COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

DIVISION 1: VISION AND COLOUR

MINUTES of the 2nd Meeting of the Luo Term

Tuesday 2 June 2009

Budapest, Hungary

ATTENDANCE

Officers	Ronnier Luo	GB	DD – Director
	Miyoshi Ayama	JP	AD – Vision
	Ellen Carter	US	AD – Colour
	Mike Pointer	GB	DS – Secretary

Country Representatives	Peter Hanselaer	Belgium
	Hans Peter Grieneisen*	Brazil
	Joanne Zwinkels*	Canada
	Marjukka Puolakka	Finland
	Françoise Viénot	France
	Klaus Richter*	Germany
	Michael Pointer	Great Britain
	Klara Wenzel	Hungary
	Osvaldo da Pos	Italy
	Miyoshi Ayama	Japan
	Dong-Hoon Lee*	Korea (Republic)
	Peter van der Burgt	Netherlands
	Thorstein Seim*	Norway
	Marta K Gunde	Slovenia
	Elsie Coetzee	South Africa
	Manuel Melgosa	Spain
	Rengin Ünver	Turkey
	Ellen Carter*	USA

*Nominated representative

Technical Committee Chairs	Françoise Viénot	FR	TC1-36
	Ken Sagawa	JP	TC1-37, TC1-54
	Miyoshi Ayama	JP	TC1-42
	Robert Hirshler	HU	TC1-44
	Manuel Melgosa	ES	TC1-55
	Klaus Richter	DE	TC1-63
	Janos Schanda	HU	TC1-66, TC1-74
	Peter Bodrogi	HU	TC1-68
	Wendy Davis	US	TC1-69
	Balázs Kranicz	HU	TC1-70
	Changjun Li	CN	TC1-71, TC1-73
	Mike Pointer	GB	TC1-72

Reporters	Mike Pointer	GB	R1-39
	Changjun Li	CN	R1-42
	Joanne Zwinkels	CA	R1-46
	Thorstein Seim	NO	R1-47

Guests In addition there were approximately 7 guests present

Apologies

Paula Alessi	US	TC1-27
Gunilla Derefeldt	SE	R1-32
Juliana de Freitas Gomes	BR	
Taiichiro Ishida		TC1-61
Sharon McFadden	CA	TC1-64, R1-44
Peter McGinley	AU	
Danny Rich		L1-6
Alan Robertson		TC1-57
Gerhard Rösler	DE	
John Setchell		Division Editor
Pieter Walraven		TC1-41

Total attendance: Approximately 32 persons

1. WELCOME

The Division Director, Ronnier Luo, welcomed all those present and thanked the hosts, the Hungarian CIE, for providing facilities for the meetings at the Loránd Eötvös University, Budapest, Hungary. The President of CIE, Franz Hengstberger, then made some opening remarks.

2. ATTENDENCE

18 countries were officially represented. However not all representatives were present for the whole of the Division meeting.

3. MEMBERSHIP

The following changes in national representative were noted:

China: Haisong Xu
Japan: Miyoshi Ayama
Finland: Marjukka Puolakka (name change)

4. CONFIRMATION OF THE AGENDA

The Agenda, as presented via PowerPoint and appended to these Minutes, was agreed.

5. MINUTES

The Minutes of the 2008 meeting held in Stockholm, Sweden, were approved after three amendments:

- Osvaldo da Pos (IT) was present for the TC meetings and part of the Division meeting.
- In Minute 7.1 R1-44: change US to CA for Sharon McFadden.
- The establishment of Reporter: *Hue angles of elementary colours* was at the request of ISO/TC 159/SC 4/WG 2 *Visual display requirements* and not as stated.

6. MATTERS ARISING FROM THESE MINUTES

There were no matters arising not covered by items on the agenda.

7. DIVISION OFFICER REPORTS

7.1 Director

The Director highlighted the following points:

- Dr. Todor Kehlibarov, the Representative from Bulgaria, died in October 2008. Those present were invited to stand for a minute in remembrance.

- ***Latest publications***

TC1-66: Janos Schanda	CIE 184:2009, Indoor Daylight Illuminants
TC1-57: Alan Robertson	Joint ISO/CIE Standard ISO 11664-4: 2008(E)/CIE S 014-4/E:2007, Colorimetry – Part 4: CIE 1976 L*a*b* Colour Space
TC1-57: Alan Robertson	Standard CIE S 014-5/E:2009, Colorimetry - Part 5: CIE 1976 L*u*v* Colour Space and u', v' Uniform Chromaticity Scale Diagram

- ***BA and Division ballots in progress***

TC1-27: Paula Alessi	Specification of colour appearance for reflective media and self-luminous displays, with the TR title of 'CIE TC1-27 Summary Report.'

Secretary's Note: This report now has the title 'Testing colour appearance model performance via cross-media colour matching experiments.'

TC1-56: Michael Brill	Improved colour matching functions, with the TR title of 'Reappraisal of Colour Matching and Grassmann's Laws'.

- ***TCs and Rs approved following the Stockholm meeting***

TC1-73 (C) Real Colour Gamut
Chairman: Changjun Li CN
To recommend a gamut representative of real (non-fluorescent) surface colours and defined by associated spectral reflectance data.

R1-46 (C) Evaluation of Whiteness
Reporter: Joanne Zwinkels CA
To review the current status of whiteness measurement and recommend future requirements.

R1-47 (C) Hue Angles of Elementary Colours
Reporter: Thorstein Seim NO
To review the current literature on elementary (unique) hues for potential imaging applications.

- ***TC approved after the Stockholm Meeting:***

TC 1-74 (C) Methods for Re-Defining CIE D-Illuminants
Chairman: Janos Schanda HU
To investigate the issue of smoothing the values of the D illuminants such as described in CIE 15:2004 Appendix C and to propose the calculation methods for new definitions of the D Illuminants.

The result of the ballot, conducted by email, was 24 for, 0 against with 1 abstention.

- ***TCs that met at the Budapest mid-term meeting:***

TC1-55 Uniform Colour Space for Industrial Colour-Difference Evaluation
TC1-63 Validity of the Range of CIEDE2000
TC1-68 Effect of Stimulus Size on Colour Appearance
TC1-69 Colour Rendering of White Light Sources
TC1-70 Metameric Samples for Indoor Daylight Evaluation
TC1-72 Measurement of Appearance Network

TC1-74 Methods for Re-Defining CIE D-Illuminants

- ***Update from the BA Meeting***

  - A book is to be produced in 2010 on Solid State Lighting & LEDs
  - The final date for ballot of the ILV is 26 July 2009
  - New CIE Guidelines are to be implemented:
    - Memberships and operation of CIE TCs
    - Approval of TC reports
    - Approval of CIE/ISO standards
  - Membership and operation of CIE TCs
    - i. Technical Committees
    - TC and TCC for 4 year term
    - A detailed work plan
    - To apply for continuation to be approved by the Division and BA
    - ii. Technical Committee Members
    - To fill in a form to TCC, DD and DS to show a clear commitment by addressing the expert areas and areas of contribution to the TC
    - iii. Publications
    - To list only those who make significant contributions to the work

7.2 Editor

The DE has carried out the following activities:

- Compile the Activity Report for 2009
- Edit the reports from:

R1-19	Heterochromatic Brightness Matching
TC1-27	Media Colour Appearance
TC1-44	Daylight Simulators
TC1-56	Colour Matching
TC1-58	Mesopic Photometry

7.3 Secretary

The main actions of the DS since the last meeting were as follows:

- Produce and distribute the Minutes of 2008 Stockholm meeting.
- Contribute to and distribute the 2009 Activity Report.
- Set up ballots for the 2009 meeting place and a new TC.
- Set up the 2009 Budapest Division meeting.
- Send/receive approximately 940 emails!

8. TECHNICAL COMMITTEE REPORTS

8.1 Vision: Miyoshi Ayama

TC1-36 Fundamental Chromaticity Diagram with Physiologically Significant Axes: Françoise Viénot FR

Part 1 of a TR has been published as CIE Publication 170-1:2006.

Part 2 of this TR is being prepared as CIE publication 170-2, which will contain the following chapters:

Ch. 6. Photometric aspects: the choice of the spectral luminous efficiency functions $V_F(\lambda)$ and $V_{F,10}(\lambda)$ is currently being circulated to TC members for approval with a response expected by the end of June 2009.

$V_F(\lambda)$ is modelled:

§ with the CIE L- and M-cone fundamentals, optimally weighted to fit experimental data,

§ with the lens and macular pigment optical density of the CIE fundamental observer.

Ch.7. Development of 2-dimensional chromaticity diagrams (*x*, *y*) and (*l*, *s*) which will use a method proposed in J.H.Wold, A.Valberg, General Method for Deriving an XYZ Tristimulus Space Exemplified by Use of the Stiles-Burch 1955 2° Color Matching Data, *J. Opt. Soc. Am. A*, Vol.16, No.12, p.2845, December 1999.

Ch.8. Conclusions and recommendations

Ch.9. Tables of data

TC1-37 Supplementary system of Photometry: Ken Sagawa JP

A draft TR was prepared after the Stockholm Division meeting and circulated to members. From comments received a second draft will soon be available for circulation. The final draft should be available by the end of 2009.

TC1-41 Extension of VM(λ) Beyond 830nm: Pieter Walraven NL

Work on this subject will commence when Chapter 6 in Part 2 of the TC1-36 report has been approved.

TC1-42 Colour Appearance in Peripheral Vision: Miyoshi Ayama JP

The text of the 1st draft of a TR is almost complete; only the figures and the formatting are required.

TC1-54 Age-Related Change in Visual Response: Ken Sagawa JP

The CIE Guidelines for Accessibility, which contain vision data and design guidelines for better visibility and lighting for older persons and persons with disabilities, is now in the final stage of publication. Once published the data that contributed to these Guidelines will be documented by this TC.

TC1-58 Visual Performance in the Mesopic range: Liisa Halonen FL

The sixth draft of a TR has been distributed to TC members and there were two negative votes. A private meeting was held in Budapest to resolve this situation and work will now progress to produce a seventh draft. After TC approval, the TR will then progress to Division and BA ballot.

TC1-60 Contrast Sensitivity Function for Detection and Discrimination: Eugene Martinez-Uriegas ES

No report. The DD will contact the TCC with a deadline for a 1st draft of a Technical Report.

TC1-67 The Effects of Dynamic and Stereo Visual Images on Human Health: Hiroyasu Ujike JP

The final draft of the TR on PSS (PhotoSensitive Seizures) will be circulated to members after discussion at the 4th meeting of the TC in Utrecht, Netherlands, later in June 2009. This meeting coincides with the 2nd International Symposium on Visual Imaging Safety. Work will then start on drafting the TR on VIMS (Visually Induced Motion Sickness).

R1-19 Specification on Individual Variation in Heterochromatic Brightness Matching: Hirohisa Yaguchi JP

The report has been edited and is now completed. It could be considered for publication in a CIE Collection.

R1-36 Action Spectra for Glare: Judith Fekete HU

No report. The DD will contact the reporter and request a final report by the end of October 2009.

R1-37 Definition of the Visual Field for Conspicuity: Nana Itoh JP

No report. The DD will contact the reporter and request a final report by the end of October 2009.

R1-40 Scene Dynamic Range: Jack Holm US
No report but the DD and DS had contacted the reporter who had indicated his willingness to continue this work. An earlier report is available in the 2009 Activity Report.

R1-43 Standard Deviate Observer: Boris Oicherman IL
No report. The DD will contact the reporter and request a short report by the end of October 2009.

R1-44 Limits of Normal Colour Vision: Sharon McFadden CA
A second report has been prepared based on a more extensive review of the literature. The review focuses on recent research on the relationship between colour deficiency and colour discrimination, colour matching and colour appearance, and on variability in these three aspects of normal colour vision. The report is attached to these Minutes. It was agreed to now close this Reportership: 16 in favour, 0 against with no abstentions.

The formation of a new TC is proposed in the above report.
Limits of Normal Colour Vision
Terms of Reference:
1. To document the correlation between performance on colour matching, colour discrimination, colour naming, and colour deficiency tests and factors such as variation in the peak spectral sensitivity of the M and L cones, density of the lens, density of macular pigment, variation in the optical density of the cones, L to M cone ratio, rod intrusion, illumination level, stimulus size, gender, stimulus duration and identify any substantive gaps in the existing literature.
2. Using the above database, develop a model or models that will allow the prediction of the effect of the above factors on colour discrimination, colour matching, and colour naming performance.

However, no chair was suggested, or forthcoming at the meeting. It was agreed therefore that the DD/DS will publicise the requirement for this work to be done.

Secretary's Note: Subsequent to the meeting, John Barbur from City University, London, has agreed to take on the Chairmanship of this TC.

8.2 Colour: Ellen Carter

TC1-27 Specification of Colour Appearance for Reflective Media and Self-Luminous Displays: Paula Alessi US
After receiving TC member and D1 Editor comments and approval, the final report has now been sent to the CB for Division and BA ballot. This completes the work of TC1-27 which will be disbanded when the report is finally published.

TC1-44 Practical Sources for Daylight Colorimetry: Robert Hirschler HU
The 3rd draft report has been discussed and edited. The 2nd draft has been reduced from 51 pages, 40 figures, 11 tables to 32 pages, 14 figures, 10 tables and includes the following sections:

- Daylight simulator technologies
- Daylight simulators for visual assessment
- Daylight simulators in colour measuring instruments
- Conclusions, recommendations
- *ANNEX.* Standard methods for the evaluation of daylight simulators (only giving references)

The report contains the following recommendations:

1. **Competing technologies**
   a. Colour matching booths
      - The current most widely used filtered tungsten + UV and fluorescent lamp technologies already produce acceptable daylight simulators for D50 and D65 (claimed also for D75).
      - Manufacturers are urged to exploit more fully the potential of filtered xenon short-arc lamps, because very high quality simulation would be achievable, and the SPD of the source in the booths may be more similar to that used in spectrophotometers.

   b. Spectrophotometers
      - For spectrophotometers there is very little ground to recommend any source other than the currently nearly exclusively used pulsed xenon lamps.

2. **Methods for the evaluation of daylight simulators**
   The formation of a new TC is recommended with the following Terms of Reference:
   a. to intercompare standard and other published methods for the evaluation of daylight simulators, with particular reference to the rendering of (UV or visible excited, white or coloured) fluorescent specimens, and select or develop a method considered adequate in all respects; and
   b. to develop standard methods for the adjustment and verification of the UV/visible balance in colour matching booths and in single-monochromator spectrophotometers.

3. **Recommendation of standard daylight sources**
      - The standardisation of any particular source (as “best representing daylight”) is not recommended.

The schedule for the 4th Draft is as follows:

- Ready to be sent for TC ballot: 30 June 2009
- Ballot to be closed: 15 September 2009
- Sent to CB/Division 1 for balloting: 30 September 2009

TC1-55 Uniform colour space for Industrial Colour-Difference Evaluation: Manuel Melgosa ES

The TCC presented a PowerPoint report of the recent activity of this TC which is attached to these minutes.

TC1-56 Improved Colour Matching functions: Michael Brill US

After receiving TC member and D1 Editor comments and approval, the final report has now been sent to the CB for Division and BA ballot. This completes the work of TC1-56 which will be disbanded when the report is finally published.

TC1-57 Standards in Colorimetry: Alan Robertson CA

The Standards being written by TC 1-57 will be parts of the S014 series as follows:

CIE S014-3 Colorimetry - Part 3: CIE Tristimulus Values
CIE S014-4 Colorimetry - Part 4: CIE 1976 L*a*b* Colour Space
CIE S014-5 Colorimetry - Part 5: CIE 1976 L*u*v* Colour Space
CIE S014-6 Colorimetry - Part 6: CIE DE2000 Colour Difference Formula

Part 4 (CIELAB) has been completed and is now published as ISO 11664-4: 2008(E)/CIE S 014-4/E: 2007: Colorimetry - Part 4: CIE 1976 L*a*b* colour space.

Part 3 (CIELUV) has been completed and is now published as CIE S 014-5 /E:2009

Colorimetry - Part 5: CIE 1976 L*u*v* Colour Space and u', v' Uniform Chromaticity Scale Diagram. It will now follow the ‘fast track’ process to become an ISO standard.

A fourth draft of Part 3 (Tristimulus values) has been through a three-month period for comments by liaison committees but no comments were received.
A TC ballot on the fourth draft is underway with a closing date of 14 June, 2009.
The standard method is summation from 360nm to 830 nm at 1 nm intervals using 1-nm bandwidth data. Certain abridged methods are permitted if it is demonstrated that the resulting errors are insignificant for the purpose of the user:

  Wavelength range 380 nm to 780 nm
  Colour-matching functions rounded to 4 significant figures
  Wavelength intervals of 1, 2, 3, 4 or 5 nm
  Non-integer wavelength intervals up to 5 nm with interpolated cmf’s or input data
  For all these abridgements, the bandpass should be matched with the wavelength interval or an integer multiple thereof. (Not critical for reflectance and transmittance measurements)

Abridged methods for wavelength intervals greater than 5 nm are not covered by this Standard pending the recommendations of TC 1-71.

The final work of the TC will be Part 6 (CIEDE2000). A first draft will be produced soon and will be based on CIE Publication 142:2001. It will refer to Sharma’s algorithm for computing h'bar and will include an informative annex on Nobbs’ method for lightness, chroma and hue splitting. (See report from R1-39 below.)

TC1-61 Categorical Colour Identification: Taiichiro Ishida JP
This TC last met in Stockholm in 2008 and the TCC apologies for not attending the D1 meeting in Budapest. The AD will write to the TCC requesting that he produce a first draft of a TR by the end of October 2009.

TC1-63 Validity of the Range of CIEDE2000: Klaus Richter DE
This TC met in Budapest as part of the Mid-Term Meeting. The report from the TCC is attached to the Minutes.

TC1-64 Terminology for Vision, Colour and Appearance: Sharon McFadden CA
The BA ballot for the ILV was issued in April 2009 and, in addition to the Division Director, the Chair of TC1-64 will review and vote on the ILV. To date, there has been only one response to the request to review additional terms for the next version of the ILV.

- Work plan
  - Review terminology in recent D1 technical reports
  - Collate feedback from TC1-64 members
- Issues
  - No information on overall plan for handling future updates to ILV
  - Additional members required for this TC

TC1-66 Indoor Daylight: Janos Schanda HU
CIE 184:2009 *Indoor daylight illuminants* has now been published and thus the work of this TC is complete. It was voted 16 in favour, 0 against and 0 abstentions to close the TC. The TCC was thanked for bringing this TC to a successful conclusion.

TC1-68 Effect of Stimulus Size on Colour Appearance: Peter Bodrogi HU
This TC met in Budapest as part of the Mid-Term meeting. It is preparing a TR which will cover the following:

- The viewing situations of different relevant applications:
  - outdoor building facades
  - indoor painted walls
  - large self-luminant displays
  - small and large colour patches on displays
- Describe and compare the trends of the colour appearance shifts for the different viewing conditions
- Describe and compare existing formulae

The concept of Equivalent Colour is introduced:

- A small, 2° size stimulus in a standard viewing condition that appears the same as the large stimulus
- To be used to quantify the appearance of a large (>20°, uniform or nearly uniform) stimulus
- CIECAM02 is designed for small-size *related colours* (1°-10°)
- The large stimulus can also be *unrelated* or the other stimuli are in the periphery of the field of view.
- A *model* of the colour size effect predicts the CIECAM02 *J*, *C*, *H* correlates of the *equivalent* colour as functions of similar correlates of the "*inherent*" colour of the large stimulus
- The *inherent* colour can be computed by CIECAM02 e.g. by replacing the large uniform stimulus with a 2° stimulus of the same tristimulus values and using an appropriate adopted reference white

The following work is noted:

- Xiao K, Luo RM, Hong G, Taylor C. Modelling Colour Stimulus for Different Sizes. Proceedings of AIC Color 05, Granada, Spain; 2005. pp 1067–1070.
- G. Kutas, P. Bodrogi, Color Appearance of a Large Homogenous Visual Field, *Color Res. Appl.* 33/1, pp. 45-54, 2008.
- Osvaldo da Pos, Annarita Rapanà, Alessandra Gliro, How Size Can Affect Colour Perception, Proc. AIC 2008, Stockholm, 2008.
- Karin Fridell Anter, What Colour is the Red House? Perceived Colour of Painted Facades. NCS Publication, 338p, 2000.
- Gombos, K, Schanda, J. Interrelationship Between Size and Brightness dimensions of appearance, CIE Expert Symposium on Visual Appearance, Paris, 19-20 October (2006).
- Masato Sato, Kazumi Nakayama, Kazuyuki Natori, A Study on the Area Effect for Wall Colours, J. Archit. Plann. Environ. Eng. , AIJ, No. 555, pp. 15-20, 2002.

TC1-69 Colour Rendering of White Light Sources: Wendy Davis US

This TC met in Budapest as part of the Mid-Term meeting. The past year has been dedicated to conducting experiments related to the development, testing, and validation of a new colour rendition metric.

The following papers or posters were presented at the Mid-Term Conference:

- Colour Rendering of LED Sources: Visual Experiment on Difference, Fidelity, and Preference, S. Jost-Boissard, M. Fontoynont, & J. Blanc-Gonnet
- Colour Rendering: an Object Based Approach, K. Smet, W.R. Ryckaert, G. Deconinck, & P. Hanselaer
- The Effect of LED Lighting on Performance, Appearance, and Sensations, F. Vienot, M-L. Durand, & E. Mahler (partly related to color rendering)
- Studies on the Effect of Illuminance on Color Rendering, W. Davis & Y. Ohno
- Re-defining the Colour Rendering Index, P. Bodrogi, S. Bruckner, & T.Q. Khanh
- How to Improve Visual Clarity?, K. Tóth, L. Balázs, K. Wenzel, B.V. Nagy, & G. Ábrahám
- Implications of Human Colour Constancy for the Lighting Industry, Y. Ling, P. Bodrogi, & T.Q. Khanh
- Colour Preference under Different Illuminants - New Approach of Light Source

Colour Quality, F. Szabó, P. Csuti, & J. Schanda

The following experiments & proposals were presented at TC meeting:

- Janos Schanda: discuss some items
- Osvaldo Da Pos: data on preference for light sources
- Françoise Viénot: summary of her proposals on CRI
- Yoshi Ohno: preference experiment on saturation of objects and skin
- Peter Bodrogi: new results and planned experiments
- Sophie Jost-Boissard: experiment on face complexion

The TC is asking for contributions of code and data by the end of 2009 and to decide on a new metric by mid February 2010.

TC1-70 Metameric Samples for Indoor Daylight Evaluation: Balázs Kranicz HU

This TC met in Budapest as part of the Mid-Term meeting. It was agreed that the new metamers be made available and that the Terms of Reference of the TC be changed such that a revision of CIE Publication 51.2 be produced.
Additional Term of Reference:

> To update CIE Publication 51.2 to cover metameric samples over the visible wavelength range 380 nm to 780 nm and add indoor daylight illuminants and associated metameric samples.

This revision was approved with 15 votes for, 0 against and 0 abstentions.

In addition, it was proposed that a new TC was needed:

Testing the CIE Method for Quantifying Daylight Simulators

Terms of Reference:

1. Test the validity of the CIE method (Publication 51.2) for quantifying daylight simulators with reference to white and coloured fluorescent specimens for illuminants D50, D55, D65, ID50 and ID65.
2. To recommend modification to the method if required.

No chairman however, was forthcoming for this work.

TC1-71 Tristimulus Integration: Changjun Li CN

- Claudio Oleari (IT) and Gerhard Roesler (DE) joined the TC.
- In 2000 Claudio Oleari published a method in Color Research & Application. The method was recommended by the members of the TC for comparison. Claudio Oleari joined the TC to help in further clarifying the computations of his method and he will help to make comparisons. Currently, based on his method, procedures for computing weighting tables are being developed.
- Gerhard Roesler is interested in the work of this TC and will provide light source data as required.

Currently, Draft 1 of a TR is being written which will be completed soon. The following methods are included for further comparisons:

- ASTM Table 5
- ASTM Table 6
- Venable method
- Optimum weights by Li, Luo and Rigg
- Least Square Weights by Wang, Li and Luo
- Direct Selection method
- ‘CIE-R’ method
- Oleari ‘s Local Power Expansion

Further discussions and actions must be taken before testing can start using 1 nm data:

- Mike Brill and Hugh Fairman provided 3534 reflectance spectra each defined between 360 nm and 780 nm at 10 nm intervals. The set includes Munsell, NCS and OSA-UCS data. They were in fact measured between 400 nm and 700 nm and the data at 360 nm, 370 nm, 380 nm and 390 nm put equal to the values at 400 nm. A similar method was applied to the upper end beyond 700 nm. These data can then be interpolated to 1nm data as standard. Possible drawbacks with this method are: a) the two ends are flat which seems not to be natural, and b) there is a possible bias in the interpolation method used.
- Janos Schanda also suggested using the SOCS data from ISO. The SOCS data set has about 53,000 reflectance spectra defined between 360 nm and 780 nm at 10 nm intervals. However, it seems that this set of data was also generated/ measured between 400 nm and 700 nm and then extrapolated to the range of 360 nm to 780 nm using the nearest available data point. Hence, the two ends are also flat for this dataset, and they also have to be interpolated to give 1 nm data.
- CIE has defined 1 nm SPDs for illuminant A and D65. For other illuminants /light sources, there is no 1nm data. For example, CIE (CIE Publication 15:2004) defined the F-illuminants at 5nm intervals. Is it allowable to interpolate them to 1 nm? Gerhand Roesler has provided measured 1 nm data for F2 and F11. What other F-illuminants should be used and from where is it possible to get the 1 nm data if interpolation is not to be used?
- Janos Schanda also suggested that HID and LED lamps should be used for testing as well. Now the question is what kind of HID and LED illuminants should be considered and where can their 1 nm SPDs be obtained?

TC1-72 Measurement of Appearance Network: MapNet: Mike Pointer GB
This TC met in Budapest as part of the Mid-Term meeting.

- Achievements 2007-2008:
  MApNet is established with 73 members on the mailing list
  Subject areas have been decided and Technical Leaders appointed
  A second Expert Symposium on Appearance is being discussed
  A database of relevant published work has been established by one network member: >1300 references
  Consideration being given to the establishment of separate Technical Committee.

- Achievements 2008-2009
  Major reports from Technical Leaders by year end – produced in parallel with the Division 1 Activity Report.
  The Second Expert Symposium on Appearance will be held at the Catholic University College St-Lieven, Gent, Belgium in 2010.

- Next Goals 2009-2010
  Establish an Organising Committee for the Second Symposium on Appearance
  Produce Activity Report for January 2010
  Continue to work towards establishment of Technical Committees on specific subjects

NB. This TC will be closed in 2011.

As a result of discussions in the TC meeting the following Reportership was proposed:

3D Aspects of Visual Appearance Measurement
Terms of Reference:

1. To review the activity of relevant organisations related to 3D vision, 3D image capture, 3D model storage and 3D display where these are relevant to visual

appearance issues
2. To establish a database of key research articles, technology and terminology related to 3D aspects of visual appearance
3. To establish an international panel of experts able and willing to advise on 3D matters
4. To liaise with other CIE divisions

Reporter: David Simmons GB

This was approved with 15 votes for, 0 against and 1 abstention.

TC1-73 Real Colour Gamut: Changjun Li CN

From last October, the Chair of this TC has been considering the selection of experts to invite to be members of this TC and real activity will start soon. Currently, the TC has the following members.

Maeng-Sub Cho KR	Michael Pointer GB
Jin-Seo Kim KR	Krisztián Samu HU
M Ronnier Luo GB	Pei-Li Sun TW
Jan Morovic ES	Francisco Miguel Martínez Verdú ES

TC1-74 Methods for Re-defining CIE D Illuminants: Janos Schanda HU

This TC held its inaugural meeting in Budapest as part of the Mid-Term meeting.

R1-32 Emotional Aspects of Colour: Gunilla Derefeldt SE

Gunila Derefeldt sent her apologies for not being able to attend the Division meeting and asked that someone else be found to continue the work.
It was agreed to shut this Reportership (13 votes for, 0 against and 1 abstention) and establish a new Reporter:

Colour Emotion and Harmony

Terms of Reference:
To review methods for relating the emotion and harmony responses to coloured stimuli with associated colorimetric measurement of those stimuli.
Reporter: Li-Chen Ou TW

This was approved with 14 votes for, 0 against and 0 abstentions.

R1-39 Alternative Forms of the CIEDE2000 Colour-Difference Equations: Mike Pointer GB

Since CIE S 014:6 on CIEDE2000 is proposing to include an informative annex on Nobbs' method for lightness, chroma and hue splitting, it was proposed that the work of this Reporter was completed and it should be closed: 14 votes for, 0 against, 0 abstentions.

A question was raised as to whether this method should be included in a revision of CIE Publication 15:2004. It was agreed that this, and other data, should be considered for future revisions and that a person be sought to chair a TC with suitable Terms of Reference.

R1-42 Extensions of CIECAM02: Changjun Li CN

This Reporter reported on the work of TC8-11 *CIECAM02 Mathematics* which had an open meeting during CIC16 (IS&T Color & Imaging Conference) in Portland, US, in November 2008. In this meeting the following were discussed:

- Are problems with CIECAM02 due to the model or ICC PCS?
- What is the domain of applicability of CIECAM02? Does it include D65, A, D50, D55, D75, D90, F1-F11, white LED, and a metal halide discharge lamp.
- What is the applicable range of the luminance level (La)? Can it be as high as 7000 cd m^{-2} and as low as 20 cd m^{-2}?
- Is the Q (brightness) prediction correct?

- Work by Michael Brill and Sabine Susstrunk published as ‘Repairing gamut problems in CIECAM02: A progress report’, Color Research & Application, Volume 33, Issue 6, Page 493, December 2008.
- Work by Li, Esther, Luo and Verdu submitted to Color Research & Application, 2009.
- Work by Graham Gill in the Proceedings of the 16th Color Imaging Conference, 2008: ‘A solution to CIECAM02 numerical and range issues.’

Following this report it was decided to modify the Terms of Reference of the Reporter to be:
To liaise with CIE Division 8 TC 8-11 CIECAM02 Mathematics

This was agreed with 13 votes for, 0 against and 1 abstention.

It was also proposed to set up a new TC:
A Comprehensive Model of Colour Appearance
Terms of Reference:
To derive colour appearance models that include prediction of the appearance of coloured stimuli viewed in typical laboratory conditions:
that appear as unrelated colours
that are viewed under illumination down to scotopic levels
that include consideration of varying size of stimulus
Chairman: M Ronnier Luo GB
Members: Changjun Li CN

This was agreed with 13 votes for, 0 against and 1 abstention.

R1-46 Whiteness: Joanne Zwinkels CA
A report is appended to these minutes that includes a recommendation to establish a TC:
Improvement of the CIE Whiteness and Tint Equations
Terms of Reference:
To recommend improvements or modifications to the existing CIE Equations for Whiteness and Tint to extend their scope of application to a wider range of instrument conditions and white materials; e.g. various tints and levels of fluorescence.
Chairman: Robert Hirschler HU
Members (possible): R Seve FR, S Rydefalk FL, B Jordan CA, M Brill US.

This was agreed with 14 votes for, 0 against and 0 abstentions.

It was also agreed to shut this reportership: 14 votes for, 0 against and 0 abstentions.

R1-47 Hue Angles of Elementary Colours: Thorstein Seim NO
A report is appended to these minutes that includes a recommendation to establish a TC:
Unique Hue Data
Terms of Reference:
To study and report on unique hue data, including an analysis of the scatter of those data: this to include practical viewing conditions.
Chairman: Sophie Wuerger GB?

This was agreed with 10 votes for, 0 against and 3 abstentions.

It was also agreed to shut this reportership: 14 votes for, 0 against and 0 abstentions.

A presentation was given by Kaida Xiao on work carried out at the University of Liverpool in the UK entitled “Unique hues: observer variability and age dependency.” This presentation is attached to these Minutes.

An additional proposal from ISO/IEC JTC1/SC28 (Klaus Richter) to form a Reporter on CIE Lightness and CIE Chroma of Elementary Colours to investigate and recommend the definition of a model to define elementary colours was rejected: 4 votes for, 2 against and 8 abstentions.

There was a discussion on the use of the term of ‘elementary hue’ and it was agreed that in future the CIE term ‘unique hue’ would be used. It was further proposed that ISO adopt this term for future use.

Further recommendation concerning the application of the concept of unique hues to device characterisation will be referred to Division 8.

9. LIAISON REPORTS

9.1 L1-1 AIC: Paula Alessi

A report is attached to these Minutes.

9.2 L1-2 CCPR (Consultative Committee for Photometry and Radiometry): Michael Stock

No report.

9.3 L1-3 ISO/TC6/WG3: Paper, Board and Pulp – Optical Properties: Joanne Zwinkels CA

A PowerPoint report is attached to these Minutes.

9.4 L1-4 ISO/TC38/SC1: Textile: Colour Fastness & Measurement M Ronnier Luo

A report is attached to these Minutes.

9.5 L1-5 ISO/TC42: Photography: Jack Holm US

No report.

9.6 L1-6 ISO/TC130: Graphic Technology: Danny Rich US

A report is attached to these Minutes.

9.7 L1-7 ISO/IEC JTC1/SC28 Office Equipment: Klaus Richter DE

A report is attached to these Minutes.

9.8 L1-9 International Association of Lighthouse Authorities: Ian Tutt GB

A report is attached to these Minutes.

9.9 L1-8 ISO/TC159/WG2 Ergonomics: Ken Sagawa JP

A report is attached to these Minutes.

10 NEW WORK ITEMS – in addition to those recorded above

The following were approved:

10.1 TC (V): Evaluation of Visual Performance in the Real Lit Environment

Terms of Reference:

To investigate and report on current research on visual performance that relates to psycho-physical and physiological measurements in the real lit environment, and to produce a plan for future work.

Chairman: Ingrid Vogels NL
Possible Members: Dragon Sekulovski, Steve Fotios, M Ronnier Luo, Monica Billger, Yoshiki Nakamura, AIST (representative)

The establishment of this TC was approved: 14 affirmative, 0 negative, 0 abstentions.

Secretary's Note: Subsequent to the meeting, Ingrid Vogels declined to take up the role of Chairman of this TC. Monica Billger, from Chalmers University of Technology, Göteburg, has now accepted to take on the role.

10.2 Reporter (V): Above-Threshold Pulsed Lights

Terms of Reference:
To review methods for photometric prediction of the brightness and color of supra-threshold pulsed signal lights
Reporter: Ian Tutt GB
This is a joint Report between D1, D2 and D4. Dennis Couzin will liaise with D2 and Ian Tutt with D4.

The establishment of this Reporter was approved: 14 affirmative, 0 negative, 0 abstentions.

11. NEXT MEETING

The management team of D1 are still investigating possible venues for the 2010 meeting of D1 and will try to provide information within the next three months.

Secretary's Note: Subsequent to the meeting, an invitation has been accepted to hold the next meeting at Princeton, New Jersey in the USA on 17-18 June 2010. The plan is as follows:

Monday 14 June	*ASTM (American Society for Testing and Materials)*
Tuesday 15 June	*Technical Committee E12 Color and Appearance*
Wednesday 16 June	*ISCC (Inter Society Color Council) Conference*
Thursday 17 June	*CIE D1 Technical Committees*

12. ANY OTHER BUSINESS

None.

CLOSE OF MEETING

The Director thanked everyone for attending, and the hosts for their organisation of the practical aspects of the meeting.

Dr Michael R Pointer
Secretary – CIE Division 1
August 2009

CIE DIVISION 1
VISION AND COLOUR

Second Meeting of the Luo Term

15 June 2009

AGENDA

	Opening Session
9:00 – 9:30	1. Opening and welcome by Director, Ronnier Luo
	2. Apologies for absence
	3. Membership
	4. Approval of agenda
	5. Approval of minutes of Stockholm meeting
	6. Matters arising from those minutes
	7. Report from the Director: Ronnier Luo
	8. Report from the Editor: John Setchell
	9. Report from the Secretary: Mike Pointer
	10. Country attendance
	Business Session
09:30 – 11:00	11. Report of the Vision Section: Miyoshi Ayama
11:00 – 13:00	12. Report of the Colour Section: Ellen Carter
13:00 – 14:00	Lunch break
14:00 – 14:45	13. Liaison reports
14:45 – 15:30	14. New work items
15:30 – 16:00	15. Any other business: Location of next meeting
16:00	16. Close of meeting

There will be a break for coffee/tea during the morning and afternoon sessions.

Mike Pointer
Division Secretary

Additional Attachments

TC1-55 Uniform Colour Spaces report

TC1-63 Validity of CIEDE2000 report

R1-44 Limits of Normal Colour Vision report

R1-46 Whiteness report

R1-47 Hue Angles of Elementary Colours report

Kaida Xiao (University of Liverpool) presentation

L1-1 AIC report

L1-3 ISO/TC6/WG3 Paper, Board and Pulp – Optical Properties report

L1-4 ISO/TC38/SC1: Textile: Colour Fastness & Measurement report

L1-6 ISO/TC130: Graphic Technology report

L1-7 ISO/IEC JTC1/SC28 Office Equipment report

L1-8 International Association of Lighthouse Authorities report

L1-9 ISO/TC159/WG2 Ergonomics report

TC1.55

Uniform Color Space for Industrial Color Difference Evaluation

- **Year Established:** 1999
- **Terms of Reference:**

To devise a new uniform color space for industrial color-difference evaluation using existing experimental data.

- **Chairman:** M Melgosa ES (since May 2005)
- **Members:** 21 people from 9 different countries

D Alman US
R Berns US
E Carter US
G Cui GB
M Fairchild US
R Kuehni US
M R Luo GB
J Nobbs GB
C Oleari IT
D Rich US
K Richter DE
B Rigg GB
A R Robertson CA
J Romero ES
G Rösler DE
R Shamey US
M Vik CZ
K Witt DE
J H Xin CN
H Yaguchi JP

- **Advisor:** R Huertas ES

Previous CIE TC 1-55 meetings:

Leeds (UK), June 2006.

Barcelona (SP), June 2008.

Contents

Relationship between ∆E and ∆V: STRESS

Color difference formulas proposed after ΔE_{00}

Existing experimental datasets

Future work

Measuring the relationship between ΔE and ΔV

P.A. García, R. Huertas, M. Melgosa, G. Cui. *JOSA A*, 2007

$$PF/3 = \frac{100[(\gamma - 1) + V_{AB}] + CV}{3}$$

$$STRESS = 100\left(\frac{\sum(\Delta V_i - F\Delta E_i)^2}{\sum \Delta V_i^2}\right)^{1/2}$$

0 ≤ *STRESS* ≤ 100 Ideal Value: *STRESS* = 0

STRESS allows to know whether two color-difference formulas are statistically significant with respect to a given set of visual data

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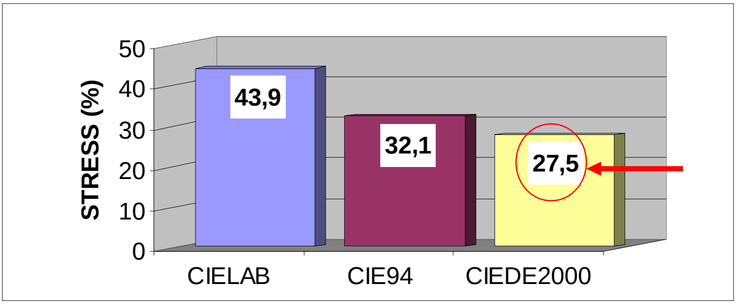
STRESS (%) for the 3 last CIE recommended formulas

(COM Weighted dataset: 11273 pairs)

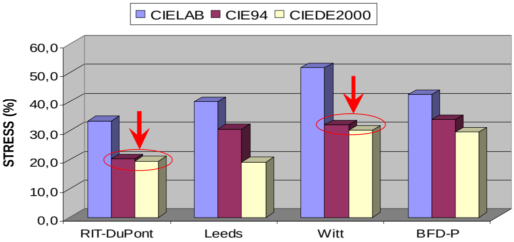
M. Melgosa, R. Huertas, R.S. Berns. *JOSA A*, 2008.



From CIELAB to CIE94 *STRESS* decreased **11.8** units.

From CIE94 to CIEDE2000 *STRESS* decreased **4.6** units (2.5 times lower).

Revision of individual datasets in COM



Ø **There are discrepancies among the 4 individual datasets in COM**:

ü The RIT-DuPont dataset was wrongly used at ΔE_{00} development.

ü ΔE_{00} is not significantly better than ΔE_{94} for the RIT-DuPont and Witt data.

Revision of individual datasets in COM using a fuzzy analysis

S. Morillas, L. Gómez-Robledo, R. Huertas, M. Melgosa. Journal of Modern Optics. In press, 2009.

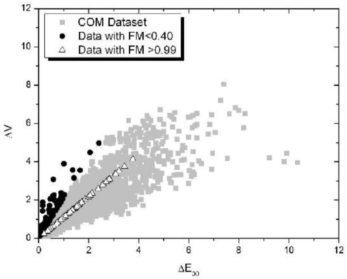


Figure 3: ΔV vs. ΔE_{00} for all data in COM. Data with lowest *FM* correspond to pairs with low colour difference for which its ΔV is overestimated. Data with highest *FM* values match with pairs of best linear correlation.

Pairs with $\Delta E_{00} < 1.5$ are particularly inconsistent within the COM dataset

ΔE_{00} has not an associated color space, and its complexity shows potential limitations of CIELAB

DIN99d [CR&A 27, 282-290, 2002]

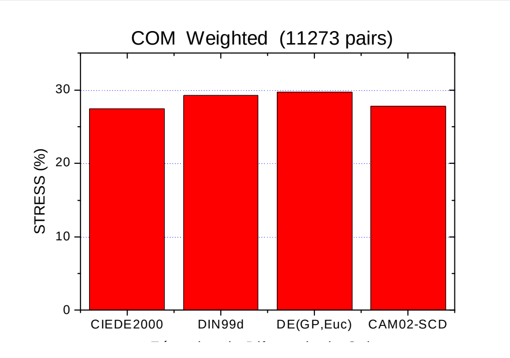
$$\Delta E_{99d} = \sqrt{(\Delta L_{99d})^2 + (\Delta a_{99d})^2 + (\Delta b_{99d})^2}$$

CAM02-SCD [CR&A 31, 320-330, 2006]

$$\Delta E_{CAM02-SCD} = \sqrt{(\Delta J')^2 + (\Delta a')^2 + (\Delta b')^2}$$

GP (Euclídea) [JOSA A 26, 121-134, 2009]

$$\Delta E_{GP,E} = \sqrt{(\Delta L_{OSA,E})^2 + (\Delta G_E)^2 + (\Delta J_E)^2}$$



STRESS results are very close to those of ΔE_{00}, but new formulas are simpler (Euclidean) and increasingly based on physiology.

A ~25% STRESS is an "unsatisfactory state of affairs" (R. Kuehni, CR&A, 2008), and new reliable experimental datasets are required.

R.S. Berns, Y. Zue "Optimizing color-difference equations and uniform color spaces for industrial tolerancing". Proc. AIC 2007, 24-28.

From RIT-DuPont and Quiao et al. dataset, four different CIECAM02 based formulas were proposed: Optimized, Optimized-Rotated, Euclidean, Euclidean-Rotated.

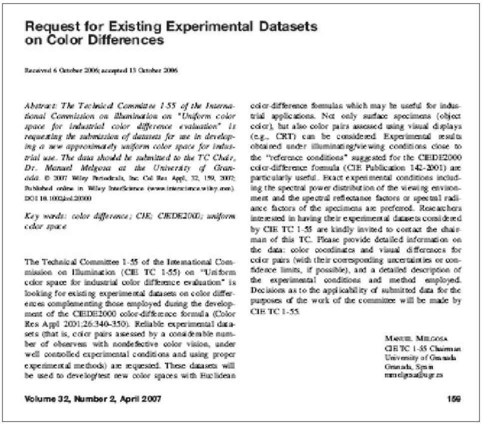
R.S. Berns "Generalized industrial color-difference space based on multi-stage color vision and line-element integration". Optica Pura y Aplicada, 41, 301-311 (2008).

From RIT-DuPont and Quiao et al. dataset, multi-stage color vision models were developed: CIECAM02 chromatic adaptation + Transformation of *XYZ* to *LMS* + Non-linear transformation of *LMS* + Opponent signals + Chroma-dependency correction.

Best STRESS obtained 18.4 (against 19.5 for RIT-DuPont using CIEDE2000)

New reliable experimental data

M. Melgosa, CR&A 2007



Request for Existing Experimental Datasets on Color Differences

Received 6 October 2006; accepted 13 October 2006

Abstract: The Technical Committee 1-55 of the International Commission on Illumination on "Uniform color space for industrial color difference evaluation" is requesting the submission of datasets for use in developing a new approximately uniform color space for industrial use. The data should be submitted to the TC Chair, Dr. Manuel Melgosa at the University of Granada. © 2007 Wiley Periodicals, Inc. Col Res Appl, 32, 159, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/col.20300

Key words: color difference; CIE; CIEDE2000; uniform color space

The Technical Committee 1-55 of the International Commission on Illumination (CIE TC 1-55) on "Uniform color space for industrial color difference evaluation" is looking for existing experimental datasets on color differences complementing those employed during the development of the CIEDE2000 color-difference formula (Color Res Appl 2001;26:340-350). Reliable experimental datasets (that is, color pairs assessed by a considerable number of observers with nondefective color vision, under well controlled experimental conditions and using proper experimental methods) are requested. These datasets will be used to develop/test new color spaces with Euclidean color-difference formulas which may be useful for industrial applications. Not only surface specimens (object color), but also color pairs assessed using visual displays (e.g., CRT) can be considered. Experimental results obtained under illuminating/viewing conditions close to the "reference conditions" suggested for the CIEDE2000 color-difference formula (CIE Publication 142-2001) are particularly useful. Exact experimental conditions including the spectral power distribution of the viewing environment and the spectral reflectance factors or spectral radiance factors of the specimens are preferred. Researchers interested in having their experimental datasets considered by CIE TC 1-55 are kindly invited to contact the chairman of this TC. Please provide detailed information on the data: color coordinates and visual differences for color pairs (with their corresponding uncertainties or confidence limits, if possible), and a detailed description of the experimental conditions and method employed. Decisions as to the applicability of submitted data for the purposes of the work of the committee will be made by CIE TC 1-55.

Manuel Melgosa
CIE TC 1-55 Chairman
University of Granada
Granada, Spain
mmelgosa@ugr.es

Other experimental datasets

ü **Y Qiao et al. data**, CR&A 23, 302-313 (1998). An extension of the RIT-DuPont research used to develop the “T function” approved in CIEDE000. Printed samples. 39 color centres, 45 observers. Anchor pair method.

ü **Leeds CRT data**, CR&A 26, 394-402 and 403-412 (2001). 134 pairs of colors for each phase (16 in total), around 5 CIE centres. 10-20 observers. Gray scale method.

ü **LCAM data** (M. Vik, Czech Republic, 2004). 284 textile pairs around 9 centers, 87 observers (5 replications). Gray scale method.

ü **NCSU data** (R. Shamey et al., CGIV, 2008). 66 textile pairs around just 1 blue centre. 26 observers. Gray scale. Work in progress.

ü **Wang & Xu CRT data**, JOSA A 25, 2908-2917 (2008). Lightness, chroma and hue tolerances for anchor pair with 3.06 CIELAB units. 180 pairs assessed by 8 observers (20 replications).

Future work

ü To use **STRESS** to test the color-difference formulas **CIEDE2000, DIN99d, CAM02, GP(Euclidea), Berns (2007-08),** using each one of the next 5 experimental datasets: **Y. Qiao et al. data (1998), Leeds CRT data (2001), LCAM data (2004), NCSU data (2006), Wang & Xu CRT data (2008).**

ü To start the proposal of a new color space for industrial color-difference evaluation, if statistically significant improvements upon CIEDE2000 were obtained.

Thank you very much for your attention !

CIE TC 1-63: Validity of the range of CIE DE2000

Year Established: 2003

Terms of reference:

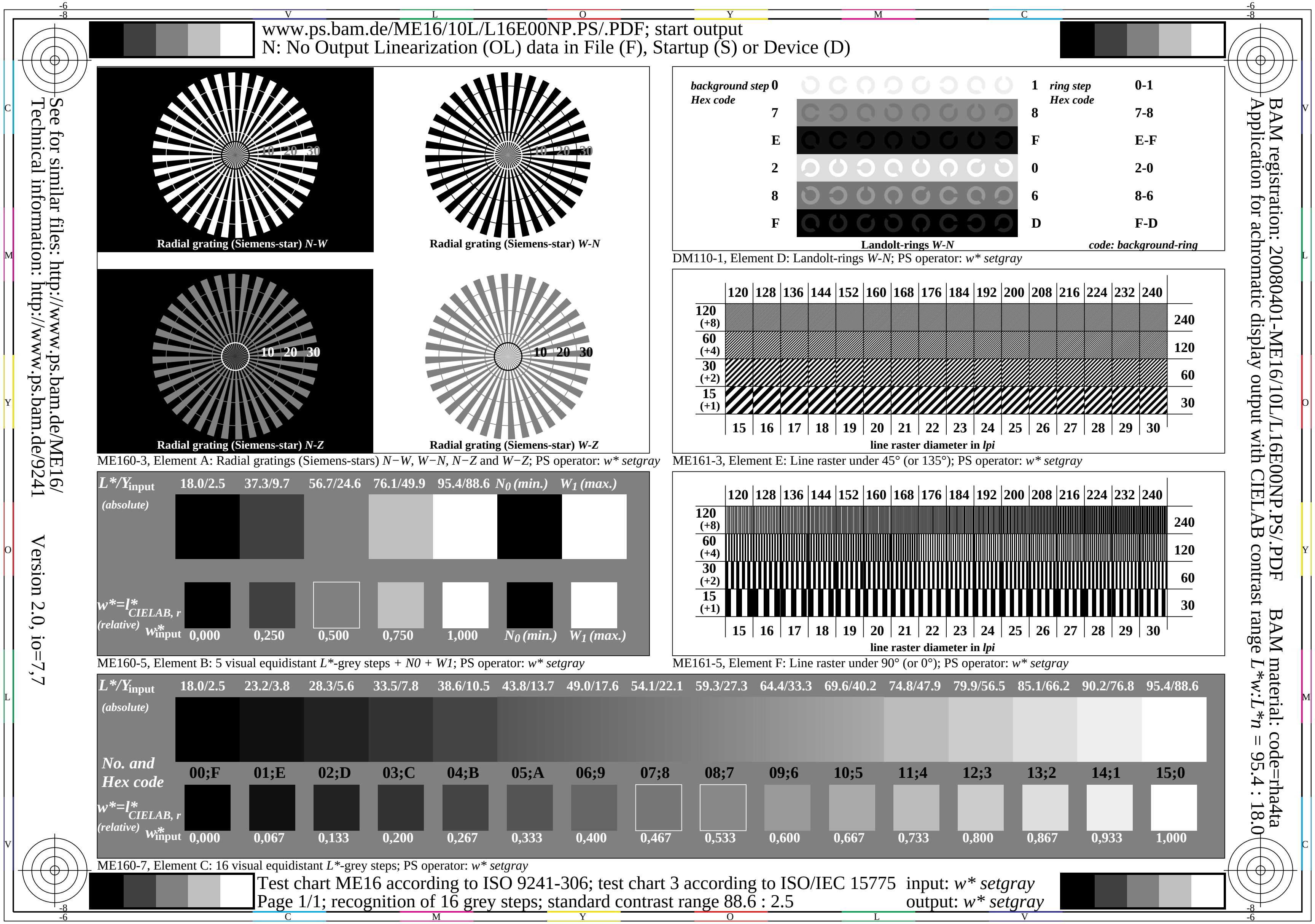
To investigate the application of the CIE DE2000 equation at threshold, up to CIELAB colour differences greater than 5

Chairman: Klaus Richter (DE)

Results of different countries for large colour differences:

At the moment only qualitative statements for the results of the four countries were given. For large colour differences $\Delta E^* > 10$ the correlation between visual results and CIELAB is better compared to CIEDE2000 according to 3 countries (CZ, DE, ES). The results of GB have shown for large colour differences only a better performance for CIELAB, if the samples are divided in two groups with $10 < \Delta E^* < 40$ and $40 < \Delta E^* < 140$ and here with two different slopes.

There are publications of *Kittelmann* (2005), *Vik* (2007), *Melgosa* (2007, 2008) and *Luo* (2007) with the experimental results in the four countries DE, CZ, ES, and GB. The CIE TC1-63-test charts are now implemented in different standards, for example ISO/IEC 15775: 1999, ISO 9241-306:2008, DIN 33872-3, -4 and -6 (in print). One example for work places is shown in the following



www.ps.bam.de/ME16/10L/L16E00NP.PS/.PDF; start output
N: No Output Linearization (OL) data in File (F), Startup (S) or Device (D)

Radial grating (Siemens-star) *N-W*
Radial grating (Siemens-star) *W-N*
Radial grating (Siemens-star) *N-Z*
Radial grating (Siemens-star) *W-Z*

ME160-3, Element A: Radial gratings (Siemens-stars) *N−W*, *W−N*, *N−Z* and *W−Z*; PS operator: *w* setgray*

background step *Hex code*	*ring step* *Hex code*	*code: background-ring*
0	1	0-1
7	8	7-8
E	F	E-F
2	0	2-0
8	6	8-6
F	D	F-D

Landolt-rings *W-N*

DM110-1, Element D: Landolt-rings *W-N*; PS operator: *w* setgray*

ME161-3, Element E: Line raster under 45° (or 135°); PS operator: *w* setgray*

ME161-5, Element F: Line raster under 90° (or 0°); PS operator: *w* setgray*

L/Y*input (absolute)	18.0/2.5	37.3/9.7	56.7/24.6	76.1/49.9	95.4/88.6	*N0 (min.)*	*W1 (max.)*
w=l**CIELAB, r (relative) *w**input	0,000	0,250	0,500	0,750	1,000	*N0 (min.)*	*W1 (max.)*

ME160-5, Element B: 5 visual equidistant *L**-grey steps + *N0* + *W1*; PS operator: *w* setgray*

L/Y*input (absolute)	18.0/2.5	23.2/3.8	28.3/5.6	33.5/7.8	38.6/10.5	43.8/13.7	49.0/17.6	54.1/22.1	59.3/27.3	64.4/33.3	69.6/40.2	74.8/47.9	79.9/56.5	85.1/66.2	90.2/76.8	95.4/88.6
No. and Hex code	00;F	01;E	02;D	03;C	04;B	05;A	06;9	07;8	08;7	09;6	10;5	11;4	12;3	13;2	14;1	15;0
w=l**CIELAB, r (relative) *w**input	0,000	0,067	0,133	0,200	0,267	0,333	0,400	0,467	0,533	0,600	0,667	0,733	0,800	0,867	0,933	1,000

ME160-7, Element C: 16 visual equidistant *L**-grey steps; PS operator: *w* setgray*

Test chart ME16 according to ISO 9241-306; test chart 3 according to ISO/IEC 15775 input: *w* setgray*
Page 1/1; recognition of 16 grey steps; standard contrast range 88.6 : 2.5 output: *w* setgray*

See for similar files: http://www.ps.bam.de/ME16/
Technical information: http://www.ps.bam.de/9241
Version 2.0, io=7,7

BAM registration: 20080401-ME16/10L/L16E00NP.PS/.PDF BAM material: code=rha4ta
Application for achromatic display output with CIELAB contrast range *L*w:L*n* = 95.4 : 18.0

Test chart of ISO 9241-306:2008 for display output, see
http://www.ps.bam.de/ME16/10L/L16E00NP.PDF

According to the terms of reference, TC1-63 should investigate the application of the CIE DE2000 equation at **threshold**, up to CIELAB colour differences greater than 5.

Therefore new experiments at threshold have been started four years ago. Many more experimental results at threshold from *P. Kittelmann* may be available before the end of 2009 as function of many parameters, for example field size, and sample distance.

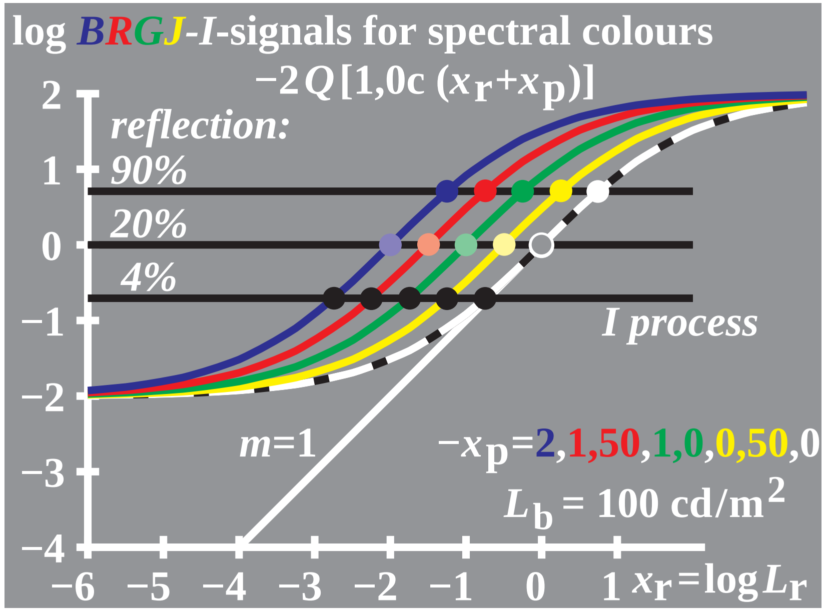
The preliminary result at threshold is the following:

Both standard CIELAB and CIE DE2000 fail to describe the threshold data in agreement to the results of *Melgosa* (2007).

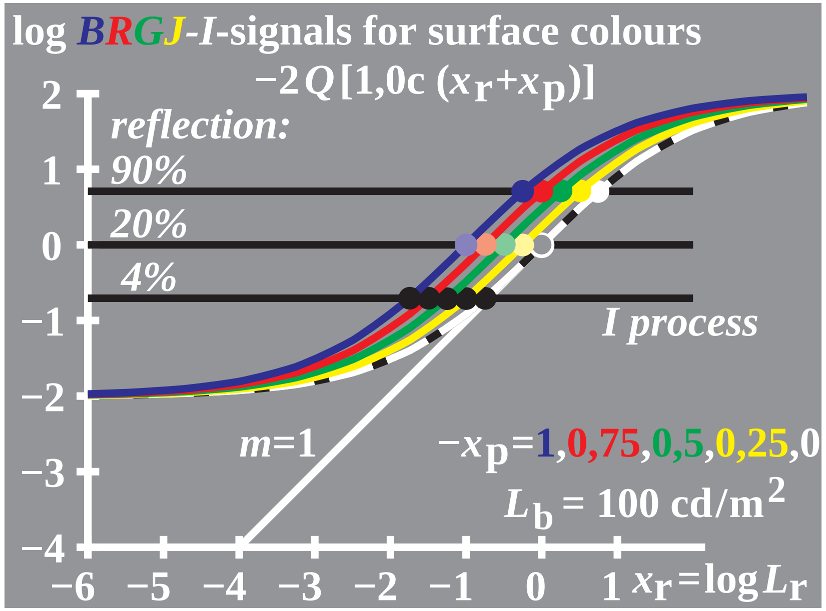
A new model based on physiology may explain the problems.

According to the physiological processes measured by *Valberg* (2005) there are three response processes in the retina:

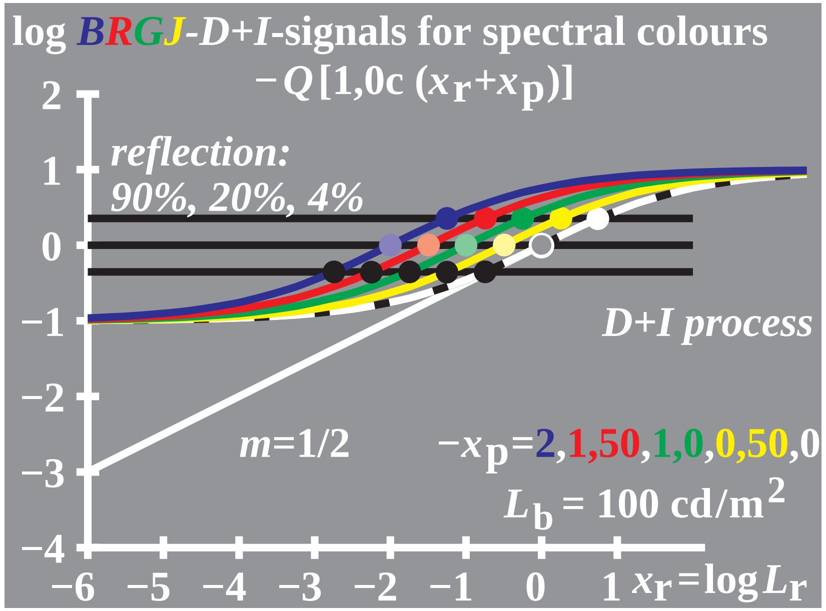
Increment *I*
Decrement *D*
Sum *D+I*
The increment responses *I* correspond to the *Weber-Fechner* law
The sum responses *I+D* correspond to the *Stevens* law


log BRGJ-I-signals for spectral colours

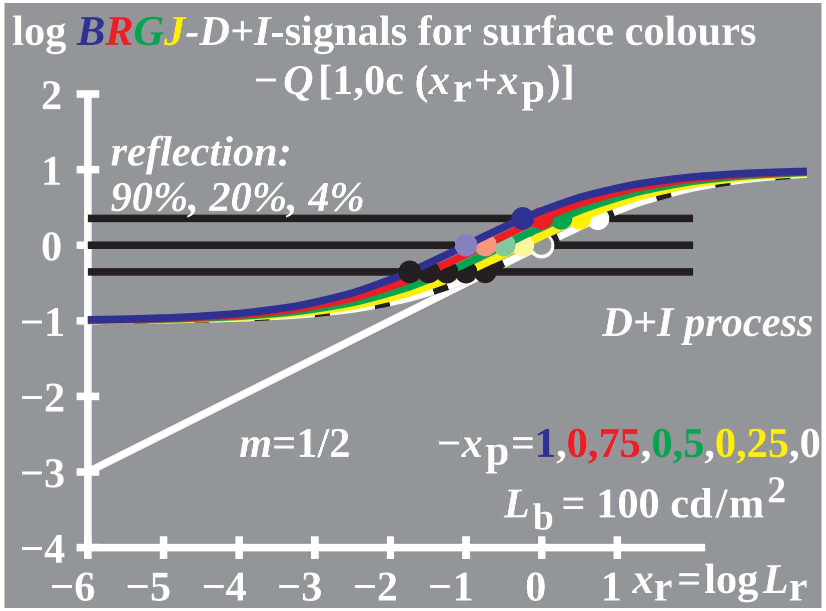
ZE171−1


log BRGJ-I-signals for surface colours

ZE171−2

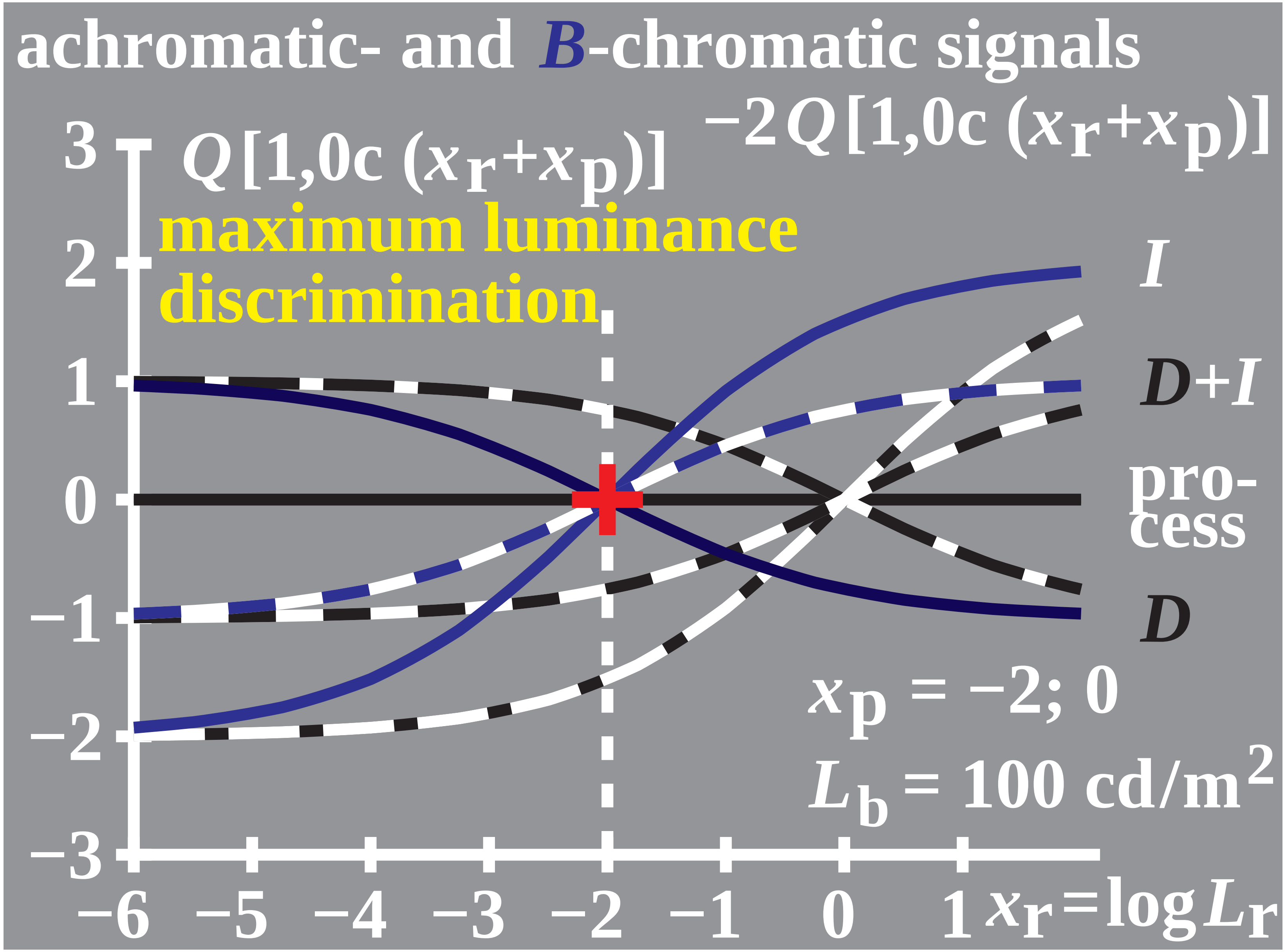

log BRGJ-D+I-signals for spectral colours

ZE171−3


log BRGJ-D+I-signals for surface colours

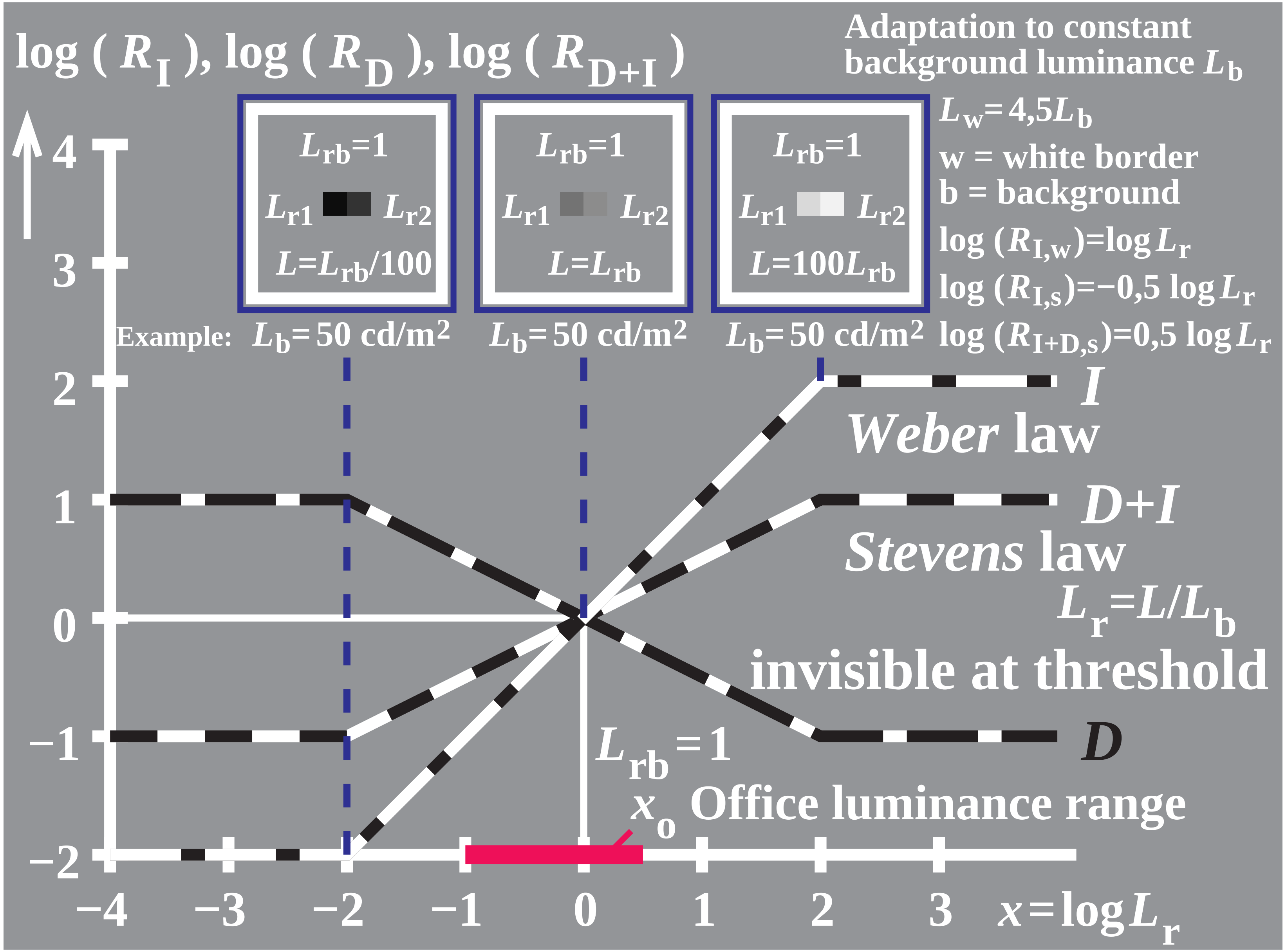
ZE171−4

Colour Responses; physiological processes Increment *I*, Decrement *D*, and *D*+*I*



ZE170−7

Model achromatic and blue responses: Increment *I*, Decrement *D*, and sum *D*+*I*



ZE290−31

Model for *Weber-Fechner-* and *Stevens*-law with processes *I, D,* and *D+I*

Linear threshold metric for complementary optimal colours based on the cone tristimulus values *LMS* of CIE 170-1.

It is appropriate to use the CIE cone tristimulus values *LMS* to describe the threshold.

However, we use the symbols *PDT* (for Protanopic, Deuteranopic and Trintanopic vision) here instead of *LMS* to avoid confusion with Luminance *L*, colourfulness *M* and the spectral power distribution $S(\lambda)$. At least we need the Luminance *L* and $S(\lambda)$ in the following.

$$\Delta E^*_{\mathrm{PDT,b}} = \mathrm{const}\ \{\ [\ (\Delta P_{01b}\ )\ /\ P_{01b}\ ]^2 + [\ (\Delta D_{01b}\ )\ /\ D_{01b}\ ]^2 + [\ (\Delta T_{01b}\ )\ /\ T_{01b}\ ]^2\ \}^{1/2} \qquad (1)$$

$$\Delta E^*_{\mathrm{PDT,c}} = \mathrm{const}\ \{\ [\ (\Delta P_{01c}\ )\ /\ P_{01c}\ ]^2 + [\ (\Delta D_{01c}\ )\ /\ D_{01c}\ ]^2 + [\ (\Delta T_{01c}\ )\ /\ T_{01c}\ ]^2\ \}^{1/2} \qquad (2)$$

The indices b and c are used for the basic and complementary colours. For the basic and the complementary colour and any source with the spectral power $S(\lambda)$ and the standard normalisation $\Sigma\, p(\lambda)\ S(\lambda) = 1$ it is valid

$$P_{01b} = \ \Sigma\, p(\lambda)\ r_{\mathrm{b}}(\lambda)\ S(\lambda) \qquad (3)$$

$$P_{01c} = \ \Sigma\, p(\lambda)\ [\ 1 - r_{\mathrm{b}}(\lambda)]\ S(\lambda) = 1 - P_{01b} \qquad (4)$$

According to the *Weber-Fechner* law it is valid for *any* tristimulus value *Y* at any Luminance *L*

$$\Delta Y_{01b}\ /\ Y_{01b} = \ \Delta Y_{01c}\ /\ Y_{01c} = \ \mathrm{const} \sim\ 1/100 \qquad (5)$$

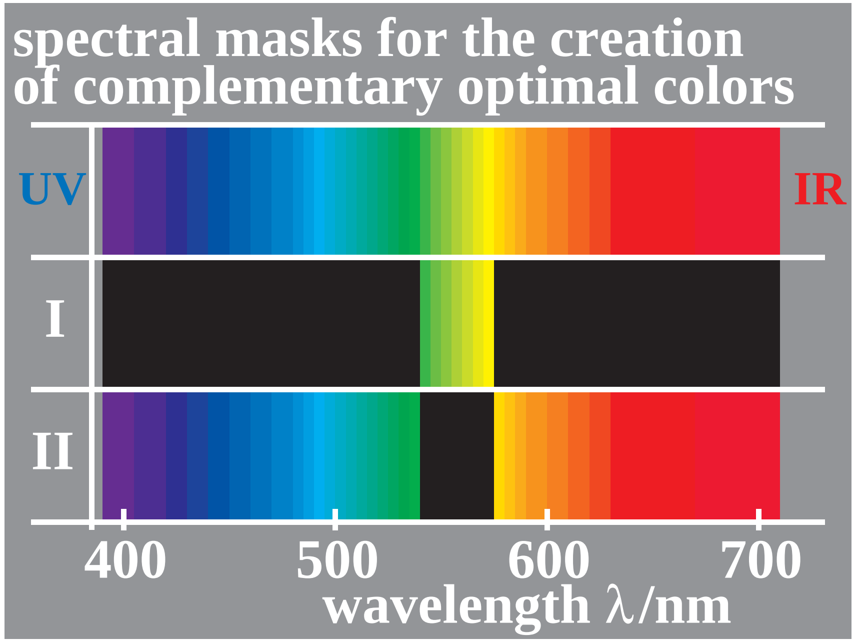
Therefore we can expect

$$\Delta P_{01b}\ /\ P_{01b} = \ \Delta P_{01c}\ /\ P_{01c} = \ \mathrm{const} \sim\ 1/100 \qquad (6)$$

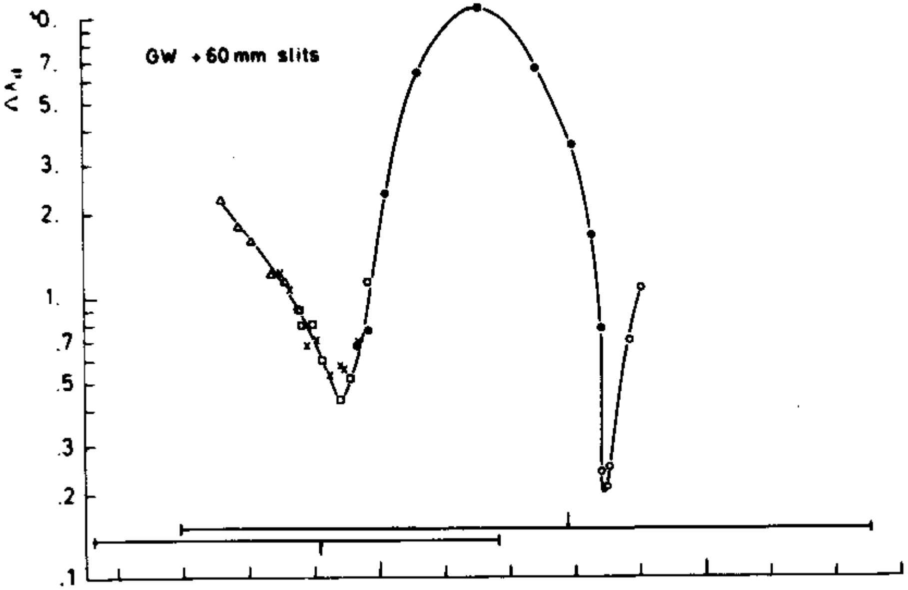
and similar for *D* and *T.* Therefore for any basic and complementary colour the threshold is ***equa***l

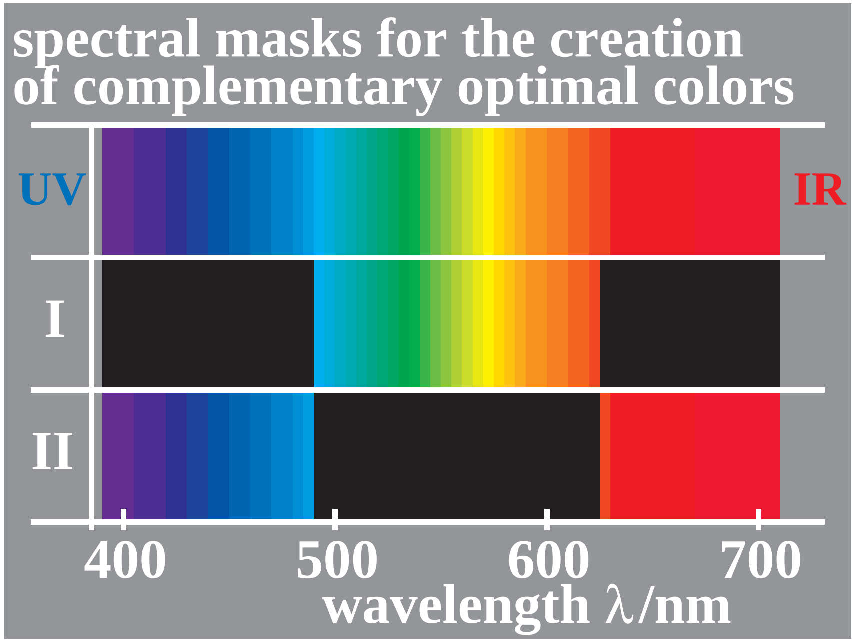
$$\Delta E^*_{\mathrm{PDT,b}}\ = \Delta E^*_{\mathrm{PDT,c}} = \ \mathrm{const} \sim\ 1/100 \qquad (7)$$

Complementary optimal colours and threshold Experiments and equation result:

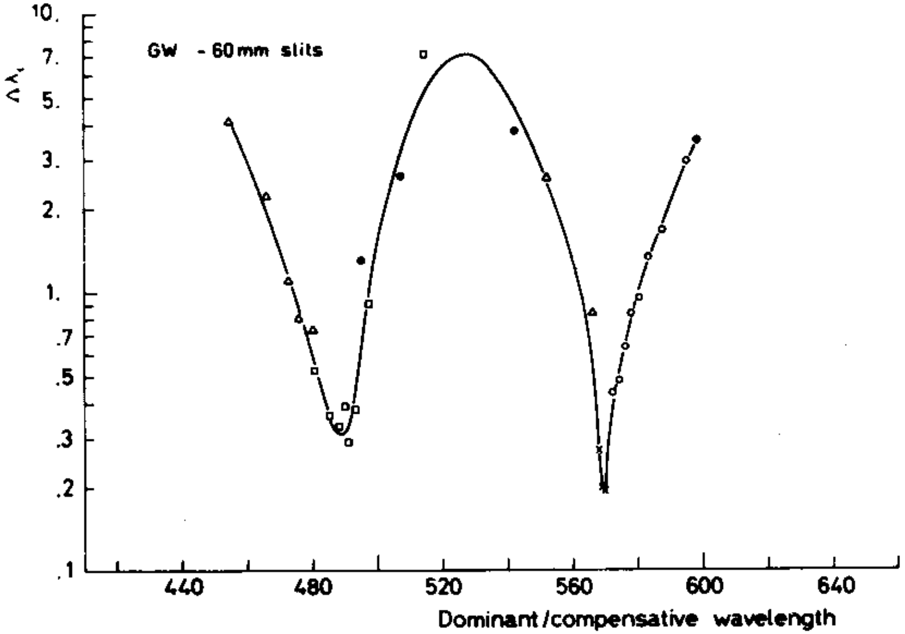


M8250−1N





M8250−2N



Experimental result:
The threshold is equal for complementary optimal colours

Experimental verification, see *Holtsmark, T. and Valberg, A.* (1969), Colour discrimination and hue, Nature, Volume 224, October 25, S. 366-367

Summary

With the *physiological processes Increment I*, *Decrement D* and the *sum D+I* the door seems open to describe threshold data.

A smooth change is now possible to combine the ***Weber-Fechner*** and the ***Stevens*** law for colour differences at the three ranges: threshold, CIELAB range 1 to 5, and larger.

Equations based on cone sensitivities seem to describe the equal threshold for complementary optimal colours. This experimental result has been published by *Holtsmark and Valberg* (1969).

Second Report for R1-44: Limits of Normal Colour Vision

Reporter: S. McFadden (CA)

Terms of Reference: To review the literature to see what information is available to establish the limits of normal colour vision.

Introduction

As stated in last years report, the impetus for this Reportership was a paper presented by Barbur, Rodriguez-Carmona, and Harlow [1] at the ISCC/CIE Expert Symposium on 75 Years of the CIE Standard Colorimetric Observer. The paper documented their efforts to establish a better test for assessing colour deficiency based on the "the statistical limits of colour discrimination in 'normal' trichromats". Thus, the goal of a TC arising out of this Reportership would not be to recommend the most suitable colour vision tests, but would be to link the assessment of colour deficiency to the measurement of normal colour vision. Hopefully this would lead to not only improved assessment of the severity of colour vision loss, but also better characterization of normal colour vision capabilities.

Last years report focused on the suitability of existing and proposed tests for assessing the limits of normal colour matching, colour discrimination and colour appearance. It concluded that the current tests and standards are inadequate for reliably and consistently describing the limits of normal colour vision because very little of the research to date appears to:

- systematically evaluate the colour matching, colour discrimination or colour naming performance of a wide range of colour deficient individuals;
- systematically measure the performance of a large number of colour normal individuals on tests of colour deficiency; or
- integrate the data from studies of colour discrimination etc. with the data from studies of colour deficiency.

Results of review

As a result of a more detailed review of the literature, it does appear that the colour matching and colour discrimination performance of a wide range of colour deficient individuals has been evaluated (e.g.[2-5]). The limitation with most of these studies is that the characterization of colour deficient versus colour normal is based on the results of clinical tests of colour vision capability. Since these tests can fail colour normals and pass the minimally colour deficient, a battery of colour vision tests are often used to ensure that all the people assessed can be characterized as colour deficient according to the categories outlined in the previous report. The unintended effect is that these studies probably fail to characterize the performance of people with minimal colour deficiencies. This possibility was pointed out by Wright [2] in his comprehensive review of the assessments of spectral sensitivity performance of people with a wide range of colour deficiencies. He noted that some people that perform normally on colour confusion tests will fail the lantern test because of reduced sensitivity to long wavelengths. These types of people would not have been included in the studies assessing the capabilities of people with abnormal colour vision that he reported. An additional problem is that many studies fail to report the criterion used on any given colour deficiency test or the conditions under which the test was performed. Consequently it is difficult to compare the populations used in different studies.

On the other hand, it does seem to be the case that there are relatively few studies that systematically measure the performance of a large number of colour normal individuals on tests of colour deficiency and then compare those results with their colour matching and colour discrimination performance. A recent study by Barbur, Rodriguez-Carmona, Harlow, Mancuso, Neitz, and Neitz [6] is somewhat of an exception. They compared the chromatic discrimination performance (using the CAD test) of 67 colour normals with their match point and range on the anomaloscope. They found no systematic relationship between the two measures. Unfortunately, there is no discussion of within subject variability on either of the tests. Other studies that may provide some data on the limits of human colour vision are those carried out on female carriers of a defective colour gene [4, 5, 7, 8]. These studies find that such females often perform within the normal range on colour deficiency tests, although they do make some errors, but they can perform differently on tests of vision capability. For example, a recent study [5], using a subjective colour dissimilarity task with women heterozygous for colour deficiency, found that they tended to have a distorted colour space. Although such studies are not a substitute for the evaluation of people with normal colour vision, including them in large scale studies does ensure a more heterogeneous test population.

In parallel with studies assessing the colour matching, colour discrimination and colour appearance performance of colour deficient observers, there have been many studies assessing the variability in the performance of colour normals on these types of tasks (e.g.[2, 9-12]). This variability is attributed to such factors as variation in the peak spectral sensitivity of the M and L cones, density of the lens, density of the macular pigment, variation in the optical density of the cones, and rod intrusion [11, 13]. As well, performance has been shown to vary as a function of stimulus size, illumination level [14], and gender [15]. Finally, the methodology (e.g. method of adjustment, ‘n’ alternative forced choice) may also affect the range of performance on any given measure of colour vision capability [16]. While the individual effect of each of these factors has been reasonably well studied, the cumulative effect or interaction amongst variables is less clear. Moreover, there appears to be little data on the extent to which these factors may affect performance on colour vision tests. Are a small number of errors on a colour confusion test, for example, due to genetics, physiology, methodology, sloppy test procedures or even motivation? Since details about how the colour vision tests were administered or even what criterion was used are often not provided in studies of normal variability in colour vision as well as studies of colour deficiency, it is difficult to answer this question.

Overall, my review of the two sets of literature leads me to the conclusion that that there is probably no absolute threshold for normal colour vision. This conclusion does not mean that it is not possible to define a threshold for any current or future test and to be able to reliably divide a given population into those that pass and those that fail. Moreover, to the extent that a subset of tests is assessing the same aspect of colour vision capability, they are likely to be correlated. The problem is in assessing whether a person, who is borderline on a particular test or passes some tests and fails others, is likely to perform poorly in colour vision sensitive tasks. It is this issue that seems to drive much of the continuing interest in colour vision testing and has led to the development of a wide range of occupational colour tests. The problem with that approach is that it leads to a proliferation of tests whose usefulness outside a specific industry is unknown. Moreover, the relevance of a test may change as the industry evolves. For example, does a colour vision test based on samples of cloth adequately assess the colour vision capability of people working on electronic displays? Some recent work by Webster et al. [10] suggests it may not. They found the variability in selection of unique hues both larger and different in form from what would be predicted for the subjects used by Stiles and Burch [17, 18]. They hypothesized that part of the difference could be due to the use of non-spectral lights in their study. Similarly, Oicherman, Luo, and Robertson [19] found that the impaired performance, in a metameric matching task, of two individuals with borderline colour deficiency, varied as a function of the type of display (CRT versus LCD) used.

An alternative to the development of industry specific tests is to define the limits of normal colour vision through a combination of systematic experimentation and modelling. The recent work by Barbur and his colleagues [6] is a good starting point. In that study, colour discrimination performance was collected on a wide range of individuals and compared with performance on the anomaloscope. In addition, they used modelling to predict the effect of optical density and separation of the L and M cones. However, discrimination is only one aspect of colour vision. As the study by Oicherman et al [19] showed, an individual who performs normally on colour confusion tests such as the

Ishihara colour plates and the Farnsworth 100 hue test, may fall outside the normal range on a colour matching task. In a related study [11], the same authors found that the variability in performance of their “colour normal” subjects was much larger than would be predicted by the Standard Deviate Observer. These finding suggests that there is a requirement to better define the limits of normal colour matching data. Similarly, research on the variability in perception of unique hues [10, 16] indicates that there is considerable variability in the perception of colour appearance by colour normals.

Defining the limits of normal colour vision would certainly seem to be within the mandate of CIE Division 1. It is related to the work in TC1-36 on the development of a fundamental chromaticity diagram with physiological axes, TC1-54 on age related changes of visual response, and TC1-61 on categorical colour identification among others. Moreover, it provides a different way of looking at the concept of a Standard Deviate Observer – a concept that has been heavily criticized as been unrepresentative of the real variation in colour matching. The extensive data available on the variability of colour normal and colour deficient vision suggests that the problem is not necessarily one of data collection, but of documenting the existing data and using it to develop models that would improving our understanding of the limits of colour vision and allow us to predict when performance on colour vision sensitive tasks are likely to be impacted. Such a task would seem to fall more within the expertise of colour scientists than ophthalmologists, but both disciplines should contribute to such an effort to ensure a useful outcome for all concerned.

Conclusion

At this point, I do not think there is any benefit in continuing R1-44. I believe that the review conducted to date clearly points to the need for a more systematic approach to assessing colour vision capability. Determining if this can be done using the current literature will require input from a broad range of experts conducting research in colour deficiency, colour discrimination, colour matching and colour appearance.

Recommendations

I would recommend that R1-44, be closed and Division 1 pursue the possibility of forming a Technical Committee.

If there is sufficient interest in setting up a Technical Committee to establish the limits of normal colour vision, I would propose the following Terms of Reference:

1) To document the correlation between performance on colour matching, colour discrimination, colour naming, and colour deficiency tests and factors such as variation in the peak spectral sensitivity of the M and L cones, density of the lens, density of macular pigment, variation in the optical density of the cones, L to M cone ratio, rod intrusion, illumination level, stimulus size, gender, stimulus duration and identify any substantive gaps in the existing literature.

2) Using the above database, develop a model or models that will allow the prediction of the effect of the above factors on colour discrimination, colour matching, and colour naming performance.

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R1-46
Evaluation of Whiteness

- **Year Established:** 2008
- **Reporter:** Joanne Zwinkels CA
- **Terms of Reference:**

  To review the current status of whiteness measurement and recommend future requirements.

CIE Method for Evaluation of Whiteness

D65/10° CIE whiteness and tint

$W_{10} = 800*(x_n – x) + 1700*(y_n – y)$

$T_{w,10} = 900*(x_{n,10} - x_{10}) – 650*(y_{n,10} – y_{10})$

Only applicable if:

$-3 < T < 3$

$40 < W_{10} < 5Y – 280$

“samples ...do no differ much in colour and fluorescence,.. measured on the same instrument at nearly the same time.”

CIE 15:2004

Background(1)

Whiteness Assessment of Paper Samples at the Vincinity of the Upper Whiteness Limit

L. Coppel, S. Lindberg, S. Rydefalk
STFI-Packforsk, Stockholm, Sweden

Proc. 26th CIE Session, Beijing, China, 4-11 July 2007: D1-D10, CIE 178:2007

ISO TC6/WG3 liaison report to D1 in June 2008

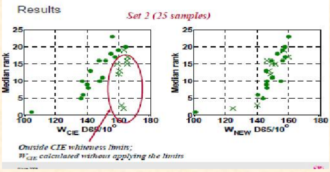
Highlighted problems with CIE Whiteness equation for highly fluorescent paper samples

- Recommended Reportership

Background (1) cont’d

FINDINGS by Swedish Researchers:

- Many commercial papers perceived as white fell outside the upper CIE whiteness limits
- Introduction of a penalty function replacing CIE whiteness limits – gave improved correlation



→ Not the first time such a proposal has been made

Proposed Solutions

Uchida, H. “A new whiteness formula”, *Color Res. Appl.*, 1998, **23**(4), 202-209.

- Non-linear whiteness formula; replace sharp limits with concave penalty function

Aksoy, B. Ph.D. Thesis 2004, Western Michigan Univ.

- Whiteness decays exponentially along a* and b* axes

Coppel, L, **Lyndberg**, S. and **Rydefalk**, S., in *Proceedings of CIE*, Beijing 2007.

- Similar to Uchida but use convex penalty function

Seve, R., in *Physique de la couleur*, Masson, Paris, 1996.

- Modification of hyperbolic formula by Ganz
- Modify tint limits – different for blue and yellow side of ref. illuminant

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Background (2)

Need for Whiteness Evaluation for different illumination conditions

ISO Standard 11476 Paper and board – Determination of whiteness for C/2° (indoor illumination conditions)

- assumed that the CIE Whiteness formulae can be applied to illuminant C conditions.

Question?

Is this valid for CIE illuminant C, D50, and for new CIE indoor daylight illuminant conditions?

Deficiencies of Current CIE Equation

- Poor correlation with visual rankings for FWAs with W~140 to 160 (near CIE limits).
- Strictly only applicable to CIE standard illuminant D65 conditions
- For the yellow side of white, $\lambda_{dominant}$ does not agree with the wavelengths given by the line T=0 (are in general much higher)
- The neutral reference is slightly too greenish.

Recommend: New TC

Terms of Reference:

To recommend improvements or modifications to the existing CIE Equations for Whiteness and Tint to extend their scope of application to a wider range of white materials, e.g. that differ significantly in tint and fluorescence, or contain high levels of FWAs.

Members (possible):

R Seve (FR), R Hirschler (HU), S Rydefalk (FL), B Jordan (CA)

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CIE Div 1, R1-47 Hue angles of Elementary Colours

By

Thorstein Seim

Thorstein.seim@c2i.net

Terms of reference:

To review the current literature on elementary (unique) hues for potential imaging applications.

Norway, May 24. 2009

A request for this reportership was presented at the 53rd meeting of ISO/TC159/ SC 4/ WG 2 "Visual display requirements" on 2007-05-19 to 22, Long Beach, CA, USA:

> Conclusion31/2007
> ISO TC159/SG4/WG2 "Visual Display Requirements" realizes that the colour spaces CIELAB and CIELUV of CIE Division 1 will soon become ISO/CIE standards. In applications we use these CIE colour spaces and device-dependent relative RGB colour spaces. For users of visual display systems a device-independent RGB colour space is useful. This produces via software the elementary hues Red, Green and Blue for the RGB data 100, 010 and 001 and equally spaced output in CIE colour spaces for equally spaced RGB input. We recommend that CIE Division 1 study the colorimetric definition of such a space, which can be used in visual display applications.
>
> Remark: We have realized that an example colour space of this type is published in CIE X030:2006, p. 139-144.

At the CIE meeting in Stockholm, june 2008, Div. 1 decided to establish a reportership in response to this request and to present the result at the next CIE meeting in Budapest 2009.

NOTE 1: The main topic of this report is to define the hue angles of elementary colours. The second question in the above request seems how to define *rgb* coordinates with the values 100, 010 and 001 for the elementary hue angles and for potential imaging applications.

1. Introduction

The concept of ”Elementary hues” is well understood by most people, and it is therefore surprising that these hues are not used more for calibration and control of imaging devices like colour printers and displays.

The purpose of this report is to establish the status of the understanding of the concept of elementary hues, as presented in the current literature, and to discuss how this understanding may be used to make practical suggestions of how to calibrate and control imaging devices.

A search in Google for “elementary hues” gave 3.7 million hits! However, the literature concerned with printing and displaying the elementary hues correctly is limited.

The main target of this study is to:

1. Review the literature on elementary hues.
   Here are some suggested research fields:

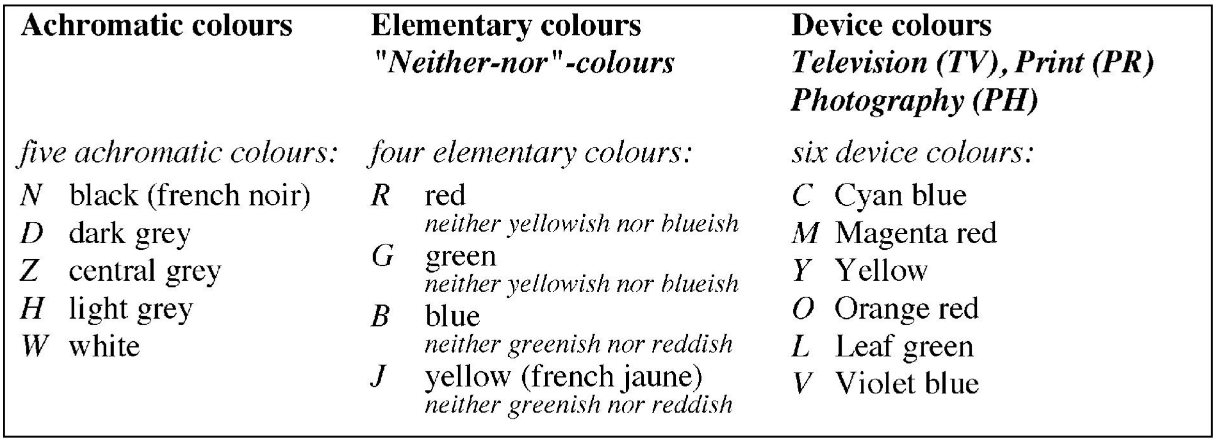
   1.1 How we perceive elementary hues. This has been studied in the field of perceptual psychology and psychophysics.
   1.2 Colour order systems: The presentation of (object) colours in an orderly fashion.
   1.3 Neuroscience: What we know of the cells in the visual pathway, from the retina to the brain.
   1.4 Modeling: Mathematical descriptions that explain visual perception, including the coding of elementary hues.
   1.5 The historical aspects of how our understanding has developed through time.

2. The use of elementary hues in imaging applications
   This task can be more precise defined as:
   2.1 To search for methods that uses the elementary hues in a device-independent way for imaging applications (i.e. in the control of the output of printers and displays).

NOTE 2: How colours are generated in the printing devices, cameras and displays is not considered here. Different printing techniques, like the use of offset rasters, ink-dots in ink-jets, pigment-powders in laser-printers and wax-based pigments in sublimation printers will all have their specific transfer functions to the created colour gamut. Displays also use different methods to produce colours. LDC displays use backlighting combined with colour-filters in the pixels, while displays with rotating micro-mirrors use colour wheels, often with more than 3 colours. Plasma displays have replaced the CRT display but works in a similar way. OLED displays uses tri-colour Light Emitting Diodes.

NOTE 3: All reproductions of colour have a limited gamut, compared to the human eye. Maximum obtainable device chroma varies with hue, and the luminance ranges are limited. Different methods are used to overcome these limitations. A method for calibrating by using the elementary hues should take these device dependent properties into account.

2. Elementary hues and device hues



Achromatic colours	**Elementary colours** ***"Neither-nor"-colours***	**Device colours** ***Television (TV), Print (PR)*** ***Photography (PH)***
five achromatic colours:	*four elementary colours:*	*six device colours:*
N black (french noir)	*R* red *neither yellowish nor blueish*	*C* Cyan blue
D dark grey	*G* green *neither yellowish nor blueish*	*M* Magenta red
Z central grey	*B* blue *neither greenish nor reddish*	*Y* Yellow
H light grey	*J* yellow (french jaune) *neither greenish nor reddish*	*O* Orange red
W white		*L* Leaf green
		V Violet blue

YE980–31

Table 1 shows the definition of elementary and device hues according to ISO/IEC 15775:1999.

2.1 Definition of elementary or unique hues

“Unique hues” was first described by Ewald Hering (1878). He proposed that any hue can be described by its redness or greenness and its blueness or yellowness. He defined red and green as opposite hues because they cannot be seen simultaneously. The same is true for blue and yellow. Based on this observation Hering postulated two colour-opponent channels, one coding for red/green and another coding blue/yellow. Unique hues then belong to hues which also may be called neither-nor hues, for example red, as neither yellowish nor bluish (See Table 1).

Today the perception of elementary hues is a well established concept, accepted by most people, independent of culture and language. (Saunders & van Brakel, 1997), and little influenced by age (Schefrin and Werner, 1990; Wuerger et. al. 2009; Wuerger, Fu, Xiao and Karatzas, 2009).

People with normal colour vision seem to be in no doubt about what we mean when we ask for an elementary hue, like unique red. Somehow we have a built-in understanding of what red is. When we are given a set of coloured samples and asked to select the red that is neither yellowish nor bluish, we normally find that the task is easy.

How people around the world select the elementary colours is shown in the “World Color Survey Database” (Cook et. al, 2005). Observers were asked to place the elementary hues in a chart consisting of 40x8=320 equally spaced Munsell chips. See figure 1a (Cook et. al, 2005. Figure1a).

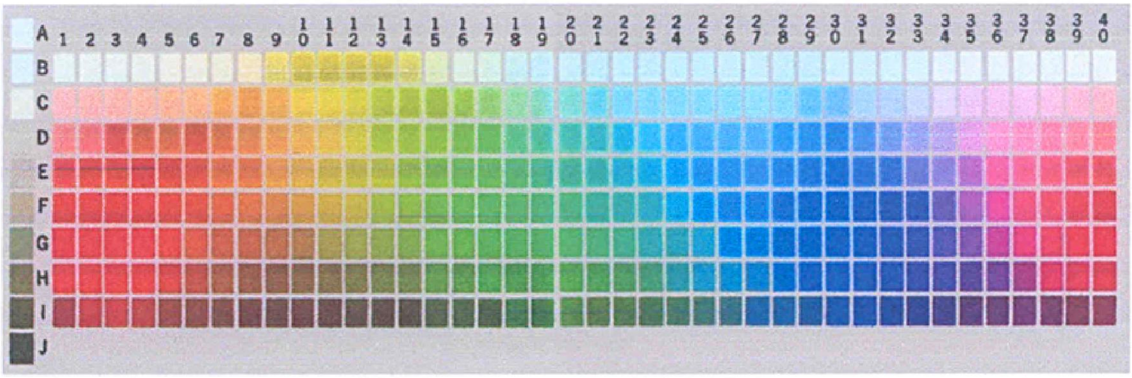


Figure 1a. The WCS stimulus array.

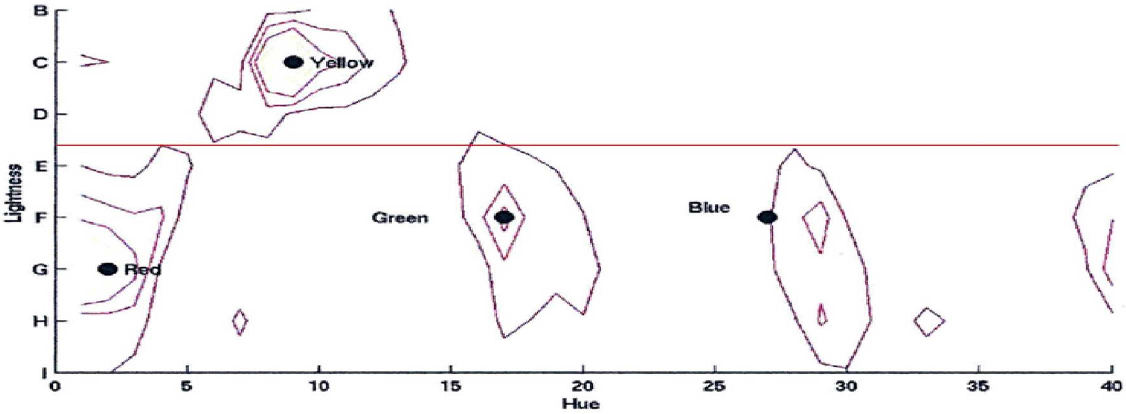


Figure 1a. Colour chart with 40x8=320 Munsell colours. From Cook et. al. (2005).

Figure 1b. Clustering of selected elementary colours.

The clustering of the “chromatic focus” peaks (e.g. the most typical elementary hues) is shown in figure 1b (Cook et. al, 2005, figure 5). The black dots are the averaged focal responses from an independent English study (Sturges and Whitfield 1995). These are found close to the Munsell hues 5R, 2.5Y, 2.5G and 7.5B. Only the last one (blue) deviates from the cluster-center at 2.5PB. The red line indicates a lightness that nearly none of the observers selected.

In the following we name the elementary hues Red *R*, Yellow *J* (for yellow in French: jaune), Green *G* and Blue *B*. *J* is used for yellow in order to avoid confusing it with

CIE luminance factor *Y* or the device hue *Y*. Hues lying between *R* and *J* will be referred to as *RJ*, between *B* and *G* as *BG*, and so on. In the *Natural Colour System NCS* 100 steps are used between two elementary hues. Therefore, for example *G*50*B* may be used for a hue angle in the middle between the hue angles of the elementary hue *G* and the elementary hue *B*.

2.2 Device colours

The hue of the device colours depends on the type of imaging device we look at. Up to six chromatic device colours might be used. These are listed in Table 1.

2.3 Different naming of the concept of elementary hues:

In Norway we say: "A much-loved child have many names". The same might be said for the concept of elementary hues. They have been called:

1. Chromatic elementary hues or colours
2. Unique hues
3. Primary hues or colours
4. Focal hues or colours
5. Urfarben
6. Psychologically pure hues or colours, or just pure hues or colours
7. Elementary colours
8. Simple colours
9. Basic colours
10. Perceptual universals

"Simple colours" has been used by *Leonardo da Vinci* and *Miesche*r (Miescher 1970).

The term elementary hues were chosen by the CIE for this reportership. It is used in the NCS system and there is an easy translation to any language.

2.4 Achromatic hues

Hering included blackness and whiteness as opponent perceptions (Hering, 1878). In the CIELAB colour space the origin of the (elementary) hue angles is the achromatic point in the *a*,b** plane. The preferred naming of achromatic colours is listed in Table 1.

NOTE 4: For real applications the measurement data differ usually up to 5 CIELAB in *a** and/or *b**, and independent for White *W* and Black *N*. Usually both colours are still accepted as achromatic.

3. Colour order systems and elementary hues

The selection of the elementary hues by CIE should, in addition to be based on newer data, also use the information contained in previously developed colour order systems.

3.1 The Munsell Renotation System

This system is based upon experiments where the observer scales colours uniformly (Newhall et. al. 1943). In the Munsell System the elementary hues are approximately placed at hue 5R, 5Y, 5G and 5PB (Richter 1996).

3.2 The elementary hue system of Karl *Miescher* (1948)

The Miescher System pre-dates the NCS. It presents the elementary hues R/G along the x-axis and Y/B along the orthogonal y-axis, making it a so called symmetrical hue circle. (K. Richter 1996). The 400 step colour circle of this system was produced by a special dye process to obtain a highly chromatic hue circle where the luminance of the samples varied, having dark blue colours and light yellow colours. Coordinates for the colour samples are given for Source C.

The position of the elementary hues in this highly chromatic hue circle was evaluated by a group of 24 observers. For R, Y and G any single observer, with normal colour vision, the positioning of the hues is given with a standard deviation of about 1% (about 4 degrees of 360 degrees). For the elementary blue the standard deviation was larger, about 2%.

3.3 The Natural Colour System NCS

This well-known Swedish system is based on the opponent theory of Ewald Hering (Hering 1878). The NCS system is based on experimentally defined elementary hues, having the four system axis aligned with the elementary hues. Achromatic colours are scaled according to their whiteness and blackness ratio along the z-axis.

NCS data are published in the Swedish Standard SS 01 91 02:2004. The development and use of this system is summarized by A. Hård, L. Sivik and G. Tonnquist (1996)

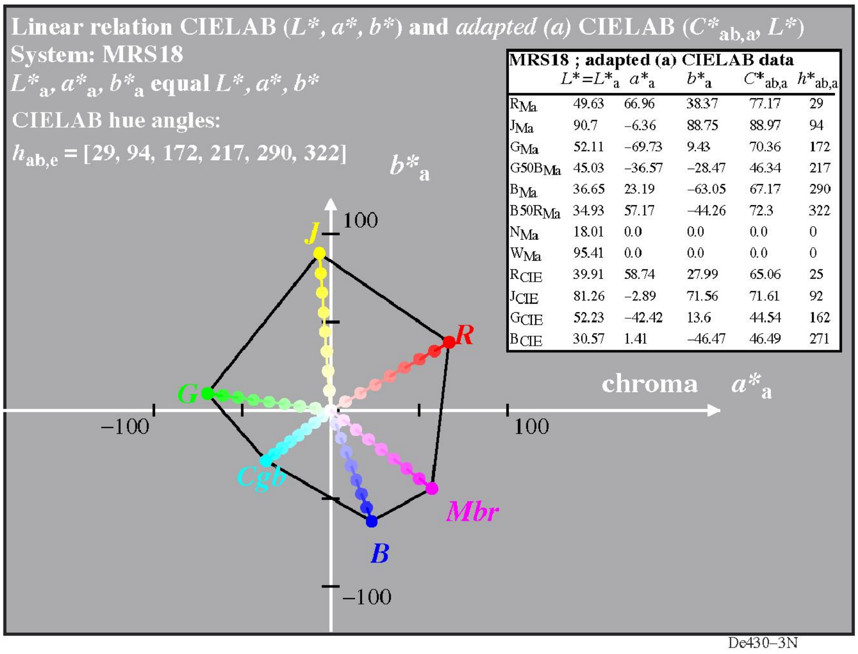
3.4 The four elementary colours selected by the CIE

The CIE has defined four highly chromatic colours as “typical” colours Red *R*, Yellow *J*, Green *G*, and Blue *B* for colour rendering purposes. The lightness of these “typical” colours is therefore high for Yellow *J* and low for Blue *B* in accordance with our daily experience with these hues. This is also typical for the Miescher and NCS hue circle.

3.5 Selection of elementary hue angles in CIELAB

The standardized CIELAB (a*,b*) chroma diagram is chosen for comparison of the different elementary hue angles found in the systems listed above (ISO 11664-4). Data for Miescher (1948), the Natural Colour System NCS (1996) and the CIE-test colours no. 9 to 12 of CIE 13.3 are presented below. The CIELAB data of the colour order system *NCS*, and the CIE-test colours are available for the CIE standard illuminant D65.

The *Miescher* data are available for CIE illuminant C. The CIELAB hue angles for CIE illuminant C and D65 are very similar because of the high chroma of the samples. None of the colours in these systems contain fluorescent material.

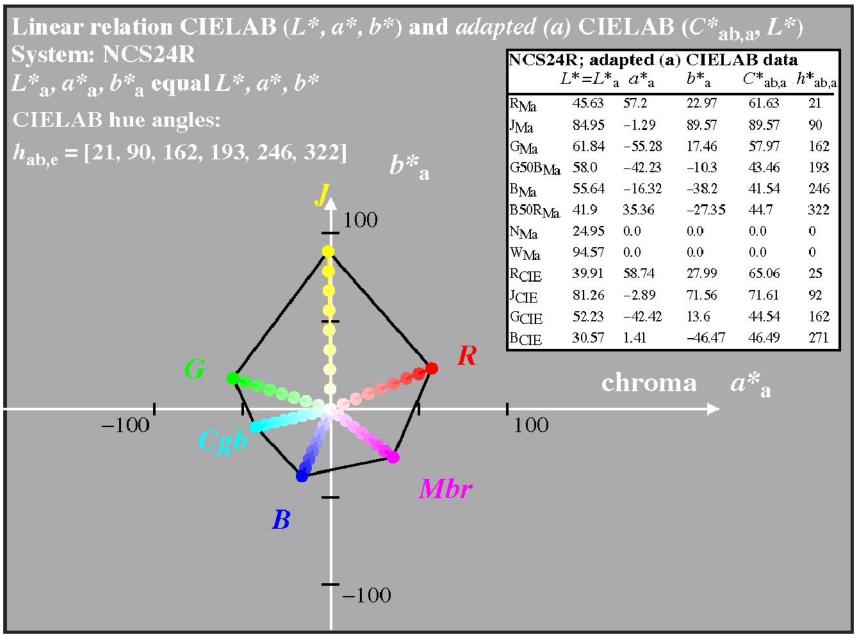


MRS18 ; adapted (a) CIELAB data

	$L^*=L^*_a$	a^*_a	b^*_a	$C^*_{ab,a}$	$h^*_{ab,a}$
R_{Ma}	49.63	66.96	38.37	77.17	29
J_{Ma}	90.7	−6.36	88.75	88.97	94
G_{Ma}	52.11	−69.73	9.43	70.36	172
$G50B_{Ma}$	45.03	−36.57	−28.47	46.34	217
B_{Ma}	36.65	23.19	−63.05	67.17	290
$B50R_{Ma}$	34.93	57.17	−44.26	72.3	322
N_{Ma}	18.01	0.0	0.0	0.0	0
W_{Ma}	95.41	0.0	0.0	0.0	0
R_{CIE}	39.91	58.74	27.99	65.06	25
J_{CIE}	81.26	−2.89	71.56	71.61	92
G_{CIE}	52.23	−42.42	13.6	44.54	162
B_{CIE}	30.57	1.41	−46.47	46.49	271

Figure 2. Elementary hues RJGB of the *Miesche*r (1948) 400-step colour circle.

Figure 2 shows the elementary colours *RJGB* and the two intermediate colours C_{gb} and M_{br} of the *Miescher* colour circle. These are all high-chroma colours of varying lightness.

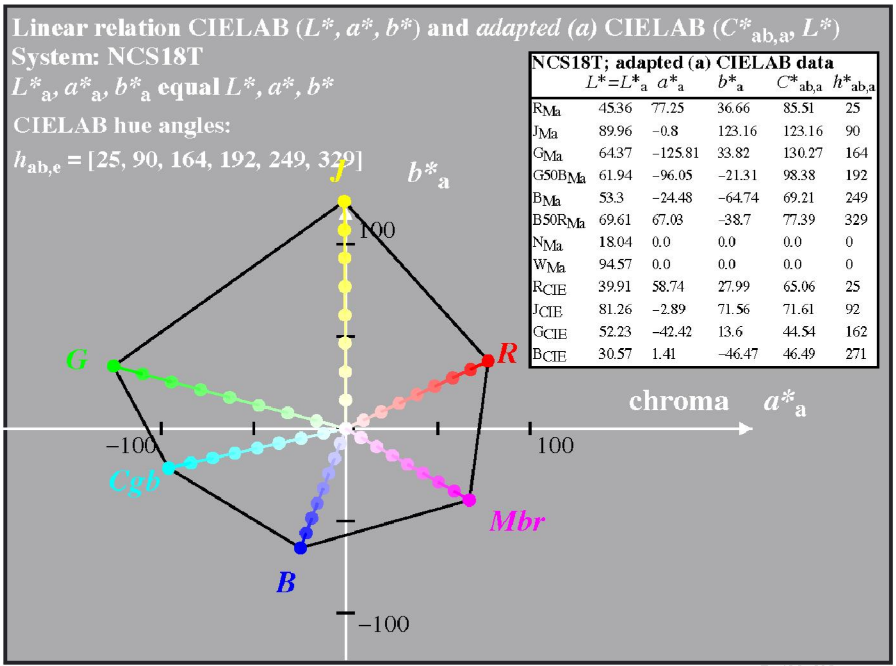


NCS24R; adapted (a) CIELAB data

	$L^*=L^*_a$	a^*_a	b^*_a	$C^*_{ab,a}$	$h^*_{ab,a}$
R_{Ma}	45.63	57.2	22.97	61.63	21
J_{Ma}	84.95	−1.29	89.57	89.57	90
G_{Ma}	61.84	−55.28	17.46	57.97	162
$G50B_{Ma}$	58.0	−42.23	−10.3	43.46	193
B_{Ma}	55.64	−16.32	−38.2	41.54	246
$B50R_{Ma}$	41.9	35.36	−27.35	44.7	322
N_{Ma}	24.95	0.0	0.0	0.0	0
W_{Ma}	94.57	0.0	0.0	0.0	0
R_{CIE}	39.91	58.74	27.99	65.06	25
J_{CIE}	81.26	−2.89	71.56	71.61	92
G_{CIE}	52.23	−42.42	13.6	44.54	162
B_{CIE}	30.57	1.41	−46.47	46.49	271

Figure 3. Elementary hues RJGB of the *NCS (1996)* 400-step colour circle.

Figure 3 shows the elementary colours *RJGB* and the two intermediate colours C_{gb} and M_{br} of the *NCS* colour circle. In the blue area the NCS hue circle is less chromatic compared to the *Miescher* hue.

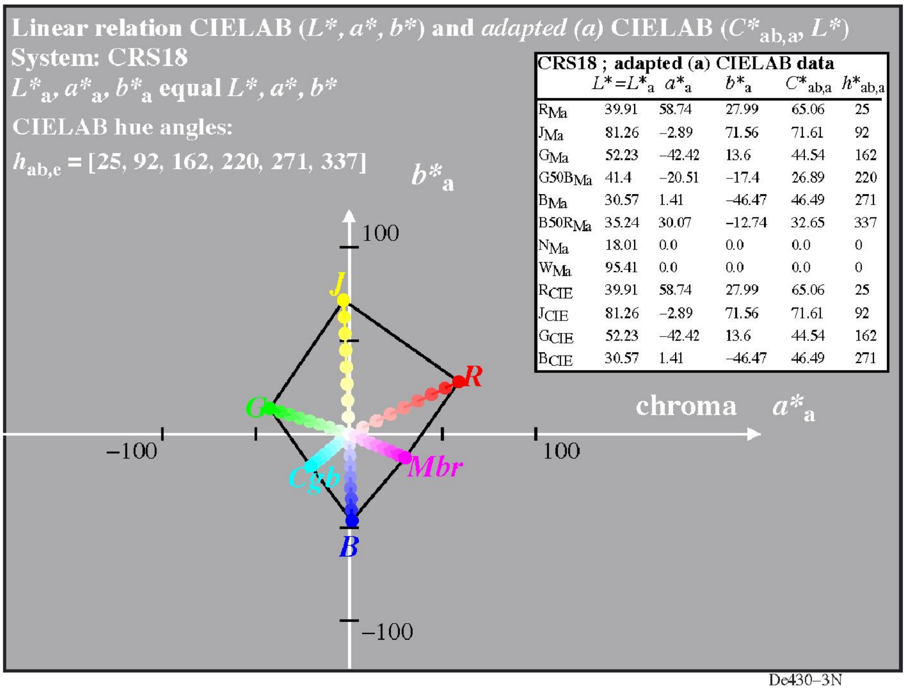


NCS18T; adapted (a) CIELAB data

	$L^*=L^*_a$	a^*_a	b^*_a	$C^*_{ab,a}$	$h^*_{ab,a}$
R_{Ma}	45.36	77.25	36.66	85.51	25
J_{Ma}	89.96	−0.8	123.16	123.16	90
G_{Ma}	64.37	−125.81	33.82	130.27	164
$G50B_{Ma}$	61.94	−96.05	−21.31	98.38	192
B_{Ma}	53.3	−24.48	−64.74	69.21	249
$B50R_{Ma}$	69.61	67.03	−38.7	77.39	329
N_{Ma}	18.04	0.0	0.0	0.0	0
W_{Ma}	94.57	0.0	0.0	0.0	0
R_{CIE}	39.91	58.74	27.99	65.06	25
J_{CIE}	81.26	−2.89	71.56	71.61	92
G_{CIE}	52.23	−42.42	13.6	44.54	162
B_{CIE}	30.57	1.41	−46.47	46.49	271

Figure 4. Reference points of elementary colours in CIELAB space according to NCS

Figure 4 shows the four extrapolated reference points of the *NCS* system. These anchor colours of the NCS system are approximately additionally neither blackish nor whitish and have the relative blackness *n**=0, the relative chroma *c**=1 and the relative whiteness *w**=0. The data in figure 4 are taken from the NCS Standard SS 01 91 02:2004 for the relative blackness *n**=0,05 and the relative chroma *c**=0,95 (not *n**=0 and *c**=1 since no data are given).



CRS18 ; adapted (a) CIELAB data

	$L^*=L^*_a$	a^*_a	b^*_a	$C^*_{ab,a}$	$h^*_{ab,a}$
R_{Ma}	39.91	58.74	27.99	65.06	25
J_{Ma}	81.26	−2.89	71.56	71.61	92
G_{Ma}	52.23	−42.42	13.6	44.54	162
$G50B_{Ma}$	41.4	−20.51	−17.4	26.89	220
B_{Ma}	30.57	1.41	−46.47	46.49	271
$B50R_{Ma}$	35.24	30.07	−12.74	32.65	337
N_{Ma}	18.01	0.0	0.0	0.0	0
W_{Ma}	95.41	0.0	0.0	0.0	0
R_{CIE}	39.91	58.74	27.99	65.06	25
J_{CIE}	81.26	−2.89	71.56	71.61	92
G_{CIE}	52.23	−42.42	13.6	44.54	162
B_{CIE}	30.57	1.41	−46.47	46.49	271

Figure 5: Elementary hues RJGB of *CIE-test colours no. 9 to 12 according to CIE 13.3*.

Figure 5 shows the elementary colours *RJGB* of the CIE-test colours no. 9 to 12 according to CIE 13.3. The two intermediate colours C_{gb} and M_{br} are calculated by linear interpolation upon the lines G–B and B–R in the CIELAB space.

3.6 Average hue angles

The hue angles of the high-chroma elementary hues are listed in the figures. If we calculate an average of Miescher, NCS, and the CIE hue angles given in Figure 2, 4 and 5 we get 26^o, 92^o, 166^o and 270^o for *R, J, G* and *B*, respectively, which happens to be quite close to the hue angles of the CIE colours 25^o, 92^o, 162^o and 271^o.

3.7 Elementary hue planes in CIELAB

The figures above only include a single, high-chroma sample for each elementary hue. Ideally, when all samples, having the same hue but different chroma and lightness, are plotted in CIELAB they should end up along the elementary hue lines in the figures above.

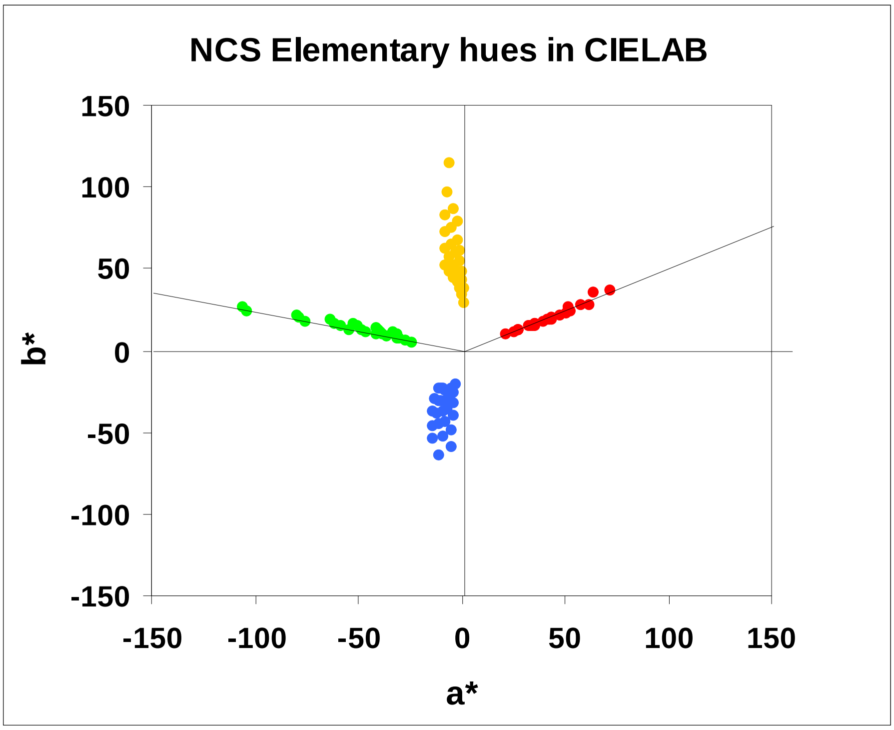


Figure 6a. All elementary hue samples in the NCS plotted in the CIELAB (a*,b*) diagram.

Figure 6a shows all colours samples of the four elementary hue planes in the NCS system. Data-points are taken from Swedish Standard SS 01 91 03 (1982). The *R* and *G* hues are close to be ideally placed in planes in CIELAB, but the J and B hues vary in hue angle, with dark samples to the right (close to the b* axis).

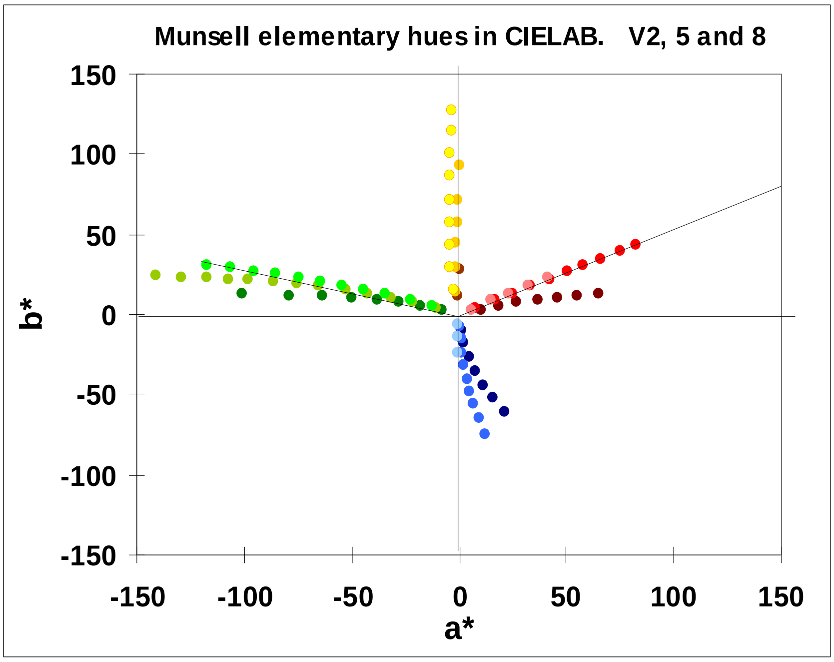


Figure 6b. All samples of hue 5R, 5G, 5Y and 5PB in the Munsell System plotted in the CIELAB (a*,b*) diagram.

Figure 6b shows all Munsell samples for 5R, 5G, 5Y and 5PB, including extrapolated data. For 5R the V5 and V8 data closely follows a straight line, with an angle similar to the NCS red hues. The V2 data deviate from this line, but most of the V2 values are extrapolated values, not experimental. For 5Y (yellow) the hue angle is nearly the same for all samples. For The high-chroma 5G (green) samples deviate from a straight line. However these are not measured but extrapolated values. For 5PB (blue) the hue angle for V2 samples deviate from V5 and V8 samples.

Based on the elementary hue data shown in figure 2 – 6 we may conclude that there is a general agreement of the elementary hue angles for R, J and G, but a relative large variation for the blue hue angle.

4. Experimental definition of elementary hues

4.1 The Jameson and Hurvich type experiments

The classical experiment of Jameson & Hurvich (1955) defined “Chromatic response functions” by using the elementary hue perception as criteria. In the experiment they selected 4 cancellation stimuli, 3 spectral colours which appeared as unique blue, green and yellow, and 700nm to represent red since elementary red is outside the spectrum.

For each wavelength of the spectral test stimulus a cancellation stimulus was added and adjusted until either the redness/greenness was neutralized, or the blueness/yellowness was neutralized. The strength of the four cancellation stimuli are shown in figure 7a and 7b. A linear transformation of the CIE Standard Observer tri-stimulus coordinates can be used to predict the experimental results. See solid line in the figures.

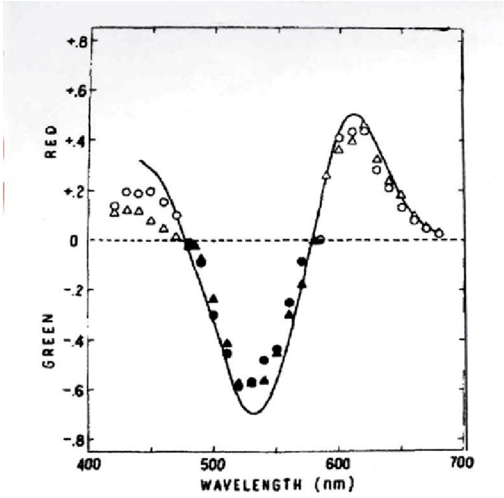
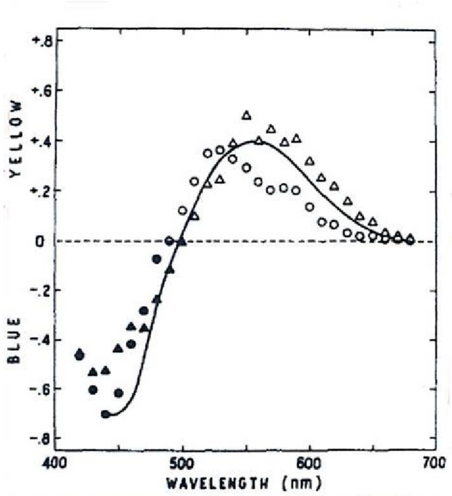


Fig. 1. **Opponent-cancellation coefficients for redness (open symbols) and greenness (filled symbols) for observers H (circles) and J (triangles), for an equal-energy spectrum. Data replotted from Jameson and Hurvich (1955). The solid line is a linear functional for the CIE Standard Observer (Judd, 1951).**



ig. 2. Yellow/blue cancellation coefficient (details as Fig. 1).

Figure 7a Cancellation of redness (open symbols) and greenness (filled symbols). **Figure 7b.** Cancellation of yellowness and blueness. (Figures from Larimer et. al. 1974)

This experiment was later repeated for several luminance levels in order to test Grassmann’s laws, and if the result could be represented by a linear transformation of colour matching coordinates. (Larimer et. al. 1974. Larimer et. al. 1975). They found that Grassman-type additivity laws could be used for the equilibrium colours of the red/green opponent process but not for the yellow/blue opponent.

Other researchers found that this non-linearity might be accounted for by assuming not one but two yellow/blue linear mechanisms (Mausfeld and Niederee 1993, Chichilnisky and Wandell 1999, Logvinenko 2005). Still, significant failures in linearity are observed, but in spite of this the linear opponent models remain in use in spite of empirical evidence. The reason is their simplicity. But they can only be used for stimuli of limited lightness and chroma ranges (Valberg et. al 1991).

4.2 Observer variation in selecting the elementary hues

Numerous experiments have been done where the observers have to select their personal elementary hues (EH). If we bundles these results we get a surprisingly large spread of the selected elementary hues (Kuehni 2001, Kuehni 2004, Abramow 2005, Kuehni 2005).

A control experiment was done in 2007, with 40 medium-saturated (Chroma 8) Munsell colours of equal luminance (Value 6). (Hinks et. al. 2007). The samples were placed on a light-grey background in a grey box and illuminated with a daylight simulator at 1424 lx. See figure 8a. After 2 min. adaptation to the scene the observers were asked to select their EHs in the usual way: Find the yellow one that is neither reddish nor greenish, and so on. Each observer repeated the hue selection after 24 hours.

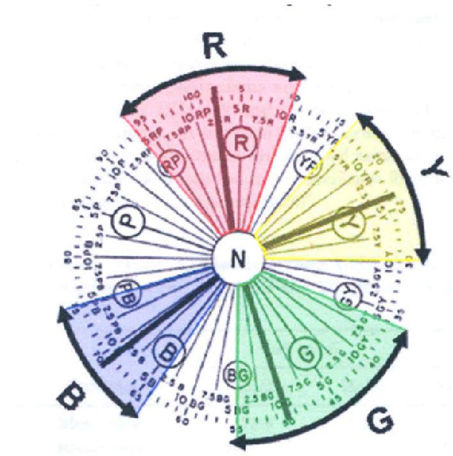


Fig. 4. (Color online) Munsell psychological hue diagram with the mean unique hues of all 102 observers (solid lines) and the corresponding ranges based on mean observer data.

Figure 8a **Figure 8b**

Figure 8a shows the 40 Munsell Chroma 8/Value 6 samples used in the experiment. In figure 8b the ranges of selected elementary hues for the 102 observers are shown, together with the mean hue angles (solid lines).

The experiment verified the large spread of selected elementary colours. See figure 8b. When the selection of elementary hues was repeated, the same observer will mostly select the same colour samples as before, or the neighbouring sample. This indicate that part of the spread must be due to variation in how elementary hues are coded in the visual system of the different observers. These variations may be due to:

a) Genetic variations changes the absorption spectrum of the cones slightly. In addition the relative number of *L, M* and *S* cones varies markedly between persons with normal colour vision.

b) The neural network that produce the perception of elementary hues may vary.
c) The adaptation of the eye might vary, making the result vary.

4.3 Other recent experiments

The hue angle spread in the experiment described above are surprisingly large. However, other experiments show less variation. In one experiment the colours was generated on a CRT screen in a dark room (Wuerger et. al. 2005). A circle of 12 coloured discs of 1.5 deg. diameter was presented on a grey (43 cd/m2) background. To select elementary red the observer pointed at the sample appearing closest to red. 12 new colours was then generated, with hues closer to the selected one. This procedure was repeated once more to get a precise value that the observer judged as neither yellow nor blue.

18 observers participated in the experiment. In all 1616 data-points, obtained for colours with different chroma and lightness, were recorded. See figure 9 (Fig. 1 in Wuerger et. al. 2005) where all data-points are displayed in a linear, L, M and S diagram. Note the different scaling on the x- and y-axis. Here the Smith/Pokorny cone sensitivities are used. Note that R does not align with the (L-M) axis.

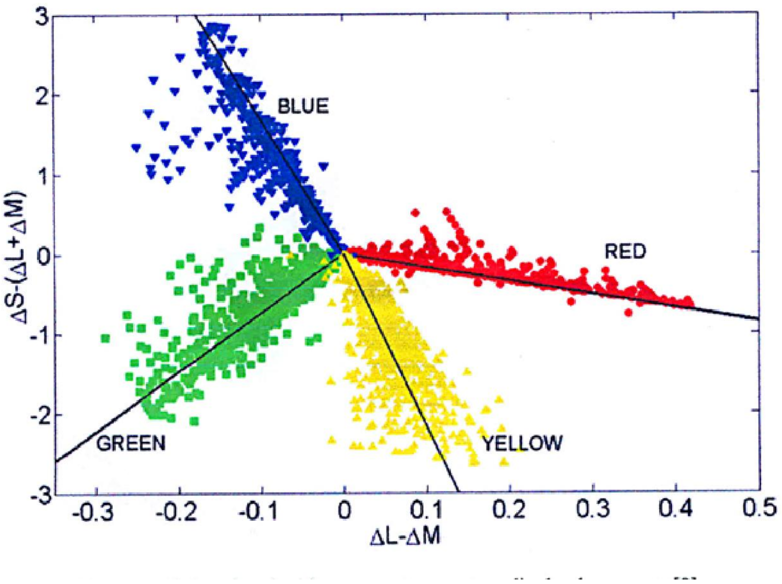


Figure 9. Distribution of 1616 data-points for the elementary hues red, yellow, green and blue. (After S.M. Wuerger et. al. 2005)

The scatter of the 1616 data-points in figure 9 appear large, but when deltaE data are plotted in the CIELAB space the variation is about 3 deltaE units for the pooled data. See figure 10 (Fig. 5 in Wuerger et. al. 2005).

As in the experiment by Hinks et. al. (2007) the inter-observer (pooled) data shows larger spread than the intra-observer (individual) spread. Still, since $\text{deltaE}_{\text{CIELAB}}=1$ is roughly the visual threshold, a spread of $\text{deltaE}_{\text{CIELAB}}=3$ is not more than the allowed tolerance of colour copiers, according to ISO/IEC 15775.

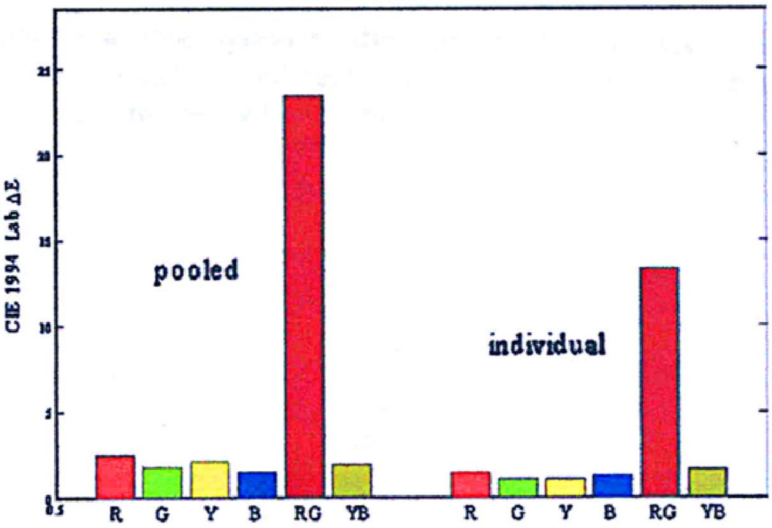


Figure 10. The mean perceptual errors in delta E^*_{ab} units for the four elementary hues. In addition the mean perceptual errors are shown when the data for elementary red and green are fitted by a single plane (RG). This implies that different yellow/blue mechanisms are silenced when the observer perceive a test-colour as elementary red compared with elementary green.

In another experiment 185 observers, aging from 18 to 75 years, were tested (under similar experimental conditions) in order to check if the selection of elementary hues varied with age (S. Wuerger et. al. 2009, Fu et. al. 2009). Their result shows no significant change of elementary hue selection with age. For all age groups the $\text{deltaE}_{\text{CIELAB}}$ was less than 3 for nearly 70% of the observers (Private communication with S. Wuerger).

4.4 General comments

The use of aperture colours and high-luminance test colours on darker backgrounds may change the state of adaptation of the eye and thus influence the results. No background will lead to variable adaptation since the eye then adapts to the test-sample. The selection of elementary hues is also influenced by the size of the colour sample, i.e. be different for the 2^o and the 10^o CIE observer (Nerger et. al. 1995). For the viewing angles of office documents only the CIE 2 degree observer is appropriate. The (achromatic) adaptation of the eye will influence the observer selection of elementary hues. A mean grey background can be applied for visual displays used at work places. Office documents, produced on paper and on displays, have both a standard lightness range between L*=18 and L*=95 according to ISO 9241-306 and ISO/IEC 15775.

Finally, adapting the eye to different light-sources (2800K to 6500K) changes the elementary hue coordinates (Pridmore 1999).

5 Models

Modeling the perception of colour is approached from two main directions. One may start with neurophysiological based studies of how visual information is coded in neural cells, or by approaching the problem from the perceptional side. A third approach (often favored by CIE) is to use the tristimulus X, Y, Z transformations of the cone primaries.

However, no models can predict the correct placement of the elementary hues in the different colour spaces. Neural coding in the retina and the LGN is relatively clearly understood, but less is known about the higher visual centra in the brain (Stoughton 2008). The response of the Parvocellular neurons in the Lateral Geniculate Nucleus (LGN) corresponds poorly with the elementary hues (Valberg 2001). In the striate cortex the –S+(L+M) from the LGN might be added to the L-M mechanism from the LGN. De Valois et. al. have shown that the number of mechanisms containing the –S+(L+M) signal is doubled in the cortex. (De Valois et. al. 2000). Based on these finding one may suggest a solution:

a) if the –S+(L+M) signal from the LGN is added to the L-M cell output then the resulting response will get an offset from the L-M LGN axis in the unique red direction.

b) if the –S+(L+M) signal from the LGN is added to the M-L cell output then the resulting response will get an offset from the M-L LGN axis in the unique green direction.

5.1 Linear models

Earlier, when the three cone spectra L, M and S were unknown, the CIE tri-stimulus values were often used to model colour vision. The CIELUV is an example of such a system. Linear models, using linear coded cone sensitivities LMS, are often based on neural responses for Parvocellular neurons in the LGN. Typical coding types found here can be expressed as (De Valois 2000):

(L – M), (M-L) and *S-(L+M)*

Many models use *L-M* as x-axis and *S-(L+M)* as y-axis in an opponent cone-excitation space. However, the weight of the L, M and S components varies significantly in these cell groups (Tailby 2008). In many experiments, with limited stimulus ranges, linear responses for L, M and S can be used. (De Valois 2000).

When the elementary hues are plotted in such diagrams the elementary red is often found close to the L-axis, but the Y, G and B hue angles deviate significantly from the axes, as shown in figure 11 below (Webster et. al. 2000).

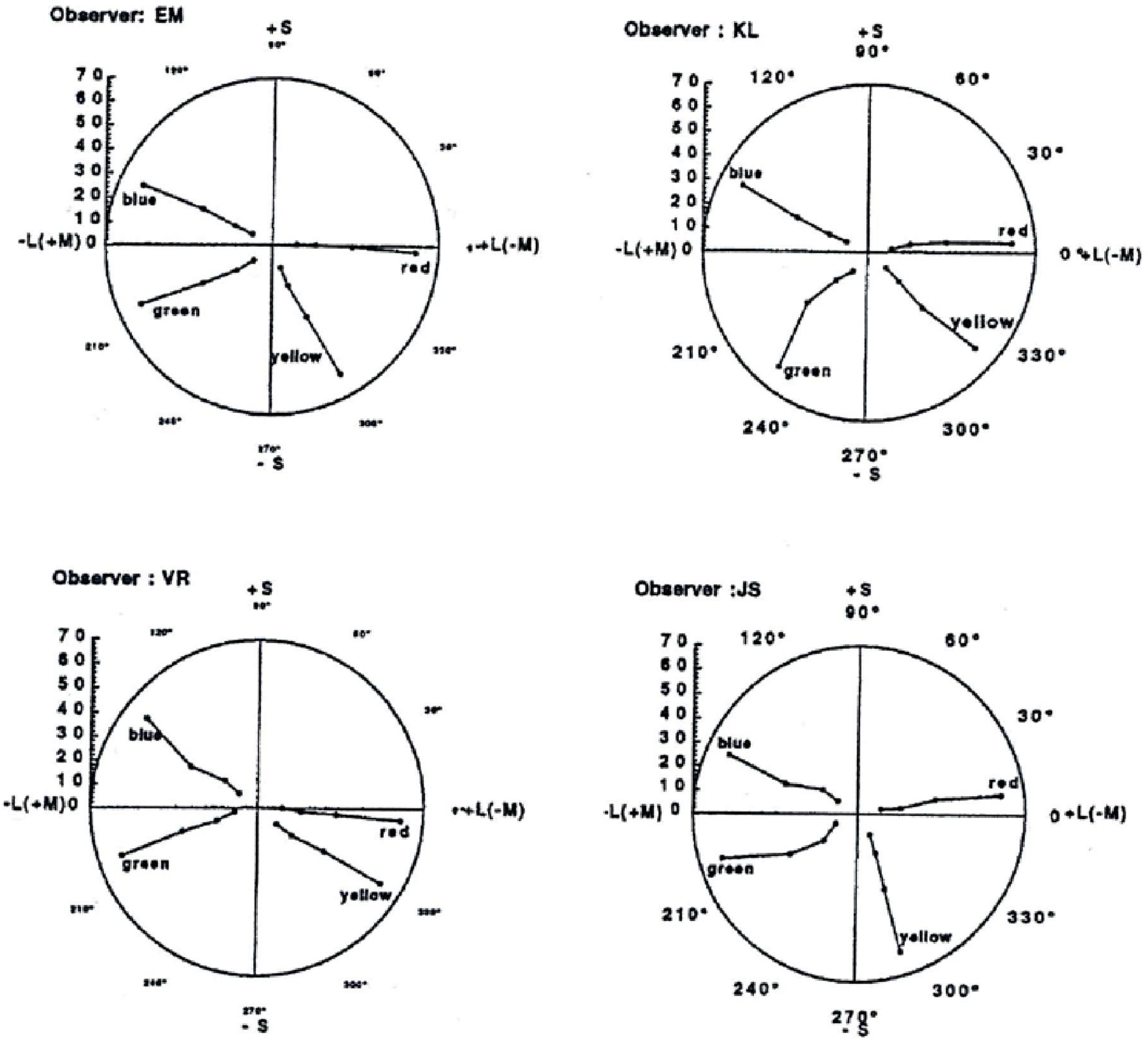


Figure 11. Variation in the selection of the elementary hues. From Webster et. al. (2000)

5.2 Non-linear models

In the linear expressions (L – M) and S – (L + M), shown above, the L, M and S may be replaced by non-linear responses. In most non-linear models the cone sensitivities are replaced with compressing functions. This compressing function can be a cube root function, as used by CIELAB, or a hyperbolic function (Seim and Valberg 1986).

For extended ranges of stimulus parameters, only non-linear models can explain experimental results. When the luminance of spectral lights are varied over a range of about 4 log-units, then hue changes due to the Bezold-Brücke effect. Also when stimulus luminance increases above a wavelength-dependent value the chromatic strength of every hue gets increasingly lower. (Valberg et. al.1991). This is shown in figure 12. for four observers. To explain this result a non-linear model was used.

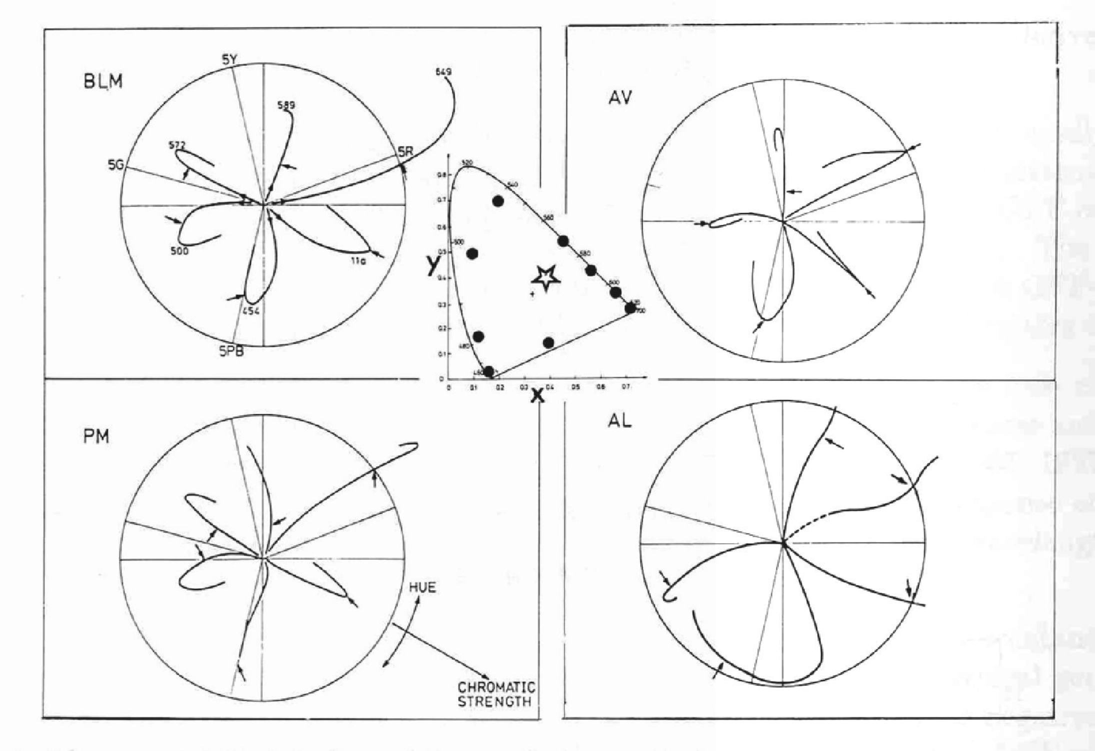


Figure 12. The perceptive increase of chroma and variation in hue angle of a stimulus of constant chromaticity is shown radiating outward as luminance increases. Further increment of luminance reduces the chroma and continues to change the hue angle. (From Valberg et. al. 1991)

M. Ayama et. al. (1987) measured the constant hue loci for Elementary red, yellow, green and blue at 10, 100 and 1000 Td for two observers. Only the hue loci of yellow at 10 and 1000 Td plotted as straight lines. The other elementary hue loci were curved.

Chichilnisky and Wandell (1999) have repeated the elementary hue cancellation experiment of Jameson & Hurvich (1955). They used CRT stimuli of moderate contrast, placed on coloured adapting backgrounds, and found that a linear L,M,S model could not be used to predict the red/green and yellow/blue boundaries of the three observers who participated in the experiment. See figure 13a and b. A geometric description (a nonlinear model) was developed to describe the result.

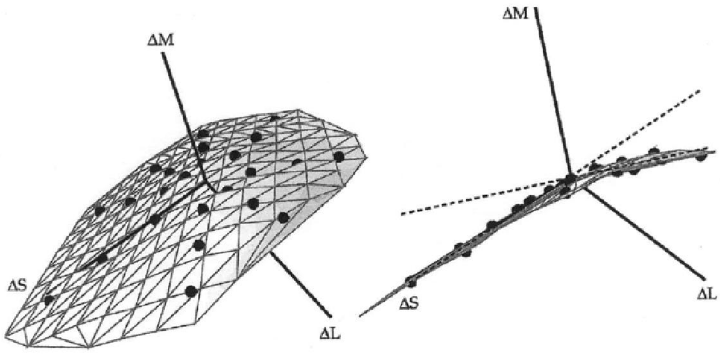


Fig. 1. Red–green classification boundary. The three-dimensional coordinates of each point represent the cone quantum absorptions associated with a red–green equilibrium stimulus, expressed as differences ($\Delta L\ \Delta M\ \Delta S$) from the background quantum absorptions. A smooth surface passing through the points is shown to aid visualization (see Section 2). The two panels show rotated views of the same data and surface. Additional dashed lines in the right view are drawn to emphasize the bend in the data. Error bars extending from points indicate ± 1 standard deviation of the psychometric function associated with the equilibrium measurement, and point in a direction joining the two stimulus primaries used (see Section 2). In this figure most error bars are smaller than the points. A total of 24 equilibrium measurements are shown though some are obscured by the surface. The background had a greenish appearance when viewed from a distance in a dark room. Background cone coordinates: (0.103 0.103 0.0617). Axis lengths: (0.0323 0.0327 0.0459). Observer: ES.

Figure 13a. The red/green boundary for colours appearing neither red nor green.

E.J. Chichilnisky, B.A. Wandell / Vision Research 39 (1999) 3444–3458 3449

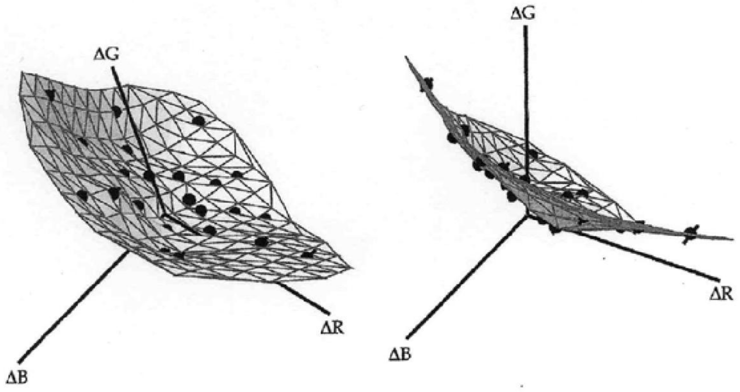


Fig. 4. Blue–yellow equilibrium stimuli viewed on a purple background. Background gun intensities relative to maximum: (0.47 0.23 0.72). Number of points: 24. Axis length: 0.49. Observer: RR. Other details as in Fig. 2.

Figure 13b. The yellow/blue boundary for colours appearing neither yellow nor blue.

5.2.1 The CIELAB colour space

By the definition of visual models the CIELAB must also be referred to as a visual model since it tries to predict uniform colour scaling by non-linear transformations of light absorbed in the cones. It was standardized in 1976. The CIELAB colour space is the preferred formula in many standards for imaging applications.

CIELAB coordinates:

Lightness $L^* = 116(Y/100)^{1/3} - 16 \quad (Y>0.8)$

“red-green”: $a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$

where n refers to source D65 (achromatic background).

“yellow-blue”: $b^* = 200[(Y/Y_n)^{1/3} – (Z/Z_n)^{1/3}]$

The angles of the elementary hues in CIELAB have been presented earlier in Ch. 3.

5.2.1.1 Comparing CIELAB with models based on neural coding

CIELAB a* and b* can be compared with neural responses. As explained above the response of opponent PC neurons in the LGN codes the L, M and S cone inputs in the following groups:

(L – M) and (M – L) as “red/green” opponent cells

S – (L + M) as “blue/yellow” opponent cells,

When we compare the CIELAB with a cone-based formula we see some similarities. The sensitivity spectrum of the S-cone is close to that of the Z tri-stimulus value. The Y-spectrum is close to the weighted sum of L and M (Stockman and Sharpe 2008), making the b* close to the “blue/yellow” LGN cell coding S-(L+M). A response similar to a* is not found in the LGN.

Separate (chromatic) adaptation of the three cones will influence the perception of elementary hues. Since CIE XYZ coordinates represent a mixture of L, M and S response a transfer equation should be used to compute the LMS before adaptation. The LMS curves CIE recommends are defined in CIE 170-1, originally proposed Stockman and Sharpe (2000).

5.2.2 Other CIE Colour Appearance Models

A large number of non-linear Colour Appearance Models (CAMs) exists. An overview of most of them is found in the book of Fairchild (2005). None of these have a neurophysiological based description of the elementary hues.

An outline of how device colours are linearized and may controlled by the use of elementary hues is presented below.

6. Printing colours

In printers the device colours of high chroma are mixed with both black and white to vary the luminance, and with each other to vary hue. In order to produce a high chroma hue gamut three to six device colours are used.

6.1 Linearization of printer-device colours

A device output linearization is fundamental for any colour management application in imaging (See ISO/IEC TR 19797 and Richter 2008). Usually a grid of 729 = 9x9x9 *rgb*-input colours is used and the device output colours are measured in CIELAB coordinates. If the six chromatic device colours X=OYLCVM and Black N and White W are measured, then DIN 33872 describes a method to calculate the intended equally spaced 729 output colours both by *rgb** and the LAB* coordinates of CIELAB. Therefore a *LAB** to *rgb** transition and an *rgb** to LAB* transition is known.

<u>*L*a*b* - rgb* (LAB** relation)</u>

With the help of the LAB*relation there are three tables of the 729 colours between the input and output colours:

rgb – *rgb** (star relation, based on 8 CIELAB colours)

rgb – *rgb*’* (star-dash relation, data *rgb*’* of real practical output)

rgb’ – *rgb** (dash-star relation, Inverse relation to reach the intended ouput)

Therefore output linearization of any device is reached if a transformation *rgb* to *rgb’* (dash) is used for example within the device.

If the input data are equally spaced between 0 and 1 in 9 steps, for example between Black and White, Black and Red, and White and Red, then for linearized output systems the three output colours series are equally spaced. This is intended in all reddish hue planes, including the elementary Red hue plane.

6.2 Transfer from device colours to elementary hues

A transfer function must be developed to transfer the device-colours to device-independent colours based on reproduction of the elementary hues. If the CIE-test colours Red, Yellow, Green, and Blue (RJGB) no. 9 to 12 of CIE 13.3 are used as elementary hues, then for the elementary hues the hue angles are h_{ab} = 26, 92, 162, and 272 degrees in CIELAB. From the closes colours in the (tri-dimensional) set of 9x9x9 colours generated by the device, the device colour for each elementary hue colour can be computed.

7. Colour displays

7.1 Linearization of display-device colours

A similar method as described for colour printers may be used for displays. One visual linearization method is given in ISO 9241-306 for work places and for eight ambient light reflections at the display surface

7.2 Transfer from device colours to elementary hues

A similar method to that described for colour printers may be used.

8. Control of the result

Printed control charts may be used as a reference and visually compared with the output of the device. For displays and projectors a reference display or projector might be used. Otherwise the output coordinates of the different imaging device can be measured. There exists 5-, 9-, 17-, 33- step colour series based on 5-step simple sub-series. Usually observers can evaluate 5-step series on a visual scale between 0 and 1. See for example the 5-step test charts of CIE TC 1-63.

http://www.ps.bam.de/ME23/10L/L23E00NP.PDF

http://www.ps.bam.de/ME05/10L/L05E00NP.PDF

8.2 Illumination used for evaluation of printed colours

For printed images the relative spectral power distribution of the illumination will influence the spectral components reflected from the pixels in the image. This, combined with the adaptation of the eye, will define the colours of the image.

Relevant standard sources are the D65, D50 and the source A, the incandescent light-bulb. The latter may be banned due to its inefficiency and replaced by new, more efficient light sources, like the LED-based light-sources.

8.3 Projective devices and ambient illumination

For displays the ambient illumination will add to that of the displayed image. Care should be taken to correct for ambient light when colour linearization is performed. (Thomas et. al. 2008)

9. Methods for calibrating colour printers and displays using elementary hues

Two proposals for calibrating colour printers and displays using elementary hues have been found in the literature:

9.1 Method based on using real observers

This method is presented by D. Karatzas and S. M. Wuerger in the paper: “Hardware-Independent Colour Calibration Technique” (2008). The idea is to avoid expensive measurement equipment and complex procedures when calibrating the elementary hues of an imaging device. This is obtained by the use of a real observer to define the elementary hues RJGB.

They use a linear model based on light absorptions in the LMS cones, called the HSV (Hue angle, Saturation, Value) model, to define the elementary colours. Here the elementary hues of the observer are presented as straight lines in the (L-M), S-(L+M) diagram.

One advantage of this method is that the observer is always adapted to the real experimental condition where the device is placed. Since the eye reacts to a highly complex visual environment a mathematical model will probably not be able to simulate it.

A short description of their procedure follows:

Task: A Device Under Test (DUT) is compared with a Reference device. On both devices the observer defines the elementary hue loci as follows:

1. Define achromatic grey through an iterative process
2. Select colours that are neither red nor green
3. Select colours that are neither yellow nor blue

At each trial the HSV coordinates of the selected colours are stored, together with the (linearized) RGB device settings. At least 24 assessments are made by the observer.

4. A device profile is obtained by localizing four planes in the HSV model, representing each of the elementary hues.
5. A 3x3 transfer matrix is generated that transfer the elementary hue data from the reference device to the DUT.
6. This matrix is then used to transfer any colour on the reference device to the DUT.

The result can then be visually evaluated by the observer (and other observers) by comparing the two device images.

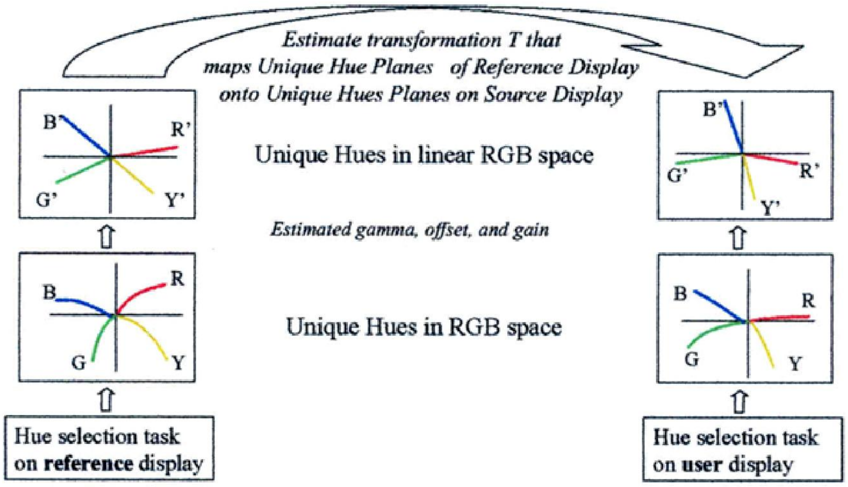


Figure 5: Transformation from source to reference display device derived from unique hue judgements.

Figure 14. A schematic description of their method

9.2 The Relative Elementary Colour System (RECS)

This System is included in a German standard and was developed by K. Richter (2008). It represent a comprehensive proposal for the application of elementary hues in image technology. See DIN 33872-1 to -6: http://www.ps.bam.de/D33872-AE.PDF

The test charts are available at http://www.ps.bam.de/33872E

The charts are found in both digital and analog form in a colour atlas.

The Relative Elementary Colour System uses the standard CIELAB space and a relative CIELAB space to transfer the CIELAB data of device colours into elementary hues , see http://www.ps.bam.de/RECS/index.html

The transformations in both directions for the standard and relative CIELAB space are given in E DIN 33872-1 to -6.

The system is developed for calibration of printing and display-devices. Linearizing methods similar to the method given ISO/IEC TR 19797 are used to make the output for the 9- and 16-step colour series equally spaced in CIELAB in the elementary hue planes RJGB and in 12 intermediate hue planes.

9.2.1 Normalization

The device colours White W and Black N and the four elementary colours Red *R*, Yellow *J*, Green *G* and Blue *B* are reference points. The relative coordinates of the RECS are scaled in relation to these reference points. These coordinates are computed from the standard CIELAB L^*, a^*, b^* coordinates (ISO 11664-4/CIE S 014-4) for CIE standard illuminant D65 and the CIE 2 degree observer.

9.2.2 Transfer equations

The CIELAB coordinates are transformed into RECS coordinates which show some similarities with the coordinates of the NCS system. Three colorimetric coordinates are used to specify the device-produced colours. These are brilliantness i^* (equal to 1 minus blackness n^*), relative chroma c^* and hue angle $h_{ab.a}$ (explained below) or elementary hue u^*.

9.2.3 Presentation system

In order to simplify the presentation of surface colours the following normalization transformation of the CIELAB coordinates was done:

The lightness L^* was replaced by relative lightness $l^* = (L^* - L^*_N)/(L^*_W – L^*_N)$ making l^* vary between 0 and 1.

L^*_N is the value for the device-black (N for Noir in French) and L^*_W is the value for device-white.

The CIELAB coordinates a^* and b^* are replaced by

$$a^*_a = a^* - a^*_N – l^*[a^*_w – a^*_N]$$

$$b^*_a = b^* - b^*_N – l^*[b^*_w – b^*_N].$$

NOTE 7: If the CIELAB data a^* and b^* are zero for the achromatic colours Black (N) and White (W) then the *adapted* (Index a) CIELAB data are equal to the standard CIELAB data.

The last term in these two equations ensures that both a^*_a and b^*_a is zero for both Black N and White W.

From this we can define chroma in adapted CIELAB:

$$C^*_{ab,a} = [a^{*2}_a + b^{*2}_a]^{1/2}$$

The adapted hue angle $h_{ab,a}$ can be expressed by

$$h^*_{ab,a} = \arctan (b^*_a / a^*_a)$$

The relative chroma c^* can then be defined by

$$c^* = C^*_{ab,a} / C^*_{ab,a,M}$$

where M represent maximum chroma of any device for a given hue. c^* varies between 0 and 1.

The new representation, called the Relative Elementary Colour System (RECS) uses the coordinates l^*, c^*, both with values between 0 and 1, and the adapted hue angle $h_{ab,a}$ to represent any surface or display colour. See Note 1.

9.2.4 Elementary hues

The hue angles for the elementary hues are defined by the coordinates of the CIE Standard colours no. 9 to 12, according to CIE 13.3. The hue angles h_{ab} in CIELAB are 26^o, 92^o, 162^o and 272^o for the elementary hues *R, J, G and B*, respectively.

Figure 15 and 16 contains some equations to calculate the *adapted* (Index a) CIELAB coordinates (a^*_a, b^*_a) for the standard device systems ORS18 (offset) and TLS00 (television). See ISO/IEC 15775.

NOTE 8: For the definition of brilliantness i^*, blackness n^*, elementary hue text u^* and others see the documents of the standard series DIN 33872.

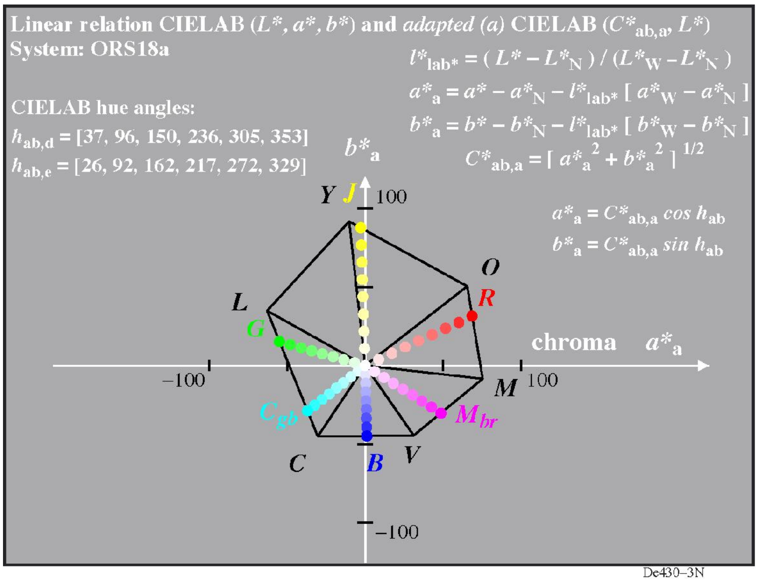


Figure 15. Device hues Y, L, C, V, M and O and elementary hues R, J, G and B for offset system ORS18. Hue angles for device (d) and elementary hues (e) are included in the figure.

For the device system ORS18 (Offset) both the coordinates (a^*_N, b^*_N) of Black *N* and (a^*_W, b^*_W) of White *W* are different from zero but the adapted coordinates are equal to zero.

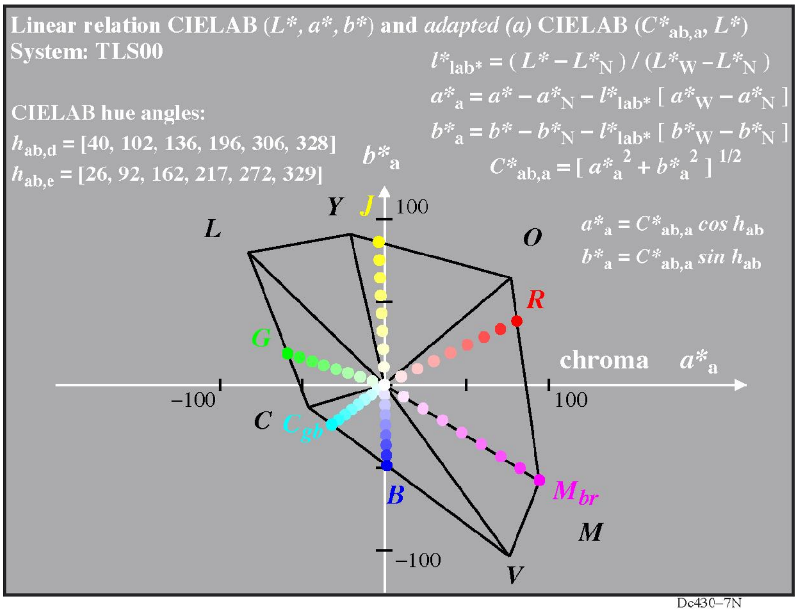


Figure 16. Device and elementary hues for television display system TLS00. (See explanation of data in figure 15).

For the device system TLS00 (Television) both the coordinates (a^*_N, b^*_N) of Black *N* and (a^*_W, b^*_W) of White *W* are equal to zero and therefore it is always valid that (a^*, b^*) = (a^*_a, b^*_a).

In Figure 15 and 16 the colours with the hue angles of the CIE-test colours no. 9 to 12 are compared with the six device colours for the standard offset print system ORS18 and a standard monitor system TLS00 according to ISO/IEC 15775: 1999. The two colours C_{gb} = G50B and M_{br} = B50R, with a hue angle in the middle between G and B, and between B and R are added in the figures.

10. Proposals

People react more strongly to errors in hue-reproduction (hue shifts) compared to errors in lightness and chroma reproduction (Taplin 2004). In addition many prefer the use of elementary hues when they evaluate a test chart reproduction, and would like to avoid the variability found when device colours are used in the reproduction.

10.1 Selection of elementary hue angles

The variation of elementary hue angles in the literature is due to individual variations as well as to different experimental conditions. While some experimenters get surprisingly large variation in observer hue angles, others get less variation. Data from the Colour Order Systems (Figure 2 –5) shows much less variation, except for elementary blue.

This experimental divergence is probably partly due to different experimental conditions and this should be clarified further by the CIE. Experimental conditions, typical for evaluation of imaging device outputs, should be preferred.

10.1.1 Proposal:

A further study of the selection of elementary hue angles should be done by the CIE to analyze the scatter of experimental defined angles. The results should appear in a CIE Technical Report.

The average of Miescher, NCS, and the CIE elementary hue angles is quite close to the hue angles of the CIE colours no. 9 to 12 (See 3.6 above). The hue angles of the CIE colours can be used as preliminary values.

10.2 Modification of “Method based on using real observers”

See *9.1: “Method based on using real observers”.* This method is presented by Karatzas and Wuerger in the paper: “Hardware-Independent Colour Calibration Technique (2007). The advantage of their method is its simplicity.

However, if CIE decide to consider this approach they should also modify it. An obvious way of doing this is to use the method presented by Jameson and Hurvich (1955). They substituted the experimental observers with the CIE Standard Observer. The same substitution can be done with the real observers used by Karatzas and Wuerger.

10.2.1 Proposal:

The modified method of Karatzas and Wuerger should be considered as a possible basis for a CIE Technical Report.

10.3 The Relative Elementary Colorimetric System (RECS)

This system fulfills most of the criteria for a CIE-based method for calibration of imaging devices. It is based on the (non-linear) CIELAB space and it includes test charts.

10.3.1 Proposal:

The Relative Elementary Colorimetric System of Richter should be considered as a possible basis for a CIE Technical Report

NOTE 9: The reflection factors of the CIE-test colours and reference samples by different sources are available. They can be used for many additional visual experiments. Colour constancy experiments suggests that the CIE-test colours remain the property “Elementary Hue” under different illuminants, for example the image technology illuminants D65 and D50.

Acknowledgments

Figure 2-5 was kindly produced for the report by Klaus Richter. He also helped me by explaining his Relative Elementary Colour System (RECS).
Arne Valberg gave me important information about elementary colours, including the Miescher System.
I am also grateful for information I received from Rolf Kuehni and Sophie Wuerger about their experiments.

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Standards and recommendations

Swedish Standard SS 01 91 03, CIE tristimulus values and chromatcity co-ordinates for the colour samples in SS 01 91 02. Edition 1982 for Source C and edition 1996 for Source D65.

ISO/IEC 15775, Information technology—Office machines—Method of specifying image reproduction of colour copying machines
by analog test charts—Realisation and application

ISO/IEC 19797:2004, Information technology -- Office machines -- Device output of 16 colour scales, output linearization method (LM) and specification of the reproduction properties

ISO/IEC 24705:2005, Information technology -- Office machines -- Machines for colour image reproduction -- Method of specifying image reproduction of colour devices by digital and analog test charts

ISO 9241-306:2008, Ergonomics of human-system interaction -- Part 306: Field assessment methods for electronic visual displays

ISO 11664-4/CIE 1976 L*a*b* Colour space

ISO TC159/SC4/WG2: Visual Display Requirements

CIE 13.3-1995: Method of measuring and specifying colour rendering of light sources New edition

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Unique Hues: observer variability and age dependency

Chenyang Fu, Kaida Xiao, Sophie Wuerger and Dimos Karatazas

Aims

- To assess unique hues in a large sample of colour-normal observers ranging from 18 to 85 years of age
- To assess the intra- and the inter-observer variability of unique-hue judgments on self-luminous display
- To assess age and gender dependency of unique hue judgment
- To determine the influence of ambient light on these unique hue settings.

Experimental Apparatus

Equipment

A CRT monitor (21-inch Sony GDM-F520) which was controlled by a DELL PC with a ViSaGe graphics card (Cambridge Research System, Ltd.).

CRT Characterisation

The CRT monitor had a correlated colour temperature of about 9300K with a peak luminance of 120 cd/m^2 , was calibrated with build-in ColourCal (CRS Ltd) and also checked with a PR 650-spectroradiometer.

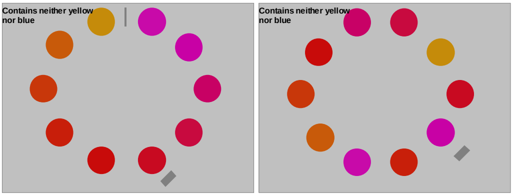
Viewing Conditions

1 In a Dark room
2 Ambient light using a D65 stimulator
3 Ambient light using a Cool White Fluorescent (CWF) light

Task Of The Observer

Unique Hue Selection Task

Patches of similar colours were arranged along an annulus at constant eccentricity and the task of the observer was to select a patch that contains neither yellow nor blue (to obtain unique red and green). Unique yellow (blue) was obtained by asking observers to select a patch that contains neither red nor green. Two different arrangements were used.



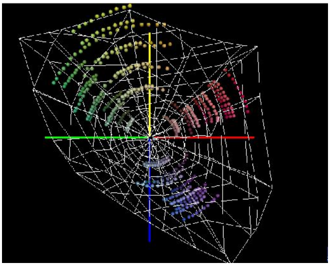
(a) *(b)*

Experimental Interface. *(a): regular pattern*; *(b): random pattern*

Test Stimuli

Test colours are carefully selected to cover a wide monitor gamut. On a particular trial, coloured patches had the same lightness *L** and chroma C_{uv}* value.

In total, 360 test colours (4 unique hues × 9 combinations of different chroma-lightness levels × 10 colour patches per test) were selected.



Each colour ball represents a colour patch, solid Line represents Gamut Boundary of CRT

Observers

- **187 naïve observers**

Age	**Below 30**	**31-40**	**41-50**	**51-60**	**Over 60**	**All**
Number	106	23	21	20	18	187

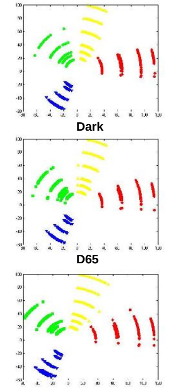
Gender	**Female**	**Male**
Number	103	84

Experimental Procedure

Each observer went through the following tests in this order:

- **Cambridge Colour Test (CCT)**
- **Instruction/Demo**
- **Unique Hue Experiment in a Dark room**
- **Unique Hue Experiment under the D65 simulator**
- **Unique Hue Experiment under the CWF**

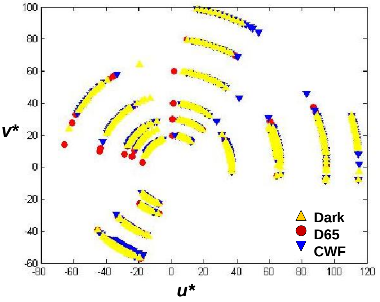
Experimental Results



Dark

D65

CWF (Cool White Fluorescent)



Scatter plots of all data points in CIELUV colour space.

Experimental Results

Unique Hue Angles in LUV space

Dark	Mean	Δ E-intra	Δ E-inter
Red	13.36	1.94	3.76
Yellow	69.66	2.41	3.44
Green	138.07	1.91	2.66
Blue	238.20	2.03	2.24

D65	Mean	Δ E-intra	Δ E-inter
Red	13.72	1.50	3.04
Yellow	70.23	2.13	3.74
Green	139.11	1.81	2.42
Blue	238.19	1.68	2.16

CWF	Mean	Δ E-intra	Δ E-inter
Red	13.57	1.48	3.30
Yellow	69.30	2.11	3.52
Green	138.73	2.04	2.56
Blue	238.00	1.71	2.04

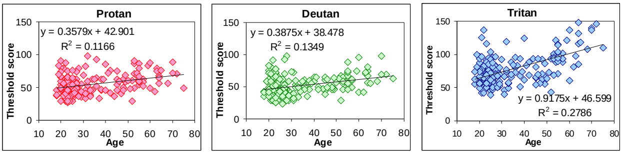
Mean hue value in *CIELUV colour* space, mean intra-observer and inter-observer variability of unique hue judgements in terms of colour difference of unique Red, Green, Yellow and Blue under three viewing conditions.

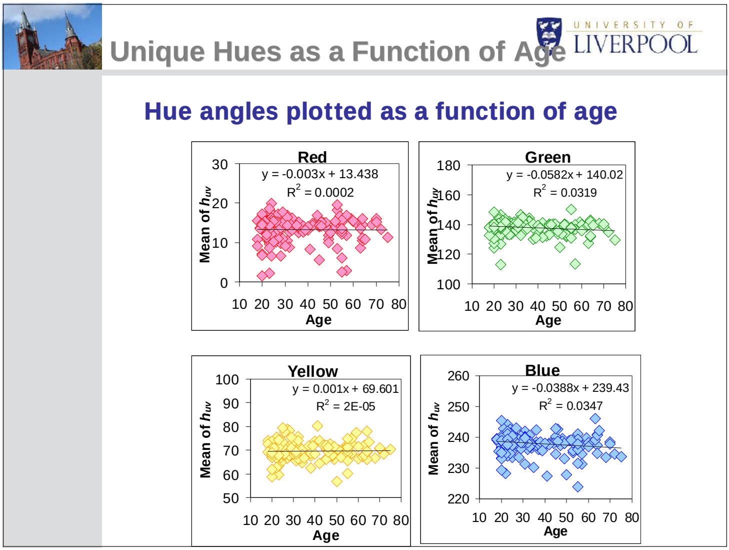
Inter-observer variability is larger than intra-observer variability, but by less than a factor of 2 for all hues.

Chromatic Sensitivity

The Cambridge colour test (CCT) was used to measure the sensitivity along the protan, deutan and tritan lines.

CCT results plotted as a function of age





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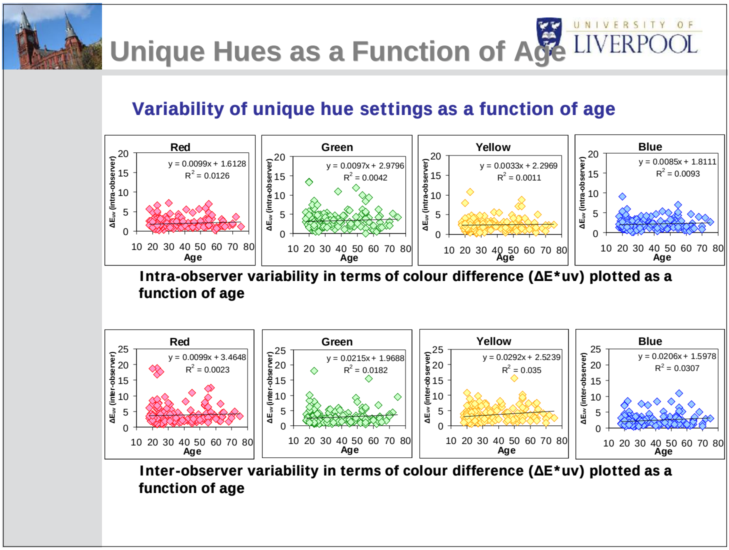
Unique Hues as a Function of Age

Hue angles plotted as a function of age



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Unique Hues as a Function of Age

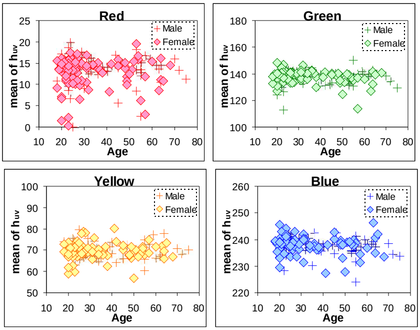
Variability of unique hue settings as a function of age

Intra-observer variability in terms of colour difference (ΔE*uv) plotted as a function of age

Inter-observer variability in terms of colour difference (ΔE*uv) plotted as a function of age

Gender Difference

Hue angles plotted as a function of age with different gender



There is no significant difference between male and female.

Conclusion

- **The chromatic sensitivity deteriorates significantly with age; but the appearance of unique hues is much less affected by age remaining almost constant ($R^2 < 0.1$).**
- **The inter-observer variability in the unique hue settings was larger than the intra-observer variability but by less than a factor of 2.**
- **There were not signifcant effects of ambient light on the unique hue settings (when unique hue judgements are made using self-luminous stimuli).**

We conclude that we obtain robust and age-invariant unique hue settings using our hue selection task.

2009 AIC Liaison Report

AIC has been very busy with many activities. Brazil: Pro-cor has been accepted as a new AIC regular member. For more details on Brazil's national color association, visit www.procor.com.br.

The AIC 2008 Interim meeting was held on Stockholm, Sweden from June 15-18, 2008, hosted by the Swedish Colour Centre Foundation. The topic of the meeting was "Colour – Effects & Affects". This was a very interesting meeting. The effects of color that were discussed included color in interior and exterior design, like the change of color impressions depending on distance, lighting, color combinations and color interactions. The affects of color that were discussed included how color affects us as in color psychology, color meaning, color associations, and color emotions. The Proceedings of this meeting have been published in hardcopy and on DVD.

The AIC 11th Congress will be held in Sydney, Australia from September 27 to October 2, 2009. The Color Society of Australia is hosting the meeting. The deadline for paper submission is January 30, 2009. Congresses are very special events for AIC since they occur only every four years. Attendance is very rewarding as very high quality papers on state-of-the-art color information are always exchanged. The 2009 Deanne B. Judd Award will be given to a deserving recipient for lifelong accomplishments in the field of color science. This 11th Congress will feature papers on Color in Nature, Color Physics, Color Chemistry, Color Vision, Applications of Color Science, Color Imaging, Color Psychology, Color Communication, Color Theory, Color in Art, Design and the Built Environment, Color in Clothing Fashion, Appearance Measurement, and Color Education. A series of pre-congress Colour Skills workshops will be offered. These workshops will be sessions providing an overview of current issues in colour vision, colour technology and colour in art and design. Additionally there will be two symposia the themes of which will be approached from the perspective of the arts and the sciences. The symposia themes are 'Good' colours, 'bad' colours, humanity and the environment and Appearance: phenomena and measurement. Papers for oral or poster presentation will be subject to review, but they are also offering the opportunity to have author full papers sent to referees. The Congress proceedings will be published in separate volumes, one exclusively for fully refereed papers. The Colour Market is a new concept for this 11th Congress. This Colour Market will have books and examples of Australian design for sale as well as displays of instruments and other products for those who work professionally with colour. The social programme includes a welcome reception as well as a banquet. The choice of excursions will include an opportunity to climb to the top of the Sydney Harbour Bridge. The colours of Australia will be highlights of pre- and post-congress tours. Destinations will include the Great Barrier Reef and the 'Red Centre'. This 11th AIC Color Congress promises to be a very enriching one. For more information, visit the congress website at www.aic2009.org.

The AIC 2010 Interim Meeting will be held in Mar del Plata, Argentina. It will be hosted by the Argentine Color Group and the topic will be Color and Food: From Production to Consumption.

The AIC 2011 Mid-term Meeting will be held in Zurich, Switzerland. It will be hosted by Procolore and the topic will be Staging Color.

Paula J. Alessi

Liaison Report for CIE Division 1 – May 2009

ISO TC6 / WG3 Paper, Board & Pulps – Optical Properties

The next plenary meeting of ISO TC6 will be November 15-20, 2009 in Berlin, Germany. The Working Group, WG3, will meet on November 15th and representatives of the five ISO Authorized Laboratories for TC6/WG3 (the so-called OPAL Group) will meet on November 12-13, 2009. The existing ISO TC6/WG3 Standards are well-advanced, as reported in the January 2009 liaison report. The main issues that will be discussed at the plenary meeting are the following:

1. The preparation of Precision Statements for the various ISO Standards that give the uncertainty due to traceability to different ISO authorized laboratories.

2. The preparation of a new ISO Standard on Basic equations for optical properties, based on a SCAN document.

3. Issues regarding deficiencies in the existing CIE whiteness equation limits for highly fluorescent white papers.

4. Presentations by OPAL and other WG3 members, e.g. on the stability of PTFE, discussion of UVB filters to implement the revised version of ISO 2469, and the implications of the 2008 CEPI-CTS round-robin comparison of k/s measurements on ISO 9416: Paper – Determination of light scattering and absorption coefficients using Kubelka-Munk theory.

Respectfully submitted,

Joanne Zwinkels
National Research Council of Canada
Ottawa, Ontario Canada

Liaison report

- ISO/TC38/SC1: Textile: Colour fastness and measurement
  - ISO 105-J05: 2007 Method for instrumental assessment of colour inconstancy of a specimen with change in illuminant (CMCCON02)
  - ISO/CD 105-A11 NC ballot
    - A method for assessing colourfastness grades by a digital imaging technique.
  - NWI: A numerical definition of standard depths

CIE Division 1 Liaison Report - ISO TC 130 Graphic Arts

ISO TC 130 met most recently the week of 18 May 2009 in Fort Worth, Texas, USA

The following standards have been updated incorporating the latest CIE Division 1 recommendations.

ISO 3664 Viewing conditions – Graphic technology and photography.
This standard now also included an informative annex the guides the user through the process of applying ISO/CIE 23603 to the assessment of D50 simulators. The ISO/CIE 23063 was found to have conflicting specifications that led to a large amount of disagreement in the results of the application of that standard to graphic arts viewing sources. ISO 3664 has been balloted and approved and should be released as a joint standard between TC 130 and TC 42 Photography later this year.

ISO 13655 Graphic technology – Spectral measurement and colorimetric computation for graphic arts images.
This standard has undergone a major revision. The work of 3664 has been incorporated as well as the recommendations from CIE Publication 142 on industrial color differences and CIE Publication 163 on fluorescence in imaging materials. The standard has taken a major step forward in attempting to document the requirements for light sources used in instruments and in viewing cabinets that provide consistent results between the objective measurements of graphic arts media and the visual evaluation of those same media.

ISO 2834 – Graphic technology – Laboratory preparation of test prints
This standard has been split into three new standards that describe how to create prints for visual and instrumental evaluation of color and appearance and the use of the optical properties to assess the resistance of the prints to external agents. The standards now encompass the preparation of test prints from paste inks used in offset lithography, letterpress and intaglio printing (-part 1), liquid inks used in gravure and flexography (-part 2) and used in screen printing (-part 3).

Other activities in TC 130 relate to the system for process control of printing (ISO 12647 series) and do not incorporate the activities of CIE Division 1 directly but have been very influential in the industry.

Respectfully submitted,

Danny C. Rich

Liaison Report of SC28 to the CIE Division 1 meeting, June 2, 2009

ISO/IEC JTC1/SC28 “Office equipment” has a Plenary Meeting next week in Busan/Korea. 13 Standard projects are under Work in ISO/IEC JTC1/SC28 in the areas: Image Quality, Productivity, Yield.

In ISO/IEC JTC1/SC28 five Working Groups (WG) are active:

1. Advisory
2. Consumables
3. Productivity
4. Image Quality Assessment

A “Office Colour Work Group” is intended to be founded at the Korea meeting.

There are 15 P-members and 14 O-members. One main working field is:

Printer Cartridge Yield Standards (ISO name, number and edition or expected)

Color ink 24711: 2007; Color toner 19798: 2007; B/W toner 19752: 2004

Color test pages 24712: 2007; Color ink photo 29102; Color test pages photo 29103

The printer market is dominated by inkjet multifunctional devices (60 Millions sold in 2009) followed by laser printers (20M) and inkjet printers (20 M).

Relations of CIE Division 1 to the work of SC28

ISO/IEC JTC1/SC28 uses the CIELAB standard in many standard documents, for example in ISO/IEC 15775, ISO/IEC TR 19797, ISO/IEC TR 24705. The colour data *rgb* used in these documents have a device-dependent relation to CIELAB.

Some statements of the new intended “Office Colour Work Group (PWG5)”

proposed Goal

To create an environment for the use of colour documents in which office workers who do not have any specialized knowledge about colors can comfortably and efficiently utilize colour equipment in various office environments

proposed Scope

PWG5 will develop standards to enhance the interoperability of colour data for exchange among office colour equipment and will develop standards that evaluate *device color property* for office color equipments. PWG5 will work jointly with the appropriate standards organizations to address these issues in both new standards and revisions of existing standards as necessary

Liaison Report from ISO/IEC JTC1/SC28 to CIE Div. 1

There is a preliminary New Work Item Proposal (doc. j28n1280) based on the German standard series DIN 33872-1 to -6 with the title

Office Machines – Method for the specification of the relative colour reproduction with YES/NO criteria - Parts 1 to 6

This preliminary NWIP consists of six parts:

- Part 1: Classification, terms and principles
- Part 2: Test charts for output properties - Testing of discriminability of 5- and 16-step colour series
- Part 3: Test charts for output properties - Testing of equality for four equivalent grey definitions and discriminability of the 16 grey steps
- Part 4: Test charts for output properties - Testing of equality for two equivalent colour definitions with 5- and 16-step colour series
- Part 5: Test charts for output properties - Testing of elementary hue agreement and hue discriminability
- Part 6: Test charts for output properties - Testing of the equivalent spacing and of the regular chromatic spacing

For download addresses of the test charts of the six parts see:

http://www.ps.bam.de/33872E

Liaison Report from ISO/IEC JTC1/SC28 to CIE Div. 1

There is a relation of DIN 33872-5 to the CIE Reportership R1-47 “Hue Angles of Elementary Colours” to be presented by *Thorstein Seim* (Norway) at this Division 1 meeting.

According to the report CIE R1-47 the hue angles of the CIE-test colours no. 9 to 12 of CIE 13.3 “Colour rendering” create a good approximation of the “Hue Angles of Elementary Colours” Red *R*, Yellow *J*, Green *G* and Blue *B* for CIE standard illuminant D65.

The Elementary hue angles in CIELAB of these CIE-test colours are:

h_{ab} = 26, 92, 162, and 272

There are at present 10 NWI listed by AWG-PWG5 “Office Colour Work Group”, for example no. 9 (doc. j28n1194)

“Colour space standards for offices”
– provide a *device independent* common colour space for office equipment.

I propose a CIE-Reportership R1-X for this topic in the following. Instead of the Elementary *hues* which are defined by a CIELAB hue angle h_{ab} the Elementary *colours* are defined by all three CIELAB data L^*, C^*_{ab}, h_{ab} (or L^*, a^*, b^*).

Liaison Report from ISO/IEC JTC1/SC28 to CIE Div. 1

Title of a new Reportership R1-4x

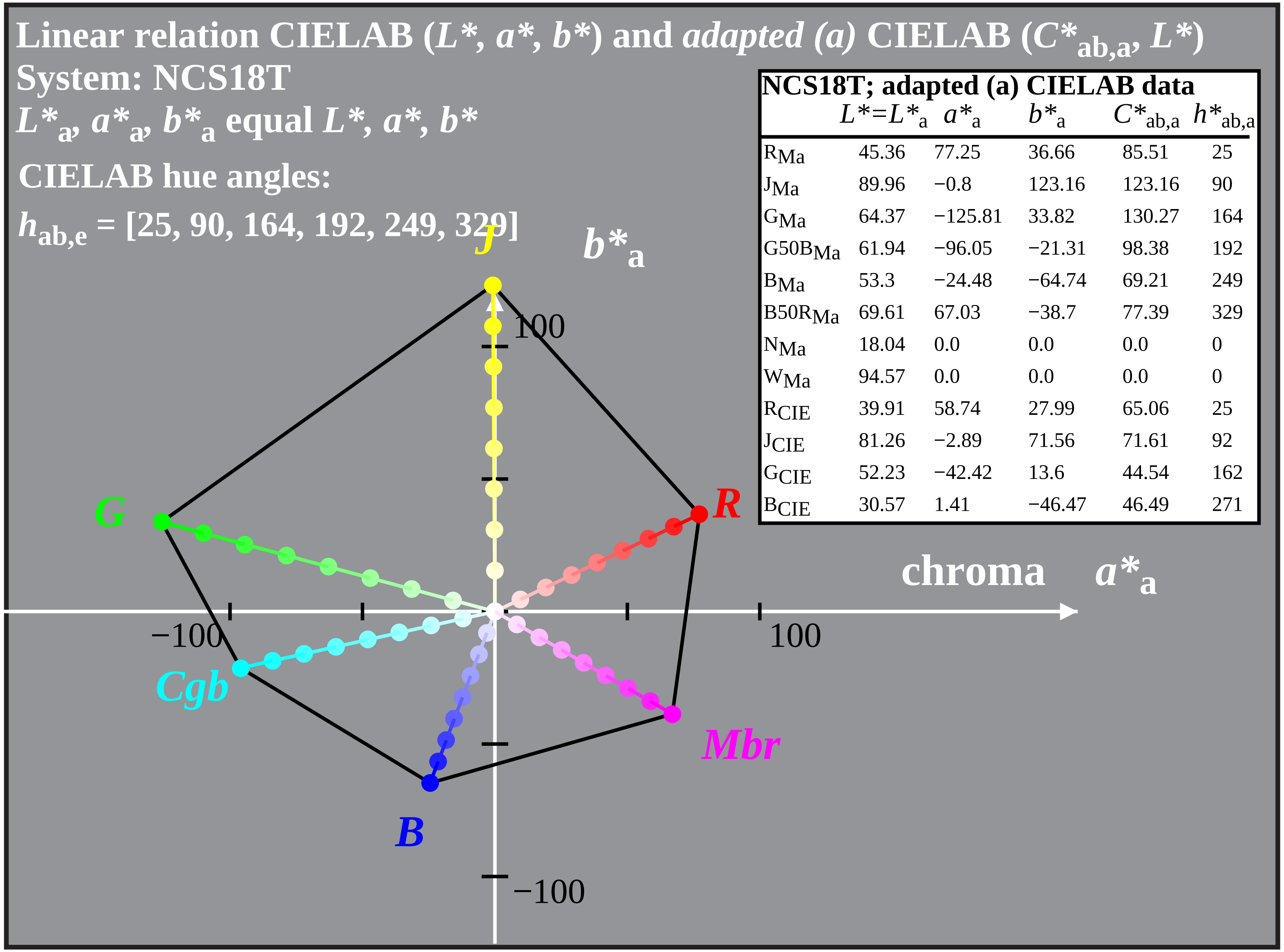
“Models to describe the Elementary colours”.

Terms of Reference:

Model and define the CIELAB data L^*, C^*_{ab}, h_{ab} of the Elementary colours for potential imaging applications if possible by LMS cone sensitivities.

Remarks:

1. The CIELAB data are the basis for a *device independent* relative *rgb* colour space, see four example CIEx030, p. 139-144.
2. For example *Elementary Hue* Red *R* is defined as neither *yellowish* nor *bluish*, compare the R1-47 report which leads to a CIELAB hue angle $h_{ab} = 26$.
3. Additionally the *Elementary Colour* Red R is neither blackish ($n^*=0$) nor whitish ($w^*=0$) and has the relative chroma $c^*=1$. This property leads in addition to the CIELAB data L^* and C^*_{ab}.
4. The CIELAB data of the four elementary colours are for example given in the *Natural Colour System NCS* for the CIE standard illuminant D65 (see Figure 1). For applications the CIELAB data of the intermediate colours C_{gb} and M_{br} are added in Figure 1 and shall be defined too.

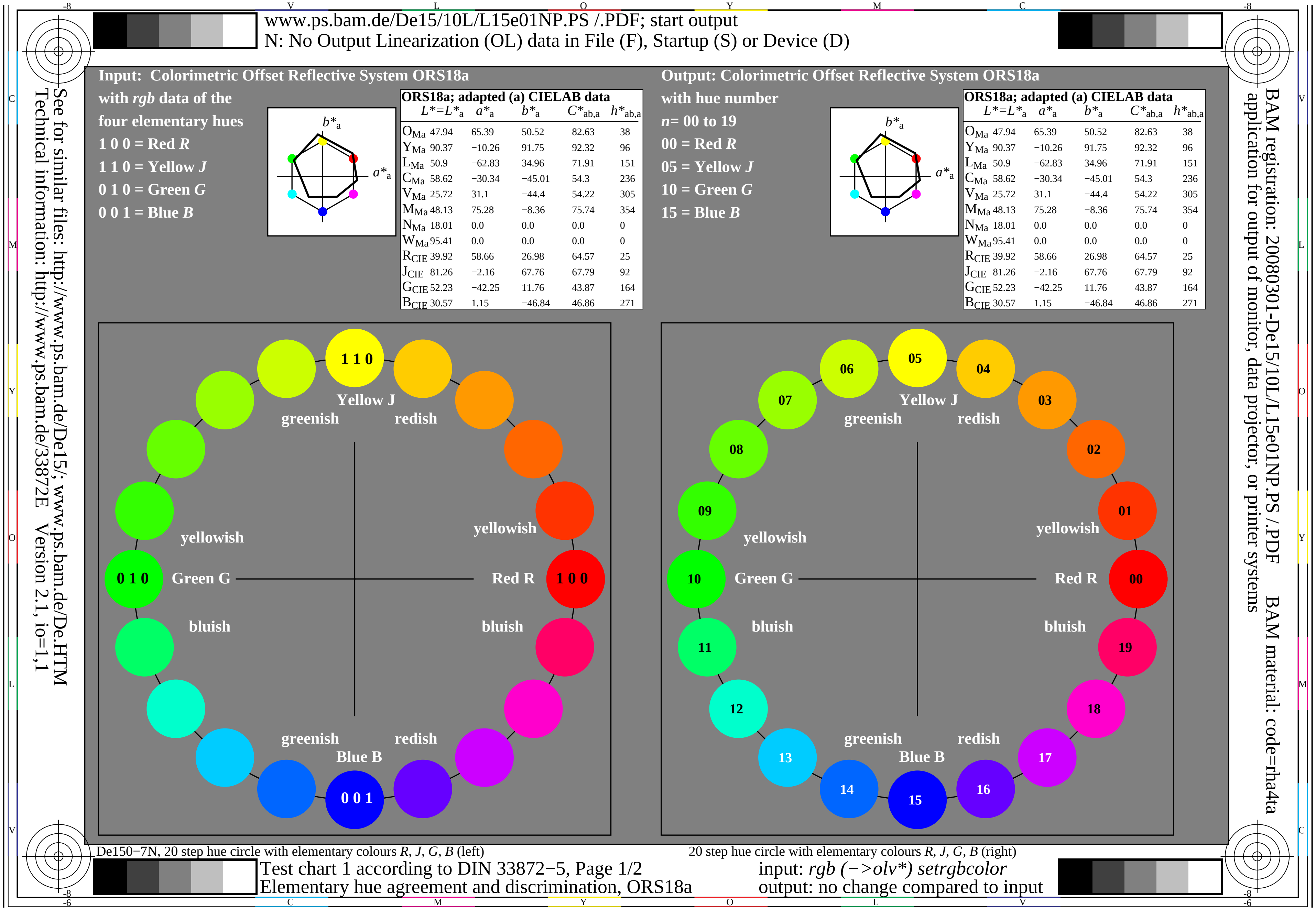


NCS18T; adapted (a) CIELAB data

	$L^*=L^*_a$	a^*_a	b^*_a	$C^*_{ab,a}$	$h^*_{ab,a}$
R_{Ma}	45.36	77.25	36.66	85.51	25
J_{Ma}	89.96	−0.8	123.16	123.16	90
G_{Ma}	64.37	−125.81	33.82	130.27	164
$G50B_{Ma}$	61.94	−96.05	−21.31	98.38	192
B_{Ma}	53.3	−24.48	−64.74	69.21	249
$B50R_{Ma}$	69.61	67.03	−38.7	77.39	329
N_{Ma}	18.04	0.0	0.0	0.0	0
W_{Ma}	94.57	0.0	0.0	0.0	0
R_{CIE}	39.91	58.74	27.99	65.06	25
J_{CIE}	81.26	−2.89	71.56	71.61	92
G_{CIE}	52.23	−42.42	13.6	44.54	162
B_{CIE}	30.57	1.41	−46.47	46.49	271

Fig. 1: The CIELAB data are taken from the Swedish Standard SS 19102:2004 for D65 and for relative blackness *n**=0,05 and relative chroma *c**=0,95 (whiteness *w**=1–*n**–*c**=0,90).

Liaison Report from ISO/IEC JTC1/SC28 to CIE Div. 1



www.ps.bam.de/De15/10L/L15e01NP.PS /.PDF; start output
N: No Output Linearization (OL) data in File (F), Startup (S) or Device (D)

See for similar files: http://www.ps.bam.de/De15/; www.ps.bam.de/De.HTM
Technical information: http://www.ps.bam.de/33872E Version 2.1, io=1,1

Input: Colorimetric Offset Reflective System ORS18a
with *rgb* data of the
four elementary hues
1 0 0 = Red *R*
1 1 0 = Yellow *J*
0 1 0 = Green *G*
0 0 1 = Blue *B*

ORS18a; adapted (a) CIELAB data

	$L^*=L^*_a$	a^*_a	b^*_a	$C^*_{ab,a}$	$h^*_{ab,a}$
O_{Ma}	47.94	65.39	50.52	82.63	38
Y_{Ma}	90.37	−10.26	91.75	92.32	96
L_{Ma}	50.9	−62.83	34.96	71.91	151
C_{Ma}	58.62	−30.34	−45.01	54.3	236
V_{Ma}	25.72	31.1	−44.4	54.22	305
M_{Ma}	48.13	75.28	−8.36	75.74	354
N_{Ma}	18.01	0.0	0.0	0.0	0
W_{Ma}	95.41	0.0	0.0	0.0	0
R_{CIE}	39.92	58.66	26.98	64.57	25
J_{CIE}	81.26	−2.16	67.76	67.79	92
G_{CIE}	52.23	−42.25	11.76	43.87	164
B_{CIE}	30.57	1.15	−46.84	46.86	271

Output: Colorimetric Offset Reflective System ORS18a
with hue number
***n*= 00 to 19**
00 = Red *R*
05 = Yellow *J*
10 = Green *G*
15 = Blue *B*

ORS18a; adapted (a) CIELAB data

	$L^*=L^*_a$	a^*_a	b^*_a	$C^*_{ab,a}$	$h^*_{ab,a}$
O_{Ma}	47.94	65.39	50.52	82.63	38
Y_{Ma}	90.37	−10.26	91.75	92.32	96
L_{Ma}	50.9	−62.83	34.96	71.91	151
C_{Ma}	58.62	−30.34	−45.01	54.3	236
V_{Ma}	25.72	31.1	−44.4	54.22	305
M_{Ma}	48.13	75.28	−8.36	75.74	354
N_{Ma}	18.01	0.0	0.0	0.0	0
W_{Ma}	95.41	0.0	0.0	0.0	0
R_{CIE}	39.92	58.66	26.98	64.57	25
J_{CIE}	81.26	−2.16	67.76	67.79	92
G_{CIE}	52.23	−42.25	11.76	43.87	164
B_{CIE}	30.57	1.15	−46.84	46.86	271

BAM registration: 20080301-De15/10L/L15e01NP.PS /.PDF BAM material: code=rha4ta
application for output of monitor, data projector, or printer systems

De150−7N, 20 step hue circle with elementary colours *R*, *J*, *G*, *B* (left)

20 step hue circle with elementary colours *R*, *J*, *G*, *B* (right)

Test chart 1 according to DIN 33872−5, Page 1/2
Elementary hue agreement and discrimination, ORS18a

input: *rgb (−>olv*) setrgbcolor*
output: no change compared to input

Fig. 2: Relation between device dependent *rgb* data and CIELAB data $L^*C^*_{ab}h_{ab}$ for ORS18a

Fig. 2 shows the relation between the device-dependent *rgb* data, for example *rgb* = (0, 0, 1) for blue, the colour output of the colour number 15 and the *adapted* CIELAB data $L^*\ C^*_{ab}$, h_{ab} of the standard offset print system ORS18a (compare table and ISO/IEC 15775). For the adapted CIELAB data it is valid $(a^*_N, b^*_N) = (a^*_W, b^*_W) = (0, 0)$ for both Black *N* and White *W*. The lightness range of the System ORS18a is between L^*=18 and L^*=95 (see table in Fig. 1).

According to Fig. 2 all *rgb*-input data in the range 0 to 1 will produce output colours with *adapted* CIELAB data $L^*\ C^*_{ab,a}$, $h_{ab,a}$ if the system ORS18a of standard offset printing on standard offset paper is used.

If the device-independent CIELAB data $L^*\ C^*_{ab}$, h_{ab} are given in a new CIE Report R1-X, then a completely **device-independent** relation between *rgb*-input data and CIELAB data $L^*\ C^*_{ab}$, h_{ab} is defined.

With this relation usually not all *rgb*-input data in the range 0 to 1 can be printed because the *visual elementary color gamut* defined by the elementary colours is larger (except in the yellow-red area) compared to the ORS18a gamut.

IALA: International Association of Marine
Aids to Navigation and Lighthouse
Authorities - Ian Tutt 05.05.2009

Research & Radionavigation
General Lighthouse Authorities
United Kingdom and Ireland

IALA Liaison Report to CIE – 5th May 2009

Events

IALA held a very successful IALABATT/IALALITES Workshop in Copenhagen in October 2008. Some 60 representatives from round the world attended the event which focussed on power supplies and signal lights for marine Aids-to-Navigation.

Figure 1 Attendees at the IALABATT/IALALITE Workshop in Copenhagen

IALA Industrial members provided an excellent display of equipment and presentations on the first day ranged from the use of super-capacitors and fuel cells to signal conspicuity and methods of determining effective intensity.

Figure 2 Marine Aid-to-Navigation Products on Display at the Workshop

The main work of the workshop was to update IALA recommendations and guidelines, and significant work was done in finalising some 23 documents.

Japan Coast Guard held an Expert Meeting in Tokyo during November 2008 on the topic of Standardization of New Lighting Methods for Marine Aids to Navigation. The meeting broached the subject of visual perception and the executive summary of the report concluded:

"1. That a flickering LED light is conspicuous and therefore has the possibility of becoming a new lighting method for marine aids to navigation however the flicker range is shorter than the nominal luminous range of the flickering light under certain conditions and thus the designing the flickering light should be done carefully. Further study and research are needed for its practical application;

2. That Effective Intensity still is a useful tool for designing of marine visual aids to navigation. The Modified Allard Method developed by CIE TC2-49 has paved the way for calculating the effective intensity of all intensity profiles including a train of pulses used in marine aids to navigation;

3. That Apparent Intensity - brightness at supra-threshold levels - is an important concept for designing marine visual aids to navigation and therefore the development of a robust and universal model is required;

4. That Conspicuity is becoming a more important consideration when designing marine visual aids to navigation in built-up areas with many rival lights. However conspicuity is a complex matter and therefore further research on this matter is desired;"

Recommendations were as follows:

"5. That research bodies as well as marine visual aids to navigation authorities are encouraged to conduct research on both apparent intensity and conspicuity. CIE and IALA should promote such research;

6. That CIE and IALA should strengthen their relationship further through higher level liaison;

7. That as the host nation of the meeting, the Japan Coast Guard should submit the report of the meeting including the copy of the presentations to the relevant committees of both IALA and CIE."

Accordingly, CIE should receive a copy of the full report of the meeting from Japan Coast Guard in due course.

New Publications

Of the recommendations approved by IALA Council in December, document E-200 was significant. It is a recommendation on Marine Aid-to-Navigation Signal Lights and is divided into six parts. The recommendation deals with colours of lights as well as measurement methods and determination of effective intensity. This and other IALA documents can be downloaded free of charge from the IALA website under 'Publications'. http://site.ialathree.org/

The Chairman of IALA EEP Committee would like to express his sincere thanks for the invaluable assistance received from CIE members during the drafting of this important recommendation.

Committee Activity

The Aid-to-Navigation Management (ANM) and Engineering, Environment and Preservation (EEP) Committees of IALA are carrying out work in the area of visual conspicuity. Several working groups are looking at topics such as the effect of synchronising buoy lights and the effect of a flickering flash, as well as trying to construct a conspicuity model. Several IALA members are carrying out their own research and the Research & Radionavigation Directorate is proposing to fund a PhD study into conspicuity related phenomena. If any CIE members would like to contribute or partner this study, please contact Ian Tutt in the first instance.

An IALA Guideline on the Conspicuity of Marine Signal Lights is currently being drafted. This will cover the characteristics and effects of the observer, the atmosphere, the target (signal light) and background.


The Observer


The Atmosphere


The Target


The Background

Other Topics of Interest

The use of LED products in marine signals is becoming more widespread with omnidirectional beacons of up to 50,000cd being available from some suppliers.

Figure 3 Ten-tier Red LED Omnidirectional Light giving around 35,000cd

The mariner's perception of such lights is often different to that predicted by photometric measurement, in particular white and red flashing lights. More knowledge is required as to why, in some instances, LEDs appear far more conspicuous than their filtered incandescent counterparts despite their photometric values being similar. Almost certainly the adaptation state of the observer plays a part. Preferential atmospheric scattering over the large distances used by mariners can also contribute. Atmospheric attenuation of shorter wavelengths can cause imbalance in the perception of red and green lights, it can also cause a colour shift in white lights making white LEDs appear yellow. As mentioned in the Japan Coast Guard report, conspicuity is a complex matter!

Tests are also being undertaken in the German Waterways Administration and in the General Lighthouse Authorities of UK and Ireland on the use of high power LED packages in existing Fresnel lenses. The Osram Ostar (17W) and the Citizen CL-L220 (16W) are two of the packages under test. Initial results show that in some lenses, intensities of 600,000cd were produced. Such LED packages offer a relatively large illuminated area, which is useful in some of the very large Fresnel lenses traditionally used in lighthouses.

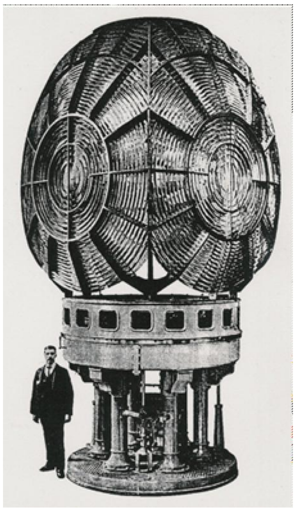


Figure 4 Hyper-radial Rotating Optic from 1908 with three Fresnel Lenses

Ian Tutt
GLA R&RNAV, Trinity House, Harwich UK
ian.tutt@thls.org

Report on Liaison ISO/TC159 “Ergonomics”

n TC159/WG2 “Ergonomics for people with special requirements”

The 2nd version of TR22411 “*Ergonomic data and guidelines for the application of ISO/IEC Guide 71 to products, and services to address the needs of older persons and persons with disabilities*” is being developed by collecting more data useful for the design for older people and people with disabilities. These data include vision data and design methods based on those data, which are in good harmonization with the CIE data and lighting methods.

n TC159/SC5/WG5 “Physical environment for people with special requirements”

ISO/CD/24502 “*Ergonomics – Accessible Design – Specification of age-related luminance contrast in visual signs and displays*” is being developed to the stage of DIS (Draft International Standard) and the voting for DIS is expected to start in June, 2009. The CIE will be asked officially for comments on this document.

In the previous voting stage for CD (Committee Draft), the CIE sent a comment that the new definition of “age-related luminance” may confuse with the already existing luminance definition and therefore should be changed. This comment was accepted so that “age-related luminance” was replaced by “age-related luminance contrast”. No serious conflict is expected in the future. The CIE further pointed out that in the calculation of age-related luminance contrast, the wavelength range, 400-700 nm, should be identical to the CIE range, 380-780 nm, for calculation in photometry and colorimetry. This comment was also accepted.

Ken Sagawa
May 14, 2009