Assessing Colour Differences near the Neutral Axis

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Introduction

- **Grey reproduction for printing industry proposed by ISO TC 130 "Graphic technology"**
  - **to map near-neutral colours from the white point of the substrate to the black point**
    - $a^* = a^*_{paper}\,[1-0.85(L^*_{paper}-L^*)/(L^*_{paper}-L^*_{cmy})]$
    - $b^* = b^*_{paper}\,[1-0.85(L^*_{paper}-L^*)/(L^*_{paper}-L^*_{cmy})]$
- **The recent colour-difference metrics, both CIEDE2000 and CMC, have major flaws in assessing colours near the neutral axis**

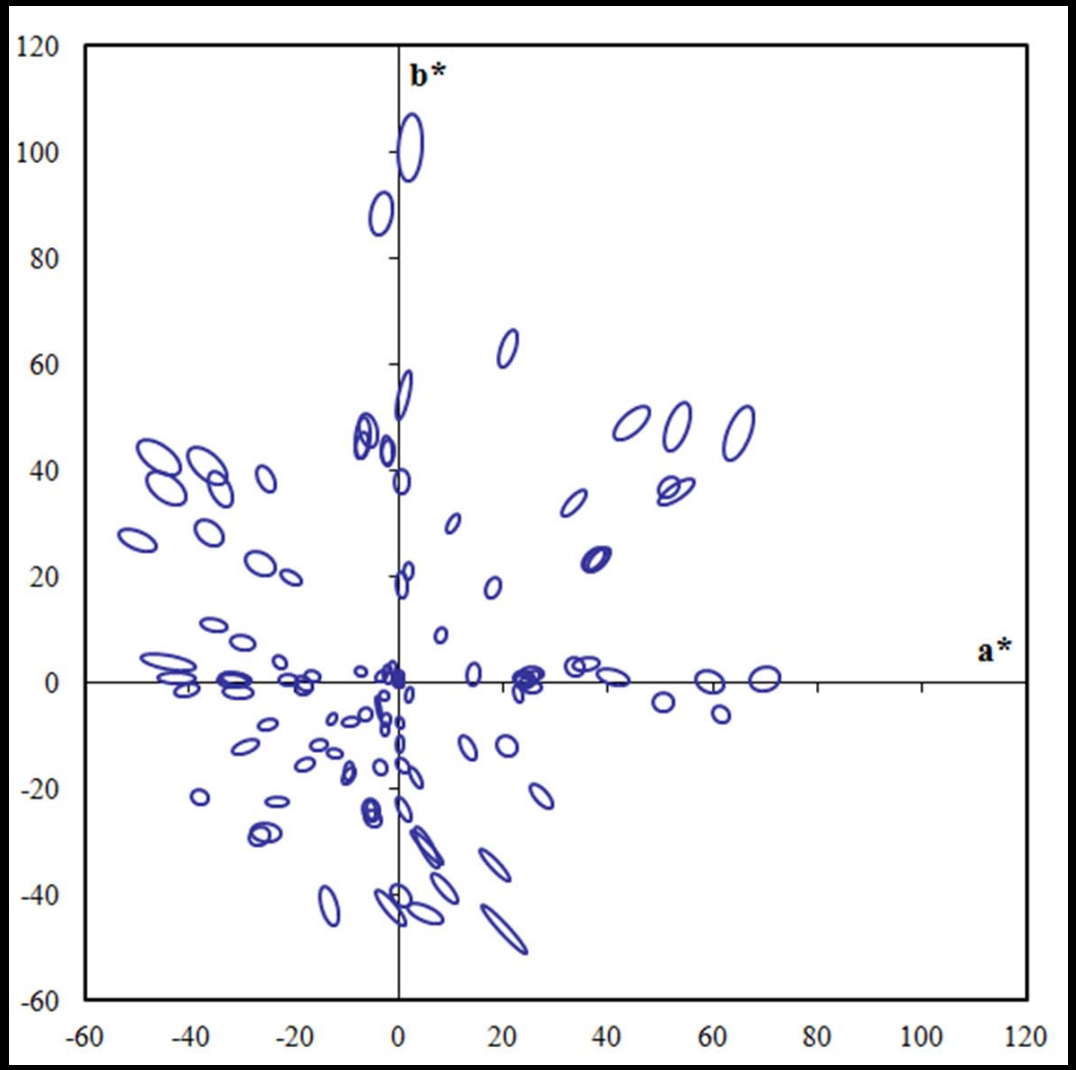
Motivation

- To investigate the visual differences between two grey stimuli, that may be different in chroma and hue
- To obtain a definition of the percept of grey near the neutral axis that is linked to a CIE colour metric

Existing BFD Data

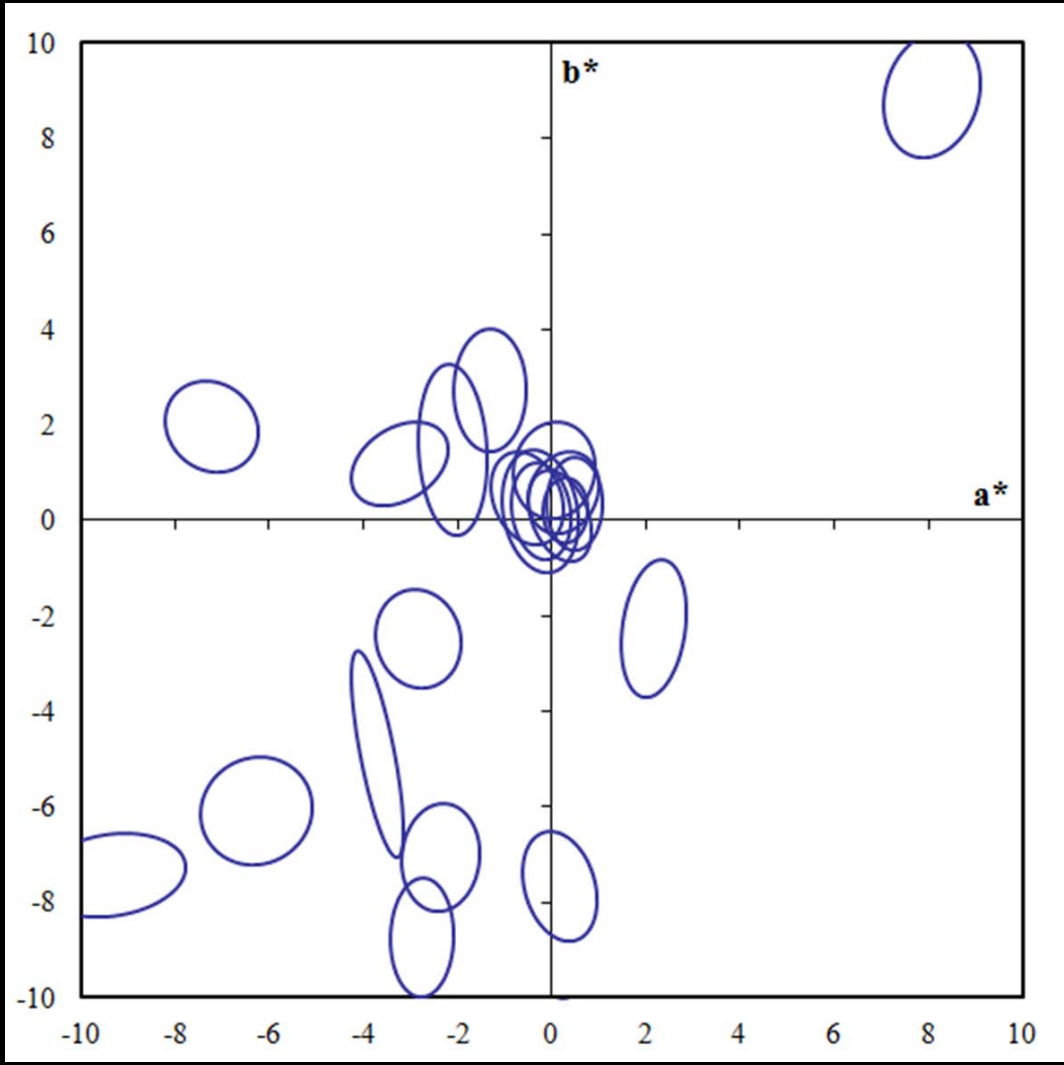
- **BFD data**
  - **In 1986, Luo and Rigg accumulated most of the available experimental data relating to small to medium colour differences of surface colours.**
  - **The data accumulated included various surface media: textile, paint, ink, etc.**
  - **Includes 2776 pairs of colour difference samples**
  - **Over 120 colour discrimination ellipses were fitted from these data sets**
  - **All ellipses from different studies were scaled to have similar sizes, but keep their orientations and shapes**

BFD ellipses



- ✓ CIELAB is a poor space
  - Not constant size circles
  - Small neutral ellipses
  - Large and long high-chroma ellipses
- ✓ Point towards the neutral point except blue

BFD neutral ellipses



- ✓ Not constant-size circles
- ✓ Orientated to around 90^{o}
- ✓ A redness-greenness scale (*a'*) in the CIEDE2000

Neutral samples in BFD data

Sub-data	Conditions	Pairs	Mean ΔE^*_{ab}	Max ΔE^*_{ab}
All Neutral	$C^*_{ab} \leq 10$	423	1.7	8.3
ΔL only	$\lvert\Delta L/\Delta E\rvert \geq 90\%$	88	2.3	6.2
$\Delta L+\Delta C+\Delta H$	$\lvert\Delta L/\Delta E\rvert$, $\lvert\Delta C/\Delta E\rvert$ and $\lvert\Delta H/\Delta E\rvert$ are < 90%	64	1.7	8.3
$(\Delta C^2+\Delta H^2)^{0.5}$	$(\Delta C^2+\Delta H^2)^{0.5}/\Delta E \geq 90\%$	271	1.5	5.1
ΔC only	$\lvert\Delta C/\Delta E\rvert \geq 90\%$	88	1.4	4.3
ΔH only	$\lvert\Delta H/\Delta E\rvert \geq 90\%$	70	1.5	5.1
$\Delta C+\Delta H$	$\lvert\Delta C/\Delta E\rvert < 90\%$ and $\lvert\Delta H/\Delta E\rvert < 90\%$	113	1.6	4.3

Performance of original formulae (*STRESS*)

Sub-data	CIELAB	CIEDE2000
BFD	42.5	29.6
All Neutral	30.2	25.1
ΔL only	28.9	28.2
$\Delta L+\Delta C+\Delta H$	31.6	27.8
$(\Delta C^2+\Delta H^2)^{0.5}$	24.2	21.2
ΔC only	26.5	21.9
ΔH only	**17.9**	**16.6**
$\Delta C+\Delta H$	25.7	22.0

- ✓ **CIEDE2000 is better than CIELAB**
- ✓ **All formulae predicted neutral data better than the full BFD data**
- ✓ **All formulae predicted ΔH better than ΔL and ΔC**
- ✓ **CIEDE2000 predicted chromatic differences better than others**

Performance of optimised k_L formulae

Sub-data	CIELAB	CIEDE2000
All Neutral	26.2	24.9
ΔL only	26.4	27.7
ΔL+ΔC+ΔH	28.7	27.1
$(\Delta C^2+\Delta H^2)^{0.5}$	24.4	21.3
ΔC only	26.6	22.0
ΔH only	**18.0**	**16.5**
ΔC+ΔH	25.7	22.2
k_L	1.5	1.1

- ✓ **CIEDE2000 is better than CIELAB, except for 'ΔL only'**
- ✓ **CIELAB has $k_L \geq 1.5$**
- ✓ **All formulae predicted ΔH better than ΔL and ΔC**

Performance of optimised k_L, k_C formulae

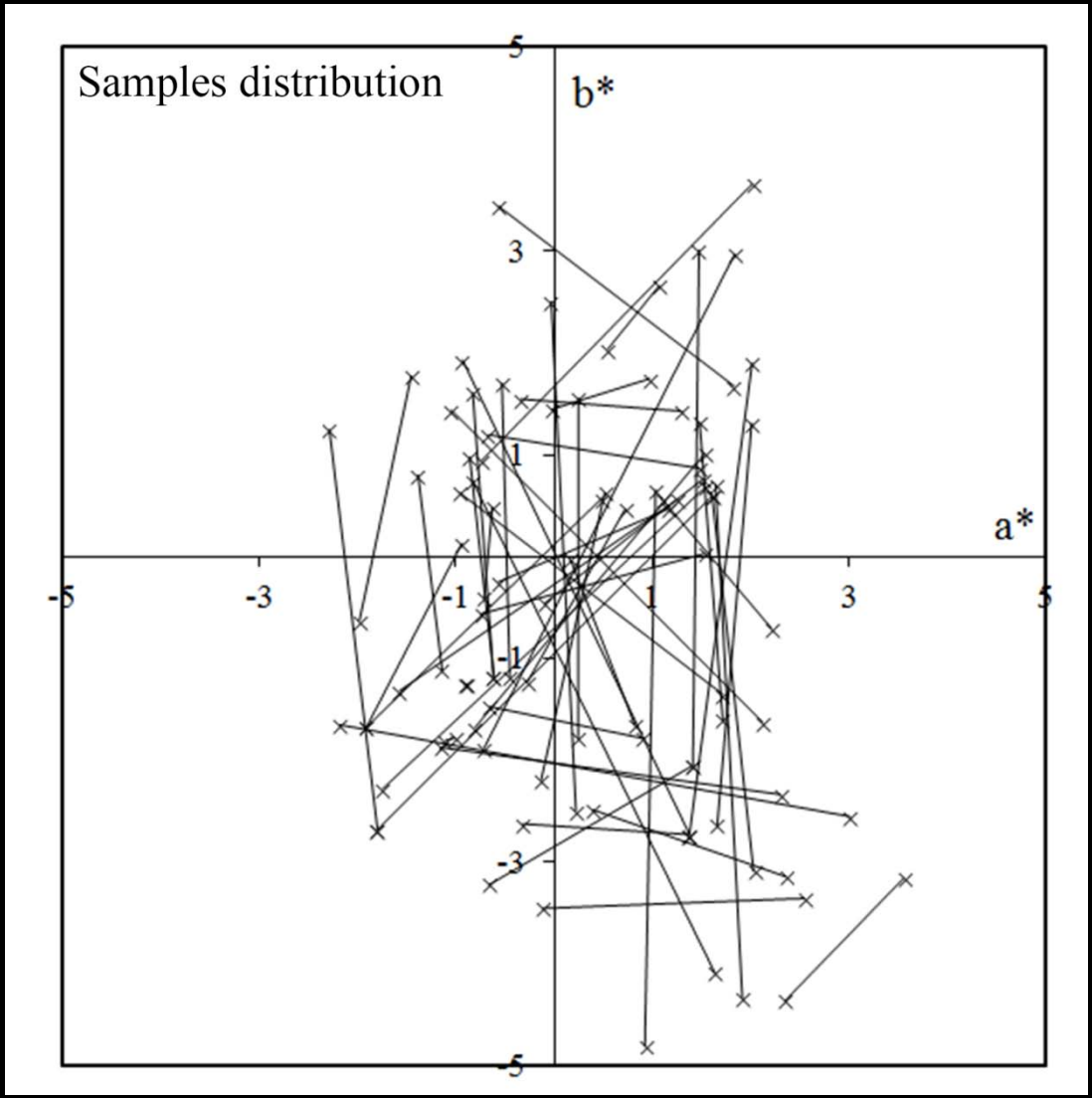
Sub-data	CIELAB	CIEDE2000
All Neutral	26.2	24.5
ΔL only	26.4	27.5
ΔL+ΔC+ΔH	28.5	27.4
$(\Delta C^2+\Delta H^2)^{0.5}$	24.3	20.7
ΔC only	26.8	21.1
ΔH only	**17.9**	**16.6**
ΔC+ΔH	25.8	21.5
k_L	1.6	1.0
k_C	1.0	0.9

- ✓ **CIELAB has $k_L \geq 1.5$, but all have $k_C \approx 1.0$**
- ✓ **All formulae predicted ΔH better than ΔL and ΔC**
- ✓ **CIEDE2000 is better than CIELAB, except for 'ΔL only'**

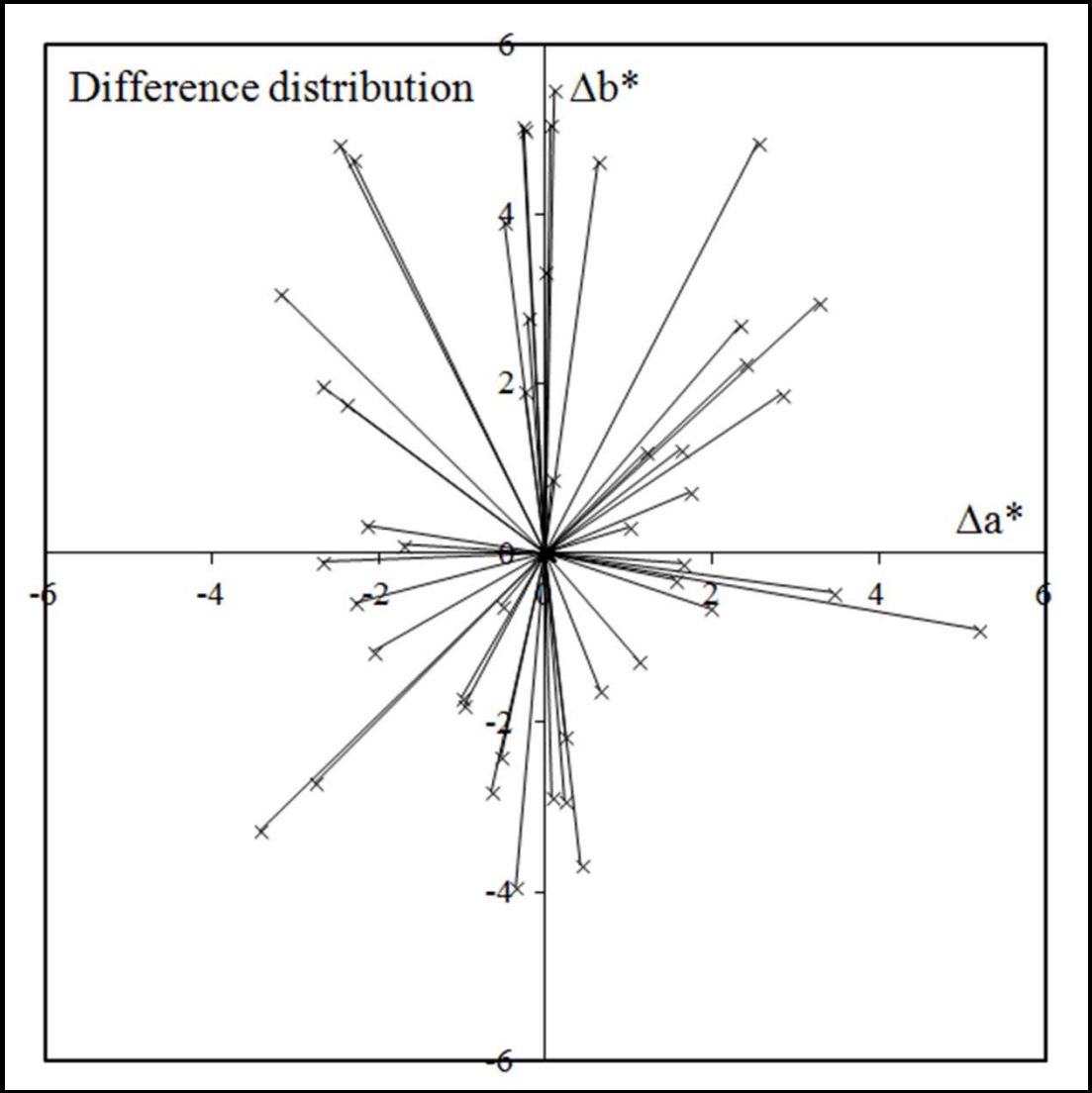
New Experimental Data

- 50 pairs of neutral printed samples
  - By an EPSON Stylus PRO 7800 ink-jet printer
  - 32 pairs mainly in hue differences
  - 18 pairs mixed with ΔL, ΔC and ΔH
- The mean CIELAB colour difference of the 50 sample pairs was 3.0 ranging from 0.1-5.5
- Grey-scale method
- 35 observations (23 observers × 1 time + 6 observers × 2 times)

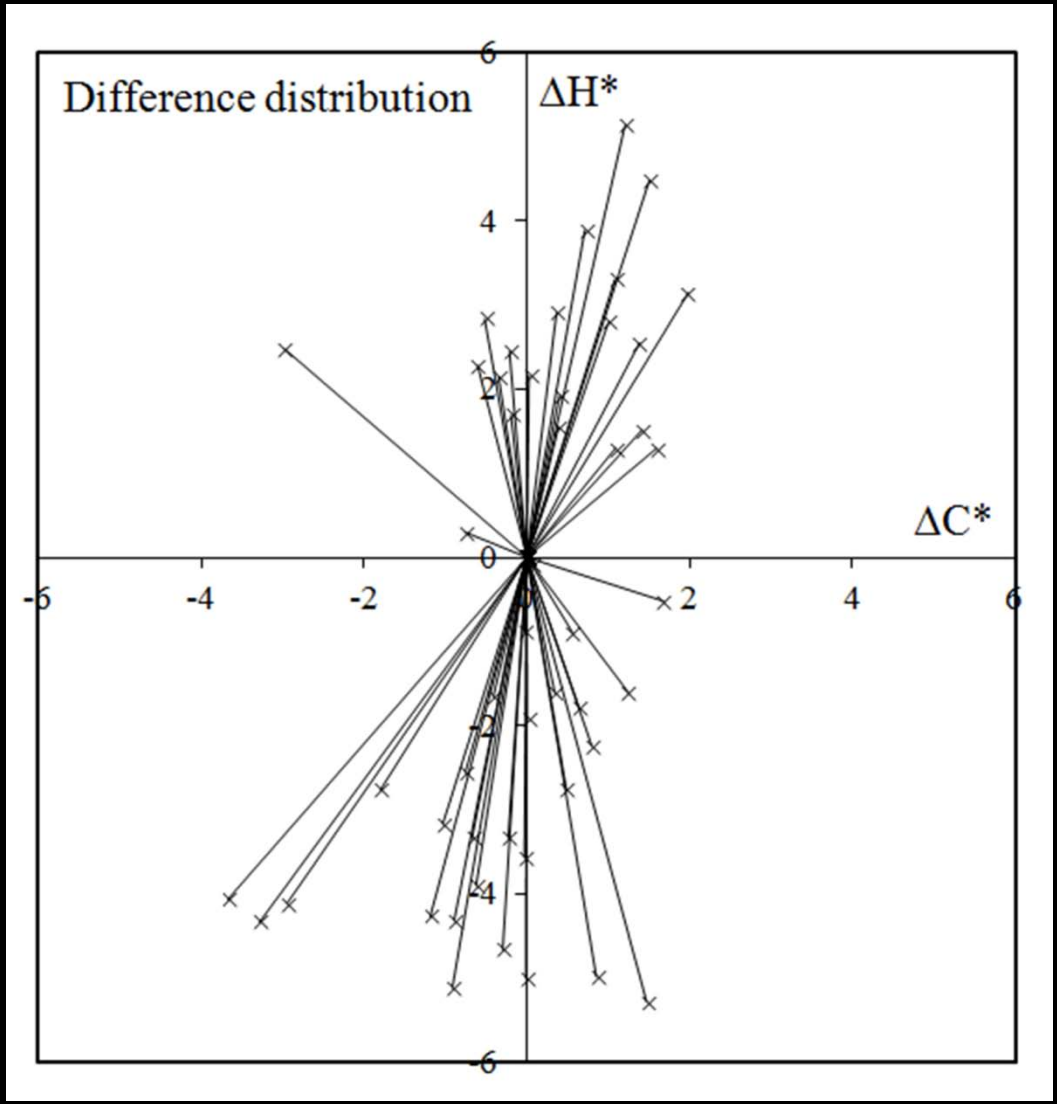
Samples distribution



Samples distribution



Samples distribution



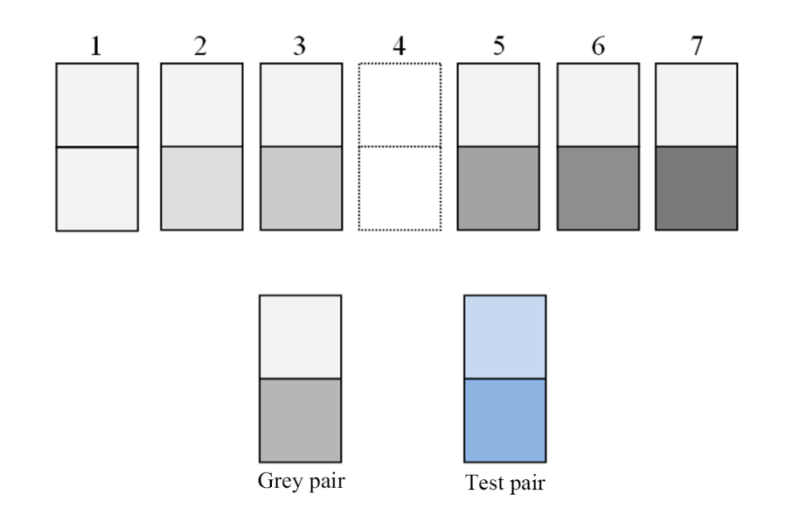
Visual Assessments

- In a dark room
- A GretagMacbeth Judge II viewing cabinet with a D65 simulator
- Illuminance level 950 lx
- The viewing geometry was about 0º/45º
- Viewing distance about 50 cm

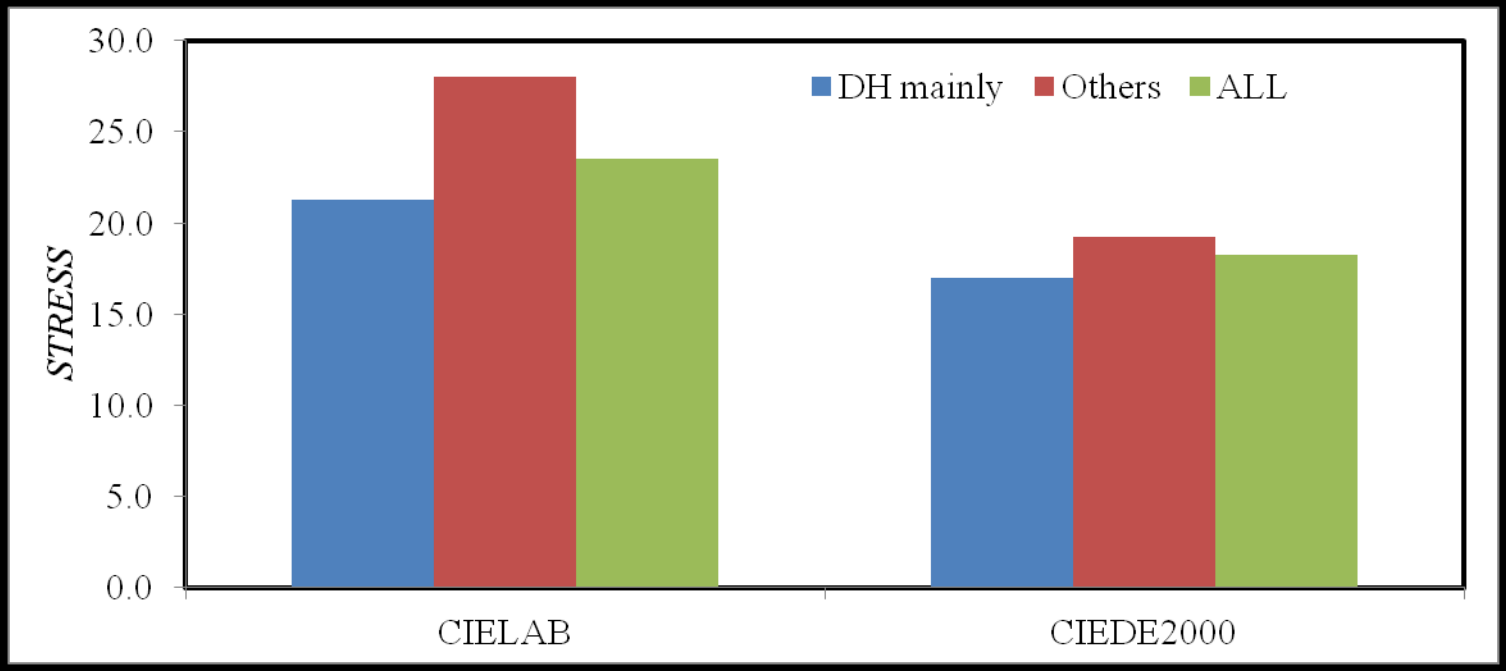
Visual Assessments

- Grey scales
  - Same size, same substrate as test pairs
  - 6 grades with ΔE* from 1.0 to 6.0
- The Observer were ask to gave the color difference grade of test pairs
- Intermediate grades are valid, e.g., 3.6
- Visual difference:

$\Delta V_{GS}=1.0123G-0.0381$



Results



- ✓ CIEDE2000 is better than CIELAB
- ✓ It is confirmed again the prediction for ΔH in neutral region is not a main problem
- ✓ ΔL and ΔC may play a main role in neutral

Conclusions

- Two datasets, existing BFD and new printed dataset, were considered
- CIEDE2000 is better than CIELAB in general
- Human eyes predicted hue difference in neutral region better than lightness and chroma differences