Comparing colour perception on LCDs with different backlights

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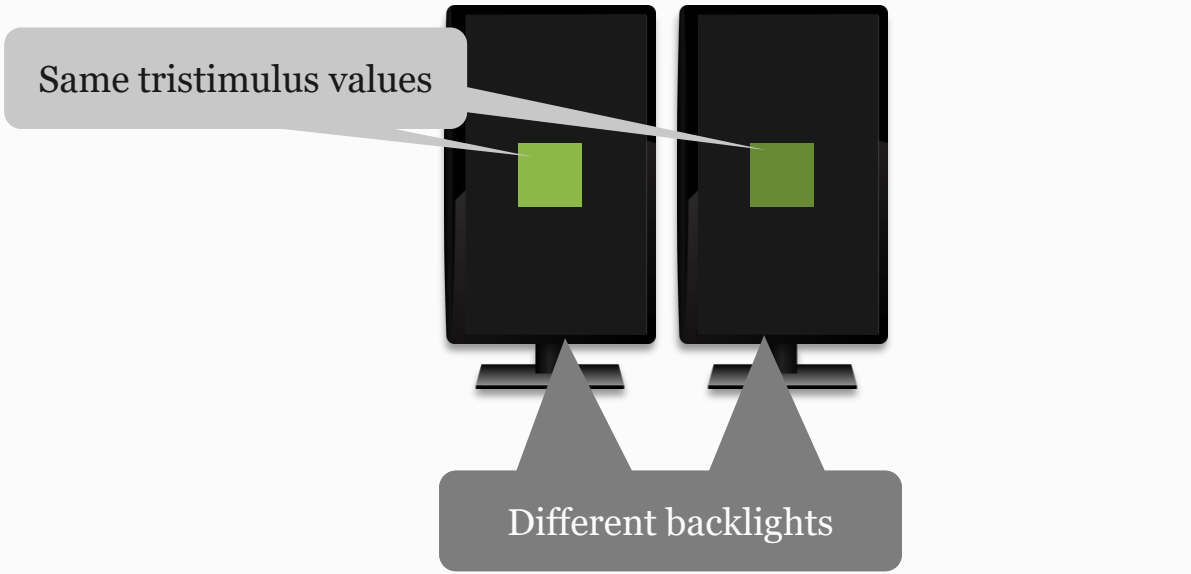
Introduction

CCFL
(broad-band)

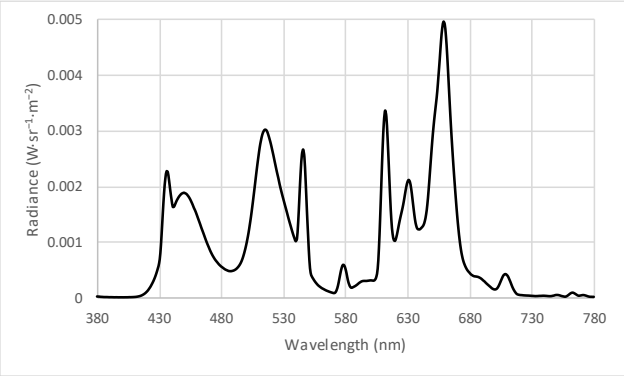
KSF LED
Mini LED
RG Phosphor Blue LED
(narrow-band)


Same tristimulus values
Different backlights

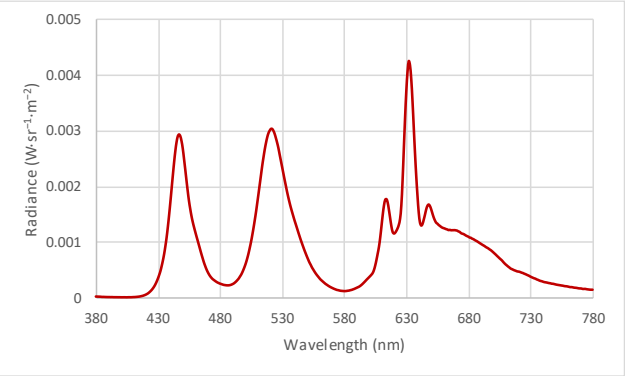

They look different !

White Colour's SPD on Different Backlights

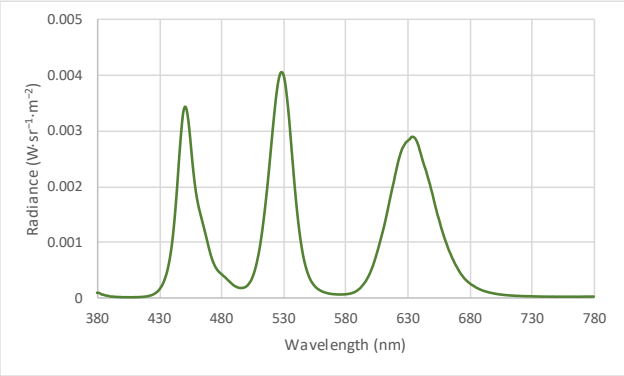
CCFL



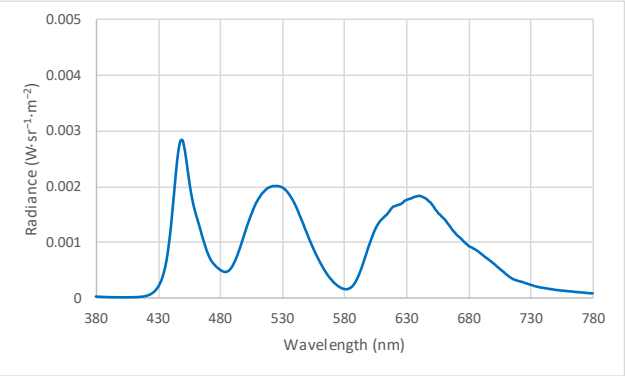
KSF LED



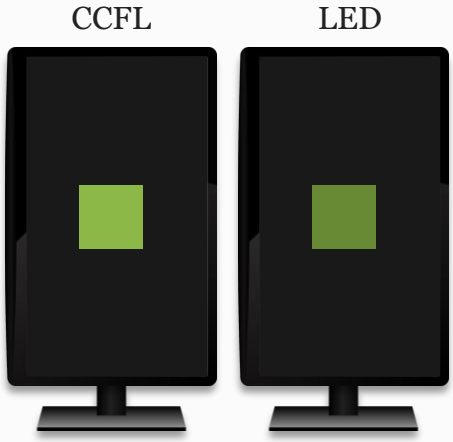
Mini LED



RG Phosphor Blue LED (RG + B LED)



In the Previous Experiment (Experiment 1)



Regarded the colour on LED display as reference colour, observers adjusted colour attributes include

1. Lightness (**L***),
2. Chroma (**C***) and
3. Hue angle (**h**)

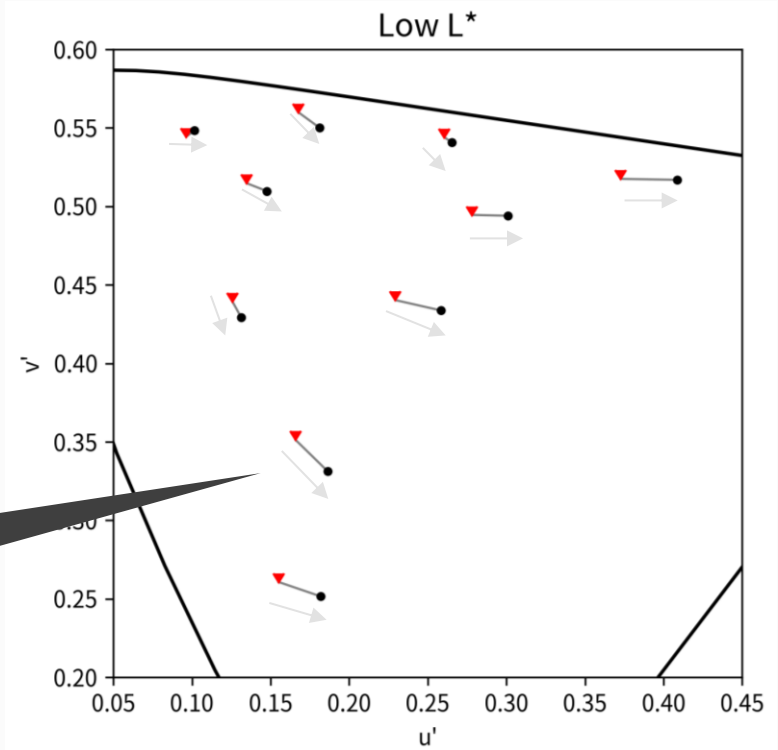
of the colour on CCFL display until they visually matched.

Colour Transformation Models (CTMs)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Original} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ 0 & 1 & 0 \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{adjusted}$$

(CCFL) (LED)

Calibrate adjusted colours to their original position



Mean Colour Transformation Models (Mean-CTMs)

KSF LED

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Original} = \begin{bmatrix} 0.9955 & 0.0067 & 0.0094 \\ 0 & 1 & 0 \\ -0.0027 & 0.0111 & 1.0163 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{adjusted}$$

(CCFL) (LED)

Mini LED

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Original} = \begin{bmatrix} 1.0220 & -0.0100 & 0.0045 \\ 0 & 1 & 0 \\ -0.0067 & -0.0061 & 1.0605 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{adjusted}$$

RG + B LED

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Original} = \begin{bmatrix} 0.9884 & 0.0216 & -0.0036 \\ 0 & 1 & 0 \\ -0.0080 & 0.0256 & 1.0063 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{adjusted}$$

Experiment 2 aimed to assess the validity and efficiency of the CTMs.

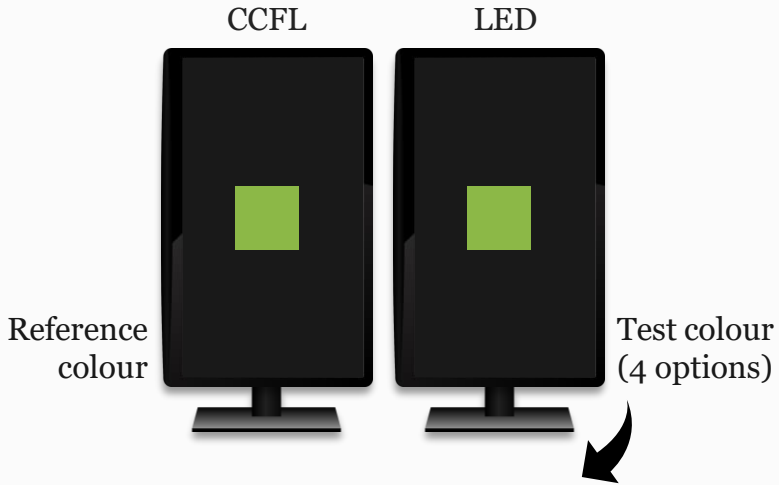
To achieve this goal, Experiment 2 was divided into 3 sub-experiments:

1. Single colour experiment
2. Colour difference experiment
3. Colour image experiment

Experimental Methods

Experiment 2.1

Single Colour Experiment

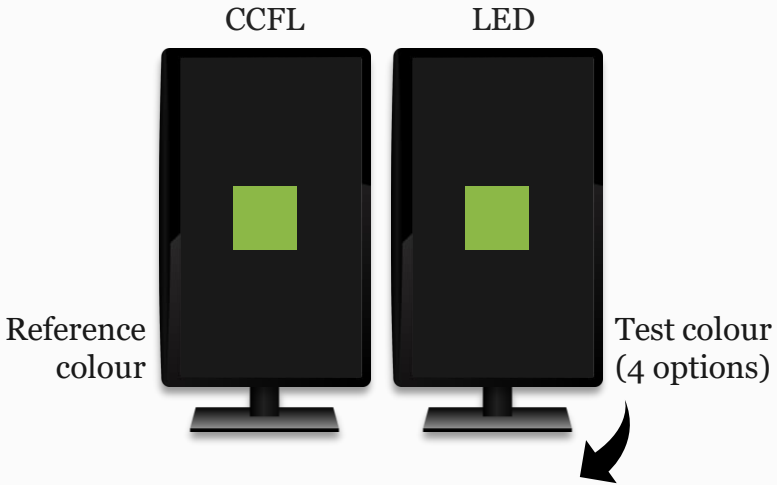


Options on LED displays include colours:

- without calibration (Original)
- calibrated by Mean-CTM (Mean)
- calibrated by CTM of individual (Individual)
- calibrated by inversed Mean-CTM (InvMean)

Experiment 2.1

Single Colour Experiment

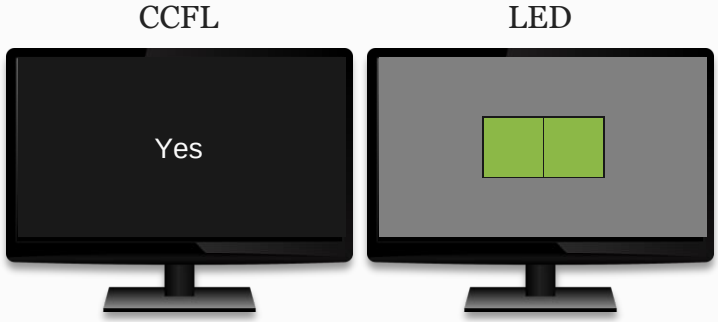


Options on LED displays include colours:

- without calibration (Original)
- calibrated by Mean-CTM (Mean)
- calibrated by CTM of individual (Individual)
- calibrated by inversed Mean-CTM (InvMean)

Experiment 2.2

Colour Difference Experiment



Colours on LED displays include:

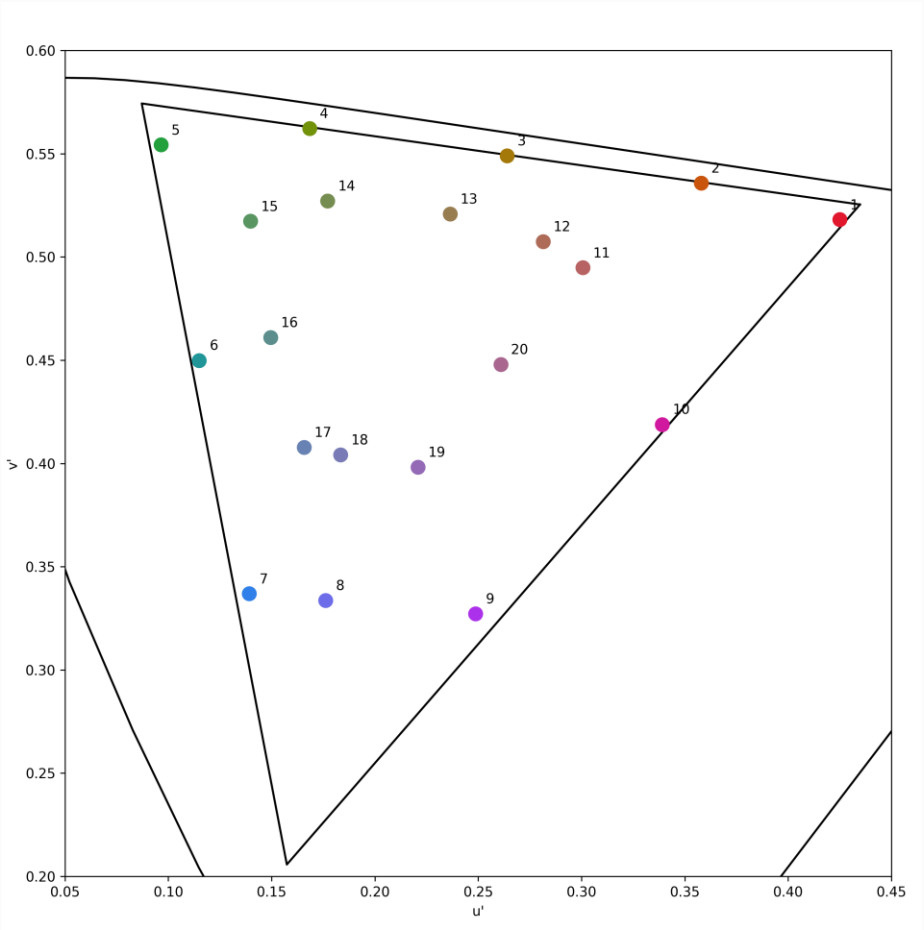
- Colour calibrated by Mean-CTM (Mean)
- Colour calibrated by CTM of individual (Individual)

Experiment 2.3

Colour image samples

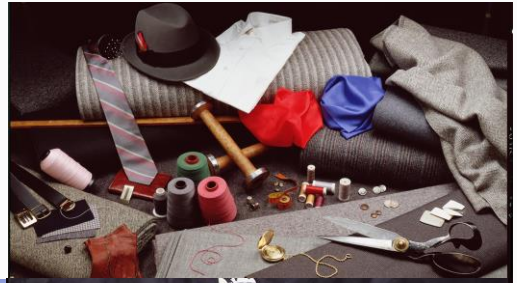
Options on LED displays include:

- Non-calibrated image (Original)
- Image calibrated by Mean-CTM (Mean)
- Image calibrated by CTM of individual (Individual)
- Image calibrated by Mean-CTM optimised under CIE 1931 2° standard (1931)



20 Single colour samples used in Experiment 2

7 Colour image samples used in Experiment 2



Observers

- Due to the usage of Individual-CTM, the observers must have participated in Experiment 1.
- To maintain high consistency, the first 30 observers who performed great repeatability were invited.
- If someone was unable to participate, substitutes starting from the 31st place would be invited.

Observers

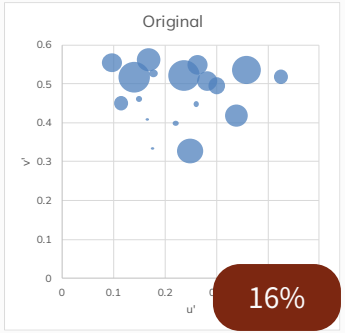
	Total	Male	Female
KSF LED	32	15	17
Mini LED	31	15	16
RG + B LED	32	14	18

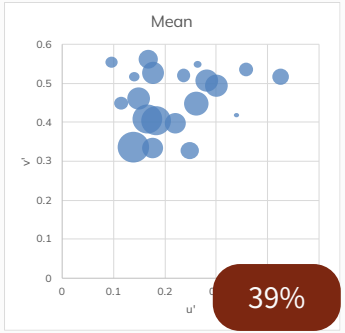
Results

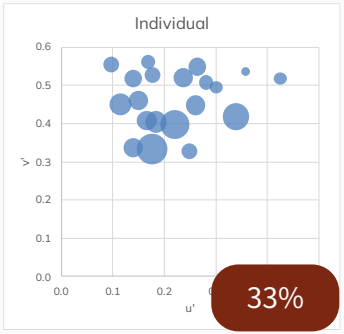
Inter- & Intra-observer variability

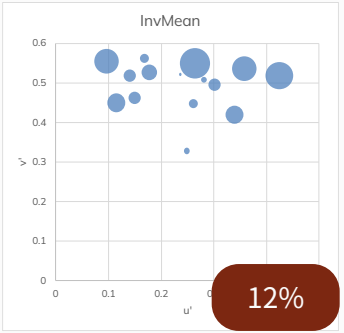
		Inter-observer variability (consistency)	Intra-observer variability (repeatability)
Exp 2.1	KSF LED	0.85	1.22
	Mini LED	0.70	0.89
	RG + B LED	0.85	1.21
Exp 2.2	KSF LED	0.47	0.53
	Mini LED	0.44	0.49
	RG + B LED	0.47	0.56
Exp 2.3	KSF LED	1.06	1.13
	Mini LED	0.84	0.96
	RG + B LED	0.96	1.24

KSF LED 2.1

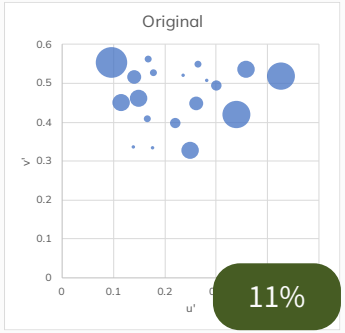


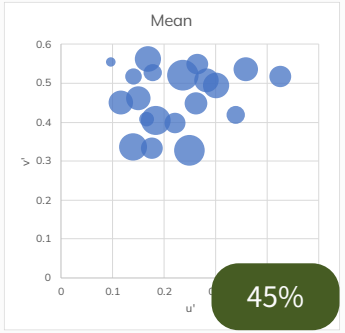


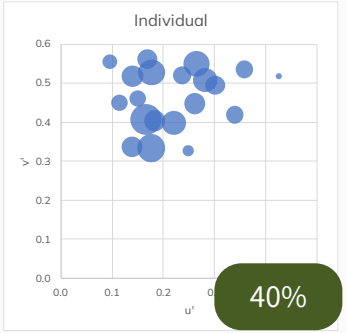


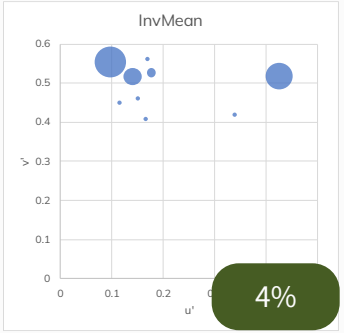


Mini LED 2.1

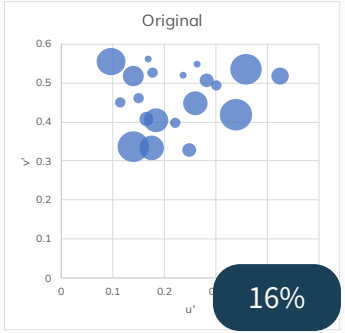


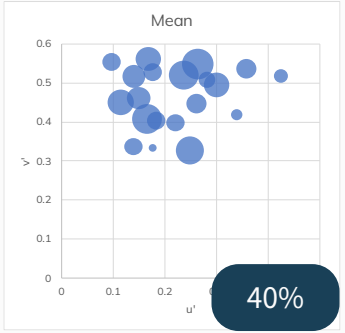


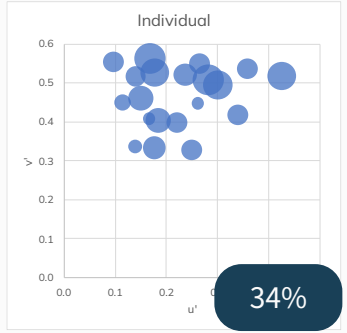


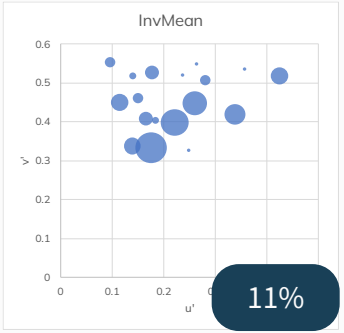


RG+B LED 2.1

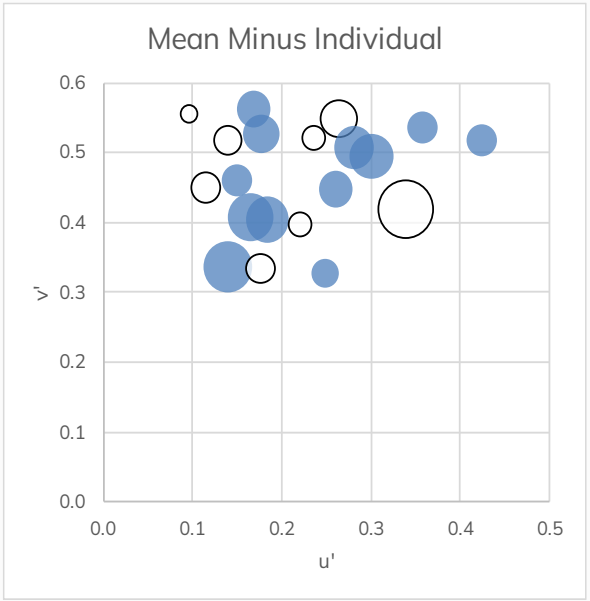




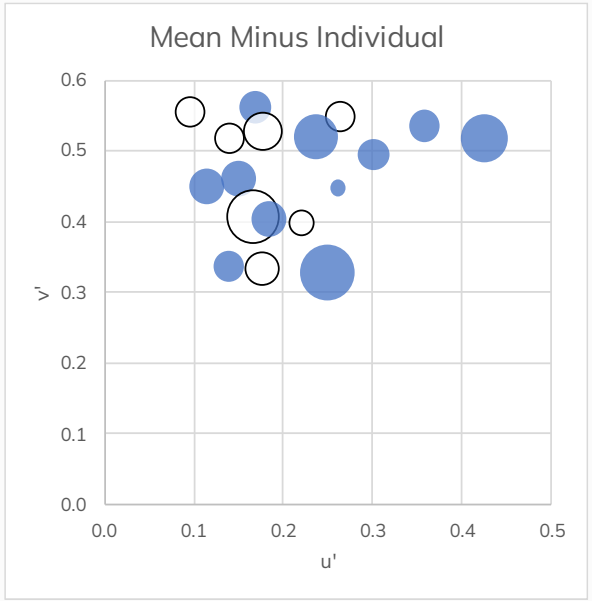




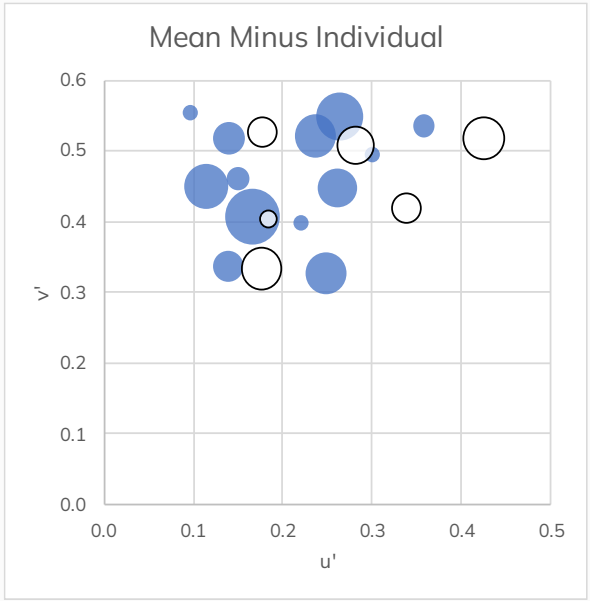
KSF LED 2.1



Mini LED 2.1

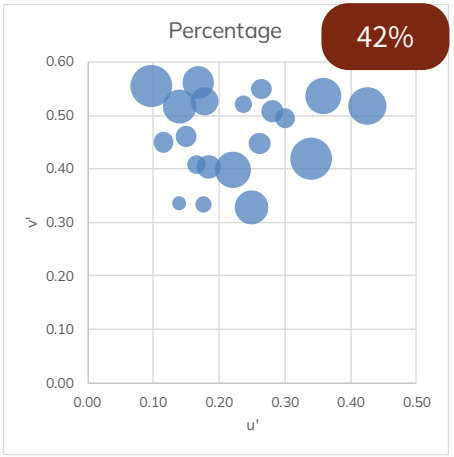


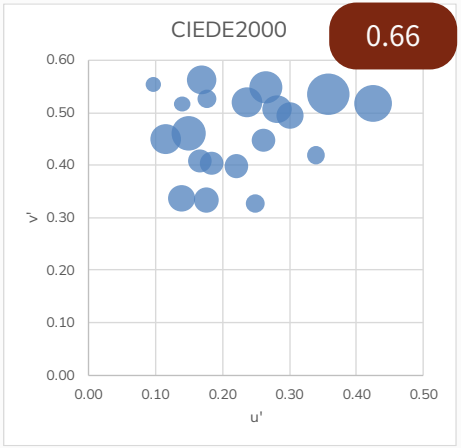
RG+B LED 2.1



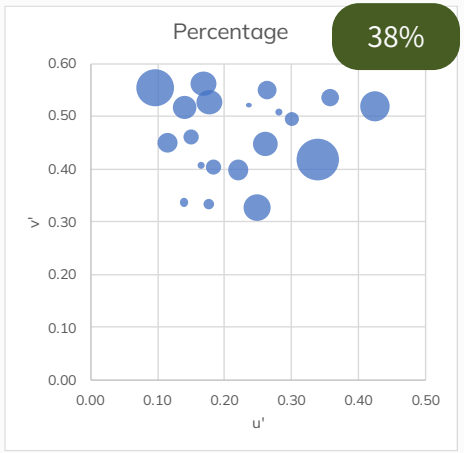
Positive value Negative value

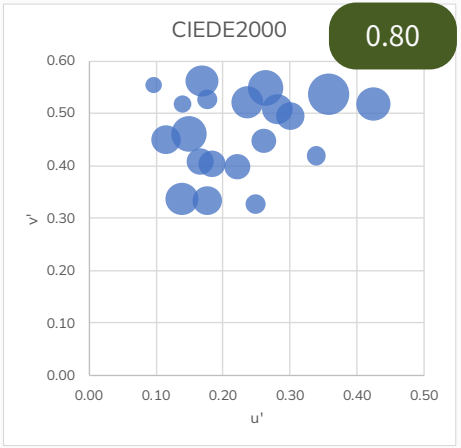
KSF LED 2.2



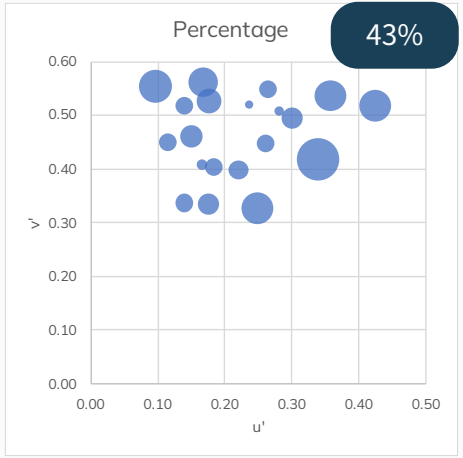


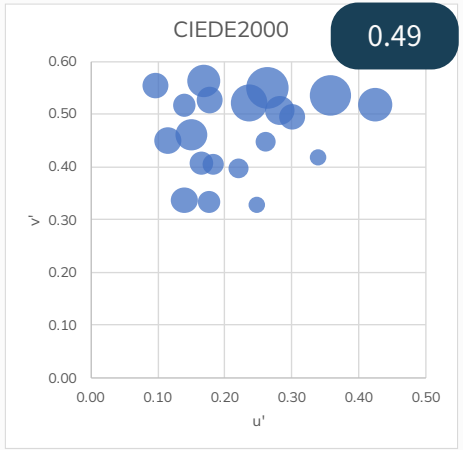
Mini LED 2.2



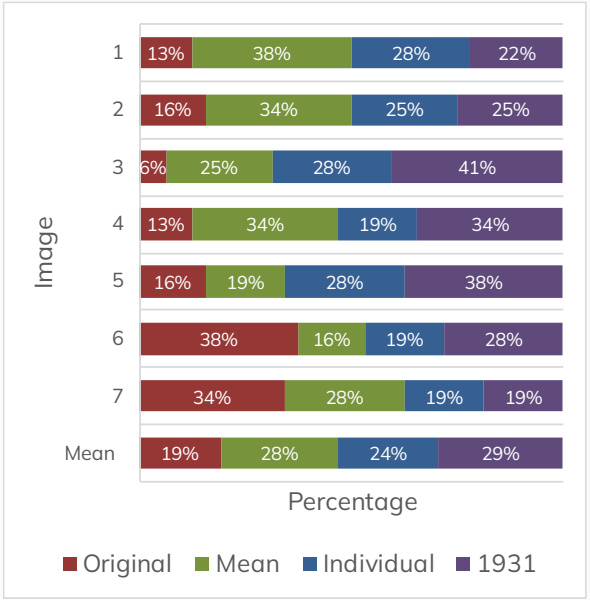


RG+B LED 2.2

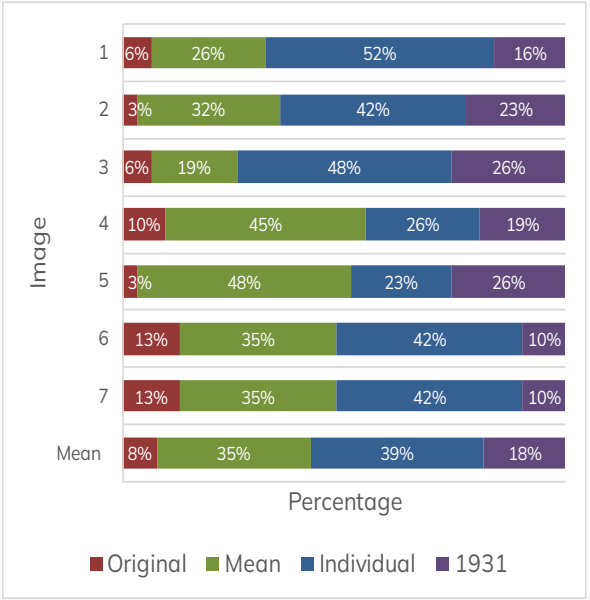




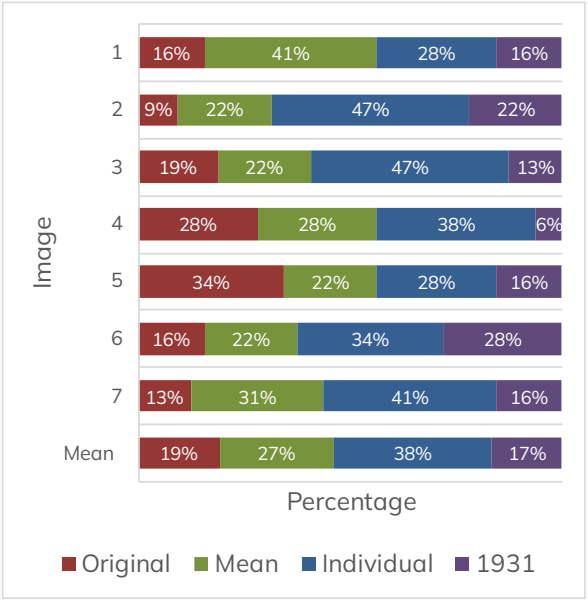
KSF LED 2.3



Mini LED 2.3

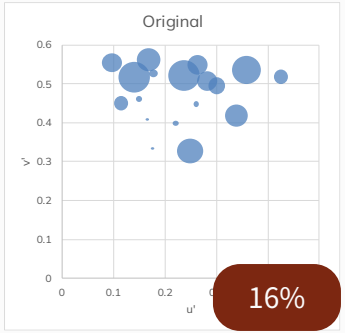


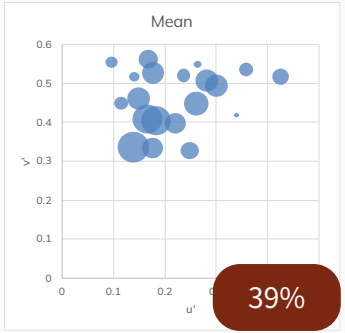
RG+B LED 2.3

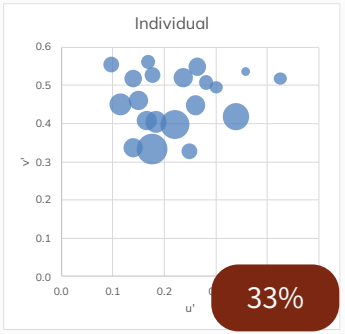


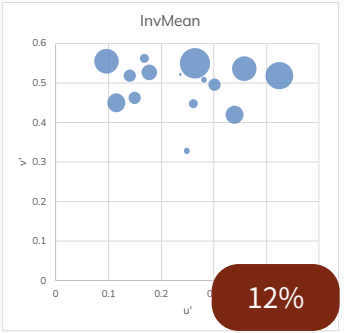
Categorisation

KSF LED 2.1

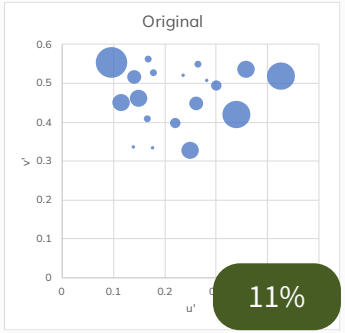


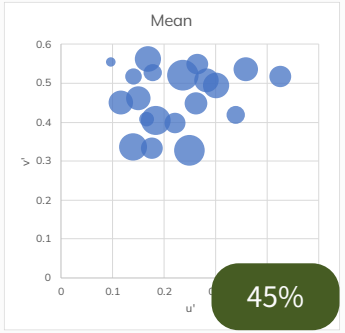


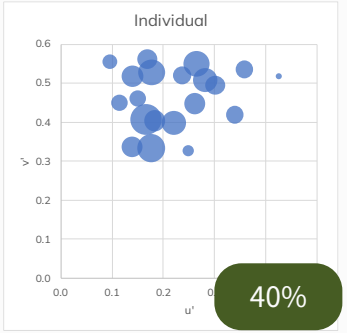


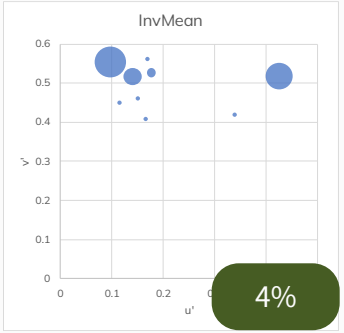


Mini LED 2.1

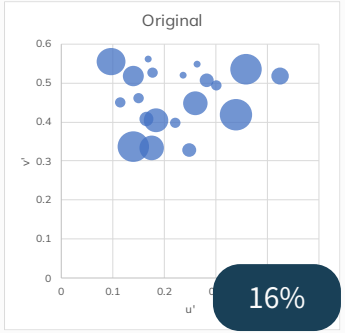


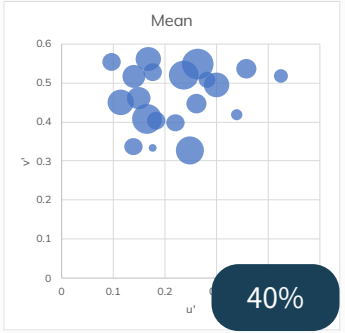


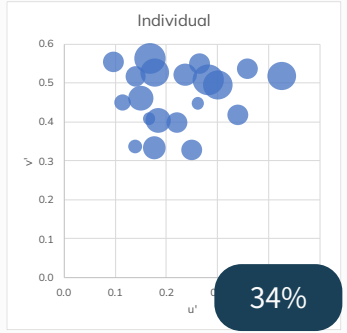


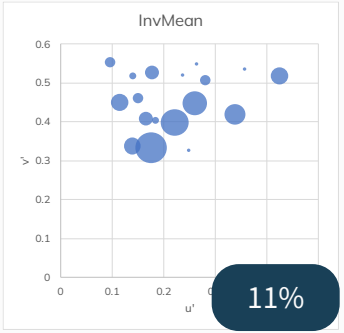


RG+B LED 2.1

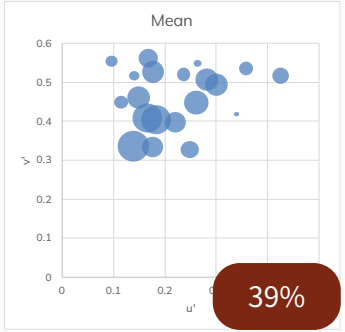


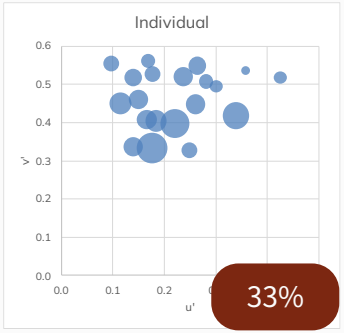






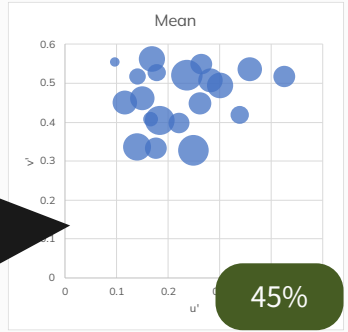
KSF LED 2.1

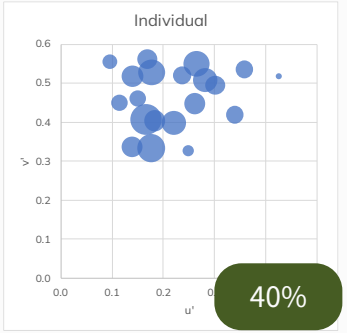




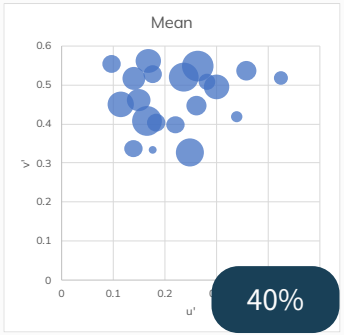
Observers might:

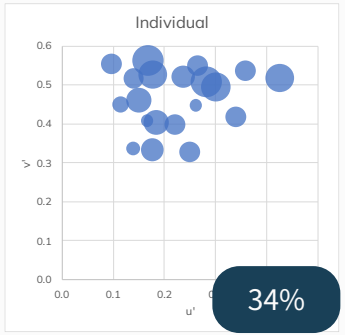
- mostly choose Mean
- mostly choose Individual
- choose half and half





RG+B LED 2.1





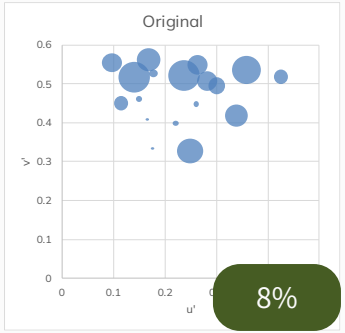
Method of categorisation

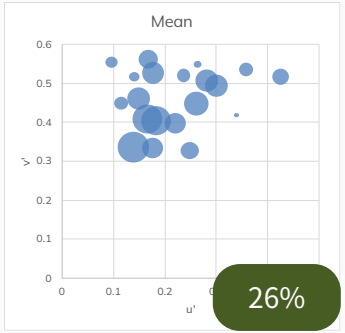
- Observers were categorised in terms of each display and sub-experiment, resulting in 9 results of categorisation in total.
- “Kmeans()” in Python sklearn was used.
- Due to different initial centroids per categorisation, 5000 times of categorising was performed. The result that appeared the most times was taken.
- The results of Mini LED show obvious disparities between subgroups.

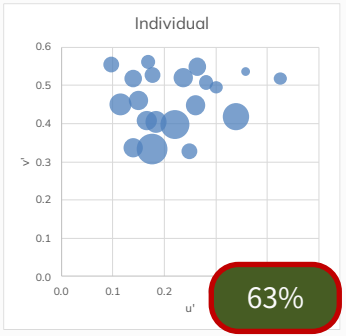
Categorisation:

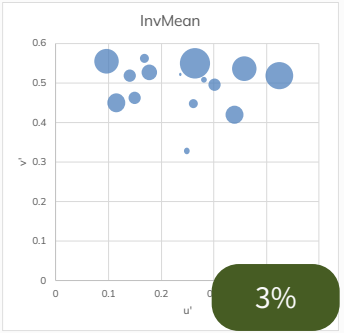
Results

Mini LED 2.1
Group 1 (8 ppl)

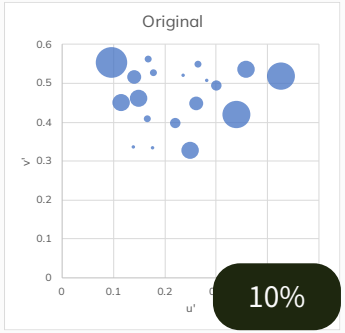


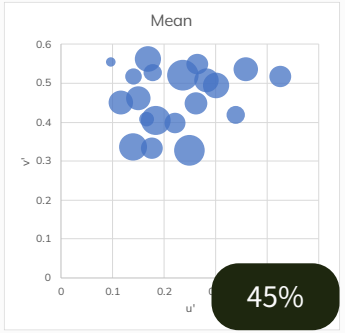


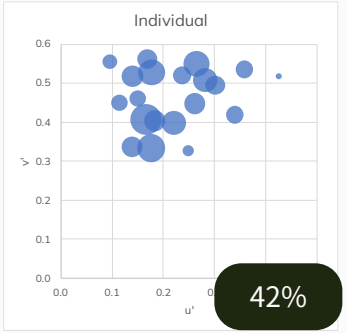


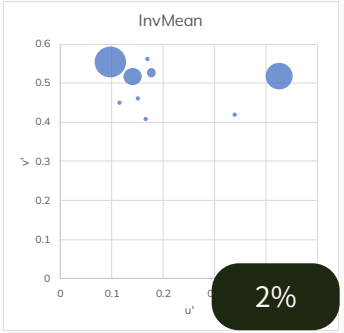


Mini LED 2.1
Group 2 (13 ppl)

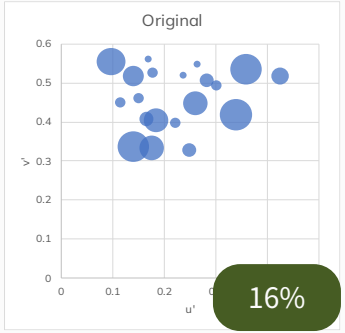


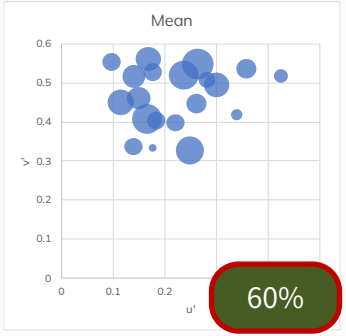


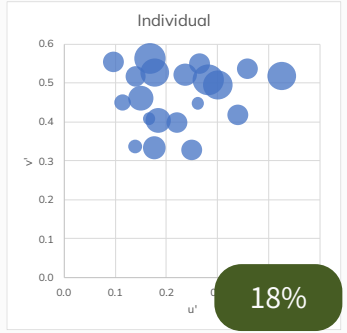


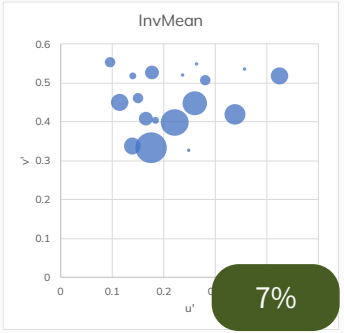


Mini LED 2.1
Group 3 (10 ppl)

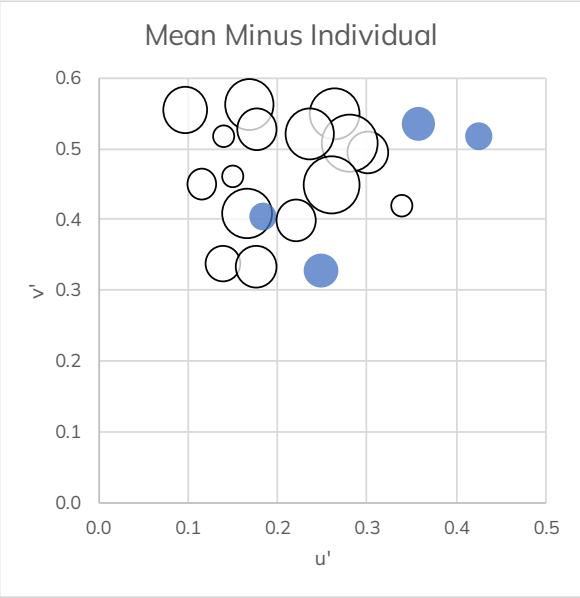






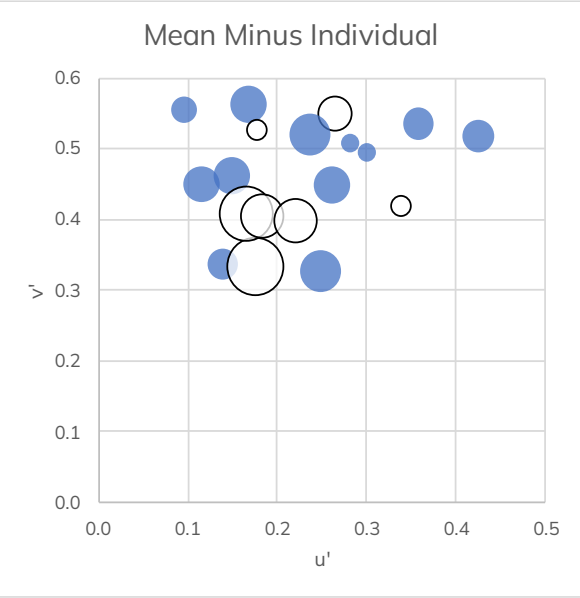


Mini LED 2.1
Group 1 (8 ppl)



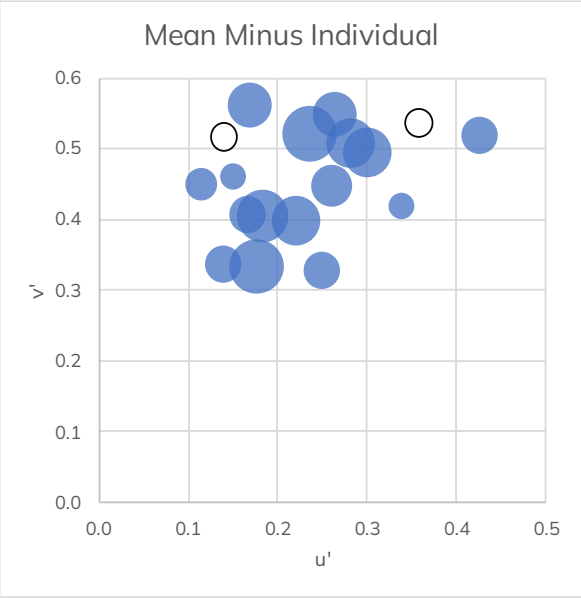
Original	Mean	Individual	InvMean
8%	26%	63%	3%

Mini LED 2.1
Group 2 (13 ppl)



Original	Mean	Individual	InvMean
10%	45%	42%	2%

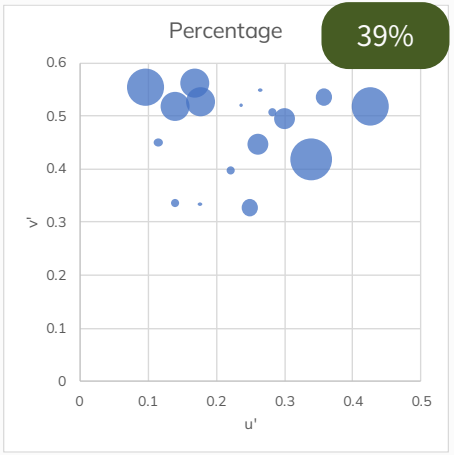
Mini LED 2.1
Group 3 (10 ppl)

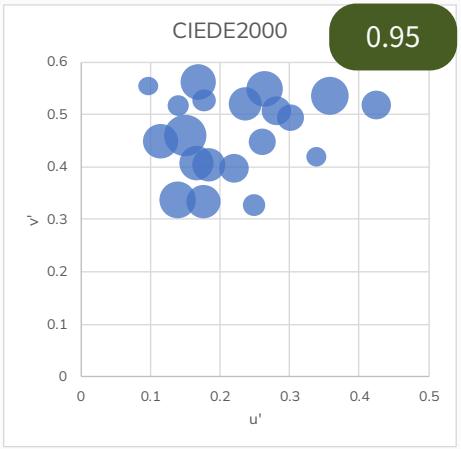


Original	Mean	Individual	InvMean
16%	60%	18%	7%

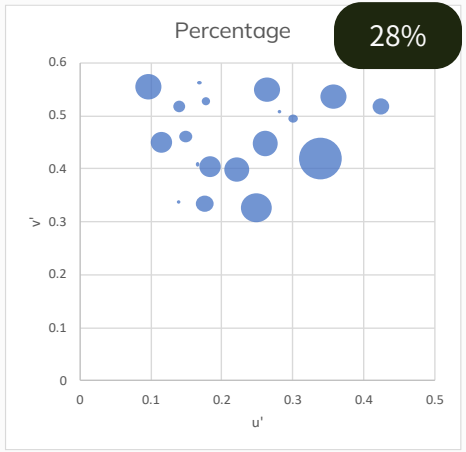
Positive value Negative value

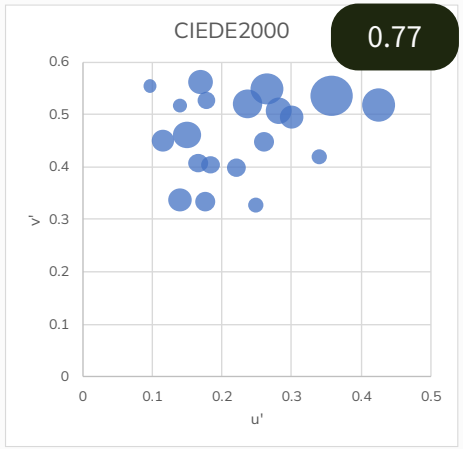
Mini LED 2.2
Group 1 (10 ppl)



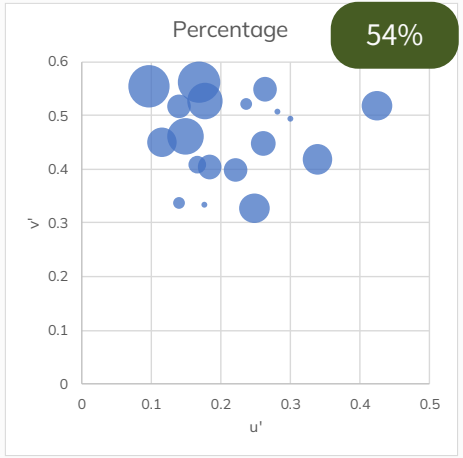


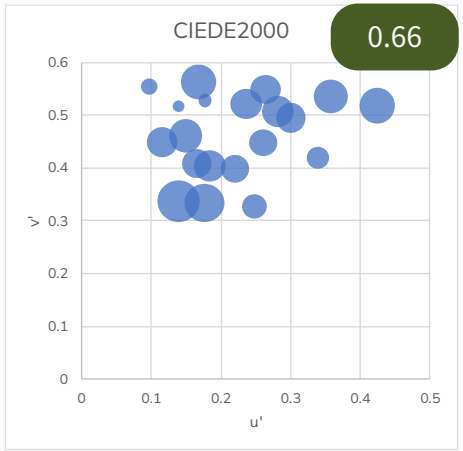
Mini LED 2.2
Group 2 (14 ppl)



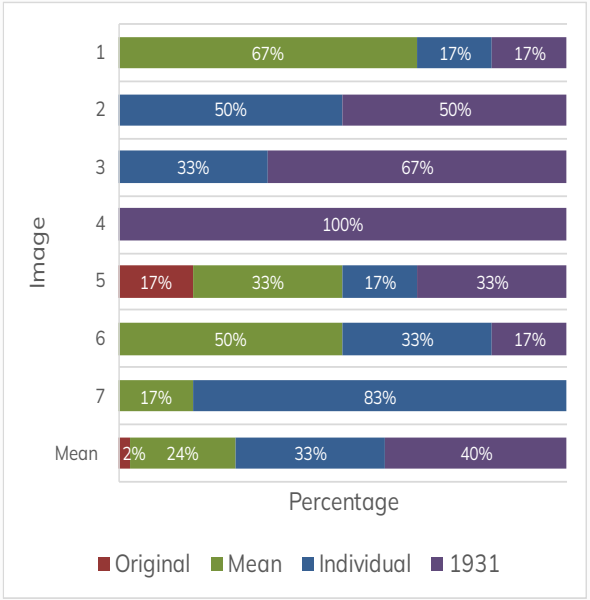


Mini LED 2.2
Group 3 (7 ppl)

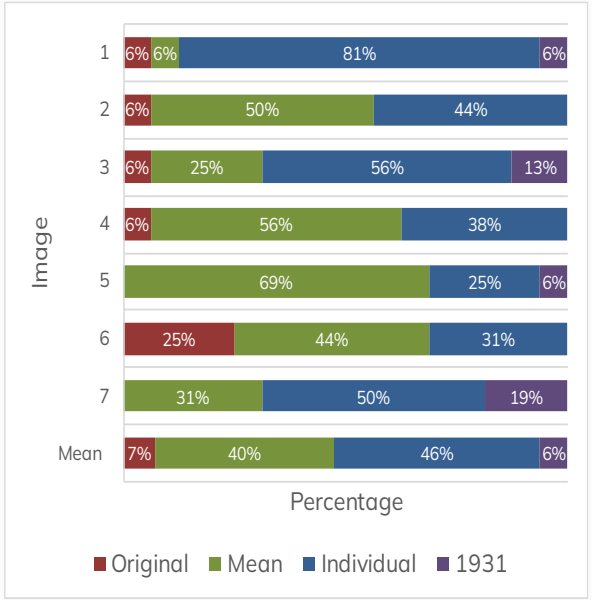




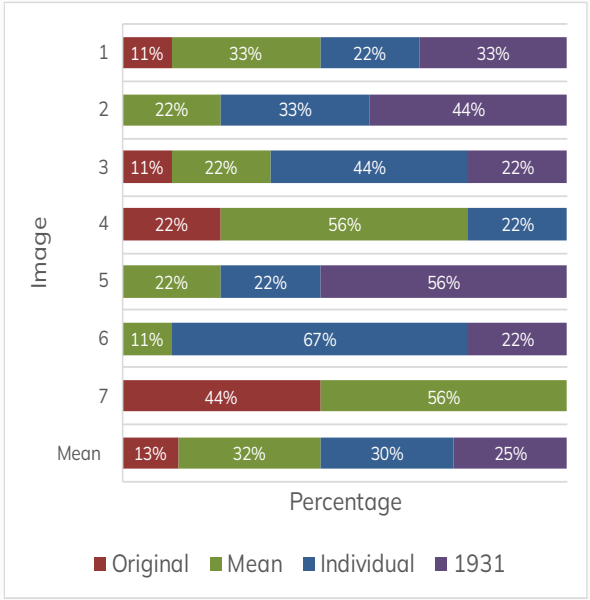
Mini LED 2.3
Group 1 (6 ppl)



Mini LED 2.3
Group 2 (16 ppl)



Mini LED 2.3
Group 3 (9 ppl)



Conclusion of Experiment 2

- Results of Experiment 2.1 indicate the Mean/Individual options were more chosen than the original option, highlighting the necessity of CTMs.
- Results of Experiment 2.2 show colour differences between Mean/Individual options were higher on narrower-band backlight display (Mini LED), indicating that the need of colour calibration for users is essential for advanced backlight technology.
- According to the results of categorisation, there were obvious differences within the observers of narrower-band backlight display.
- Future work could focus on developing multiple CTMs to calibrate colours with different chroma or hue, attempting to mitigate observer metamerism efficiently.

Thank you for your attention!

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