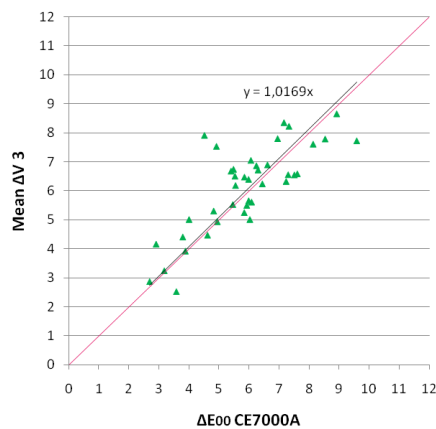
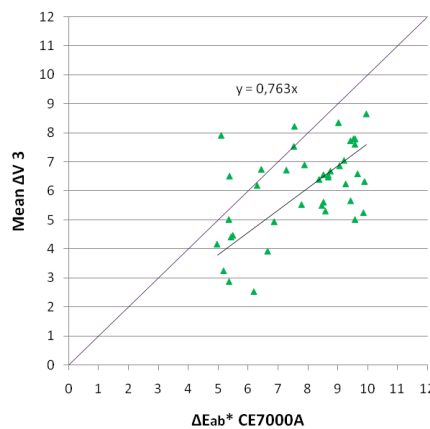
## Modelling – Finding Slope - 2

### Level 2



## Modelling – Finding Slope - 3

### Level 3

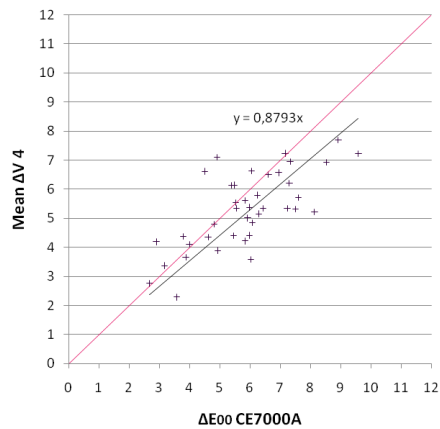
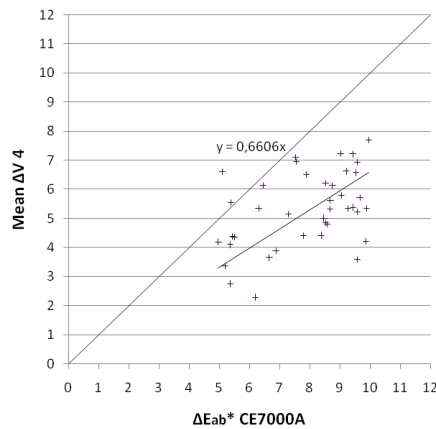


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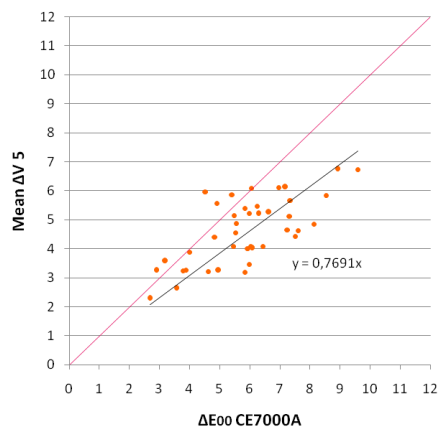
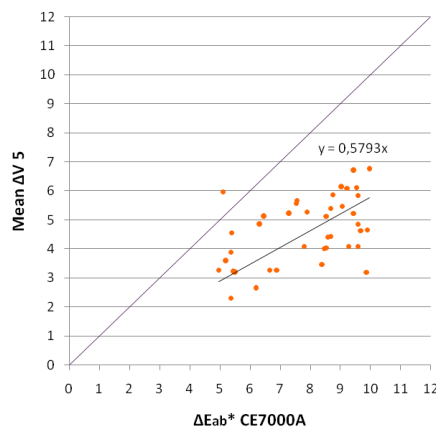
## Modelling – Finding Slope - 4

### Level 4



## Modelling – Finding Slope - 5

### Level 5

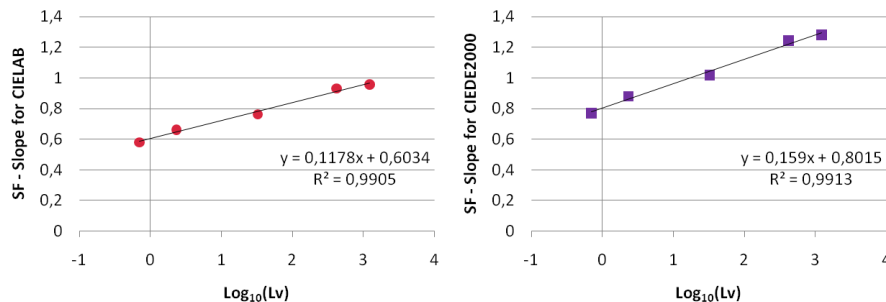


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## The Modelling of the Effect

By using the slopes from the  $\Delta V$  vs  $\Delta E$  plots as scaling factors (SF) and the common **logarithm** ( $\log_{10}$ ) of luminance from each level

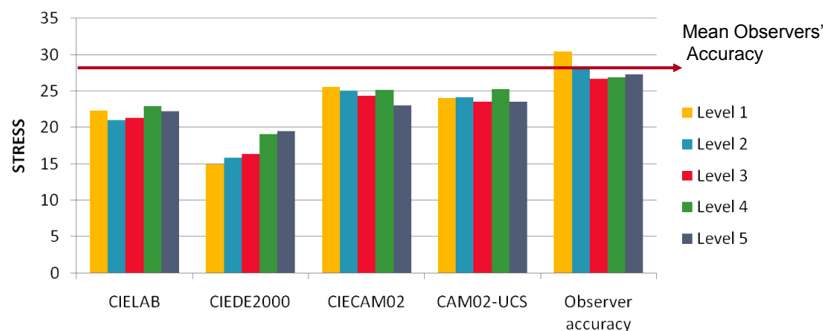
- Linear relationship



## Model Performance – STRESS

**STRESS** between perceived  $\Delta V$  and measured  $\Delta E$  difference with spectrophotometer

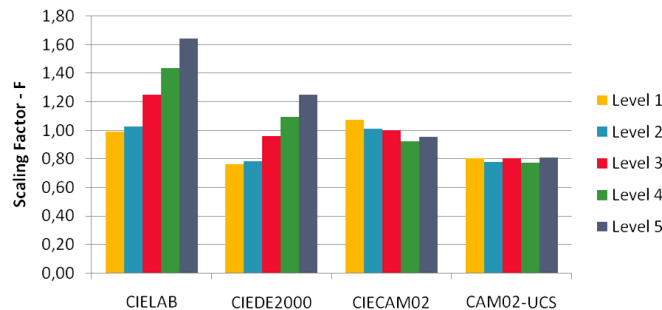
- All formulae predicted more accurately than the group of observers



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Scaling Factor -  $F$  from STRESS between perceived  $\Delta V$  and measured  $\Delta E$  difference with spectrophotometer

- CAM02-USC has slope unchanged for all levels
- CAMs include luminance variation well



## Conclusions

- Perceived colour difference could be reduced by 40% from brighter (1230 cd/m<sup>2</sup>) to darker conditions (0.7 cd/m<sup>2</sup>)
- For all luminance levels, CAM02-UCS outperformed the other formulae when examining its scaling factors.
- CIELAB and CIEDE2000 formulae can be extended to consider the luminance variation

### Further work

- Model Performance with TSR data
- Inclusion of lightness & chroma differences
- Larger luminance level range

The impact of luminance level  
on the assessments of colour appearance and difference

**Thank you...**

Questions?

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