International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

OP68

VISION EXPERIMENT ON VERIFICATION OF HUNT EFFECT IN LIGHTING

Yuki Kawashima et al.

DOI 10.25039/x46.2019.OP68

from

CIE x046:2019

Proceedings
of the
29th CIE SESSION
Washington D.C., USA, June 14 – 22, 2019

(DOI 10.25039/x46.2019)

CIE Central Bureau
Babenbergerstrasse 9
A-1010 Vienna
Austria
Tel.: +43 1 714 3187
e-mail: ciecb@cie.co.at
www.cie.co.at

VISION EXPERIMENT ON VERIFICATION OF HUNT EFFECT IN LIGHTING

Kawashima, Y., Ohno, Y.
National Institute of Standards and Technology, Gaithersburg, MD USA
yuki.kawashima@nist.gov

DOI 10.25039/x46.2019.OP68

Abstract

Hunt Effect is a phenomenon in which object colours at low light levels are perceived less saturated compared to that at higher light levels. If this effect is effective at normal indoor lighting levels, increasing the chroma saturation level at indoor lighting to some extent would make colour appearance of objects closer to that under outside daylight, thus bring higher fidelity of colours. To verify whether the Hunt Effect is effective at normal indoor lighting, vision experiments were conducted using a spectrally tuneable lighting facility simulating a real size interior room. Observers viewed real fruits and vegetables and their skin tones under different chroma levels in red-green direction at illuminance levels of 100 lx and 1000 lx, and evaluated naturalness of these targets. The results showed significant differences between 100 lx and 1000 lx; subjects perceived objects as most natural at less chroma level at 1000 lx than at 100 lx.

Keywords: Hunt Effect, colour fidelity, chroma, saturation, natural object, lighting

1 Introduction

Colour quality of lighting has largely two aspects, colour fidelity and colour perception effects. Colour fidelity shows how object colours appear under a given lighting in comparison with a reference illuminant. CRI (CIE, 1995) and Colour fidelity index (IES, 2015; CIE, 2017) are known as metrics for the colour fidelity. Especially, the CRI is defined by International Commission on Illumination, and is known and used as the only internationally accepted metric to evaluate the colour rendering performance of lighting products. On the other hand, colour perception effects include preference, naturalness or memory for colour appearance of objects under the given lighting, and various metrics for the colour perception are proposed (reviewed in Houser et al., 2013). Several studies showed that the colour fidelity metric such as CRI does not correlate well with the colour perception. It was shown that lighting with higher CRI sources is not always best preferred. Furthermore, it was shown that the preferred colours of natural objects are more saturated than the actual colours of those (Sanders, 1959; Judd, 1967) and that the colour of natural objects are memorized with higher saturation than those actual colours (Newhall et al., 1957; Bartleson, 1960). Therefore, several metrics for assessing the colour quality of lightings beyond the colour fidelity are proposed (e.g. Davis and Ohno, 2010; Smet et al., 2010).

To make a metric for the colour quality of lighting, both of the colour fidelity and colour perception effects should be considered, and these two can be affected by the Hunt Effect (Hunt, 1950). The Hunt Effect is a perception effect, by which perceived chroma of object colours appear less saturated at low light levels than at high light levels. Some studies showed that the illuminance level of lighting affect the preference for the objects, suggesting that this could be due to the Hunt Effect (Islam et al., 2013; Wei et al., 2018). If the Hunt Effect is effective at normal indoor lighting levels, it is considered that objects in indoor lighting (relatively low illuminance levels) would appear less saturated than those at outside daylight (much higher illuminance levels), and increasing the chroma saturation level at indoor lighting to some extent would make colour appearance of objects closer to that under outside daylight. Furthermore, considering the actual colours of the natural objects as those under the daylight, it can be said that increasing the chroma saturation level of the indoor lighting brings higher fidelity to the objects. However, any changes of the chroma saturation level would penalize the score by colour fidelity metrics, since these metrics quantify how close the colours of samples under a given light source appear to those under the reference illuminant.

Therefore, the chroma increase due to the Hunt effect would no longer simply be an issue of preference, but the matter related to colour fidelity.

The Hunt Effect may be playing an important role in perception of chroma increase, however, the Hunt Effect has not been fully investigated for the light levels for normal indoor lighting. To obtain such data, a vision experiment was conducted evaluating the naturalness of common objects illuminated under various chroma saturation levels under low (100 lx) and high (1000 lx) illuminance conditions. If the Hunt Effect is effective, the chroma saturation level that presents most natural colour appearance should be different under the 100 lx and 1000 lx conditions.

2 Methods

The experiment is conducted using a spectrally tuneable lighting facility simulating a real size interior room at two illuminance levels, 100 lx and 1000 lx. A number of pairs of lights, a reference and test light, are prepared and each pair of light is sequentially presented. One of the lights in a pair is always a reference light, which has neutral saturation, and the other light in the pair is one of lights having different chroma saturation levels but having the same chromaticity and illuminance as the reference light. Subjects sits in the facility room and observe objects under illumination, and choose which light makes the objects appear more natural. Thus, many different saturation levels are compared with the reference light for naturalness. From the subject’s responses, the chroma saturation level where the objects appeared most natural is determined for each illuminance level. The effectiveness of the Hunt Effect is determined from the difference between the results at 100 lx and 1000 lx.

2.1 Apparatus

The experiment was conducted using the NIST Spectrally Tuneable Lighting Facility (STLF), as shown in **Figure 1**. This facility has two real-room size cubicles, side by side, illuminated by LEDs with diffusers. The STLF has 25 channels of LED spectra (from 405 nm to 660 nm peak) and can independently control spectral distribution, correlated colour temperature (CCT), distance from the Planckian locus (Duv) and illuminance level at each cubicle. For this experiment, only the right side cubicle with off-white (achromatic) walls was used.

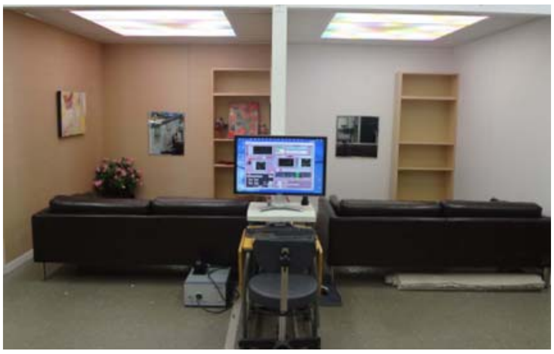

Figure 1 – View of the two cubicles of the NIST Spectrally Tuneable Lighting Facility

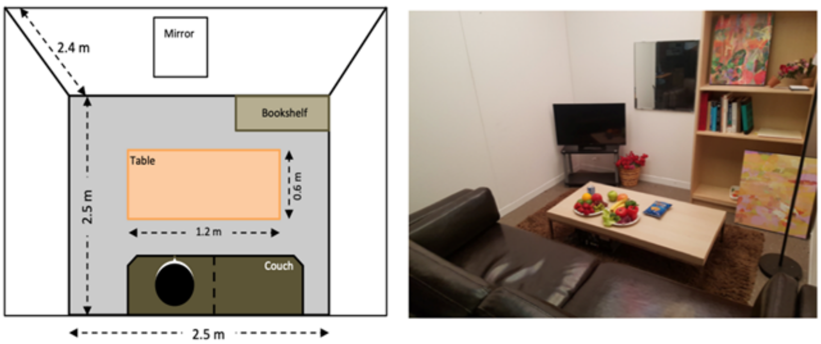

Figure 2 – The STLF cubicle layout - top view (left) and the photo of the setup of STLF (right)

The size of the cubicle is 2.5 m x 2.5 m x 2.4 m and there are a couch, a coffee table and a mirror inside the cubicle, as shown in **Figure 2**. The STLF can produce up to about 1000 lx of white light illumination on the table, depending on the spectrum of light.

2.2 Experimental conditions

The CCT of the reference and test lights were set to 3000 K or 5000 K, with Duv = 0. In each CCT condition, the illuminance of the two lights was set to 1000 lx or 100 lx. Each CCT/illuminance condition had nine different chroma saturation levels as shown in **Figure 3**. Each graph in the figure shows CIELAB a^*, b^* coordinates of 15 CQS samples (Davis and Ohno, 2010) under the test lights and the reference light. The reference light was made so that the red CQS sample had a^*, b^* coordinate as close as possible to that under the reference illuminant of CRI. The chroma saturation level of a test light was defined by chroma shift ΔC^*_{ab} for the red CQS sample from that of the reference light. The test light was set in the range of chroma shift from -16 to +16 in ΔC^*_{ab} with intervals of 4 in ΔC^*_{ab}, except chroma shift 0, whereas the reference light was always set to chroma shift 0. In addition to the chroma saturation level based on the red CQS sample, those based on the green CQS sample were used for evaluation of green fruits and vegetables (at 3000 K only). The chroma saturation level for the green direction was set in the range from -12 to 16 in ΔC^*_{ab} at intervals of 4 in ΔC^*_{ab}, since STLF could not output the chroma saturation level of ΔC^*_{ab} = 16 at 1000 lx.

Spectra for each CCT/illuminance condition are shown in **Figure 4**. To create the reference and test lights, STLF was set to RGBA spectra with narrowband peaks around 460 nm, 525 nm, 590 nm, and 660 nm. Such combination of peaks was needed to increase and decrease the chroma saturation level (smooth broadband spectra cannot achieve it). Red/amber ratio on the spectrum was varied to control the chroma saturation level in red and green directions. In addition to changing the red/amber ratio, the green channel on the spectrum was also adjusted to control the chroma shift in green direction.

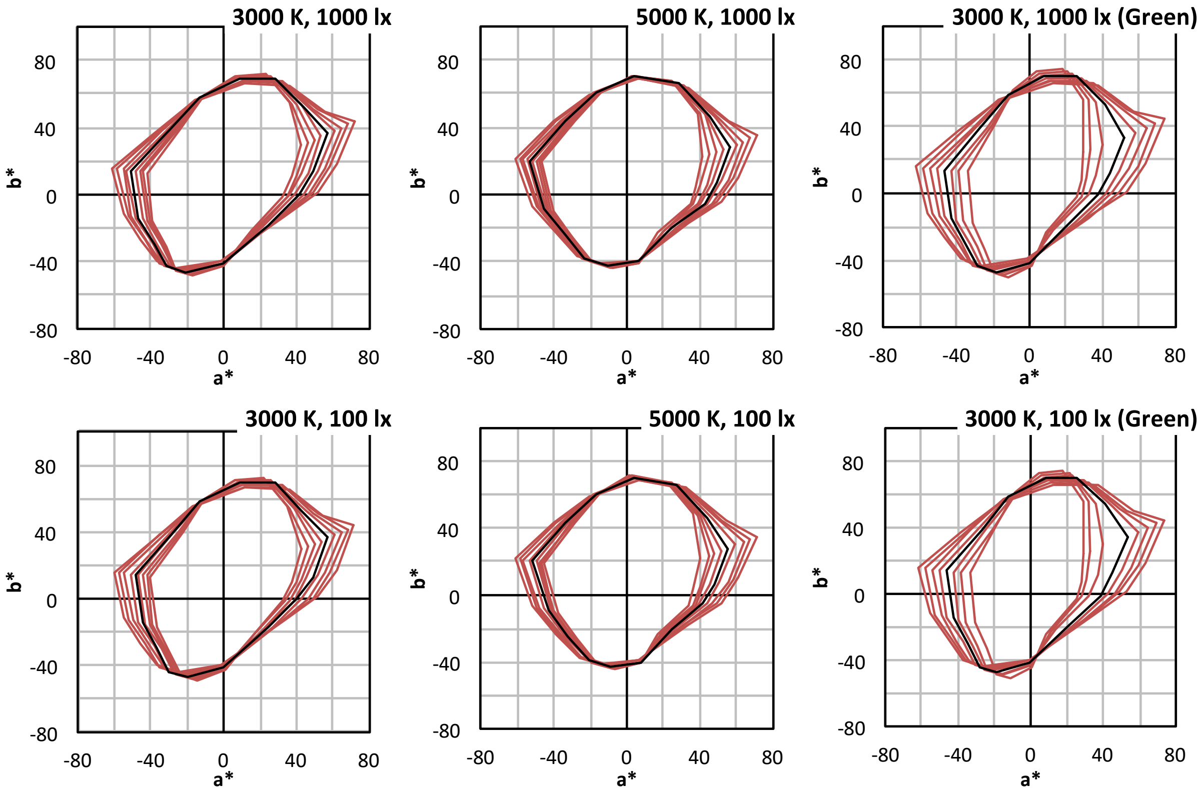

Figure 3 – Gamut area plots of the CQS 15 samples on CIELAB for each CCT/illuminance condition. The black circle is for the reference light and the red circles are for the test lights. All experiment conditions were measured before the experiment.

All experimental conditions for the test and reference lights were measured at the centre of the table in the cubicle, using an array type spectroradiometer with a small integrating sphere input, calibrated traceable to the NIST spectral irradiance scale (Yoon and Gibson, 2011). The expanded uncertainty (k=2) of the colour measurements with the spectroradiometer was approximately 0.001 in *u'* and *v'* and their reproducibility was 0.0002 in *u'* and *v'*.

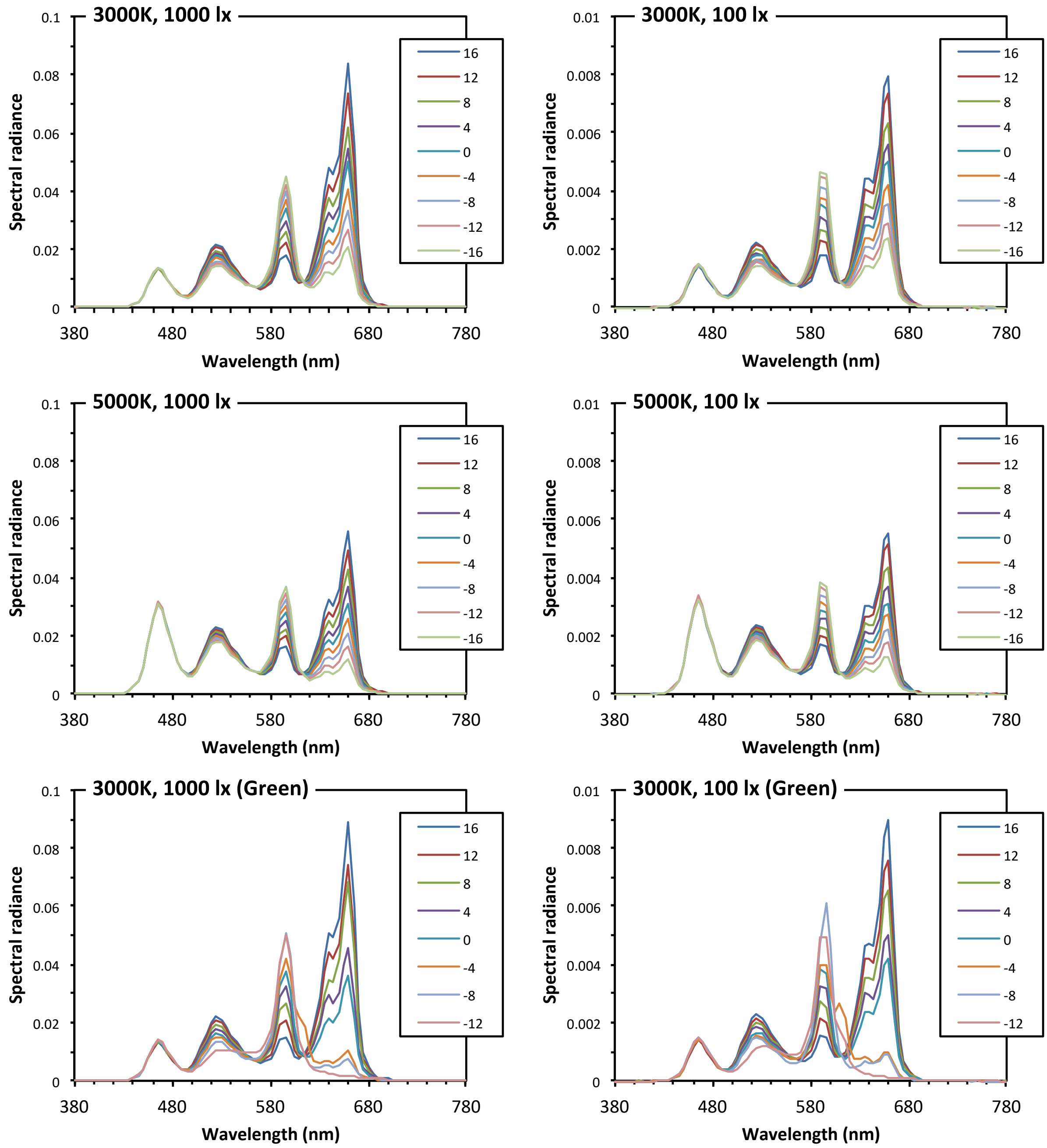

Figure 4 – The spectral distributions of the test and reference lights used in the experiment at each CCT/illuminance condition. Each line shows chroma saturation level (ΔC^{*}_{ab}) in red (four top panels) or green direction (bottom two panels)

Three types of object set of real fruits and vegetables (Mix, Red only and Green only) shown in **Figure 5** were used as the viewing targets. Items in each set were selected as the common real objects often seen in our daily life so that naturalness could be evaluated. The object set, Mix, included fruits and vegetables of various colours, a blue can of a drink and a blue bag of a snack. The Red only and Green only sets have only red and green fruits and vegetables, respectively. The fruits and vegetables were replaced every few days to keep them fresh throughout the experiment period. Items with as similar colours and sizes as possible were used each time they were replaced. In addition to these three sets, subjects' skin colour was also used as the viewing object (Skin). Subjects observed their face using the mirror in front of them or directly observed their hands and arms. Mix, Red only, and Skin sets were observed under lights with chroma saturation levels based on the red CQS sample, whereas the Green only set was observed with those based on the green CQS sample.

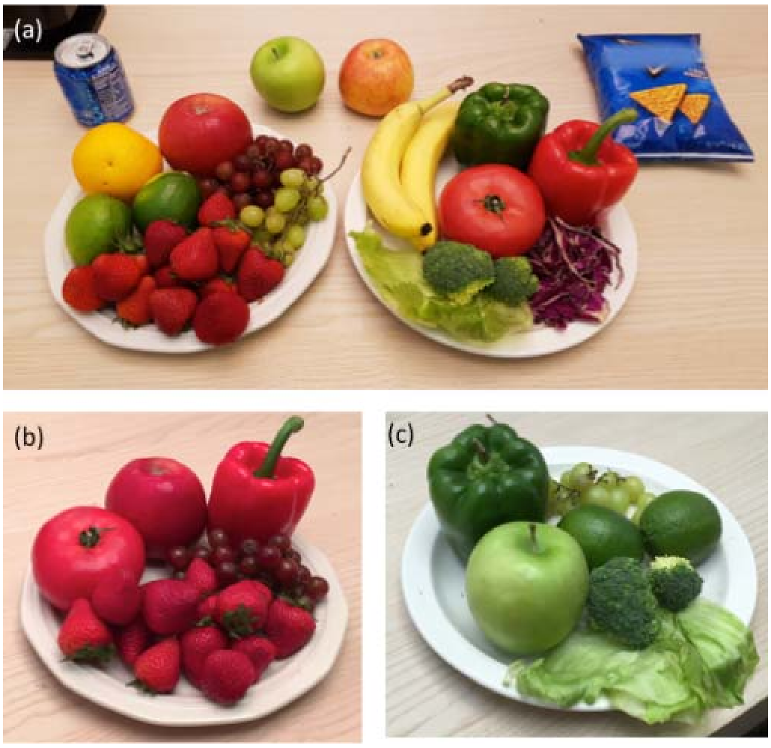

Figure 5 – The setup of viewing objects on the table used in the experiments. (a) Mix, (b) Red only, (c) Green only.

2.3 Procedures

Each subject was first tested for normal colour vision using Ishihara test before starting the experiment. After the Ishihara test, instructions for the experiment were given to the subject. After the instruction, the subject conducted practice trials until they got used to the task.

In the experiment, the room cubicle was illuminated by one of the CCT/illuminance conditions. One of the object sets was first set in the room. The experiment consisted of a number of experimental sessions. In each experimental session, eight pairs of lights were presented. One of the lights in each pair was always the reference light (neutral saturation) and the other light was one of the test lights with eight different chroma saturation levels as described in section 2.2. Two lights in each pair, called "A" and "B", were presented alternately for about 3 seconds each and repeated, and the subject was asked which light, A or B, made the colours of the object set appear more natural. The reference light was set to A or B randomly, and the subject did not know that one of the lights in a pair was always the same (reference) light. Test lights of all eight chroma saturation levels were compared to the reference light in one session.

The experimental session described above was repeated for different object sets, different CCTs (3000 K, 5000 K), and different illuminance levels (1000 lx and 100 lx). The order of these experimental conditions was randomized for each subject so that any time-sequential effects could be removed. **Table 1** shows four different orders of such experimental sessions used in the experiment. Each subject was assigned to one of these orders in a random manner but roughly the same number of subjects were assigned to each order.

When the CCT or illuminance condition was changed, the reference light (neutral saturation) of the CCT/illuminance condition was presented at least for 10 minutes to stabilize the STLF, during which the subject was adapted to the reference light for at least five minutes. During observation of Mix target (see **Figure 5**), the subject was instructed to observe all the items, not focusing only on a specific item.

Table 1 – Four orders of experimental sessions for different conditions and viewing objects

Order1

Session	CCT	Illuminance	Object set
1	3000 K	1000 lx	Mix
2			Skin
3			Red only
4			Green only
5	5000 K		Mix
6			Skin
7	3000 K	100 lx	Mix
8			Skin
9			Red only
10			Green only
11	5000 K		Mix
12			Skin
13	3000 K	1000 lx	Mix
14			Skin

Order2

Session	CCT	Illuminance	Object set
1	3000 K	100 lx	Mix
2			Skin
3			Red only
4			Green only
5	5000 K		Mix
6			Skin
7	3000 K	1000 lx	Mix
8			Skin
9			Red only
10			Green only
11	5000 K		Mix
12			Skin
13	3000 K	100 lx	Mix
14			Skin

Order3

Session	CCT	Illuminance	Object set
1	5000 K	1000 lx	Mix
2			Skin
3	3000 K		Mix
4			Skin
5			Red only
6			Green only
7	5000 K	100 lx	Mix
8			Skin
9	3000 K		Mix
10			Skin
11			Red only
12			Green only
13	5000 K	1000 lx	Mix
14			Skin

Order4

Session	CCT	Illuminance	Object set
1	5000 K	100 lx	Mix
2			Skin
3	3000 K		Mix
4			Skin
5			Red only
6			Green only
7	5000 K	1000 lx	Mix
8			Skin
9	3000 K		Mix
10			Skin
11			Red only
12			Green only
13	5000 K	100 lx	Mix
14			Skin

2.4 Subjects

Total 24 subjects having normal colour vision were recruited for the experiments. They were 12 males and 12 females with their ages from 19 to 64, consisting of 12 Asians, 11 Caucasians and 1 dark-skin person (African or Indian origin). They were the summer-internship students, NIST employees or their families, who were not experts on colour or lighting.

3 Results

At each CCT/illuminance/object set condition, the response proportion for the test light of each chroma saturation level was calculated. The response proportion is the number of subjects who chose that test light over the reference light divided by the total number of subjects. **Figure 6** shows an example of such plots of the response proportion as a function of chroma saturation level. Since there was no test light for the chroma saturation level 0, which is the same as the reference, the response proportion for the level 0 was always given 0.5. The peak of the proportion curve indicates the chroma saturation level under which the objects appeared most natural.

It was found that the peak of the proportion clearly shifted from 100 lx condition to 1000 lx condition in most cases, whereas peaks in some conditions were not clear. In **Figure 6** (left) for Mix at 3000 K, the peak occurred at ΔC^*_{ab} = -4 (slightly oversaturated) at 100 lx, and at ΔC^*_{ab} = -4 (slightly undersaturated) at 1000 lx. In this case, increasing chroma by 8 in ΔC^*_{ab} at 100 lx makes the same colour appearance of objects as at 1000 lx. On the other hand, the curves for 3000 K/Skin condition (right figure) were broader than 3000 K/Mix condition, and it is difficult to find the peaks, especially at the 1000 lx condition.

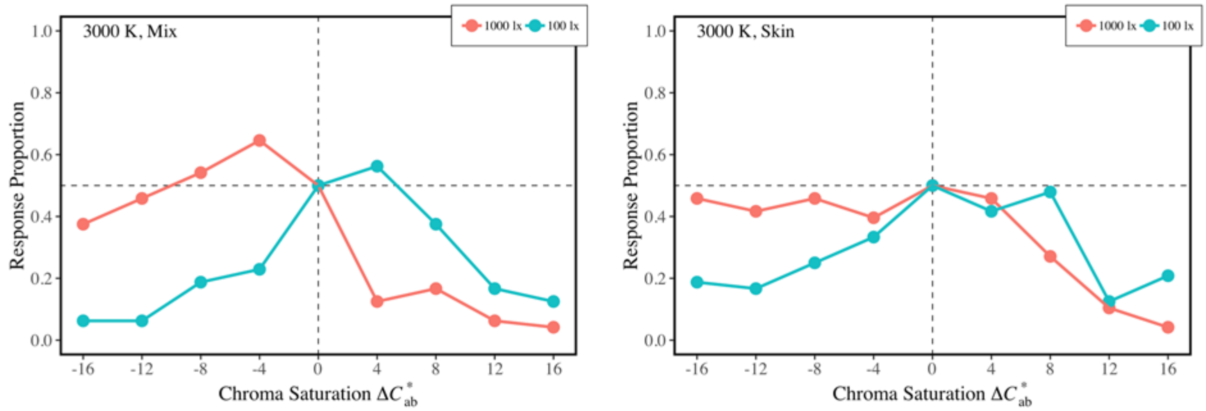

Figure 6 – The response proportions at each illuminance for 3000 K/Mix (left) and Skin condition (right). Red curves indicate the 1000 lx condition, and the blue curves indicate the 100 lx condition.

For the cases where the curve has no clear peak, a fitting model was developed and used to fit the data to determine the peak. The fitting model is a modified probability density function of skew normal distribution which can provide asymmetric curves. The model is shown as following equation (1).

$$f(x) = M \times \frac{2}{\omega}\phi\left(\frac{x-\xi}{\omega}\right)\Phi\left(\alpha\left(\frac{x-\xi}{\omega}\right)\right) \quad (1)$$

where *M* is the magnitude modulator, *α* is the skewness (asymmetry). The curve of the function is right-skewed if *α* is larger than 0, and is left-skewed if *α* is smaller than 0. The *ξ* and *ω* are the position shift and the width parameter of the function. The *φ* and *Φ* are the probability density function and the cumulative distribution function for standard normal distribution, respectively. These two functions are shown in equation (2) and (3).

$$\phi(\chi) = \frac{1}{\sqrt{2\pi}} e^{-\frac{\chi^2}{2}} \quad (2)$$

$$\Phi(\chi) = \int_{-\infty}^{\chi} \phi(t)\, dt \quad (3)$$

Results with fitting curves for all CCT/object set conditions are shown in **Figure 7**. In all conditions, the fitting model seems to provide good fitting curves. The peak shift from 100 lx to 1000 lx condition, evaluated with the fitting curve, ranged from 0.7 to 9.6 in ΔC^*_{ab} and in the same directions for all cases. The peak shift for the Green only set was much smaller ΔC^*_{ab} = 0.7) than the Red only or Mix set (9.6 and 7.6 in ΔC^*_{ab} respectively) at 3000 K. Although there was large peak shift difference for Mix between 3000 K and 5000 K, peak shifts for Skin were not so much different between CCT conditions. The peak shifts for Mix were 7.6 in ΔC^{*}_{ab} at 3000 K and 1.8 in ΔC^{*}_{ab} at 5000 K. On the other hand, the peak shifts for Skin were 3.6 in ΔC^{*}_{ab} at 3000 K and 2.1 in ΔC^{*}_{ab} at 5000 K.

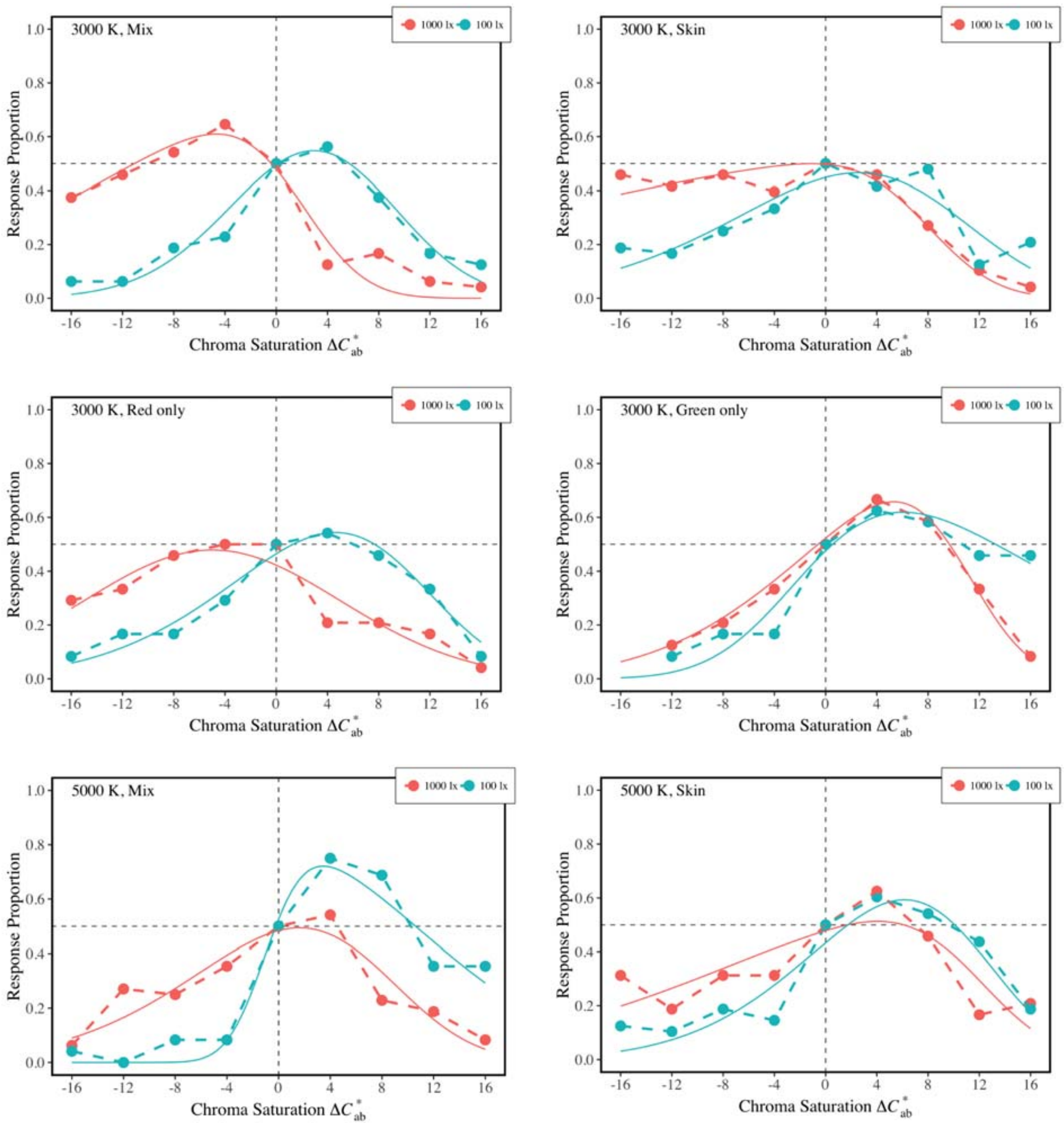

Figure 7 – Results for all CCT/object set conditions. Axes and colours are in the same way as with Figure 6. All points with the same colour are connected by dashed lines. The fitting curves are shown as solid lines on each panel.

4 Conclusions

It was clearly shown that the chroma saturation level where objects appear most natural changes from the 100 lx condition to 1000 lx condition for various targets, and the amount of shift of the peak ranged from approximately 1 to 10 in ΔC^{*}_{ab} depending on object set and CCT. This result verified that the Hunt Effect is effective in typical illuminance levels for general indoor lighting. The increased chroma in the indoor lighting can bring the perceived object colours closer to those under outside daylight. This experiment was limited to chroma saturation of only in red and green directions. Further studies are needed to determine the degree of change of perceived chroma for more different colours (hue) of object at different illuminance levels.

Acknowledgement

The authors thank Semin Oh at Ulsan National Institute of Science and Technology, South Korea, for his valuable contributions in preparing and assisting the vision experiment at NIST. The experiment using human subjects in this study was conducted under NIST Institutional Review Board approval PML-16-0001.

References

BARTLESON, C.J. 1960. Memory Colours of Familiar Objects*. *Journal of the Optical Society of America*, 50(1), 73-77. (DOI: 10.1364/JOSA.50.000073)

CIE 1995. CIE 013.3-1995. *Method of Measuring and Specifying Colour Rendering Properties of Light Sources*.

CIE 2017. CIE 224:2017. *Cie 2017 Colour Fidelity Index For Accurate Scientific Use*.

DAVIS, W. and OHNO, Y. 2010. Colour quality scale. *Optical Engineering*, 49(3), 033602. (DOI: 10.1117/1.3360335)

HOUSER, K.W. *et al.* 2013. Review of measures for light-source colour rendition and considerations for a two-measure system for characterizing colour rendition. *Optics Express*, 21(8), 10393-10411. (DOI: 10.1364/OE.21.010393)

HUNT, R.W.G. 1950. The Effects of Daylight and Tungsten Light-Adaptation on Colour Perception. *Journal of the Optical Society of America*, 40(6), 362-371. (DOI: 10.1364/JOSA.40.000362)

IES 2015. TM-30-15. *IES Method for Evaluating Light Source Colour Renditon*. New York, NY: The Illuminating Engineering Society of North America.

ISLAM, M. *et al.* 2013. User preferences for LED lighting in terms of light spectrum. *Lighting Research & Technology*, 45(6), 641–665. (DOI: 10.1177/1477153513475913)

JUDD, D.B. 1967. The flattery index for Artificial Illuminants. *Illuminating Engineering*, 62(10), 593-598.

NEWHALL, S.M., BURNHAM, R.W. and CLARK, J.R. 1957. Comparison of Successive with Simultaneous Colour Matching. *Journal of the Optical Society of America*, 47(1), 43-56. (DOI: 10.1364/JOSA.47.000043)

SANDERS, C.L. 1959. Colour Preference for Naural Objects. *Illuminating Engineering*, 54(7), 452-456.

SMET, K.A.G. *et al.* 2010. Memory colours and colour quality evaluation of conventional and solid-state lamps. *Optics express*, 18(25), 26229–44. (DOI: 10.1364/OE.18.026229)

WEI, M., BAO, W. and HUANG, H.-P. 2018. Consideration of Light Level in Specifying Light Source Colour Rendition. *LEUKOS*, 1–11. (DOI: 10.1080/15502724.2018.1448992)

YOON, H.W. and GIBSON, C.E. 2011. *Spectral Irradiance Calibrations*. NIST SP-250-89.