Vision Experiment on Perception of Correlated Color Temperature

Yoshi Ohno*1 (NIST Fellow)
Semin Oh*2 (NIST guest researcher)

*1 National Institute of Standards and Technology, USA
*2 Ulsan National Institute of Science and Technology, South Korea
Chromaticity expression for lighting

**CCT** (Correlated Color Temperature)

**D_{uv}** (Shift from Planckian locus)

The use of CCT and Duv is the intuitive way to express the chromaticity of light sources for lighting.
Correlated Color Temperature (CCT)

Temperature [K] of a Planckian radiator whose chromaticity is closest to that of a given stimulus on the CIE \((u', \frac{2}{3} v')\) coordinate.

\(CIE (u', \frac{2}{3} v')\) is the CIE 1960 \((u, v)\) coordinate, which is now obsolete.
$D_{uv}$ – Distance from Planckian Locus

Closest distance from the Planckian locus on the $(u', 2/3 v')$ diagram, with + sign for above and - sign for below the Planckian locus.

Now also in CIE 15:2018.
CIE 1960 (u, v) is obsolete

---- Officially Recommended Chromaticity Diagrams -----

CIE 1931 (x,y)

CIE 1976 (u',v')

CIE 1960 (u,v) obsolete
3.1 $u'v'$ Circle

Recommended for color difference (tolerance) specifications for lighting products – replacing MacAdam Ellipses

4 Chromaticity difference $\Delta_{u',v'}$

is expressed between two points $(u'_1, v'_1)$ and $(u'_2, v'_2)$ on the CIE $(u', v')$ diagram by,

$$\Delta_{u',v'} = \sqrt{(u'_2 - u'_1)^2 + (v'_2 - v'_1)^2}$$
Discussion in CIE

\( D_{uv} \), based on (u,v), and \( \Delta_{u'v'} \), based on (u’,v’), are making confusions in the industry.

A need for changing the definition of CCT (and Duv) to (u’,v’). Scientific data needed. Which diagram correlates better with perception of CCT?

CIE Division 1 started a reportership in 2017:

**DR 1-67**  
Revisiting Correlated Colour Temperature  
Reporter: Dr. Youngshin Kwak
NIST 2016 Experiment

Experimental Facility (Spectrally tunable double-booth)
Experimental Method (2016)

12 subjects
- 8 males and 4 females
- 20 to 71 years old
- 7 white and 5 Asians.
Results of 2016 Experiment (Re-analyzed)

2019 Experiment at NIST

**Purpose:** To investigate the perception of CCT in conditions closer to real lighting applications.

**Experimental Facility:** NIST Spectrally Tunable Lighting Facility

**Subjects:** Total 22
11 males, 11 females
Age: 18 to 64 years old

**Illuminance:** 300 lx (on the table)

**CCT:** 2700 K, 3500 K, 4500 K, 6500 K

**Evaluation:**
View the entire room.
SPDs of the lights used

a) 2700K

b) 3500K

c) 4500K

d) 6500K
Method of Experiment

Procedures

Preparation
   Ishihara test
   Practice session

At each CCT:
1) Subject adapted to
   Adaptation point for 2 min.
2) Present:
   Test – A – B – Test
3) Repeat:
   Test – B – A – Test
4) Ask which of A or B is closer (color) to Test? Also, “difficult” if choice is difficult.
Method of Experiment

![Graph showing color adaptation points and Planckian locus]

**Procedures**

**Preparation**
- Ishihara test
- Practice session

At each CCT:
1) Subject adapted to Adaptation point for 2 min.
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   - Test – A – B – Test
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4) Ask which of A or B is closer (color) to Test? Also, “difficult” if choice is difficult.
Data Analysis

1) Raw data (A or B)

<table>
<thead>
<tr>
<th>Sequence</th>
<th>CCT</th>
<th>Duv</th>
<th>Sub1</th>
<th>Sub2</th>
<th>Sub3</th>
<th>Sub4</th>
<th>Sub5</th>
<th>Sub6</th>
<th>Sub7</th>
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<td>plus</td>
<td>BD</td>
<td>B</td>
<td>B</td>
<td>B</td>
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<td>A</td>
<td>B</td>
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<td>B</td>
<td>BD</td>
<td>B</td>
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<td>3500</td>
<td>plus</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
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<tr>
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<td>minus</td>
<td>BD</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>AD</td>
<td>A</td>
<td>BD</td>
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<tr>
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<td>4500</td>
<td>plus</td>
<td>AD</td>
<td>A</td>
<td>AD</td>
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<td>A</td>
<td>B</td>
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<tr>
<td>4</td>
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<td>B</td>
<td>AD</td>
<td>AD</td>
<td>A</td>
<td>A</td>
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</tbody>
</table>

* A = uv / B = u'v' / AD or BD means it was difficult

2) Converted score data (+1 or -1)

<table>
<thead>
<tr>
<th>Sequence</th>
<th>CCT</th>
<th>Duv</th>
<th>Sub1</th>
<th>Sub2</th>
<th>Sub3</th>
<th>Sub4</th>
<th>Sub5</th>
<th>Sub6</th>
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</tbody>
</table>

* A = 1 / B = -1

0.5 *Score allocation for Difficult responses
Results of 2019 Experiment

Average of 22 subjects

Score

(u,v) is good

(u',v') is good

2016 Experiment

(u,v)

Score

(u',v')

Haploscopic
Non-Haploscopic

3000 +duv 3000 -duv 5500 +duv 5500 -duv
Observation from MacAdam Ellipses

Fig. 3 in CIE TN001:2014

Vertical length adjusted to (u,v,)

CIE 1976 \((u', v')\) diagram

NIST
Results – Gender variation

Male (11)

Score

(u,v) is good

Female (11)

Score

(u,v) is good

Score

(u',v') is good

Score

(u',v') is good

2700K 2700K 3500K 3500K 4500K 4500K 6500K 6500K

+duv -duv +duv -duv +duv -duv +duv -duv

2700K 2700K 3500K 3500K 4500K 4500K 6500K 6500K

+duv -duv +duv -duv +duv -duv +duv -duv

Score

(u,v) is good

Score

(u,v) is good

Score

(u',v') is good

Score

(u',v') is good

18
Results – Age variation

Younger group <40 (15)

Older group ≥40 (7)
Conclusions

- Correlation between the values of CCT and perception of CCT has been studied experimentally.

- It is clear that $(u', v')$ chromaticity space has better correlation at low CCTs (2700K or 3000 K) – from 2019 and 2016 results.

- At higher CCTs, the results vary and are not conclusive.

- It is desired that further experiments will be made, including conditions for other applications such as displays.

- These results will be contributed to CIE DR 1-67.
THANK YOU FOR YOUR ATTENTION

Yoshi Ohno
ohno@nist.gov