

Modeling age-related ocular media changes using the Farnsworth Munsell 100-Hue Test

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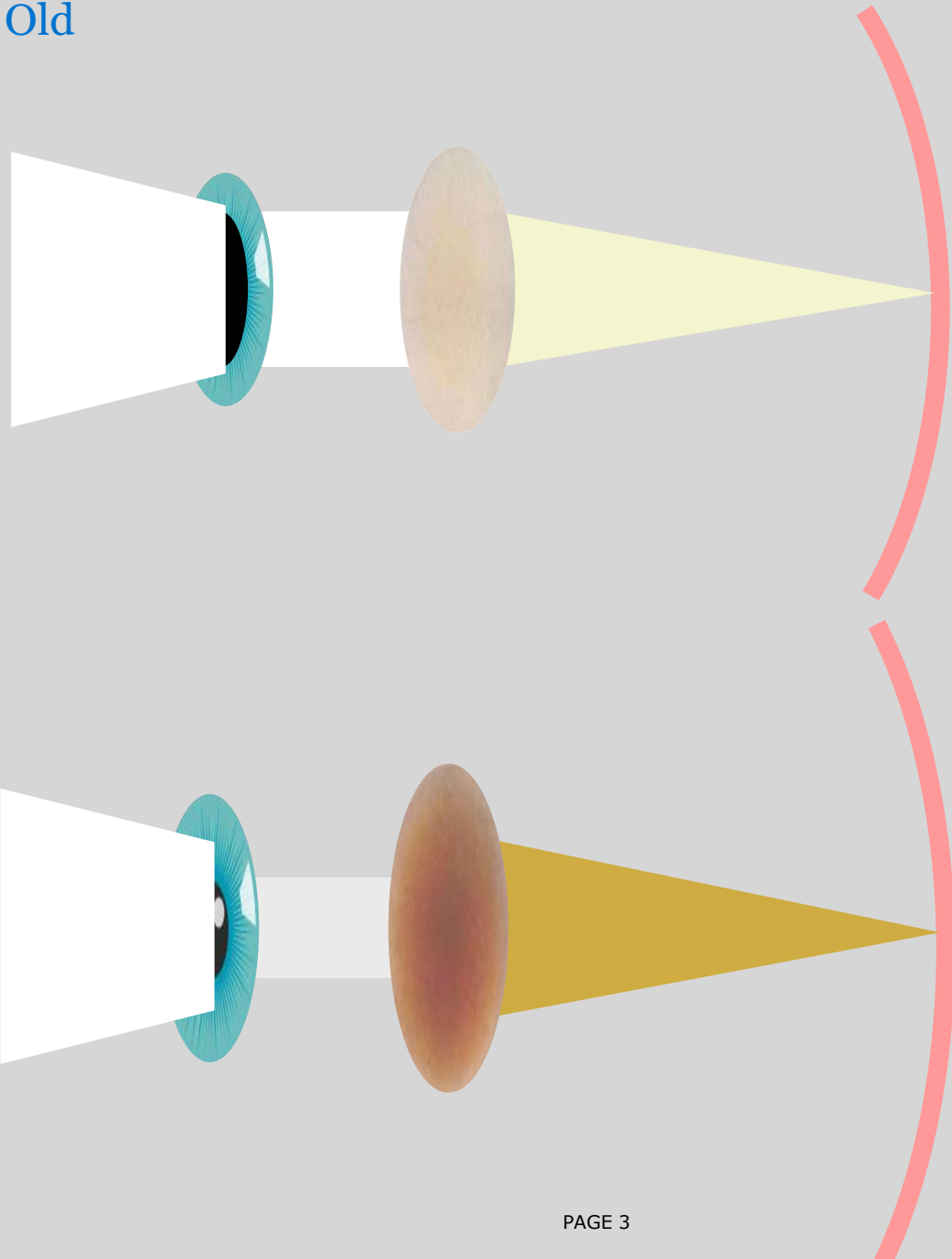
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Study Objectives

- To examine the theoretical changes in the FM100 Hue test scores produced by age-related changes in the ocular media transmittance for two different ideal observers. One observer was 32 years old, and the other, 74 years old.
 - These changes were examined with, and without, a von Kries type chromatic adaptation to determine the role that this adaptation process may have on age-related changes in hue discrimination.

Young vs Old



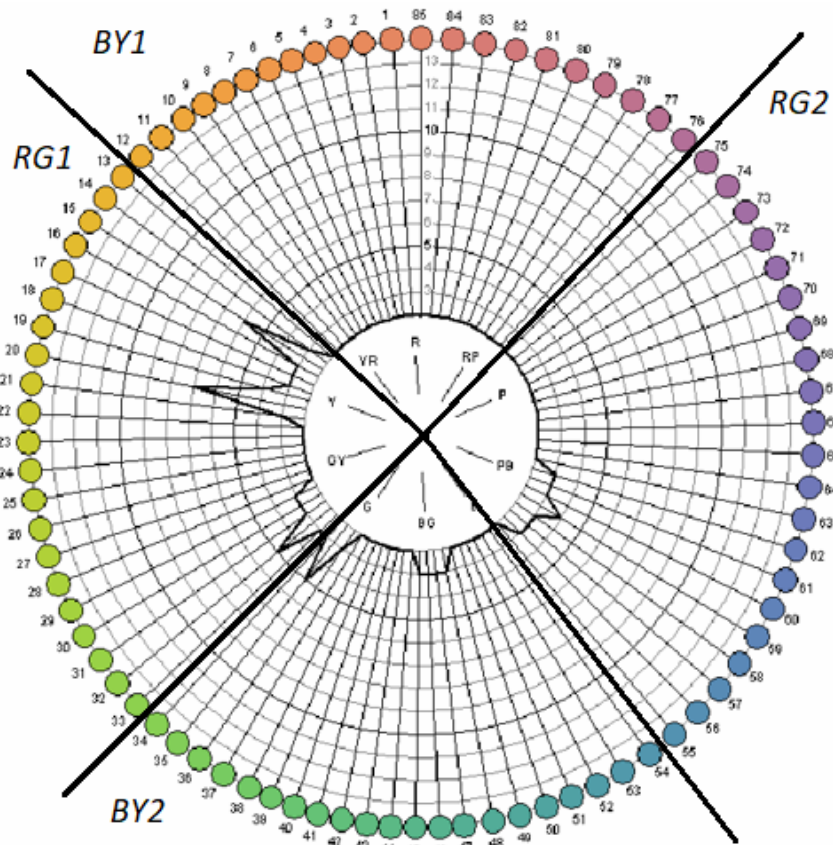
Farnsworth-Munsell Hue Test (FM100)



- Used for fine hue discrimination both clinically and for research
- 85 caps in four separate boxes
- Caps arranged in sequence to form gradual change in colour
 - 1 box at a time
- Numbers on the back of the caps are used to calculate error score for each cap.
 - Results plotted on a polar plot

1. Verriest, G. 1963. Further studies on acquired deficiency of color discrimination. *J Opt Soc Am*, 53, 185-95
2. Pinckers, A. 1980. Color vision and age. *Ophthalmologica*, 181, 23-30

Polar plot- FM100 Hue Test



- Lines are individual caps
- Circles are the error score
 - Total error scores – index of hue discrimination
 - Partition in Red-Green and Blue-Yellow Error Scores
 - Pattern of errors can determine type of defect
- With age, the error score increase
 - especially in the blue-yellow regions

Modeling transmittance of the older eye: Specifics

▪ *Lens Spectral Transmittance*

1. Pokorny et al optical density equation - calculate change in transmittance for aged lens (74 years) relative to a young adult lens (32 years) at wavelengths, 400 – 780 nm. ¹

$$\bullet D_{\lambda} = D_{\lambda_1} [1 + 0.02(A - 32)] + D_{\lambda_2} \quad (1)$$

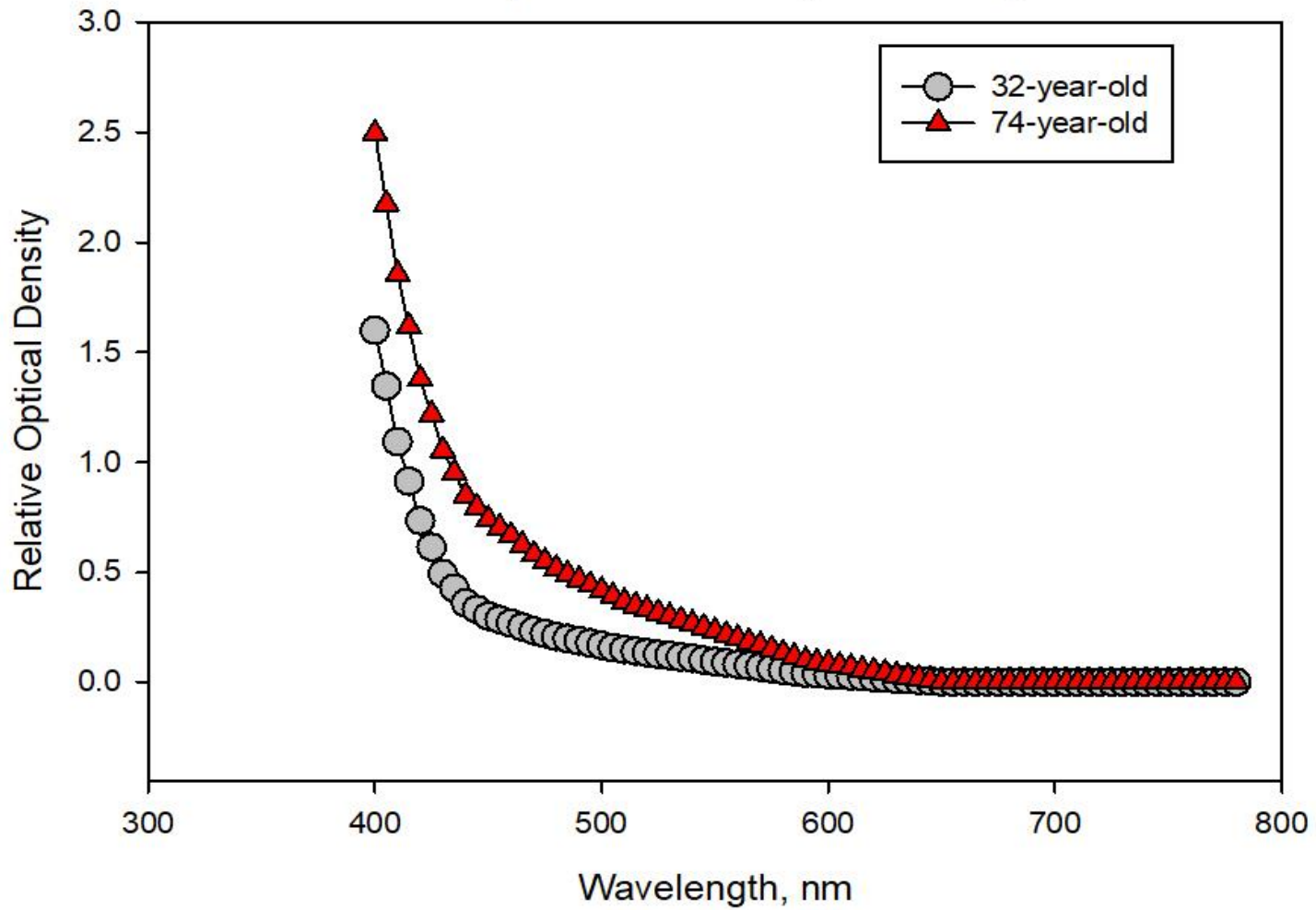
for an observer aged 20 – 60 years.

$$\bullet D_{\lambda} = D_{\lambda_1} [1.56 + 0.0667(A - 60)] + D_{\lambda_2} \quad (2)$$

for an observer aged over 60 years.

1. Pokorny, J., Smith, V. C. & Lutze, M. 1987. Aging of the human lens. *Applied Optics*, 26, 1437-1440.

Pokorny *et al.* Relative Optical Density



Pokorny, J., Smith, V. C. & Lutze, M. 1987. Aging of the human lens. *Applied Optics*, 26, 1437-1440.

Methodology: Specifics

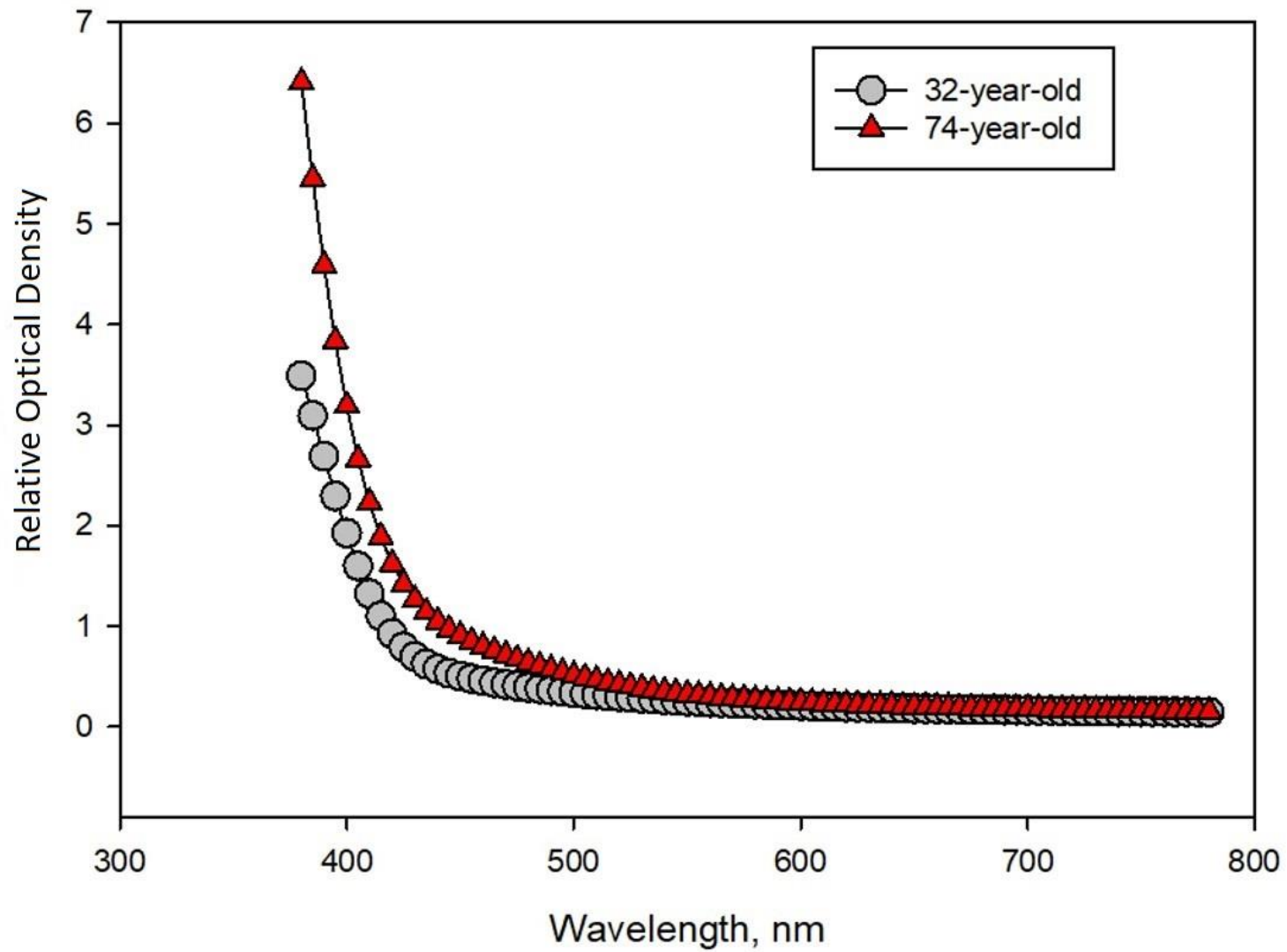
- **Ocular media spectral transmittance**

2. Optical density of human ocular media according to van de Kraats & van Norren

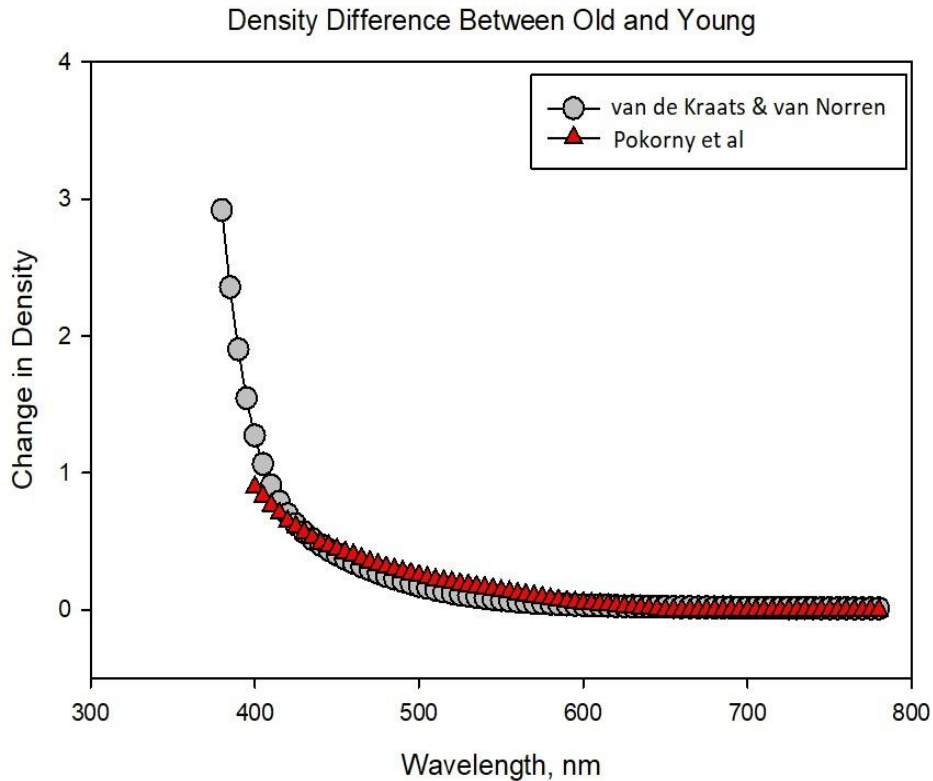
- Sum of five components
- The total density is obtained by the sum 5 functions. These are:

$$\begin{aligned} \text{Rayleigh scatter} & \quad (0.446 + 0.000031 \times \text{age}^2) \times (400/\lambda)^4 \\ \text{Tryptophan} & \quad +14.19 \times 10.68 \times \exp(-([0.057 \times (\lambda - 273)]^2)) \\ \text{Lens Young} & \quad +(0.998 - 0.000063 \times \text{age}^2) \times 2.13 \times \exp(-([0.029 \times (\lambda - 370)]^2)) \\ \text{Lens old UV} & \quad +(0.059 + 0.000186 \times \text{age}^2) \times 11.95 \times \exp(-([0.021 \times (\lambda - 325)]^2)) \\ \text{Lens old} & \quad +(0.016 + 0.000132 \times \text{age}^2) \times 1.43 \times \exp(-([0.008 \times (\lambda - 325)]^2)) \\ \text{Non-selective} & \quad + 0.111 \\ \text{absorption of media} & \end{aligned} \tag{3}$$

van de Kraats & van Norren Optical Density



Comparison of the two models



- Similar density plots for the two models
- The density difference for van de Kraats and van Norren older observer was slightly greater especially for wavelengths below 450 nm
- The density difference for Pokorny et al was slightly greater at wavelengths 480-550 nm

Overview of calculations

- Calculation X, Y and Z tristimulus values
- Feed values into CIECAM02 to calculate chromaticity coordinates
- Calculate colour differences between adjacent caps
- CIECAM02: A colour appearance model for colour management system
- Selected because
 - Incorporates a von Kries-type chromatic adaptation
 - Incorporates the luminance of the scene

Methodology: Specifics

- First step for young adult- calculate X,Y,Z values
 - For the **young observer**, the equation for calculating the tristimulus values for an individual cap

$$X_i = \sum_{\lambda=380}^{780} S_{e\lambda} r_{i,\lambda} x'_{\lambda} \Delta\lambda, \quad (4)$$

$S_{e\lambda}$ is the relative spectral emittance of D65, $r_{i\lambda}$ is the spectral reflectance of cap i and x'_{λ} , y'_{λ} , z'_{λ} are the 1931 x' y' z' colour matching functions at wavelength λ . The $\Delta\lambda$ is 5 nm.

Methodology: Specifics

“Filter for older observers”

- The spectral emittance of D65 in the equations for calculating the tristimulus values for an individual cap were modified for the old observer model based on:
- The change in transmittance between the two ages, converted into a transmittance ratio for each model by,

This ratio can be also calculated from,

$$t_{R\lambda} = \frac{t_{74,\lambda}}{t_{32,\lambda}} \quad (7)$$

$$X_i = \sum_{\lambda=380}^{780} t_{R\lambda} S_{e\lambda} r_{i,\lambda} x'_\lambda \Delta\lambda, \quad (8)$$

$S_{e\lambda}$ is the relative spectral emittance of D65, $t_{R\lambda}$ is the change in transmittance between the two ages, $r_{i\lambda}$ is the spectral reflectance of cap i and $x'_\lambda, y'_\lambda, z'_\lambda$ are the 1931 x' y' z' colour matching functions at wavelength λ . The $\Delta\lambda$ is 5 nm.

Modeling transmittance of the older eye

- Colour appearance and colour differences in CIECAM02 depend on adapting luminance (retinal illumination)
- Decrease in the retinal illumination in the older observers due to;
 - **pupil miosis**
 - **decrease in the ocular media luminous transmittance** due to increase in spectral optical density
- Pupil diameters for the two ages:
 - calculated using the Watson and Yellot's (2012) unified formula
 - Our calculations resulted in:
 - ratio of pupil area= **0.63** (old/young)
- Reduction in luminous transmittance of **0.75** & **0.83** for the two OD models
 - Total reduction in retinal illumination **0.48** & **0.54**

Table 1: Parameter settings for surface colour evaluation in a light booth

| Example | Ambient lighting in lx (cd/m ²) | Scene or device white luminance | Adapting luminance, L _A in cd/m ² | Adopted white point | Surround ratio, S _R (L _{sw} /L _{DW}) | Surround |
|---|---|---------------------------------|---|---|--|--|
| Surface colour evaluation in a light booth: Young | 500 (159.15) | 159.15 cd/m ² | 31.85 | Light booth WP X _w = 95.04 Y _w =100.00 Z _w = 108.84 | 0.20 | Average N _c = 1.00 c = 0.69 |
| Surface colour evaluation in a light booth: Old Observer (Pokorny et al.) | 500 (159.15) | 159.15 cd/m ² | 15.45 | X _w = 47.29 Y _w = 48.49 Z _w = 27.09 | 0.20 | Average N _c = 1.00 c = 0.69 |
| Surface colour evaluation in a light booth: Old observer (van de Kraats and van Norren) | 500 (159.15) | 159.15 cd/m ² | 17.12 | X _w = 49.67 Y _w = 53.76 Z _w = 29.68 | 0.20 | Average N _c = 1.00 c = 0.69 |

Table 2: Summary of CIECAM02 parameters – with adaptation

| CAM02 Parameter | Young | Old - van de Kraats | Old – Pokorny |
|---|--------------|----------------------------|----------------------|
| Degree of adaptation, D | 1.00 | 1.00, 0.67, 0 | 1.00, 0.67, 0 |
| Adapting luminance, L_A (cd/m^2) | 31.85 | 17.12 | 15.45 |
| Maximum degree of adaptation, F | 1.00 | 1.00 | 1.00 |

Prediction of FM100 Hue caps ordering

Correct ordering

| Cap | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|--------------|--------------|--------------|--------------|--------------|--------------|
| 1 | 0 | | | | | |
| 2 | 1.074 | 0 | | | | |
| 3 | 1.852 | 0.853 | 0 | | | |
| 4 | 2.934 | 1.872 | 1.133 | 0 | | |
| 5 | | 2.63 | 1.848 | 0.871 | 0 | |
| 6 | | | 3.101 | 2.183 | 1.437 | 0 |
| 7 | | | | 3.172 | 2.394 | 1.063 |
| Order | 1 | 2 | 3 | 4 | 5 | 6 |

Transpositional ordering

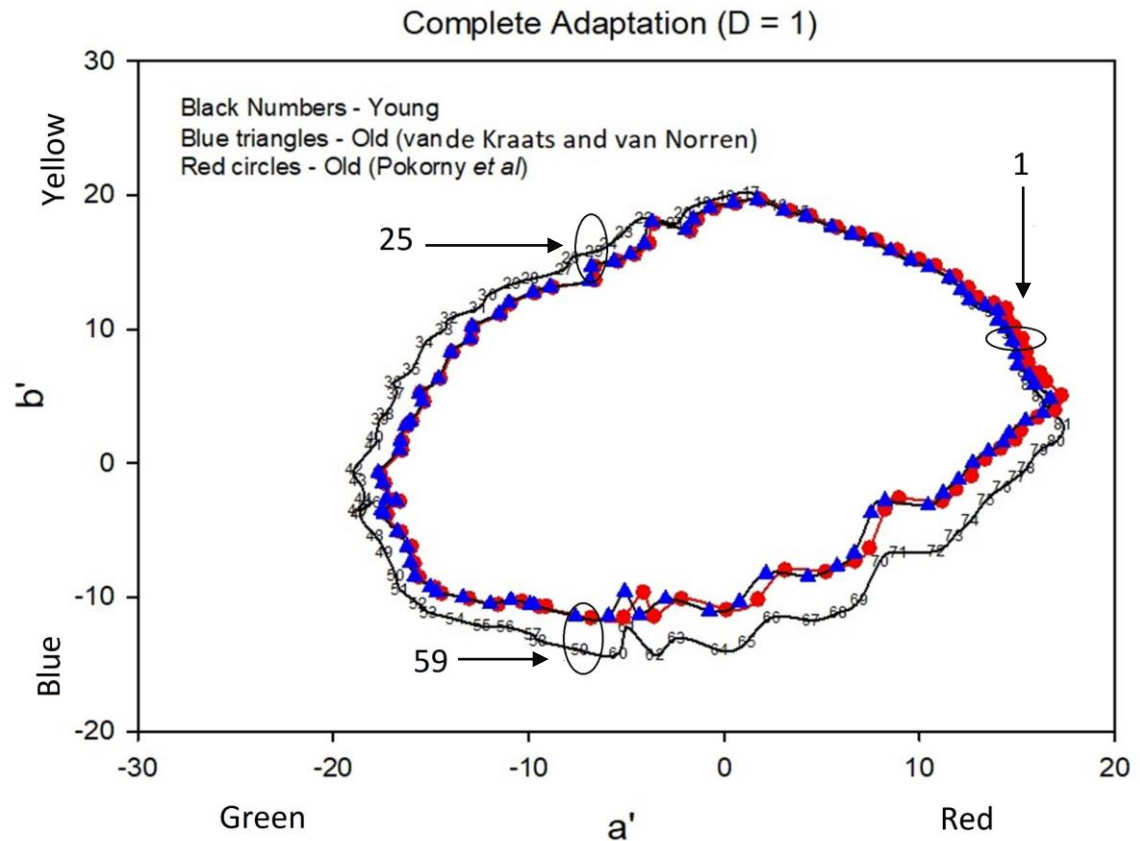
| Cap | 43 | 44 | 45 | 46 | 47 |
|-------|--------------|--------------|--------------|--------------|--------------|
| 43 | 0 | | | | |
| 44 | 1.702 | 0 | | | |
| 45 | 2.284 | 0.987 | 0 | | |
| 46 | 1.994 | 0.513 | 1.044 | 0 | |
| 47 | | 1.179 | 0.266 | 1.139 | 0 |
| 48 | | | 2.124 | 2.613 | 1.864 |
| 49 | | | | 3.768 | 3.189 |
| | | | | | 5.010 |
| Order | 43 | 44 | 46 | 45 | 47 |

- Colour difference ΔE between adjacent caps was calculated using the CIECAM02 – SCD equations.
- Between it and the immediate adjacent cap, ΔE_1 , and between the second cap, ΔE_2 , and third cap, ΔE_3 away from the cap under consideration.
 - The order was determined by the minimum ΔE between each cap and subsequent caps
 - The total error score (TES) of each predicted arrangement was calculated

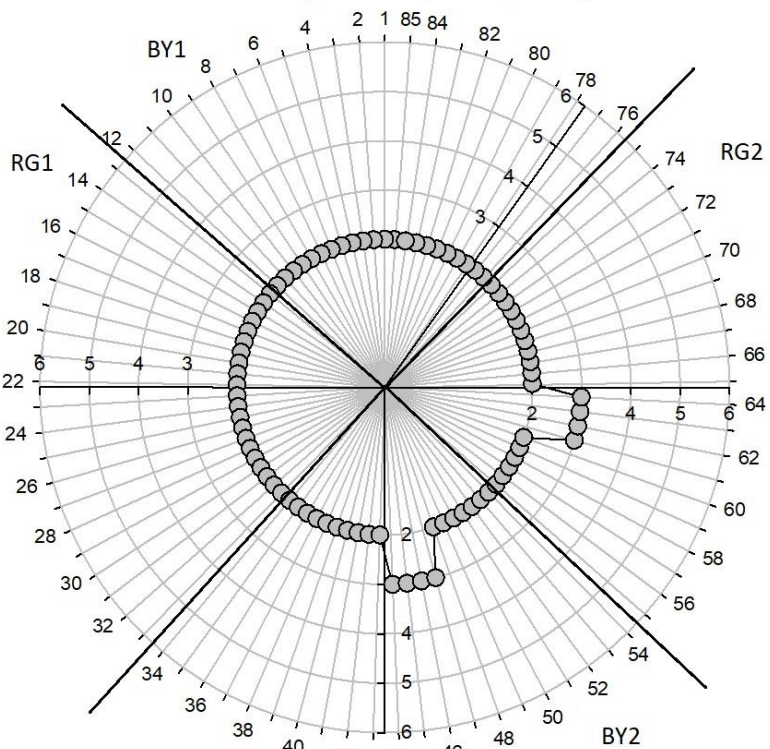
Results

Standard viewing conditions with complete adaptation

The size of gamut for the older observers was slightly smaller than the young observer indicating that most caps appeared less saturated to the older observer.

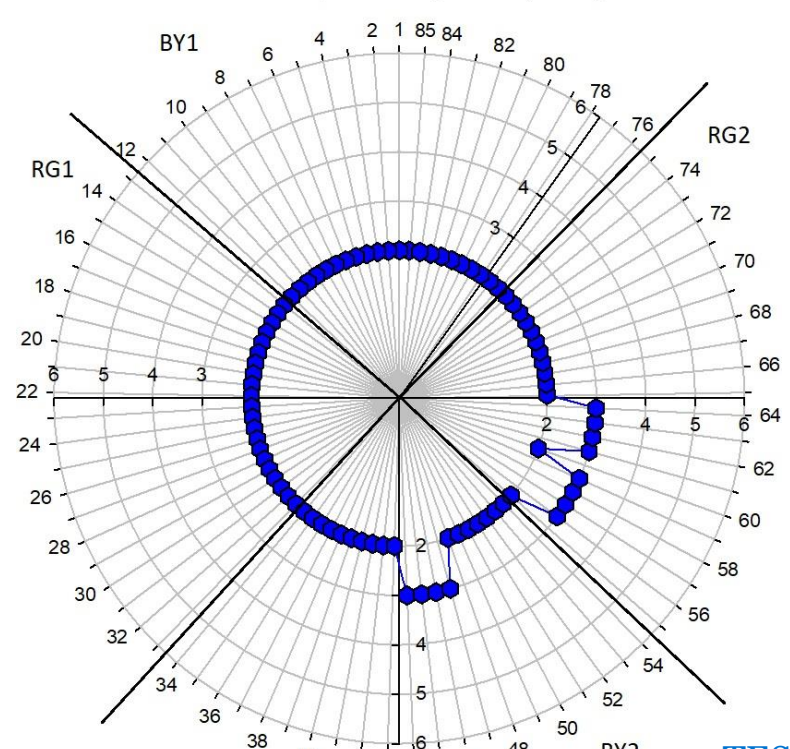


Complete Adaptation (D = 1)



TES= 8
 RG = 4
 BY = 4
 Young observer

Complete Adaptation (D = 1)



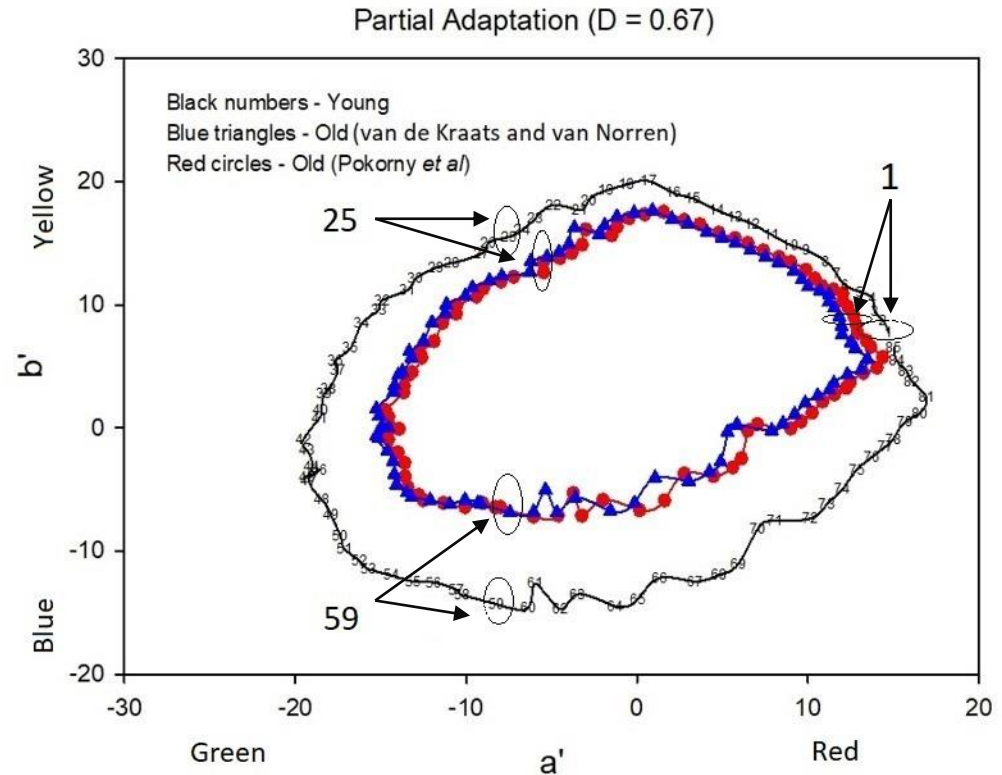
Old observers
 TES=12
 RG = 8
 BY = 4

- The arrangements for the two older observers were identical
- The errors for all 3 observers occur in the lower portion of the error plot, corresponding to blue-green hues
- Older observers have additional errors in the Red-Green quadrant: purples

Results

Partial adaptation ($D=0.67$)

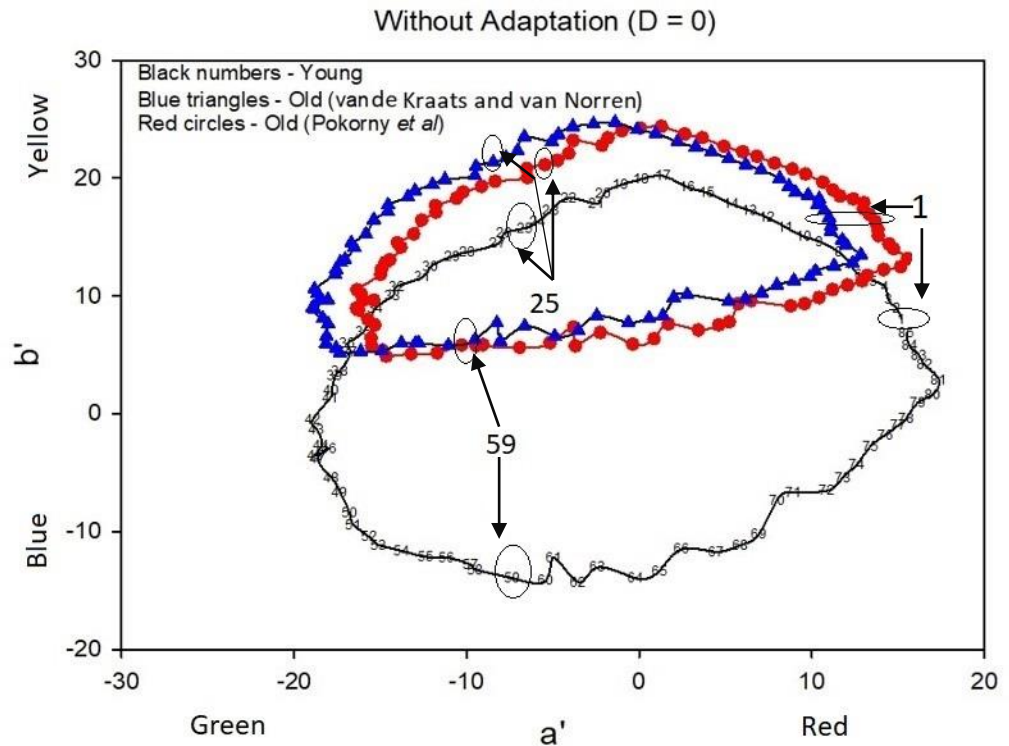
- The size of gamut for the older observers was appreciably smaller than the young observer.
- The chromaticity coordinates of the individual caps were similar for the two older observers
- The ordering and error scores were identical to the results with complete adaptation condition.



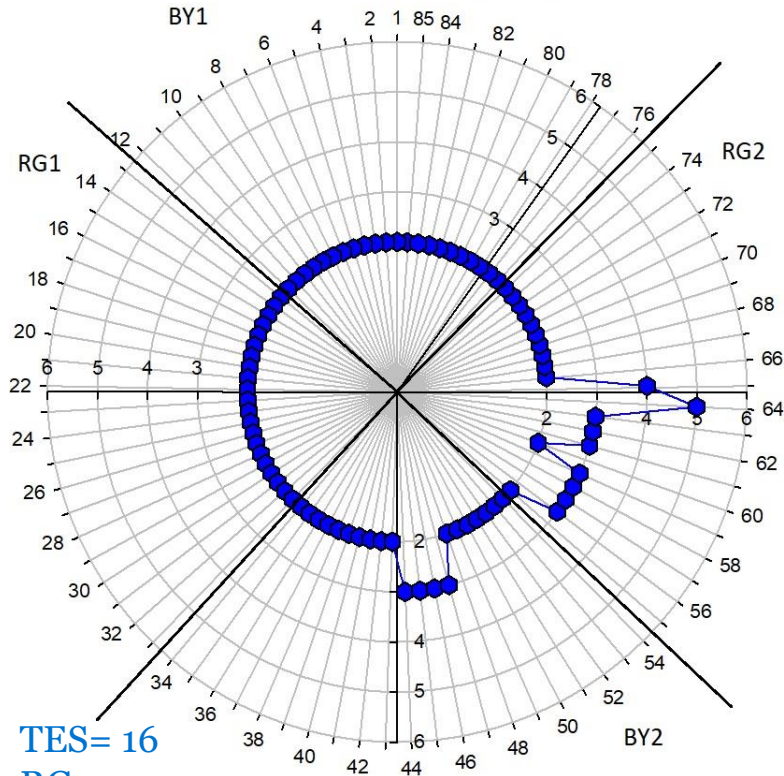
Results

No adaptation (D=0)

- The gamut for the older observers was vertically shifted towards yellow from the gamut of the young adult and decreased in size.
- Thus, a change in both hue and chroma for the older observers.

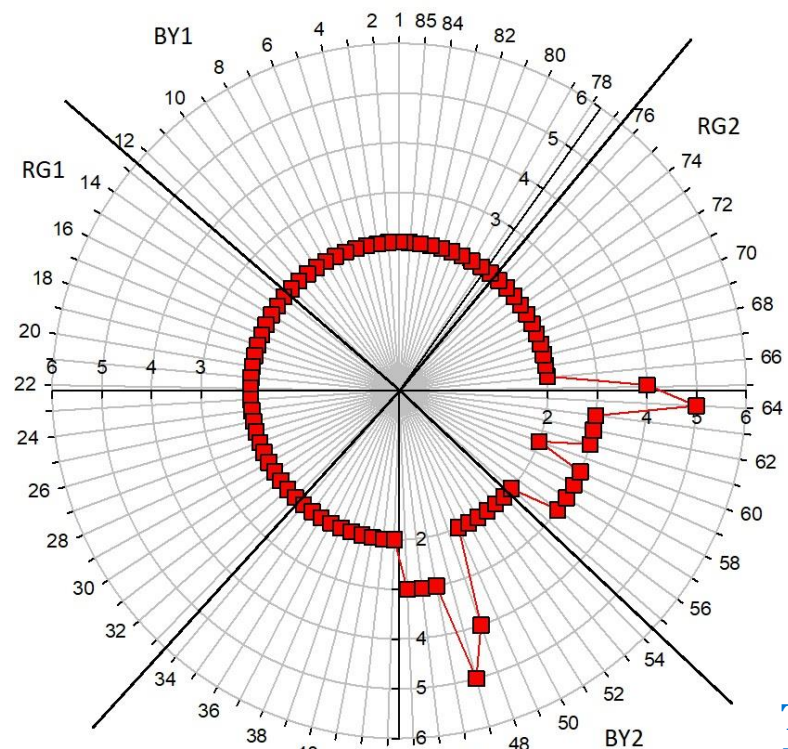


No Adaptation (D = 0)



TES= 16
 RG = 12
 BY = 4
 van de Kraats and van Norren

No Adaptation (D = 0)

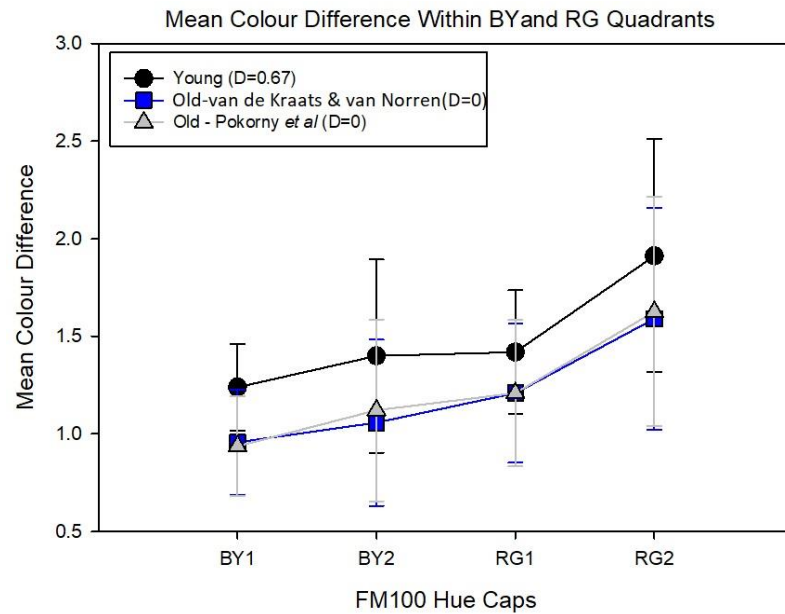
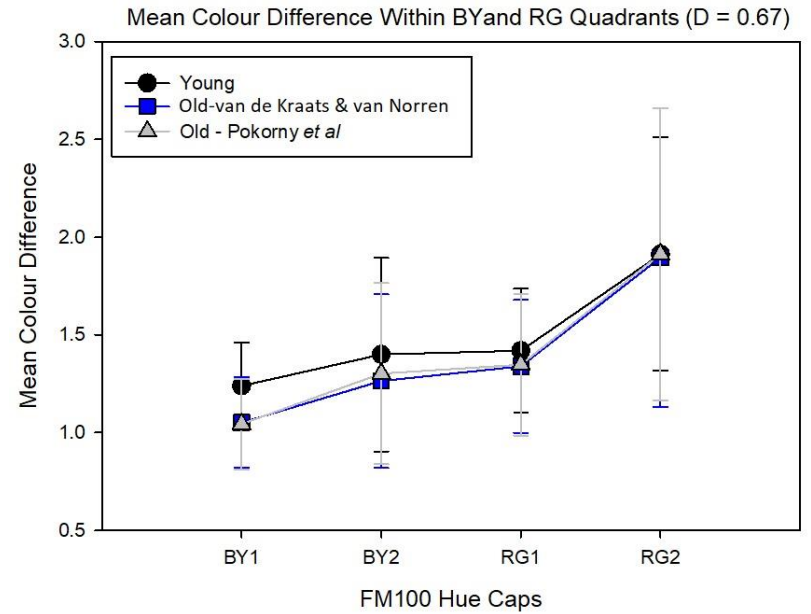
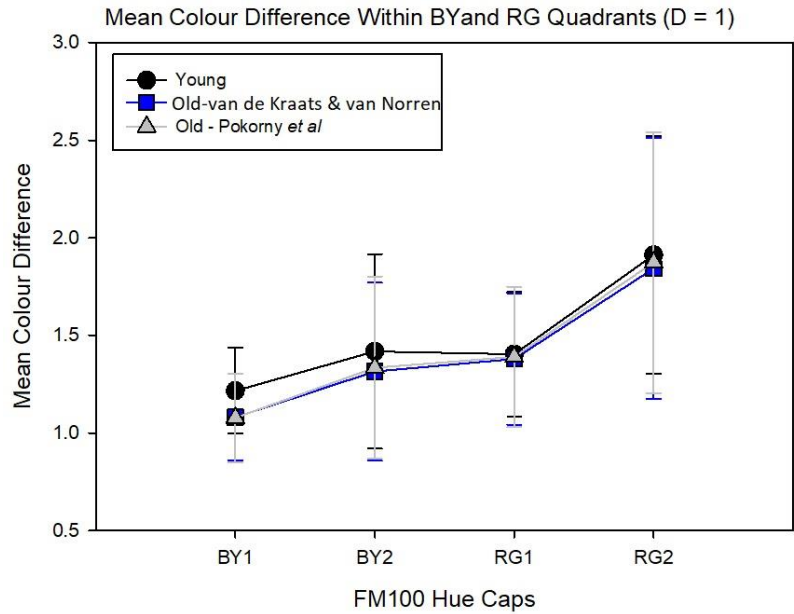


TES= 20
 RG = 12
 BY = 8

Pokorny et al

- Error scores of both older observers increased relative to the adapted states, but increase was similar for both older observer models.
- Difference between the two aged observers was in the arrangements for caps 44 to 48, [blue-green hues]

Colour differences with, and without adaptation



Discussion

- Ideal young observer: Error score (8)
- Consistent with the minimum error scores for the 30-34 years of Verriest (1963) study.
- In contrast to psychophysical studies, our model showed greater reduction in hue discrimination in the red-green axis compared with the blue-yellow axis. Shows that age-related media changes, **alone**, do not qualitatively predict FM100 arrangement.
 - Discrepancy of where the predicted errors should occur indicate that reduction in hue discrimination with age is also due to age-related changes in the neural processes
- Our findings are in contrast to Ruddock's assertions that age-related changes in colour matching and spectral sensitivity are due to media changes i.e. selective absorption of the media.¹
 - Discrepancy could be due to the experiment type i.e. age-related media changes explain the experimental data in colour matching and spectral sensitivity.
 - However, if one examines hue discrimination, then age-related changes appear to be due to neural changes.

1. Verriest, G. 1963. Further studies on acquired deficiency of color discrimination. *J Opt Soc Am*, 53, 185-95.

Discussion

- Our results indicate that a von Kries type of adaptation would reduce the errors, relative to no adaptation in the older observer, but not return the score to a young adult.
 - The FM100 scores of the subjects in a study who had clear IOLs did not change significantly when they viewed the test through yellow filters simulating the Natural IOL.¹
 - But the mean error scores for both older groups were higher than the mean for the 30-39 year old observers reported by Kinnear and Sahraie
 - Suggests that a similar chromatic adaptation is functioning adequately in the older adults, even though some age-related neural changes have occurred.

1. Cianni, R. J. & Tsai, J. H. 2006. Color perception with AcrySof Natural and AcrySof single-piece intraocular lenses under photopic and mesopic conditions. *Journal of Cataract & Refractive Surgery*, 32, 236-242

Conclusions

- Model using CIECAM02 predicts increase in error scores in the older observer but in the red-green dimension instead of blue-yellow.
 - Suggests that neural changes are also important in determining the effect of ageing on hue discrimination
 - If the thresholds for the older observers changed uniformly, there would be an increase in the blue-yellow error score because the colour differences of the FM100 are smaller along the blue-yellow axis.

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THANK YOU!