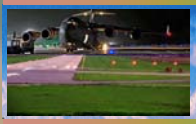


Colour Vision Assessment Course - Leipzig University
26th October 2012

Review of Human Colour Vision
a. Variability in Normal and Congenital Colour Vision
b. How to measure colour, the CAD test, definition of the standard normal CAD unit
c. Normal age-corrected colour thresholds
d. Clinical and occupational applications of colour assessment

CAD Pass/Fail Limits in Aviation
a. The use of colour signals in occupational environments
b. Work that led to the CAD Pass / Fail limits for pilots
c. EASA requirements for ATCOs

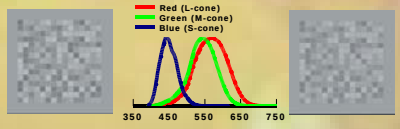
Applied Vision Research Centre

JOHN BARBUR

Applied Vision Research Centre,
The Henry Wellcome Laboratories for Vision Science,
School of Health Sciences,
City University London

City University

THE CAD TEST



COVENTIONAL COLOUR SCREENING TESTS

Ishihara / Dvorine

Nagel anomaloscope

HW lantern

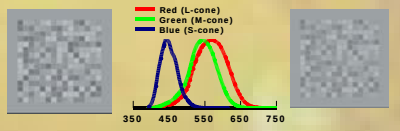
Beyne

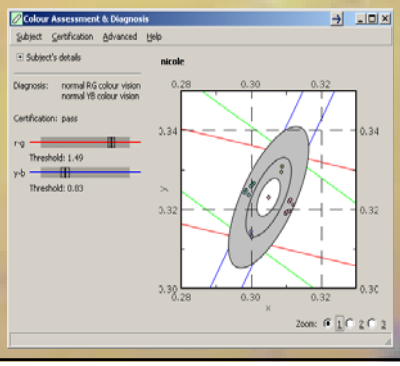
Spectrolux

Colour Vision Assessment Course - Leipzig University
26th October 2012

Working with the CAD test
a. Menu options
b. Fast screening / Certification environments
c. Advanced tests / Pass-Fail limits
d. Interpretation of results (normal, congenital and acquired deficiency)
e. Display calibration program

THE CAD TEST



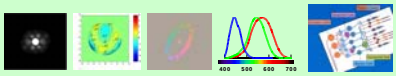


NORTHAMPTON COLLEGE OF ADVANCED TECHNOLOGY (1896)

City University (2011)

Applied Vision Research Centre, City University (1987)

The Henry Wellcome Laboratories for Vision Sciences (2005)



Applied Optics Department (1903)

BACKGROUND — The processing of colour and luminance contrast signals

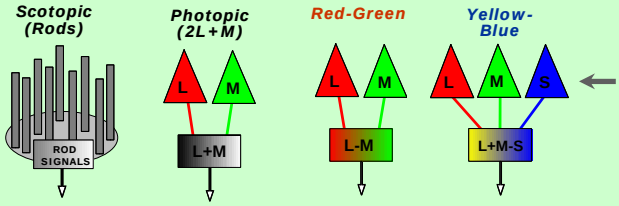
VISION INFORMATION CHANNELS

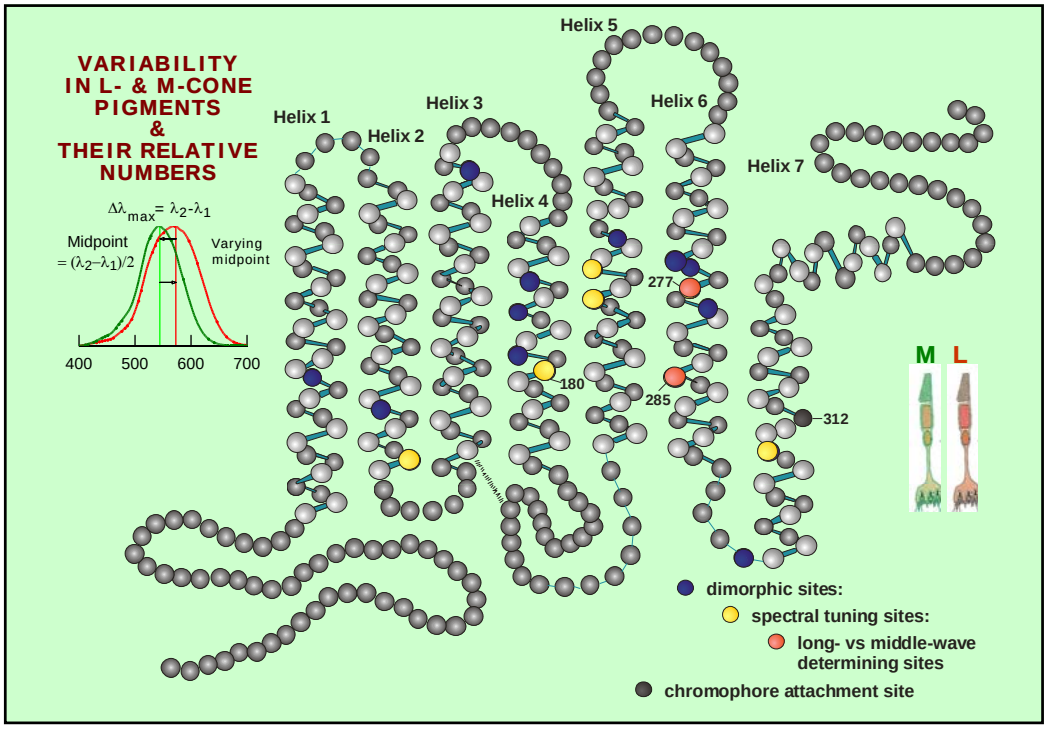
LUMINANCE CONTRAST CHANNELS

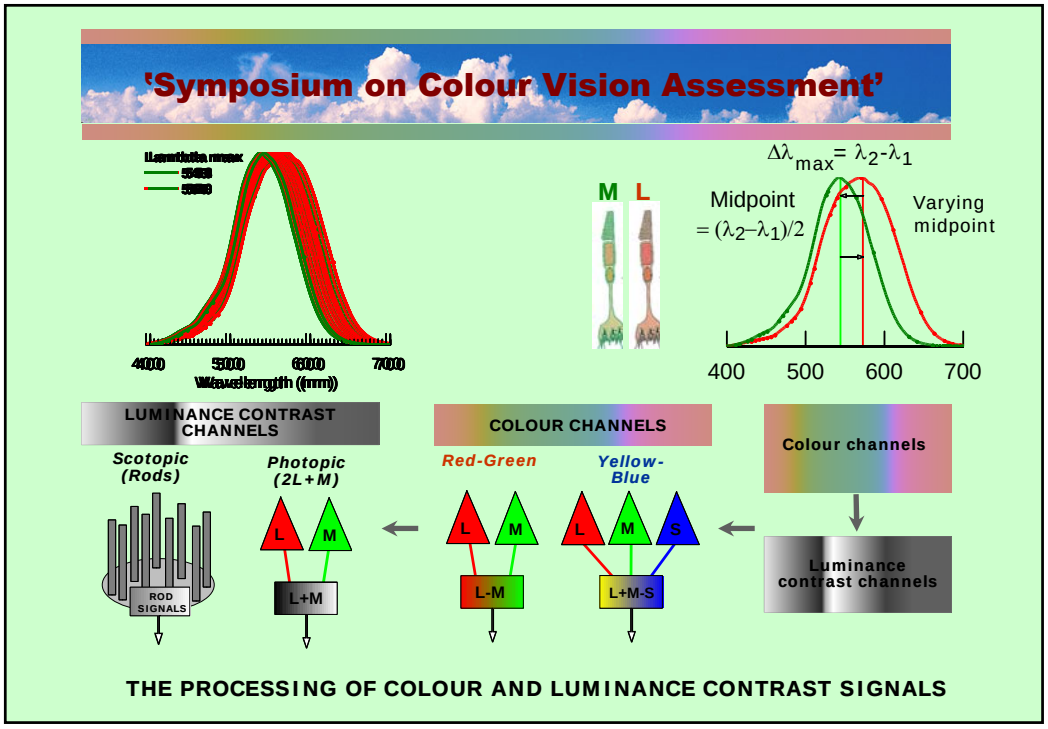
COLOUR CHANNELS

Colour channels

Luminance contrast channels

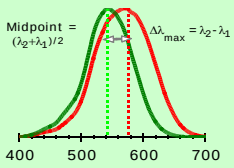



VARIABILITY IN L- & M-CONE PIGMENTS & THEIR RELATIVE NUMBERS
$\Delta\lambda_{max} = \lambda_2 - \lambda_1$
Midpoint $= (\lambda_2 - \lambda_1)/2$
Varying midpoint
400 500 600 700
Helix 1
Helix 2
Helix 3
Helix 4
Helix 5
Helix 6
Helix 7
277
180
285
312
M L
dimorphic sites:
spectral tuning sites:
long- vs middle-wave determining sites
chromophore attachment site

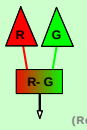

'Symposium on Colour Vision Assessment'
400 500 600 700
Wavelength (nm)
M L
$\Delta\lambda_{max} = \lambda_2 - \lambda_1$
Midpoint $= (\lambda_2 - \lambda_1)/2$
Varying midpoint
400 500 600 700
LUMINANCE CONTRAST CHANNELS
COLOUR CHANNELS
Colour channels
Scotopic (Rods)
Photopic (2L+M)
Red-Green
Yellow-Blue
ROD SIGNALS
L
M
L+M
L-M
S
L+M-S
Luminance contrast channels
THE PROCESSING OF COLOUR AND LUMINANCE CONTRAST SIGNALS

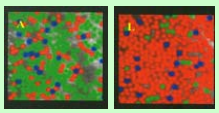
FACTORS THAT CAUSE VARIATION IN CHROMATIC SENSITIVITY

- **Genetically determined shifts in the peak spectral responsivity of cone photoreceptors**



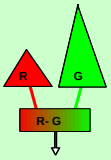
- **Variation in the L:M cone photoreceptor ratio**

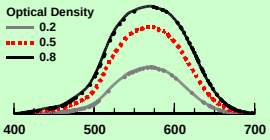




(Roorda et al, Nature, 397, 1999) with additional photographs made by Heidi Hofer

- **Differences in the optical density of L- and M- cones (Typical values in the range: 0.2 to 0.8)**





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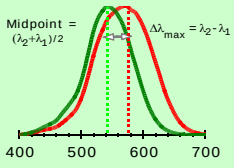

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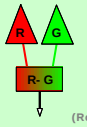

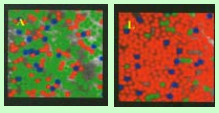

(Roorda et al, Nature, 397, 1999) with additional photographs made by Heidi Hofer

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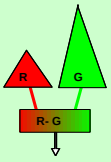
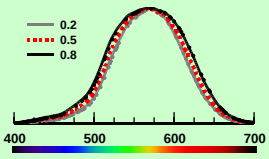
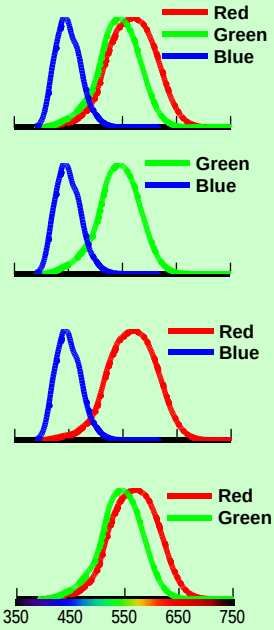




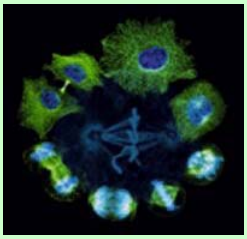
CLASSIFICATION OF COLOUR VISION

From: Sharpe, Stockman, Jaegle & Nathans, In "*Colour Vision*", 1999



Colour Deficiency
Dichromatism

	Absent Cones	"Different" cones
R	protan	prota-nomalous
G	deutan	deutera-nomalous
B	tritan	



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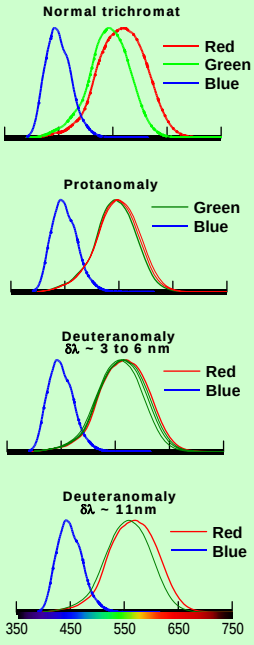
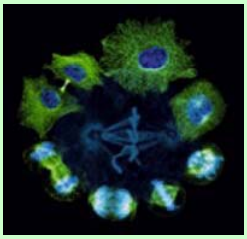
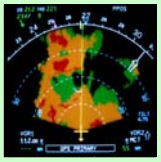


Anomalous
Trichromatism

	Absent Cones	"Different" cones
R		prota-nomalous
G		deutera-nomalous
B		



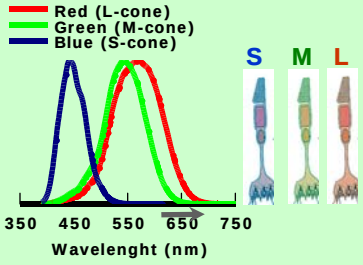
COLOUR VISION ASSESSMENT

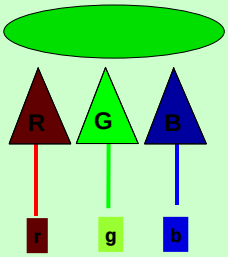


How do we quantify hue sensation and the strength of colour signals?

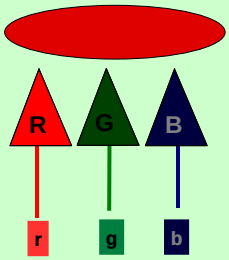
Colour charts, atlases, tristimulus values, chromaticity coordinates

Chromaticity relates directly to the ratio of cone photoreceptor signals





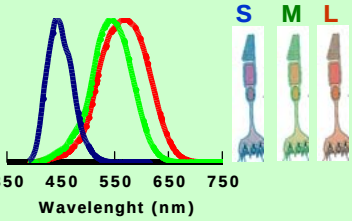
1: 15: 3



15: 3: 1

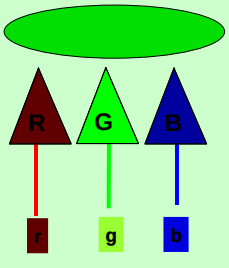
CIE (X,Y,Z) - tristimulus space

- 3D space that plots three quantities directly related to cone photoreceptor signals



CIE (x,y) – chromaticity chart

- 2D chart that plots normalised X,Y,Z tristimulus values



1: 15: 3

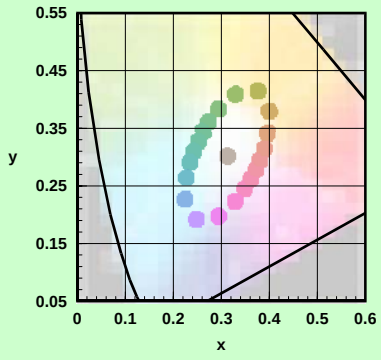
$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

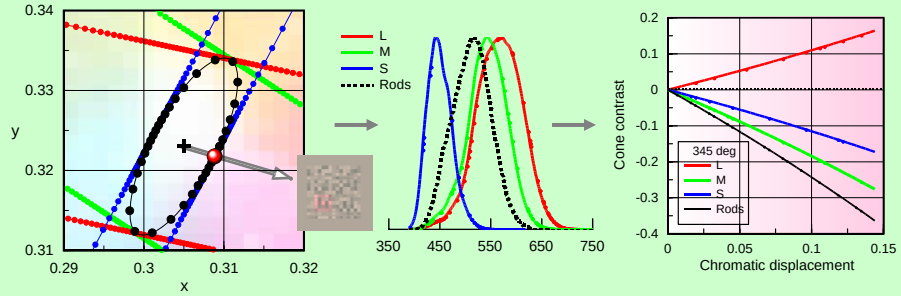
$$z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

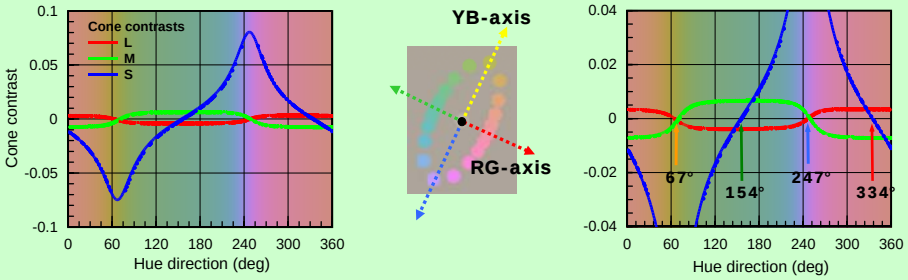
$$z = 1 - (x + y)$$



CONE SIGNALS AND THE CIE (x,y) CHROMATICITY CHART

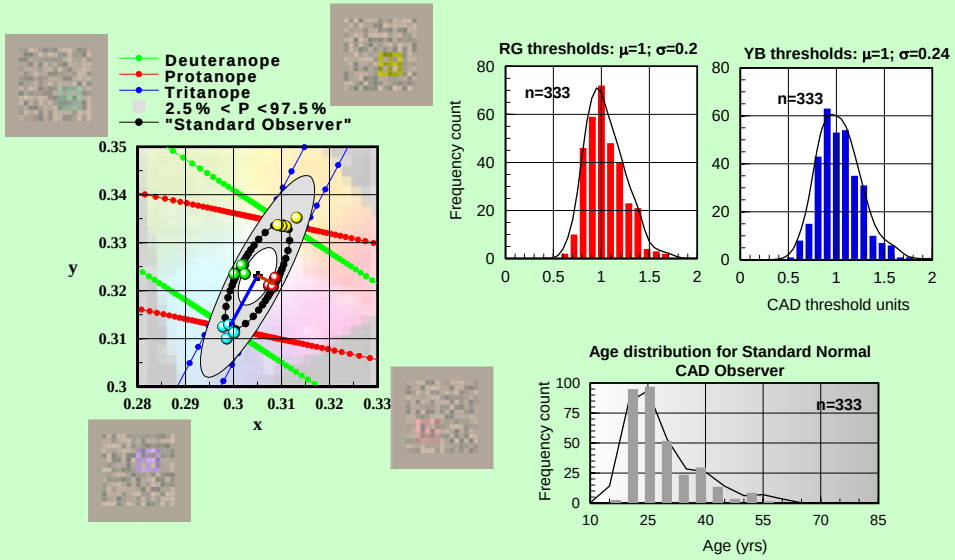


THRESHOLD CONE CONTRAST SIGNALS FOR NORMAL TRICHROMATS

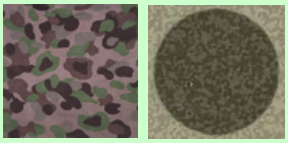


"Standard Normal" CAD Observer

BASED ON: 330 NORMAL TRICHROMATS



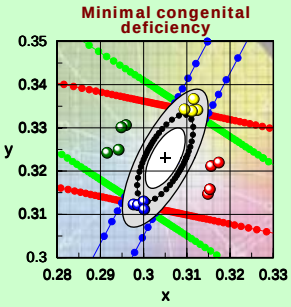
WHY DO WE BURY THE COLOURED SIGNALS IN DYNAMIC LUMINANCE CONTRAST NOISE?

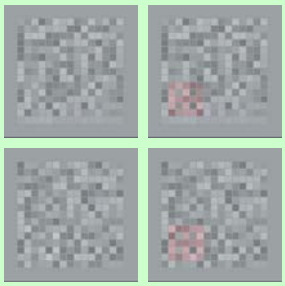


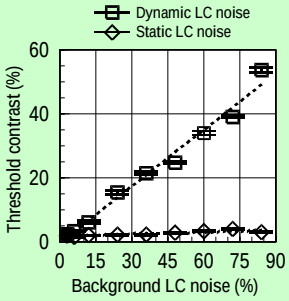
The CAD test is based on perturbation techniques for studying camouflage

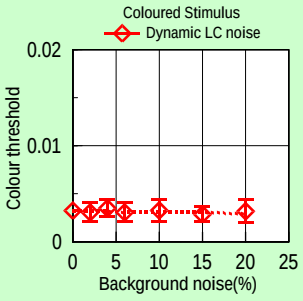
Normal Trichomat
RG=0.68
YB=0.71

Mild Deutan Deficiency
RG=2.79
YB=1.15

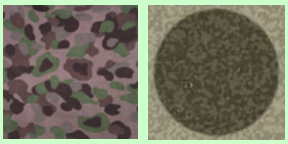








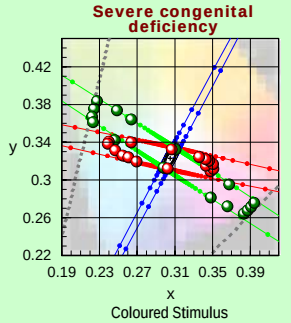
WHY DO WE BURY THE COLOURED SIGNALS IN DYNAMIC LUMINANCE CONTRAST NOISE?

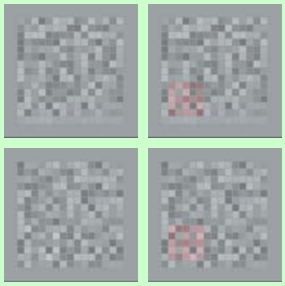


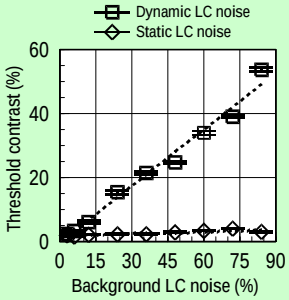
The CAD test is based on perturbation techniques for studying camouflage

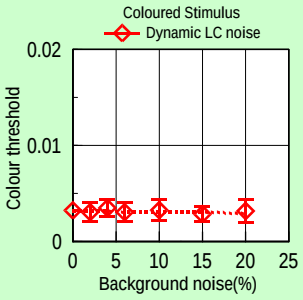
Severe Protan Deficiency
RG=12.67
YB=0.93

Deutanope (dichromat)
RG=22.44
YB=1.03

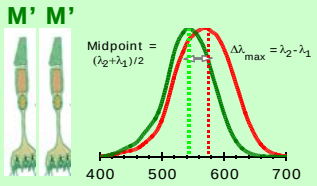


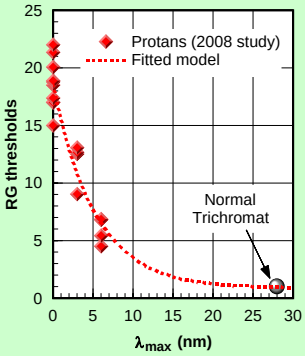


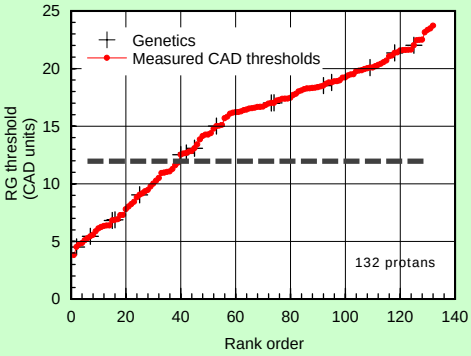




VARIATION IN CHROMATIC SENSITIVITY IN "PROTAN DEFICIENCY"



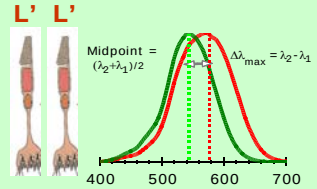


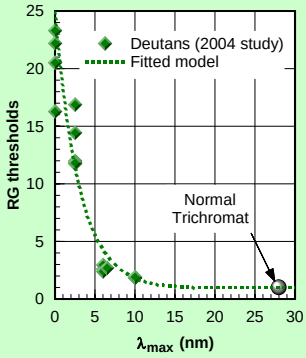


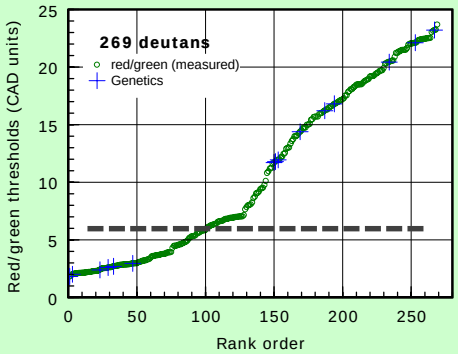
Mean lamba max: M' \ M'	529.7	529.5	529	533.3	531.6	536
Protan deficiency						
529.7	0	0.2	0.7	3.6	1.9	6.3
529.5	0.2	0	0.5	3.8	2.1	6.5
529	0.7	0.5	0	4.3	2.6	7
533.3	3.6	3.8	4.3	0	1.7	2.7
531.6	1.9	2.1	2.6	1.7	0	4.4
536	6.3	6.5	7	2.7	4.4	0

$\delta\lambda_{max}$ changes in protans

VARIATION IN CHROMATIC SENSITIVITY IN "DEUTAN DEFICIENCY"







Mean lamba max: L' \ L'	552.4	556.7	549.6	553	548.8	544.8
Deutan deficiency						
552.4	0	4.3	2.8	0.6	3.6	7.6
556.7	4.3	0	7.1	3.7	7.9	11.9
549.6	2.8	7.1	0	3.4	0.8	4.8
553	0.6	3.7	3.4	0	4.2	8.2
548.8	3.6	7.9	0.8	4.2	0	4
544.8	7.6	11.9	4.8	8.2	4	0

$\delta\lambda_{max}$ changes in deutan subjects

ESTABLISHING "NORMAL", AGE-CORRECTED COLOUR LIMITS
(Summary of exclusion criteria)

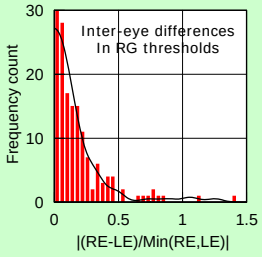
Over 400 subjects (age range 4-90yrs) were recruited from:

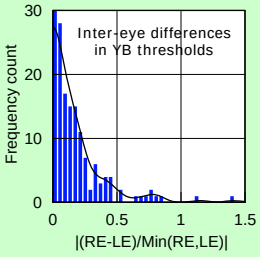
City University London

Damme Optometrie Practice, Netherlands

1. **Congenital colour deficient subjects were excluded (elevated RG thresholds and normal YB)**
2. **Subjects with medical conditions such as diabetes, hypertension and ocular abnormalities were also excluded**
3. **Subjects with abnormal fundus appearance or drusen were excluded**
4. **Subjects with a statistically significant difference in RG and/or YB thresholds between the two eyes were excluded**

Right Eye **Left Eye**





RE > LE asymmetry value

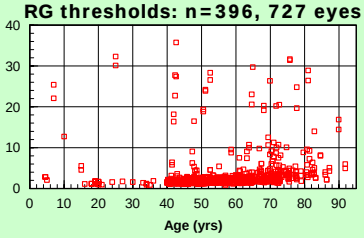
$$\frac{|RE - LE|}{\text{Smallest of } RE \text{ or } LE}$$

Limits (0.95)	RG	YB
Upper Limit	0.437	0.413

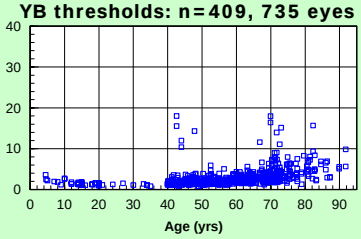
RG AND YB COLOUR THRESHOLDS VERSUS AGE

All subjects - no filtering

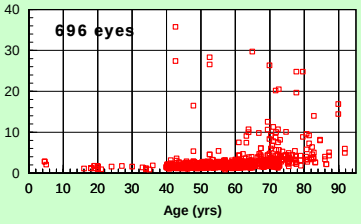
RG thresholds: n=396, 727 eyes

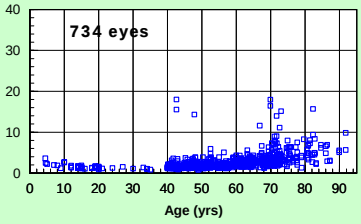


YB thresholds: n=409, 735 eyes



After filtering for congenital deficiency

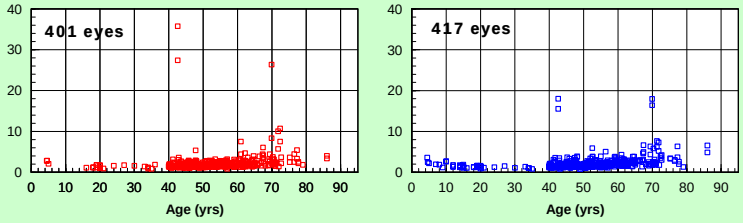




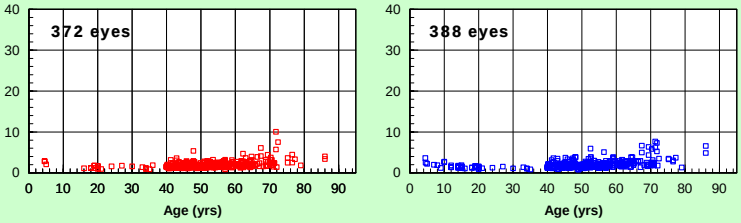
RG AND YB COLOUR THRESHOLDS VERSUS AGE

After filtering for recognized medical conditions

Hypertension (88), diabetes & hypertension (14), diabetes (7), ocular diseases (44)



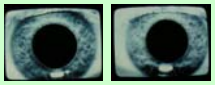
After filtering for abnormal fundus and drusen (18)

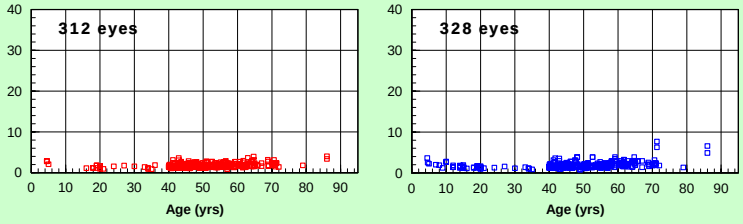


RG AND YB COLOUR THRESHOLDS VERSUS AGE

After filtering for right / left eye asymmetry (27)

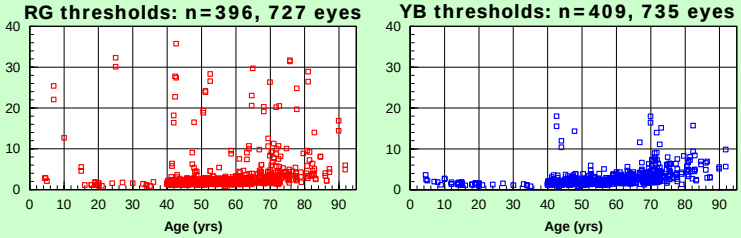
$$\left|\frac{RE - LE}{\text{smallest of } RE \,\&\, LE}\right|$$



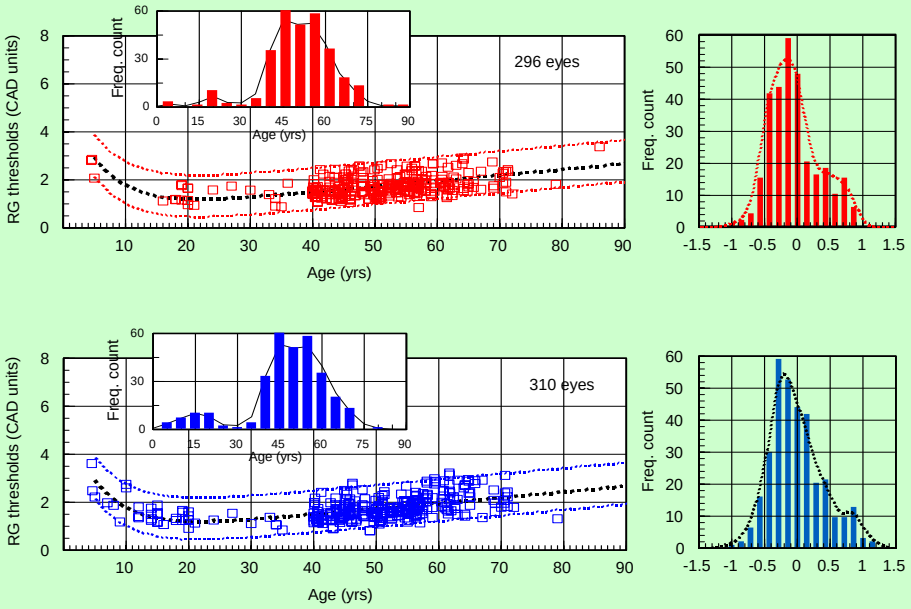


All subjects - no filtering

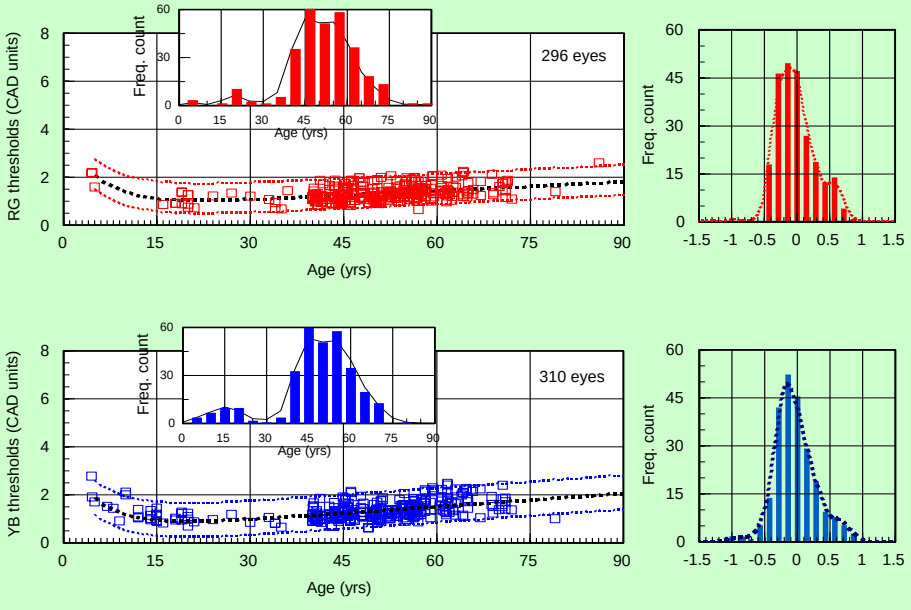
RG thresholds: n=396, 727 eyes **YB thresholds: n=409, 735 eyes**



MONOCULAR THRESHOLDS - NORMAL AGING LIMITS (±2σ)



BINOCULAR THRESHOLDS - NORMAL AGING LIMITS (±2σ)



CONGENITAL & ACQUIRED LOSS OF CHROMATIC SENSITIVITY

Prevalence of congenital colour vision deficiencies

Accepted Prevalence of Color Vision Deficiencies#						
Protanope	Deuteranope	Tritanope	P-nomalous	D-nomalous	T-nomalous	Total
1	1.1	0.002	1	4.9	0	8.002

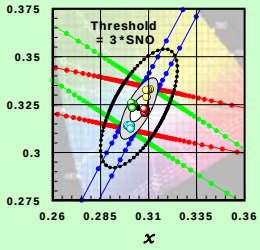
#Gegenfurtener, K.R. & Sharpe, L.T. "Color Vision, from Genes to Perception", Cambridge University Press.

Prevalence of acquired loss of chromatic sensitivity ?

Systemic and / or eye diseases / neuro-toxicity effects: prevalence is age related and loss is progressive (i.e., ~ 1% at 45 to 15to 25 % above 65 yrs)

- Autoimmune related retinopathy & neuropathy
- Melanoma associated retinopathy
- Rod-cone dystrophies
- Retinitis pigmentosa
- Optic Neuritis
- Vitamin A deficiency
- Glaucoma
- Age Related Macula Degeneration
- Diabetic retinopathy

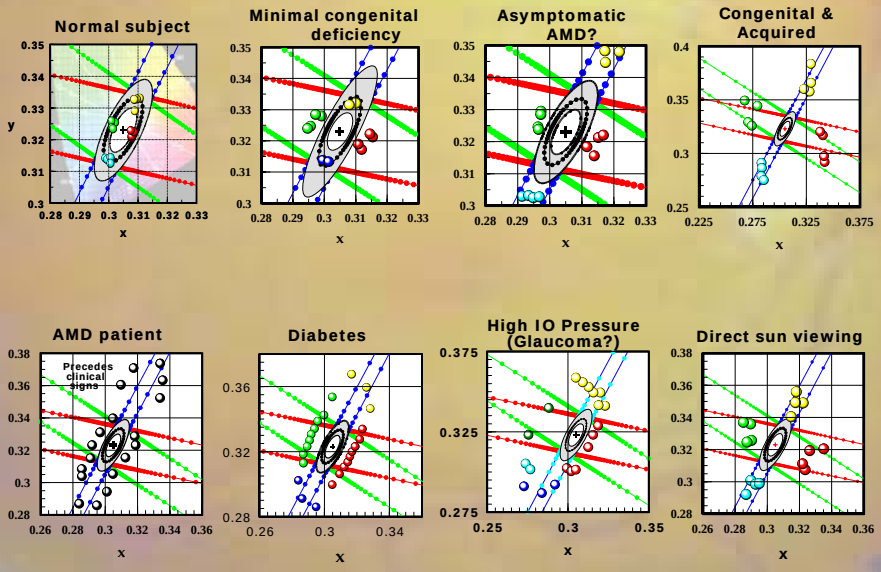
Predicted appearance of various colours in a subject with 3 times the normal colour thresholds



As seen by "normal" subject

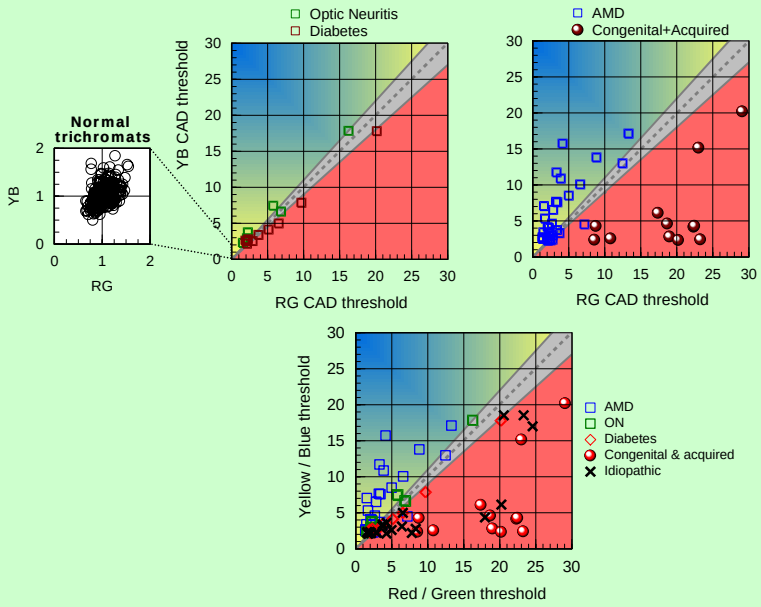
As seen by patient

CLINICAL APPLICATIONS OF COLOUR VISION ASSESSMENT: EXAMPLES OF ACQUIRED LOSS OF COLOUR VISION



CLINICAL APPLICATIONS OF COLOUR VISION ASSESSMENT

RED / GREEN v YELLOW / BLUE LOSS



CLINICAL APPLICATIONS OF COLOUR VISION ASSESSMENT:

LOSS OF COLOUR VISION IN DIABETES

219 diabetic patients (141 males, 78 females - 8 with congenital RG colour deficiency).

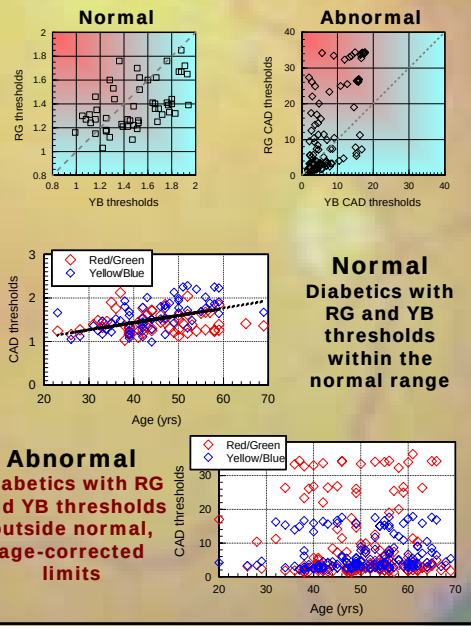
Only ~ 28% of the patients have RG and YB thresholds that fall within the normal range.

Imperial College Abu Dhabi Diabetes Centre

Inclusion criteria:

a) Best corrected visual acuity of 6/18 or better, No more than moderate non-proliferative retinopathy (R2) or
b) Moderate maculopathy (M2), and no co-existing glaucoma.
c) Cataract was not a reason for exclusion provided the acuity was adequate.

Patients had a full eye examination (including colour photography and macular OCT), a full assessment of their diabetes, and the CAD colour vision test.



Normal
Diabetics with RG and YB thresholds within the normal range

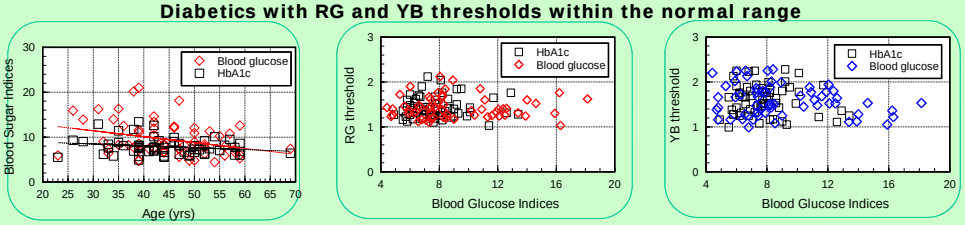
Abnormal
Diabetics with RG and YB thresholds outside normal, age-corrected limits

LOSS OF COLOUR VISION IN DIABETES: Correlation with Blood Glucose Indices

(Acknowledgments to Imran Ansari & Chris Canning: [2]Moorfields Eye Hospital Dubai)

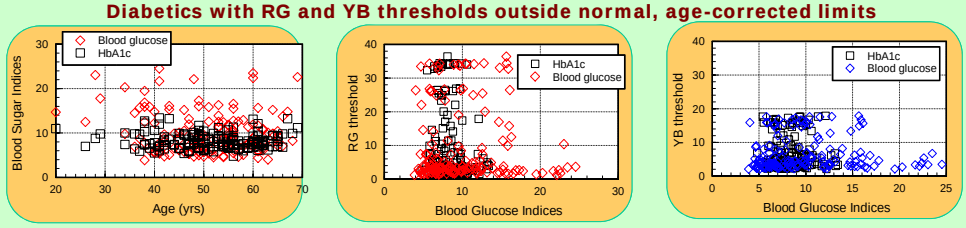
Normal

Diabetics with RG and YB thresholds within the normal range



Abnormal

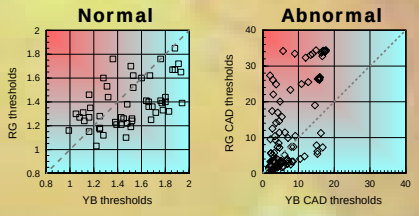
Diabetics with RG and YB thresholds outside normal, age-corrected limits

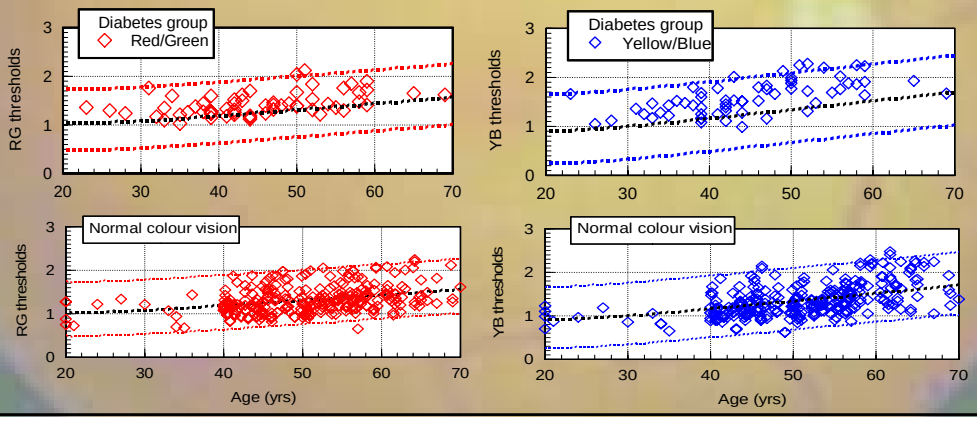


CLINICAL APPLICATIONS OF COLOUR VISION ASSESSMENT: LOSS OF COLOUR VISION IN DIABETES

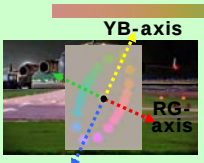
RG and YB thresholds in diabetics with colour thresholds within normal, age-corrected limits

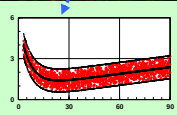
RG and YB thresholds in normal, non-diatetic trichromats

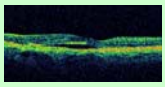


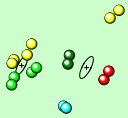


CAD TEST APPLICATIONS WITHIN OCCUPATIONAL AND CLINICAL ENVIRONMENTS









I. The test quantifies the severity of RG and YB colour vision loss with applications within occupational environments

II. The test provides age-corrected, normal limits for RG and YB thresholds from 4 to 90 years of age

III. The test provides reliable indication of acquired loss of chromatic sensitivity with relevance to the detection of preclinical diseases of the retina and / or systemic diseases that affect vision

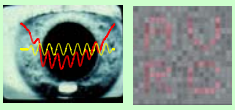
IV. The test cannot be leant and all other cues that can affect the outcome of conventional tests are eliminated

V. The test can be used to detect automatically any significant changes on repeated testing when monitoring progress of disease or effects of treatment

VI. The CAD test is supplied with display calibration facilities and pass / fail certification limits are also provided for some occupations

ACKNOWLEDGEMENTS

http://www.city.ac.uk/avrc



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