Colour Group (GB)
January Vision Meeting 2021

Effect of ageing of human visual system on spatio-chromatic contrast vision

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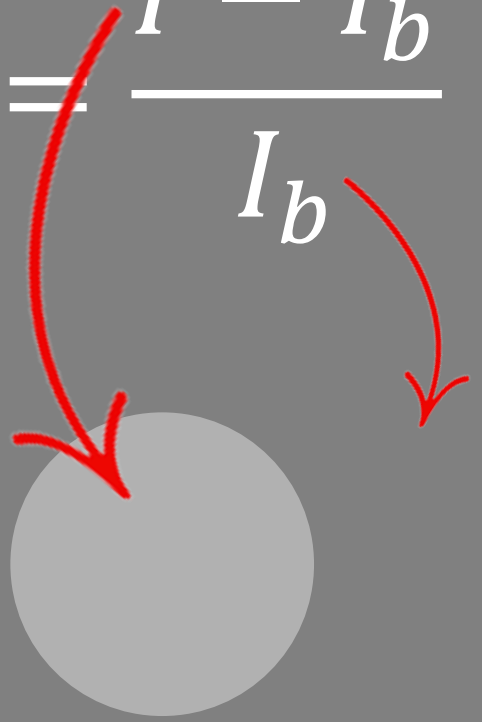
EPSRC
Engineering and Physical Sciences Research Council

How is spatio-chromatic contrast quantified?

Weber Contrast

(between background and stimulus of uniform area)

$$C = \frac{I - I_b}{I_b}$$



Michelson Contrast

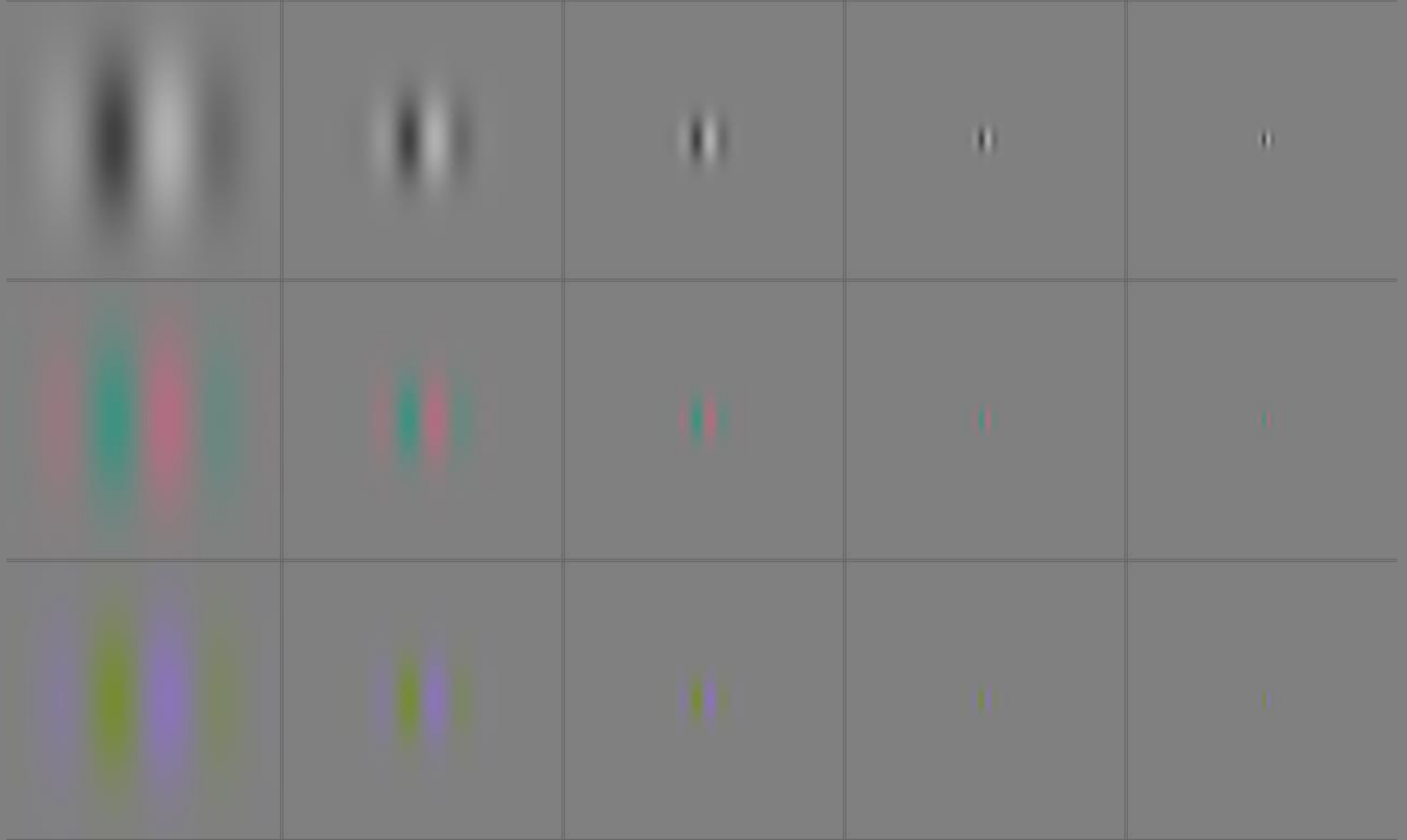
(between peaks of periodic stimulus)

$$C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

$$C = \frac{1}{3}\sqrt{\left(\frac{\Delta L}{L_0}\right)^2 + \left(\frac{\Delta M}{M_0}\right)^2 + \left(\frac{\Delta S}{S_0}\right)^2}$$

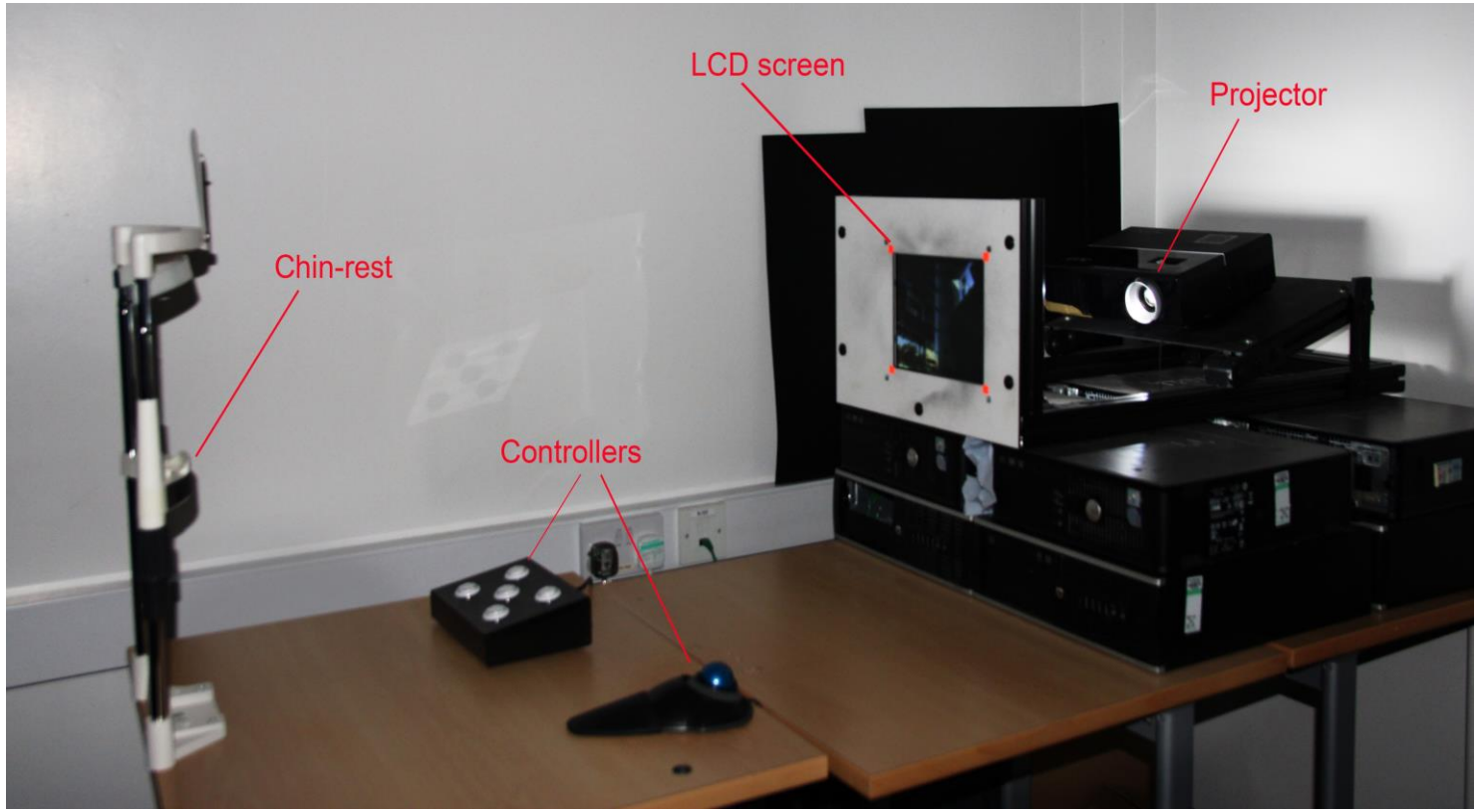
Chaparro, A., Stromeyer, C. F., Huang, E. P., Kronauer, R. E., & Eskew, R. T. (1993). Colour is what the eye sees best. *Nature, 361(6410*), 348-350.
Brainard, B. D. H. (1982). Appendix - Part IV: Cone contrast and opponent modulation color spaces. In *Human Color Vision (*pp. 563–579).

Stimuli & Experiment



APPARATUS

HDR display with peak luminance 35,000 cd/m^2 and maximum contrast: 1,000,000 : 1



METHODOLOGY

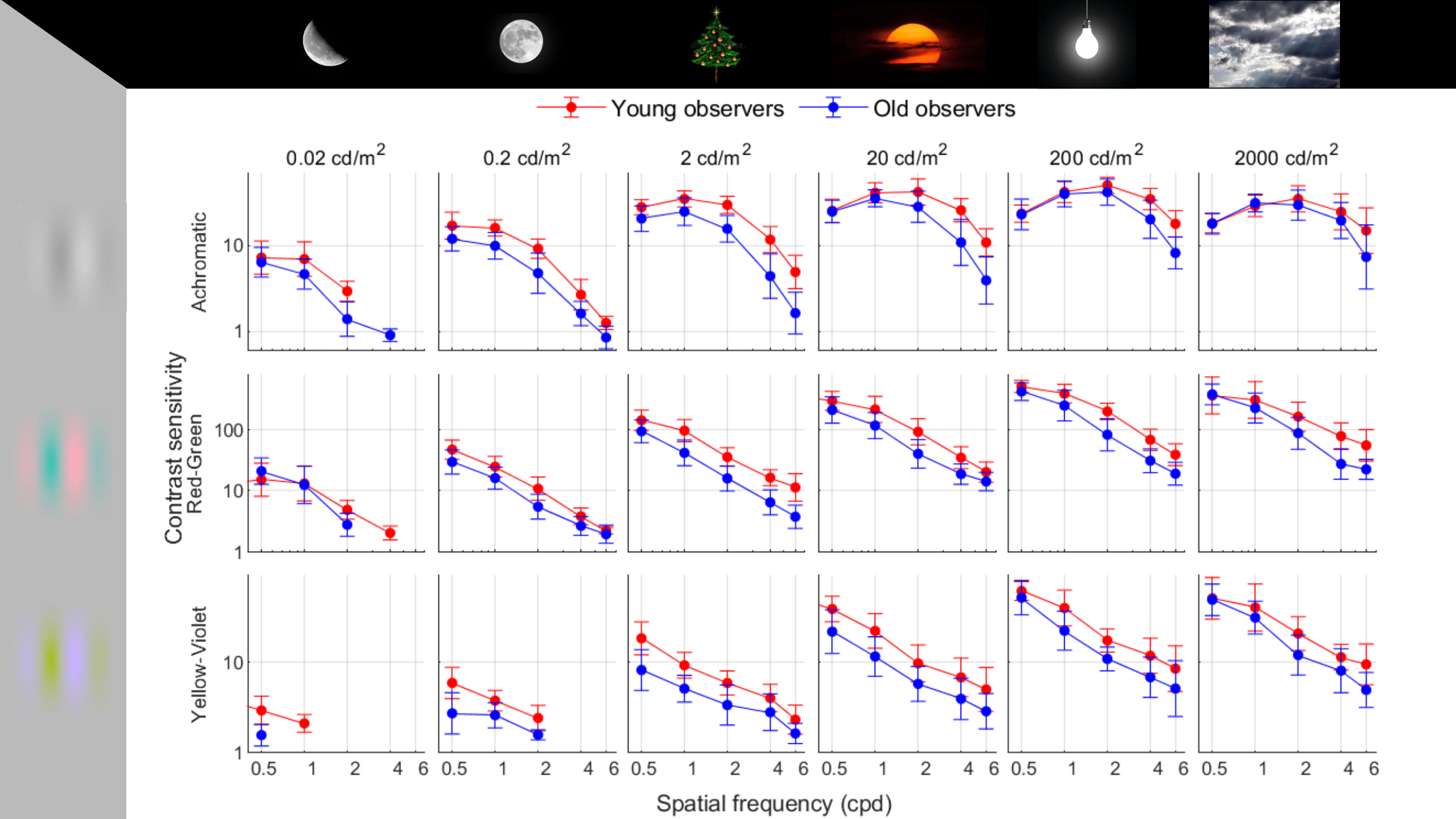
4AFC detection task

5 spatial frequencies and 3 colour directions interleaved within each session

Viewing distance: 91 cm;
Display size: 12.5^o x 9.4^o

20 young colour-normal observers (mean age: 33)
20 old colour-normal observers (mean age: 65)

Results


Young observers
Old observers
0.02 cd/m2
0.2 cd/m2
2 cd/m2
20 cd/m2
200 cd/m2
2000 cd/m2
Achromatic
Red-Green
Yellow-Violet
Contrast sensitivity
10
1
100
0.5
1
2
4
6
Spatial frequency (cpd)

Contrast sensitivity decreases with age

~ 0.3 LOG UNITS OR 3 DB

Owsley, C., Sekuler, R., & Siemsen, D. (1983). Contrast sensitivity throughout adulthood. *Vision Research*, *23*(7), 689–699.

Ageing of Human Visual System

Optical

Transmission changes in lens, cornea, ocular fluids, pupil constriction, etc.

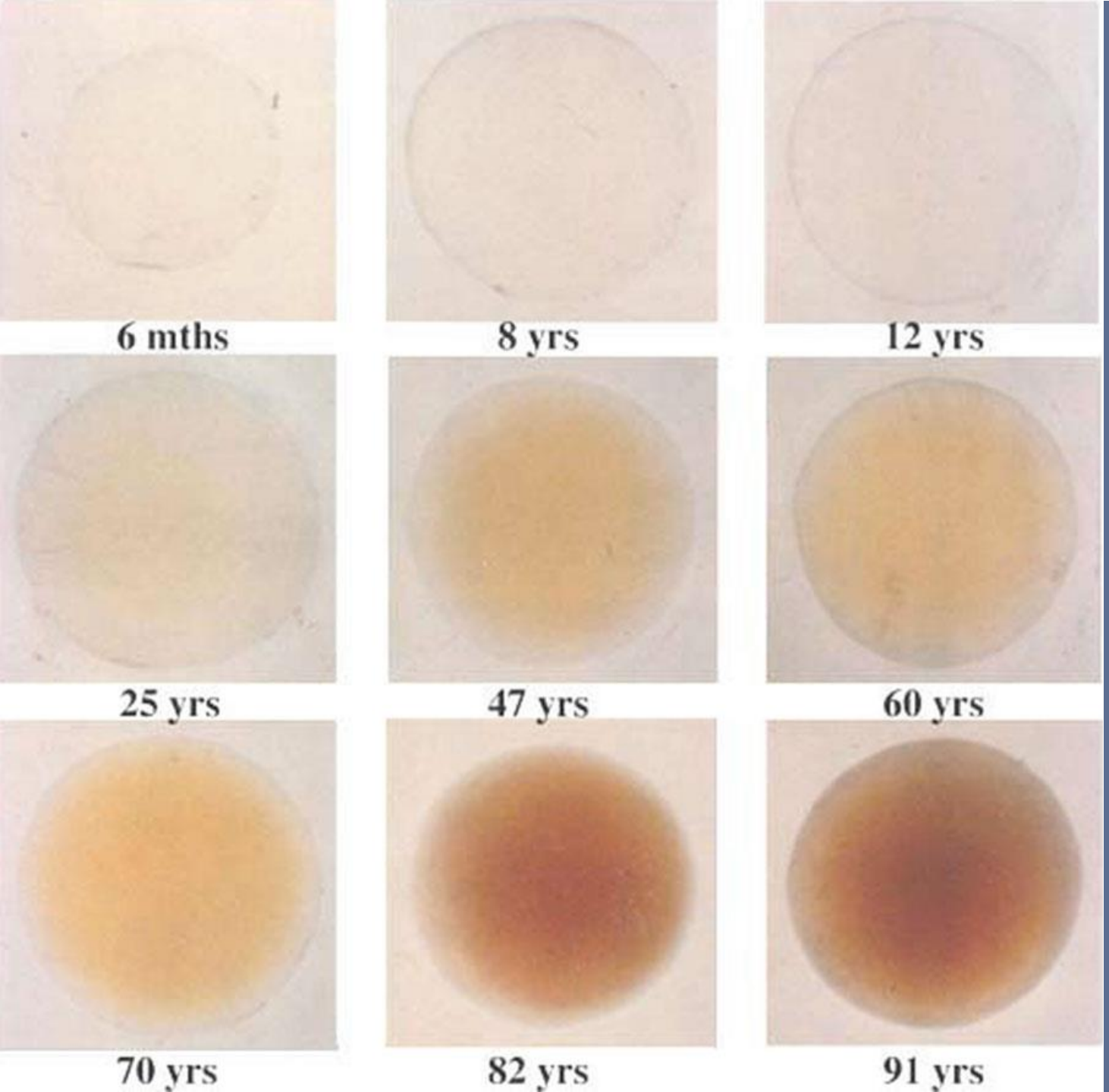
Sensory

Reduction in density of retinal photoreceptors, degradation in cone pathways

Cortical

Neural decline in visual cortex

How does ageing of pre-retinal components affect vision?

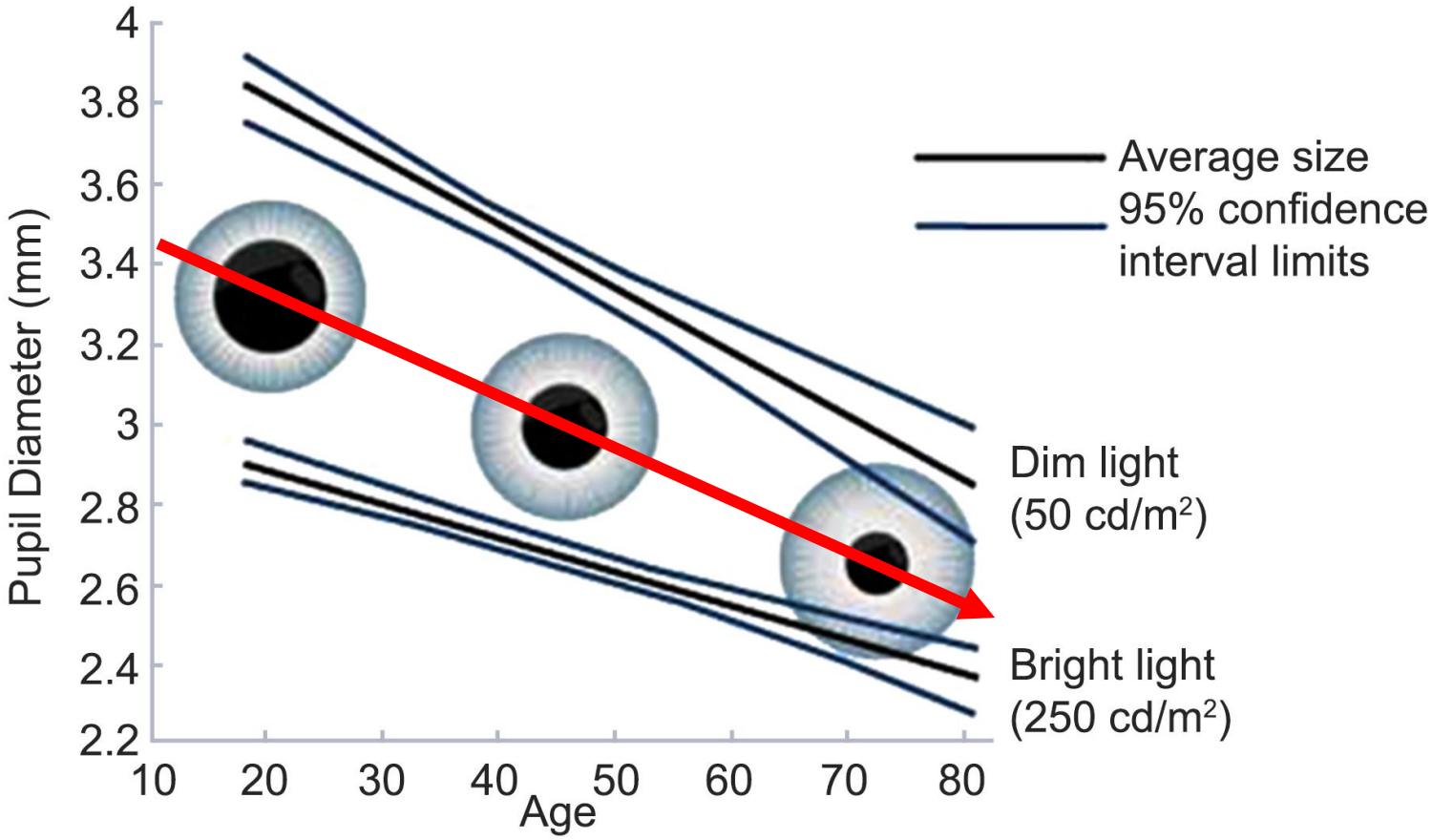


AGEING LENS

Lens yellows over time naturally even in the absence of any optical pathology

Image Source: Lerman, Sarah. (1980). *Radiant energy and the eye* (Vol. 1). Macmillan.

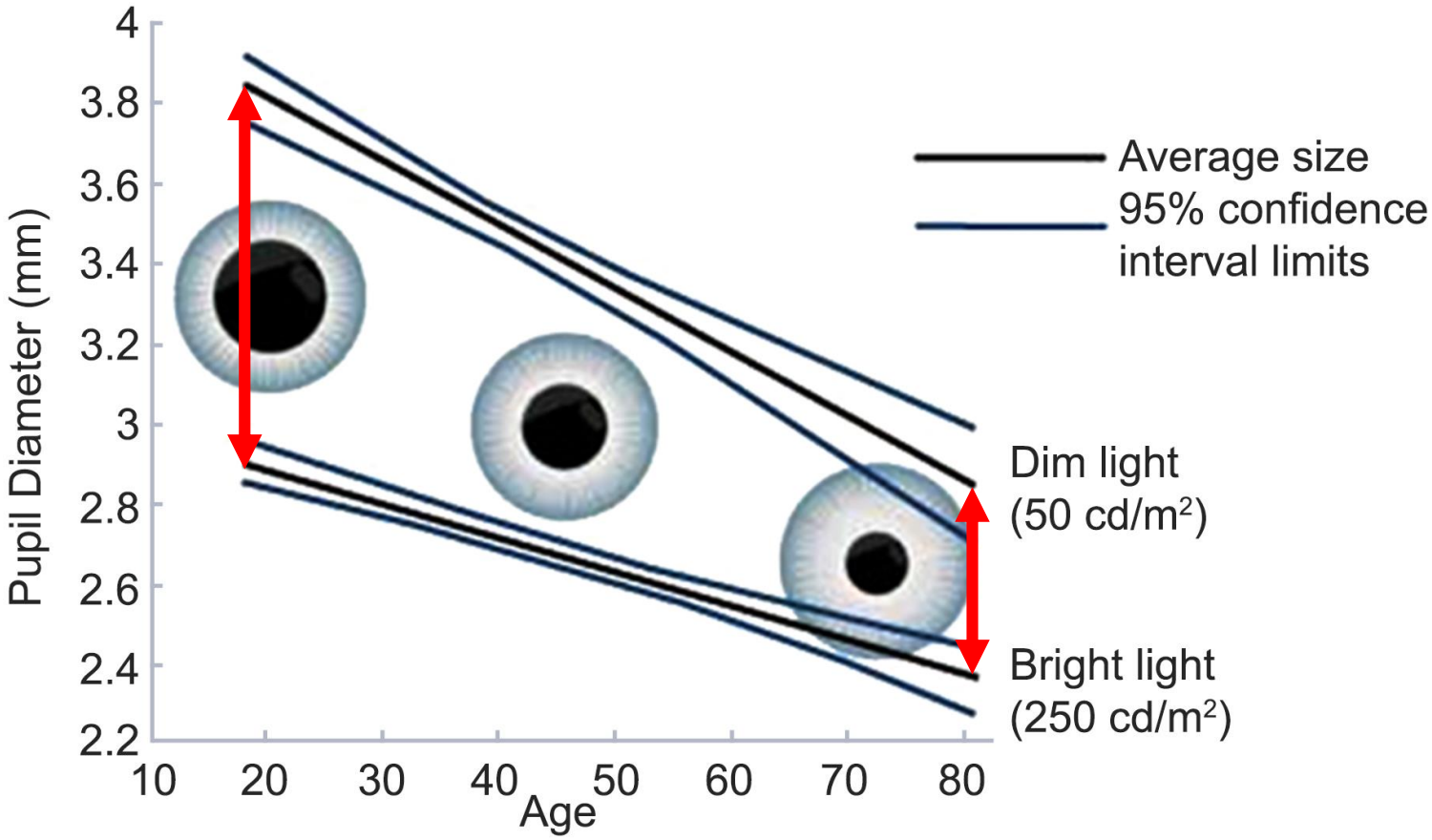
SENILE MIOSIS



- **Pupil size decreases with age**

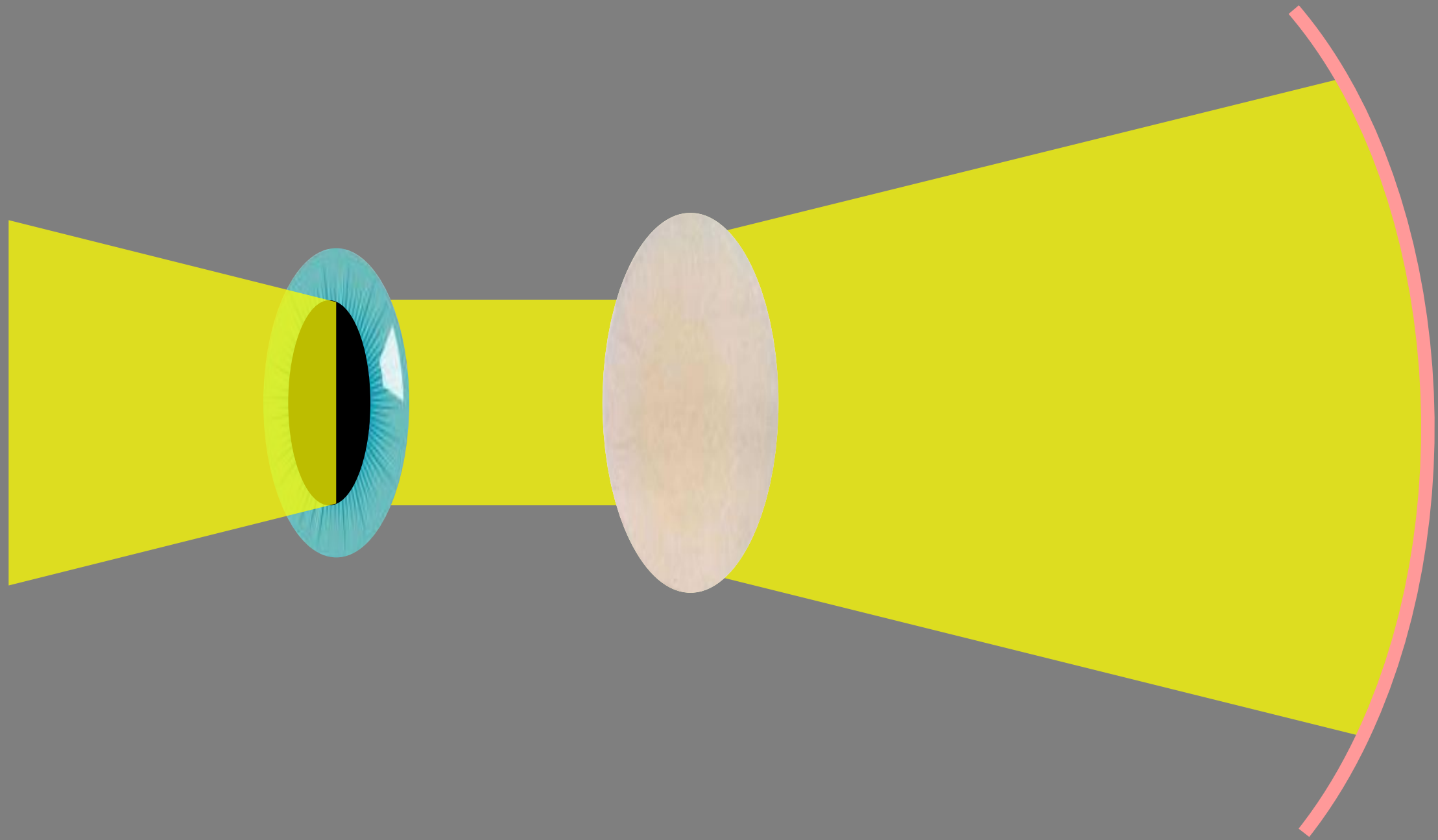
Image Source: Dumbleton K, Guillon M, Theodoratos P et al. The effects of age and refraction on pupil size and visual acuity: implications for multifocal contact lens design and fitting. Poster at BCLA Clinical Conference, May 2015.

SENILE MIOSIS

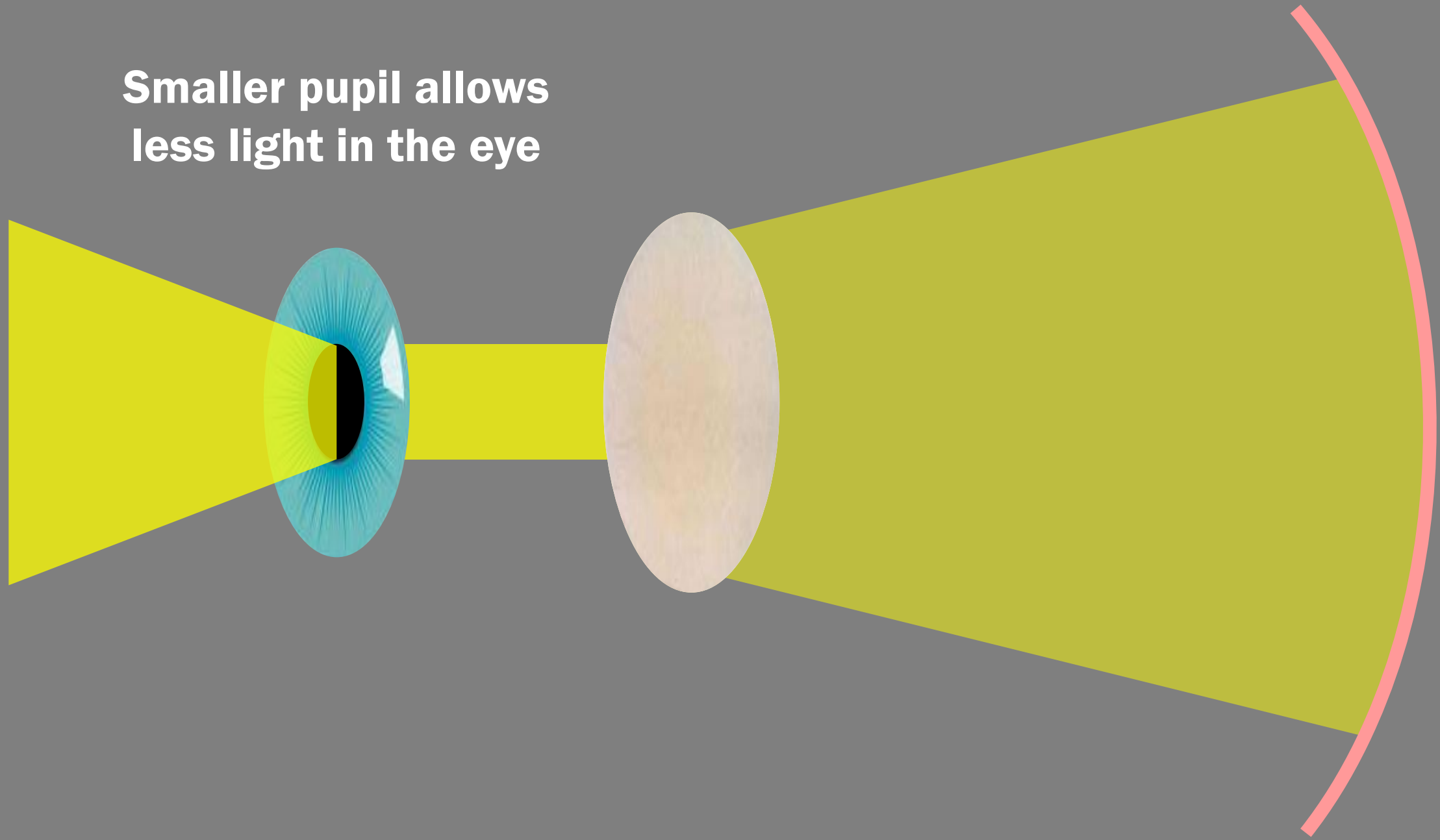


- Pupil size decreases with age
- **Pupil flexibility decreases with age**

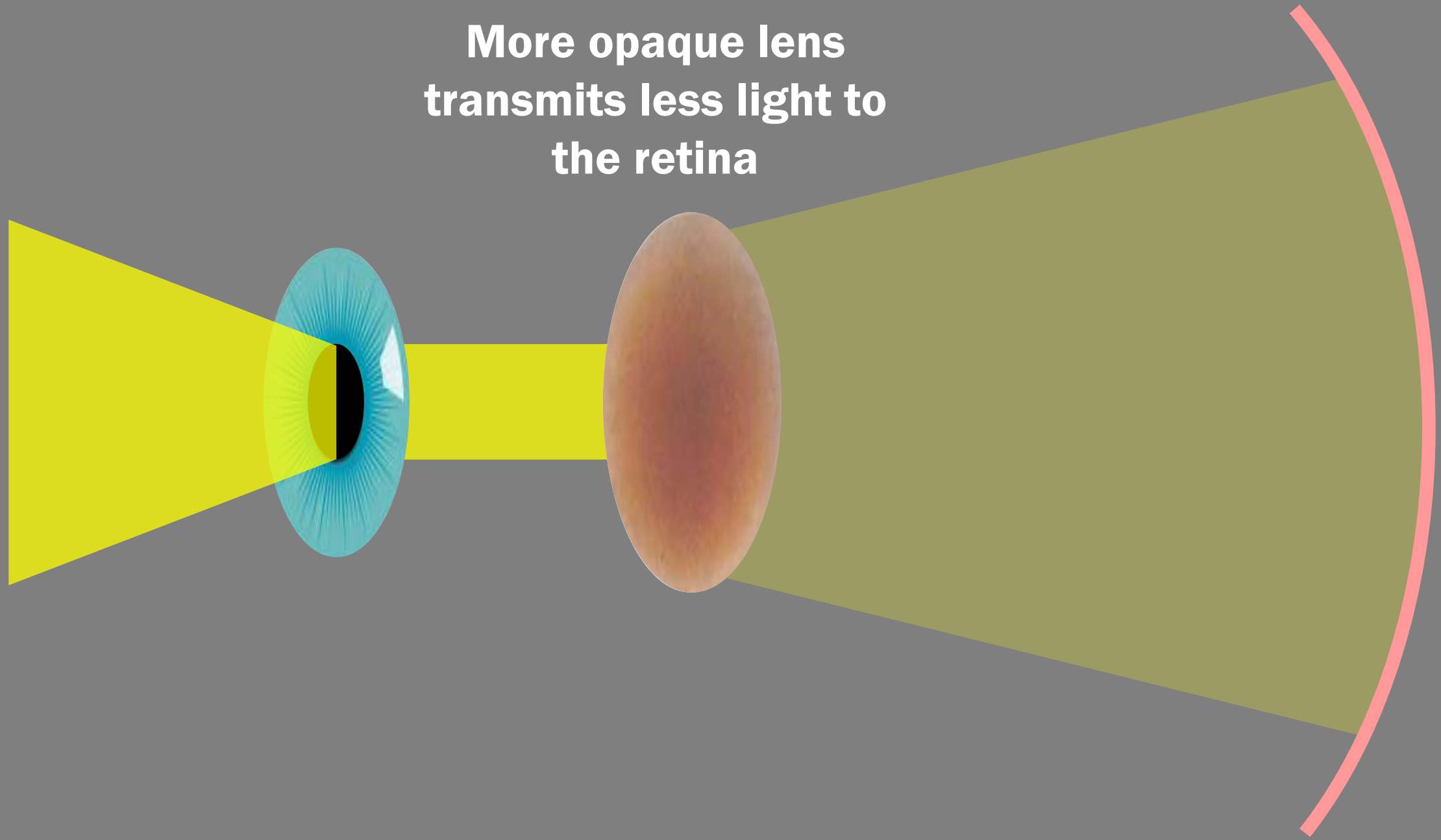
Image Source: Dumbleton K, Guillon M, Theodoratos P et al. The effects of age and refraction on pupil size and visual acuity: implications for multifocal contact lens design and fitting. Poster at BCLA Clinical Conference, May 2015.



Smaller pupil allows
less light in the eye



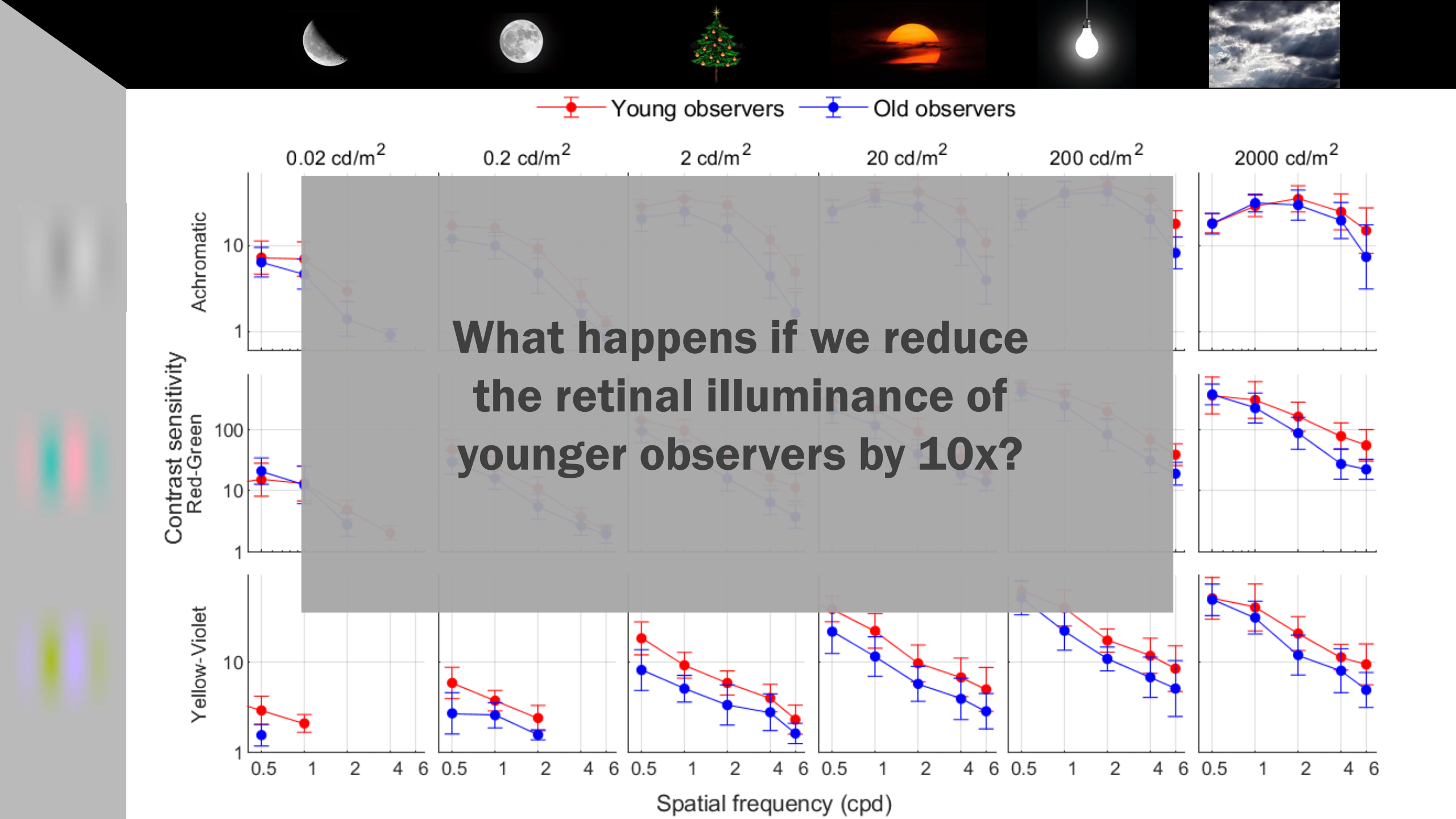
More opaque lens transmits less light to the retina



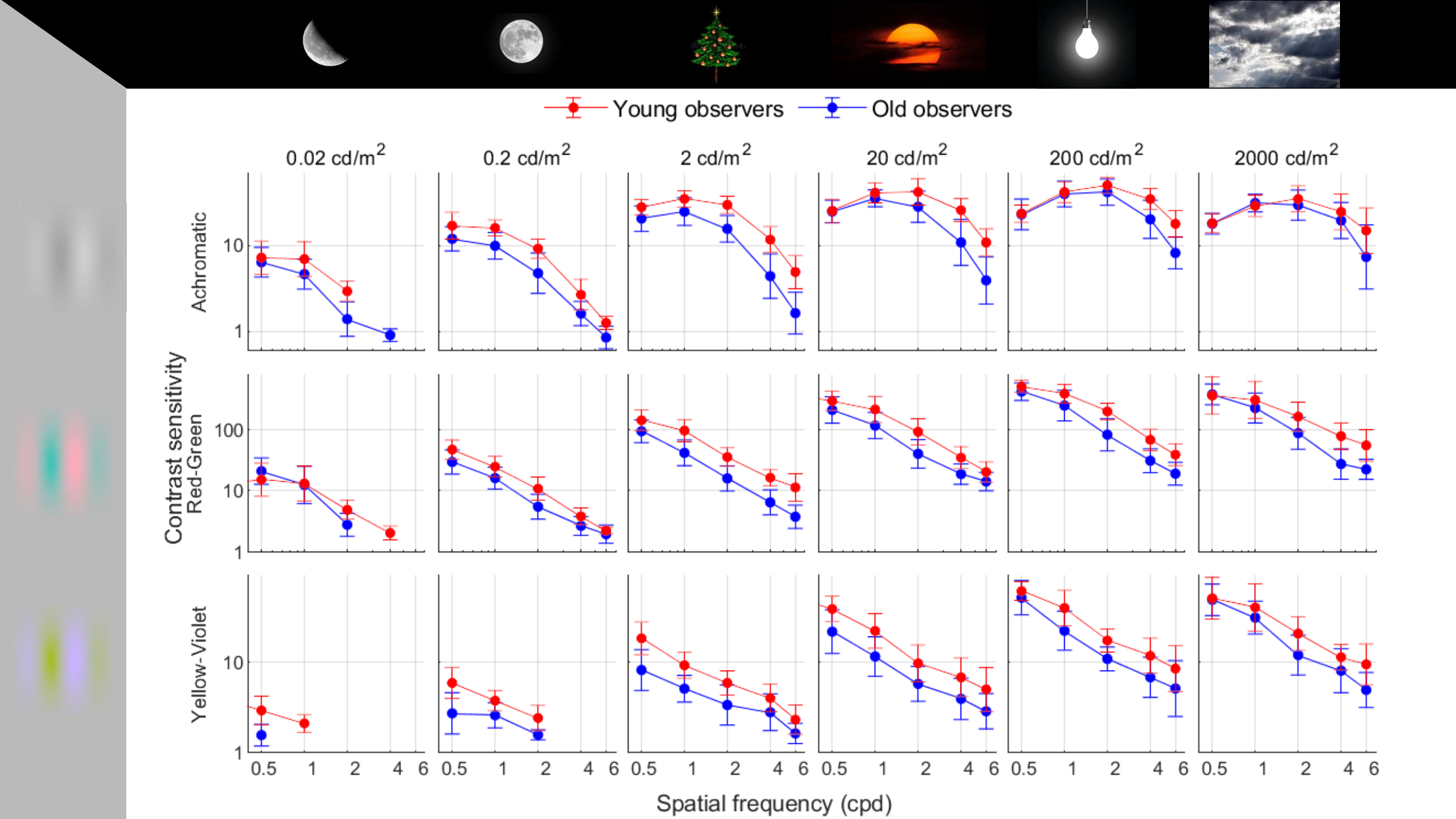
Retinal illumination decreases with age

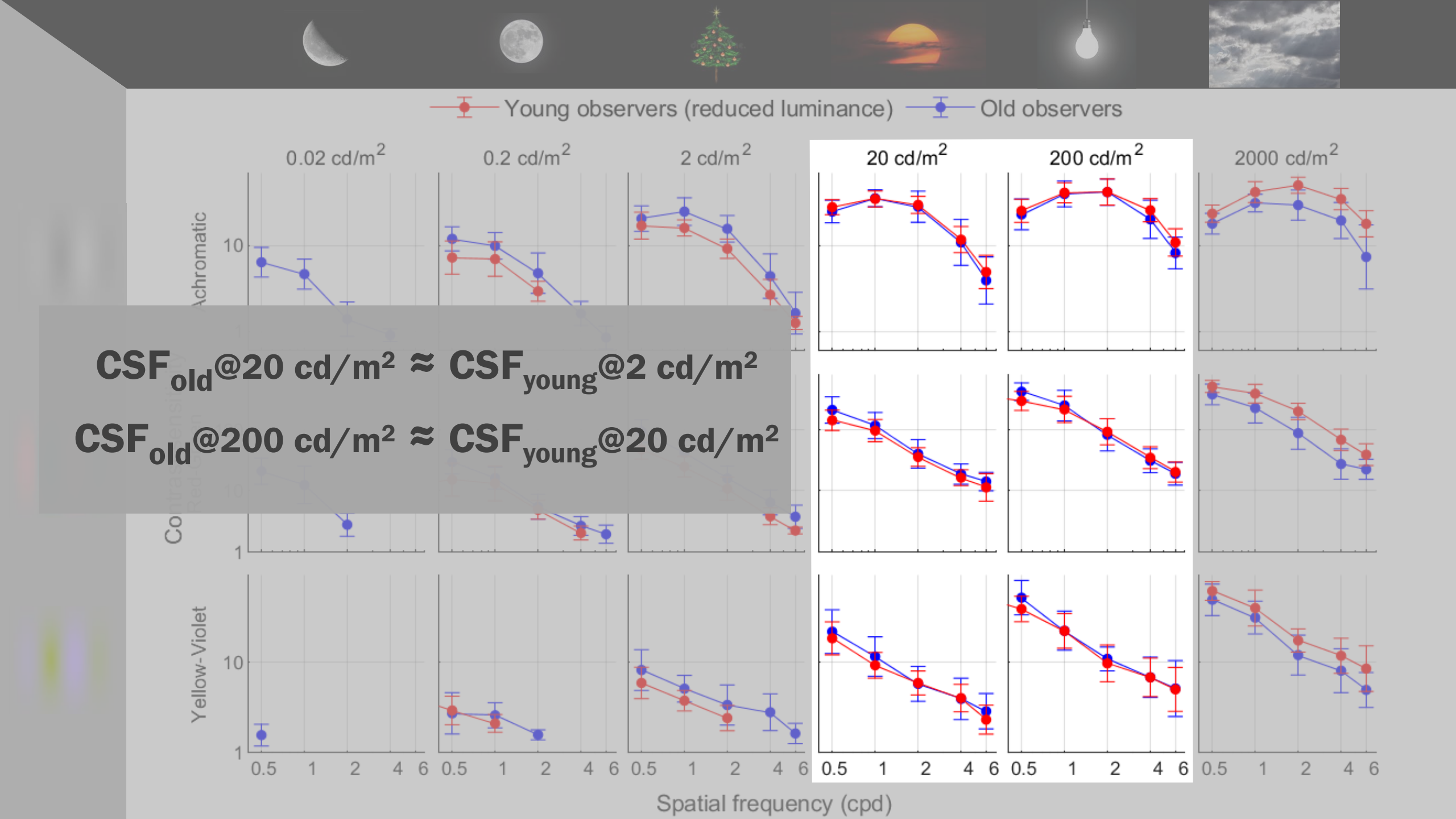
60 y.o.a transmit ~1/3 the light compared to a 20 y.o.a

Weale, R. A. (1961). Retinal Illumination and Age. *Trans. Illum. Eng. Soc.* (London), 26(2), 95–100.



What happens if we reduce the retinal illuminance of younger observers by 10x?


Young observers
Old observers
0.02 cd/m2
0.2 cd/m2
2 cd/m2
20 cd/m2
200 cd/m2
2000 cd/m2
Achromatic
Red-Green
Yellow-Violet
Contrast sensitivity
10
1
100
0.5
1
2
4
6
Spatial frequency (cpd)

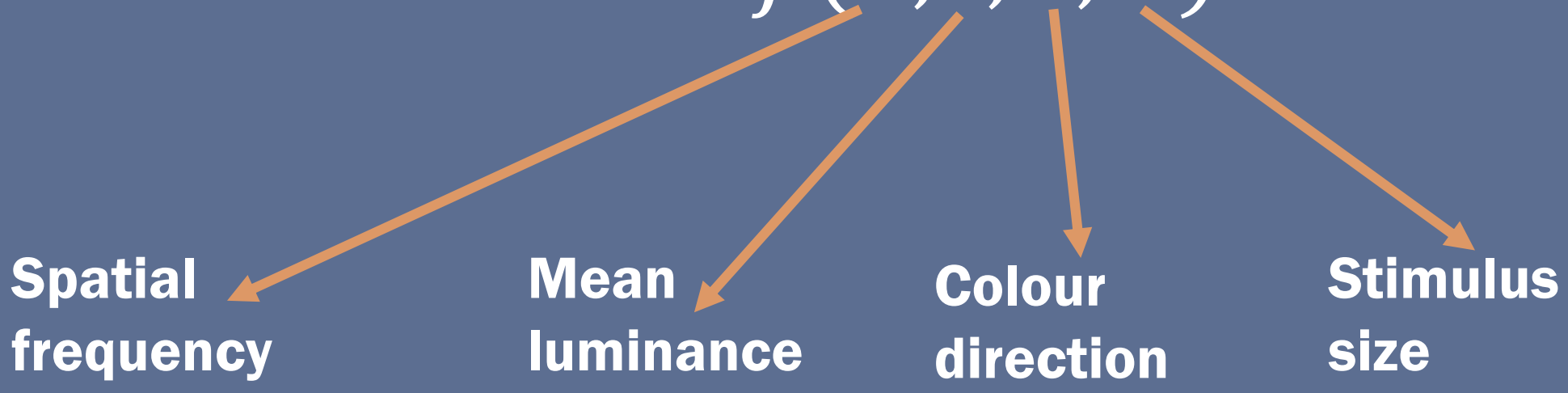


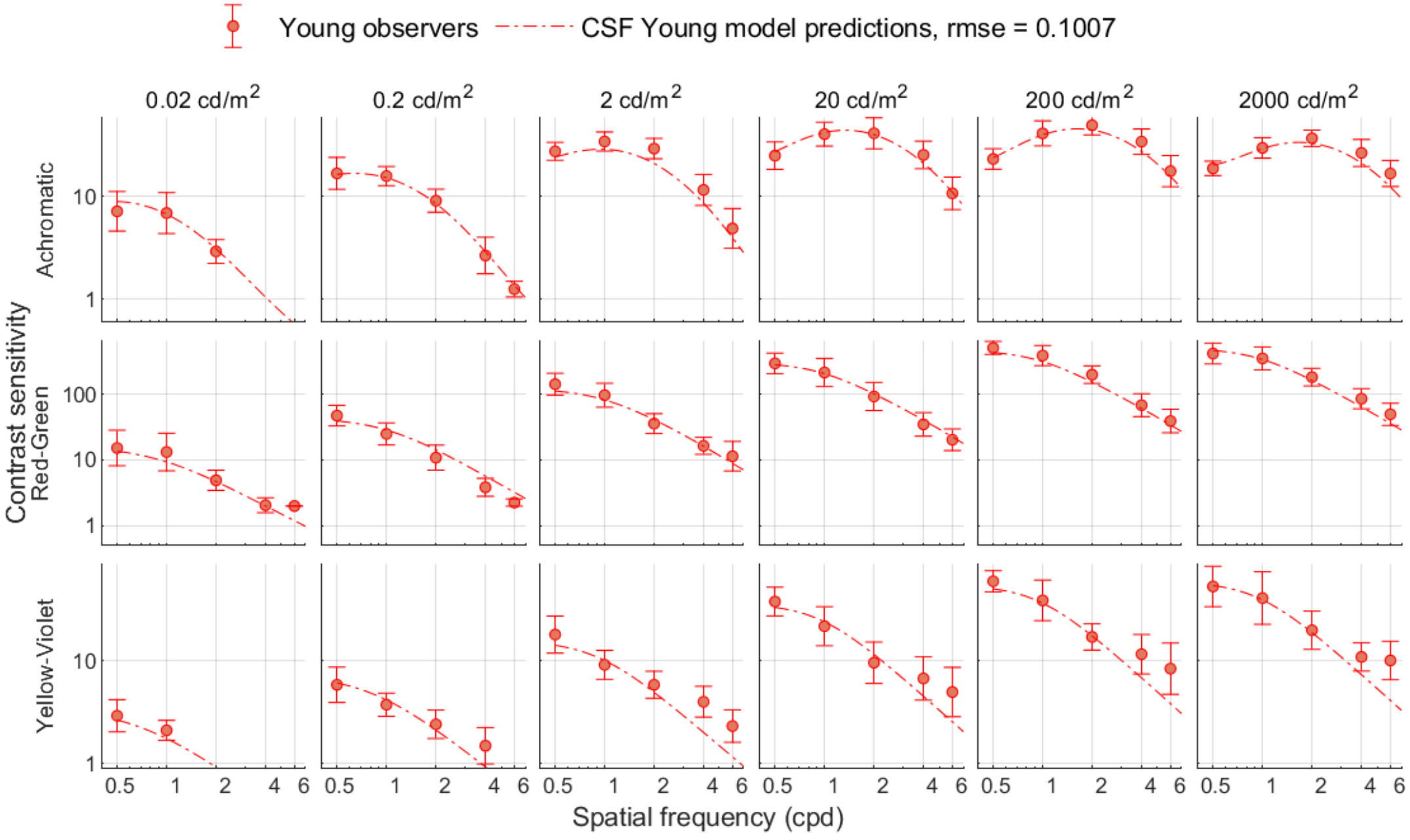
CSF_{old}@20 cd/m² ≈ CSF_{young}@2 cd/m²

CSF_{old}@200 cd/m² ≈ CSF_{young}@20 cd/m²

Reduced retinal illumination with age should explain some changes in CSFs

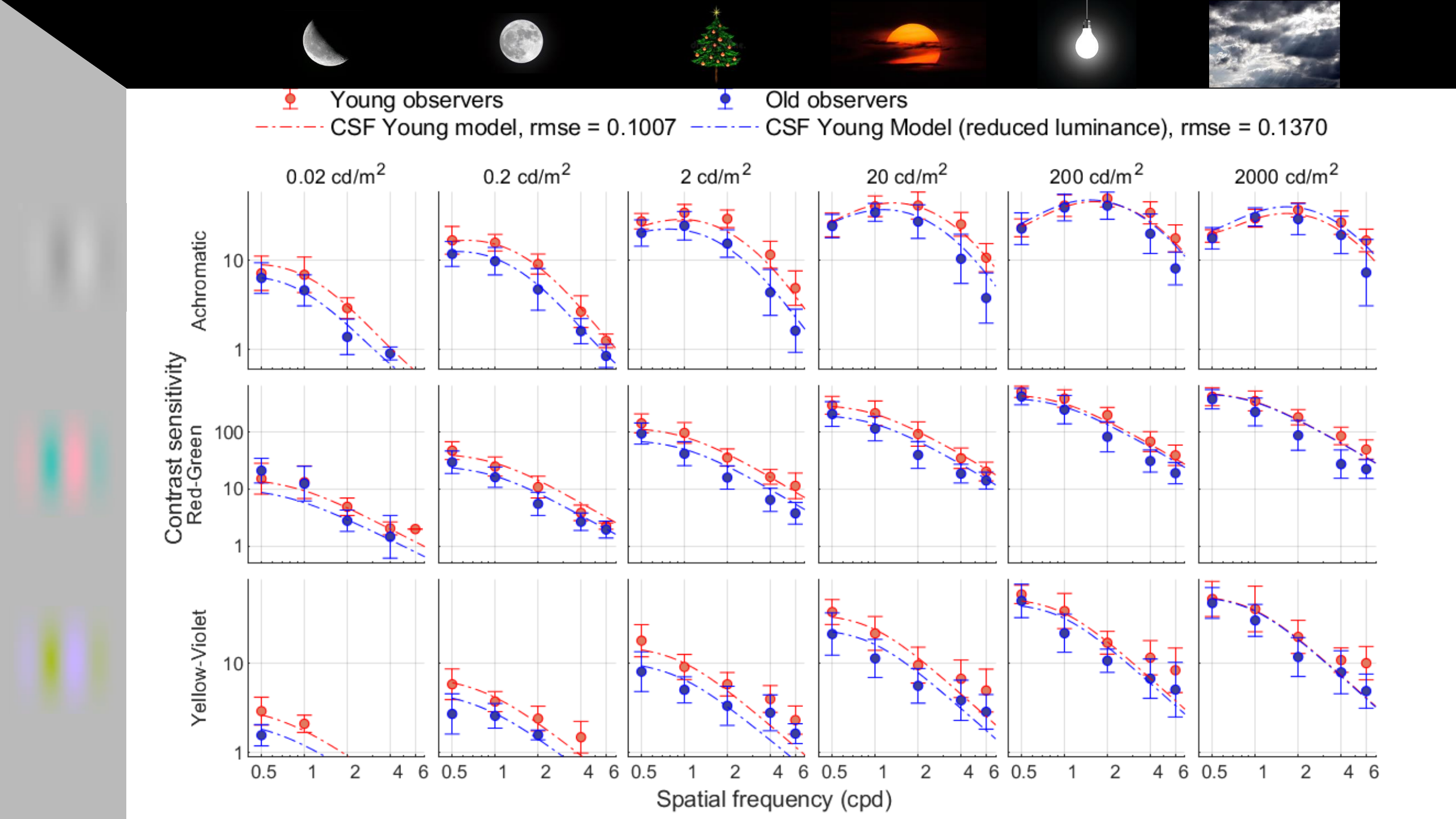
$$CSF = f(x, l, c, \sigma)$$

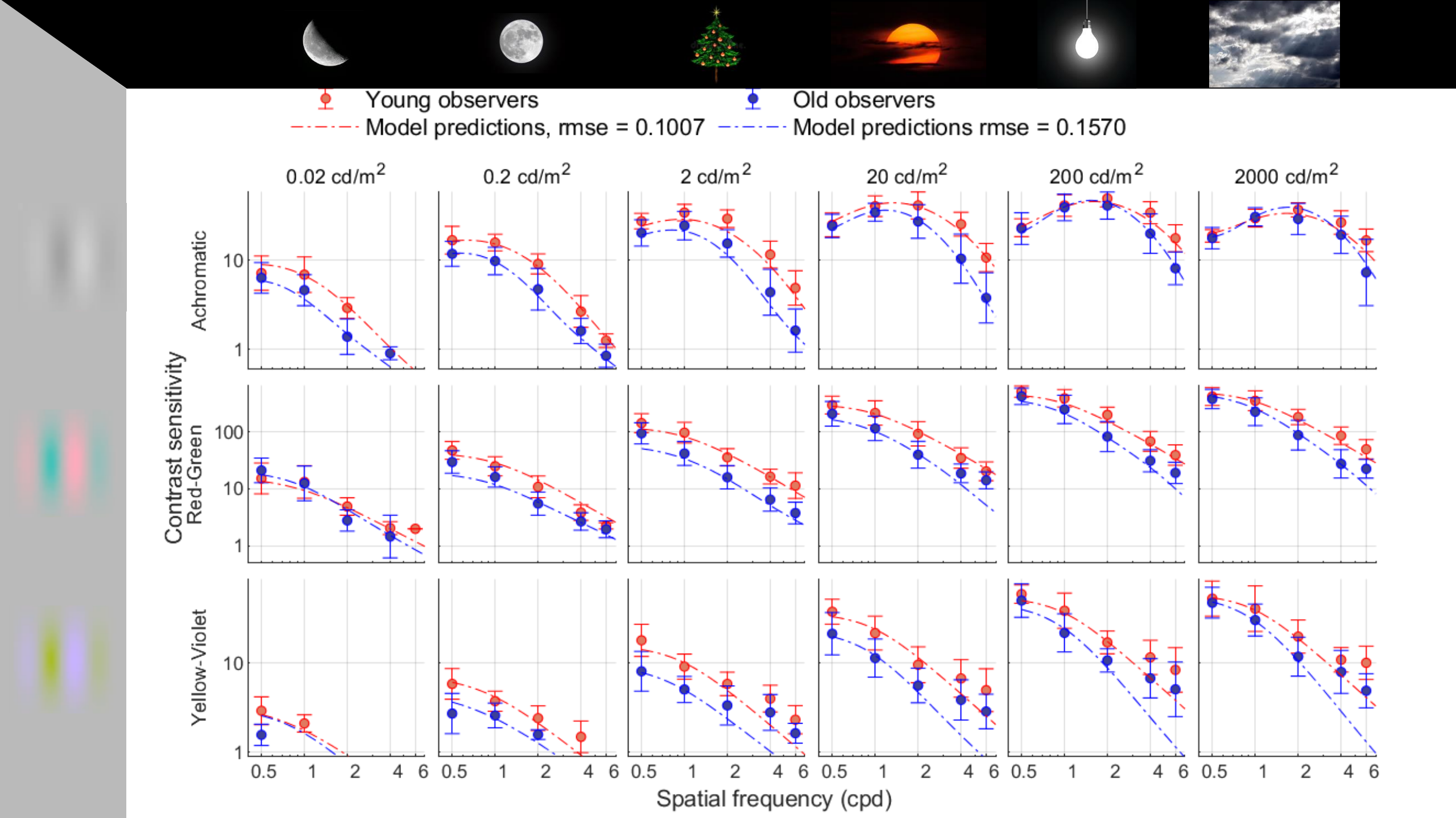



Young observers
CSF Young model predictions, rmse = 0.1007
0.02 cd/m2
0.2 cd/m2
2 cd/m2
20 cd/m2
200 cd/m2
2000 cd/m2
Achromatic
Red-Green
Yellow-Violet
Contrast sensitivity
10
1
100
0.5
1
2
4
6
Spatial frequency (cpd)

Reduced luminance values in fitted model for older observers

Observer Group	Luminances (cd/m^2)					
Young	0.02	0.2	2	20	200	2000
Old	0.007	0.07	0.7	6.7	66.7	666.7

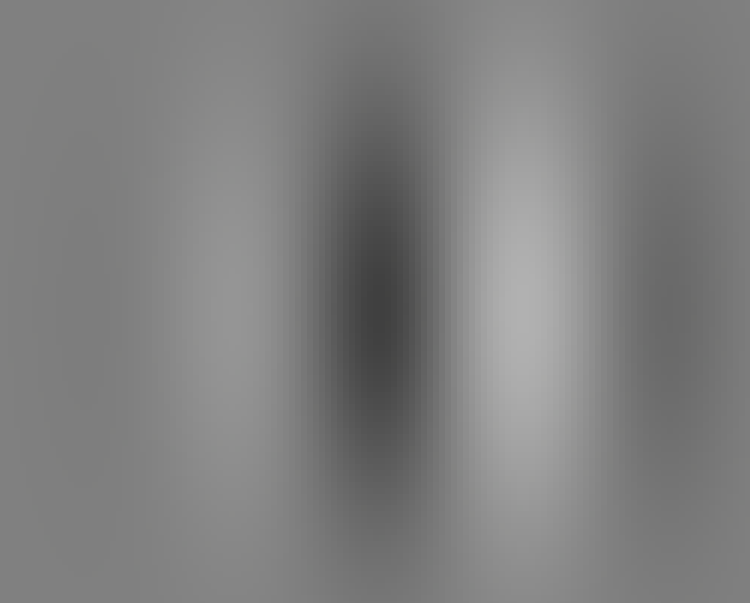

Young observers
Old observers
CSF Young model, rmse = 0.1007
CSF Young Model (reduced luminance), rmse = 0.1370
0.02 cd/m2
0.2 cd/m2
2 cd/m2
20 cd/m2
200 cd/m2
2000 cd/m2
Achromatic
Red-Green
Yellow-Violet
Contrast sensitivity
Spatial frequency (cpd)
0.5
1
2
4
6
10
100
1


Young observers
Old observers
Model predictions, rmse = 0.1007
Model predictions rmse = 0.1570
0.02 cd/m2
0.2 cd/m2
2 cd/m2
20 cd/m2
200 cd/m2
2000 cd/m2
Achromatic
Red-Green
Yellow-Violet
Contrast sensitivity
Spatial frequency (cpd)
0.5
1
2
4
6
10
100
1

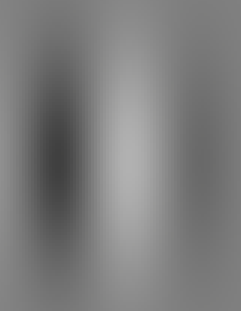
Does suprathreshold contrast vision also change with age?

Kulikowski's contrast constancy model

$$C_1 - C_{1_t} = C_2 - C_{2_t}$$



$Pattern\ 1$



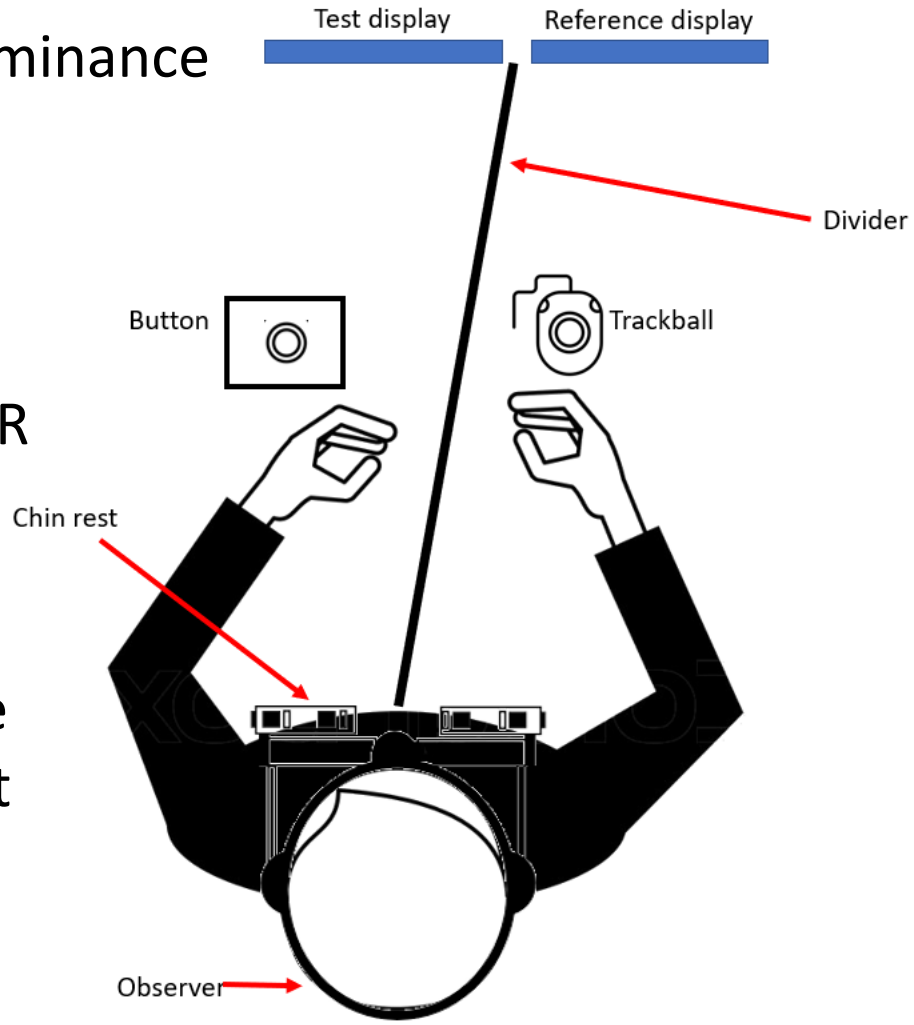
$Pattern\ 2$

EXPERIMENT SETUP

Reference stimulus displayed at fixed luminance level

Test stimulus with adjustable contrast displayed on the HDR screen at multiple luminance levels

Observers match the two stimuli such that the contrast appears similar



STIMULI

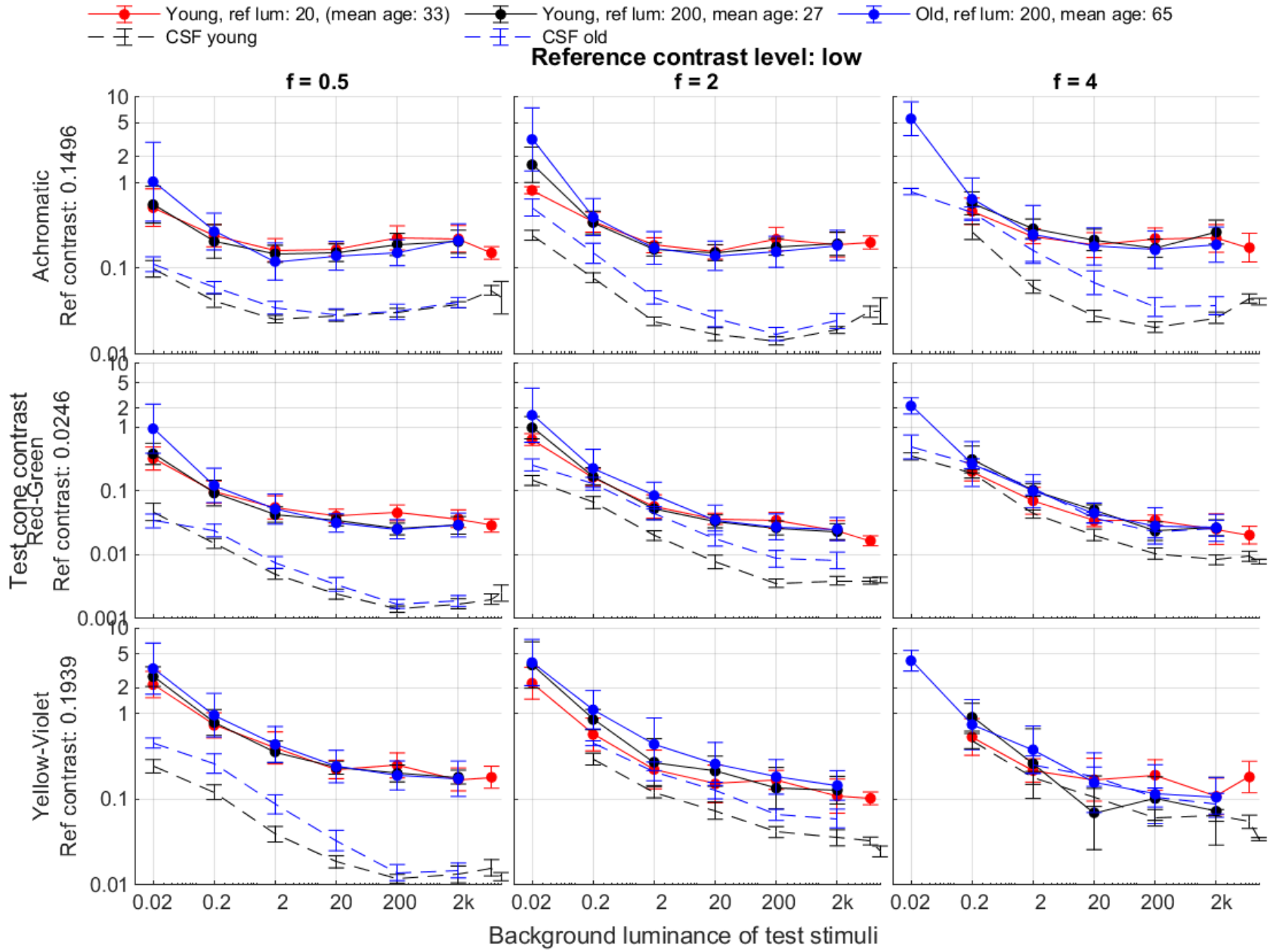
Reference stimuli: 200 cd/m^2 (old observers), 200 and 20 cd/m^2 (young observers), 0.5, 2, and 4 cpd, 3 color directions

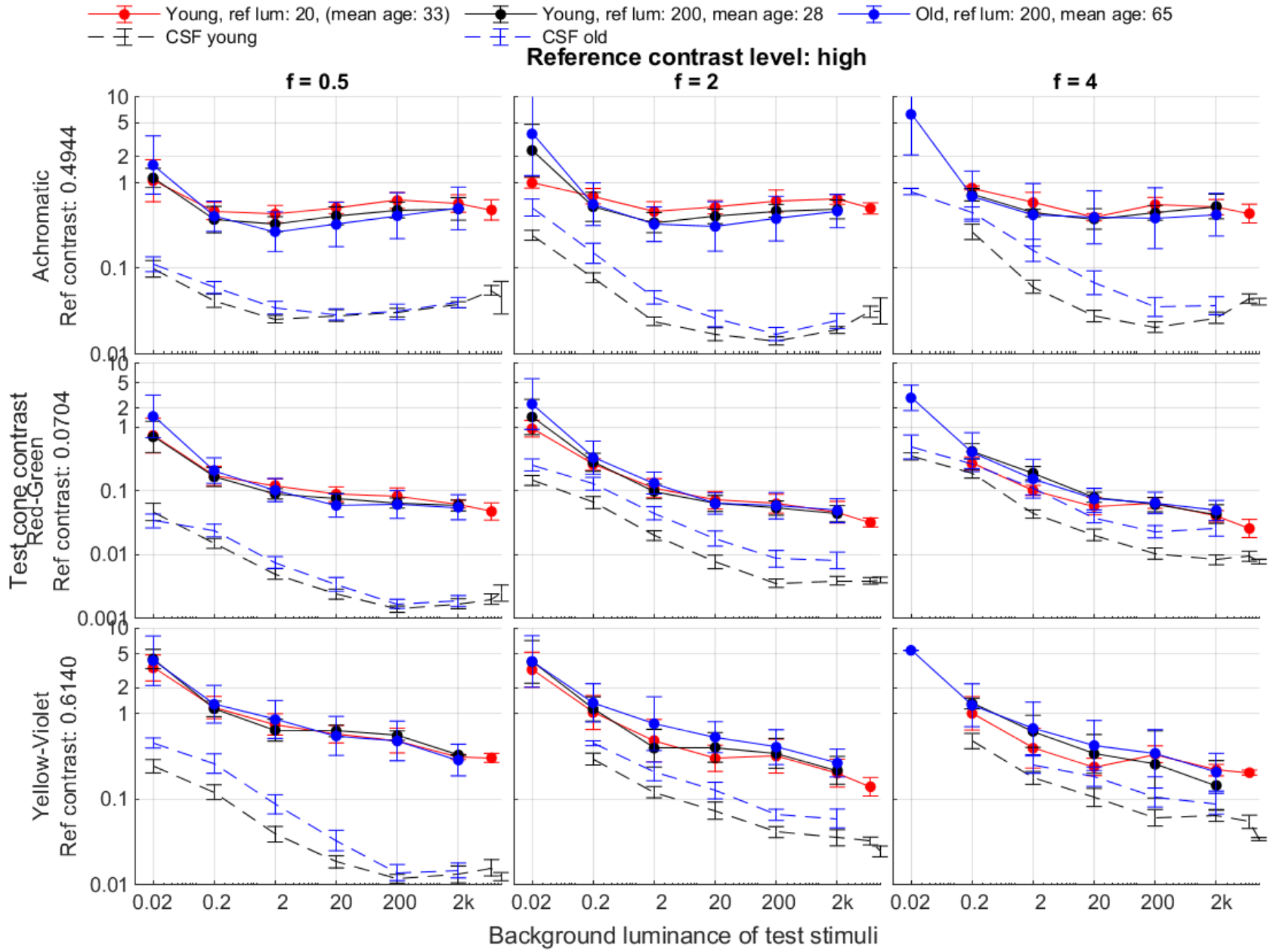
Test stimuli: Each reference stimulus matched with equivalent test stimuli at 0.02, 0.2, 2, 20, 200, and 2000 cd/m^2

Test

Reference

Results


Young, ref lum: 20, (mean age: 33)
Young, ref lum: 200, mean age: 27
Old, ref lum: 200, mean age: 65
CSF young
CSF old
Reference contrast level: low
f = 0.5
f = 2
f = 4
Achromatic
Ref contrast: 0.1496
Test cone contrast
Red-Green
Ref contrast: 0.0246
Yellow-Violet
Ref contrast: 0.1939
10
5
2
1
0.1
0.01
0.001
0.02
0.2
2
20
200
2k
Background luminance of test stimuli


Young, ref lum: 20, (mean age: 33)
Young, ref lum: 200, mean age: 28
Old, ref lum: 200, mean age: 65
CSF young
CSF old
Reference contrast level: high
f = 0.5
f = 2
f = 4
Achromatic
Ref contrast: 0.4944
Test cone contrast
Red-Green
Ref contrast: 0.0704
Yellow-Violet
Ref contrast: 0.6140
10
5
2
1
0.1
0.01
0.001
0.02
0.2
2
20
200
2k
Background luminance of test stimuli

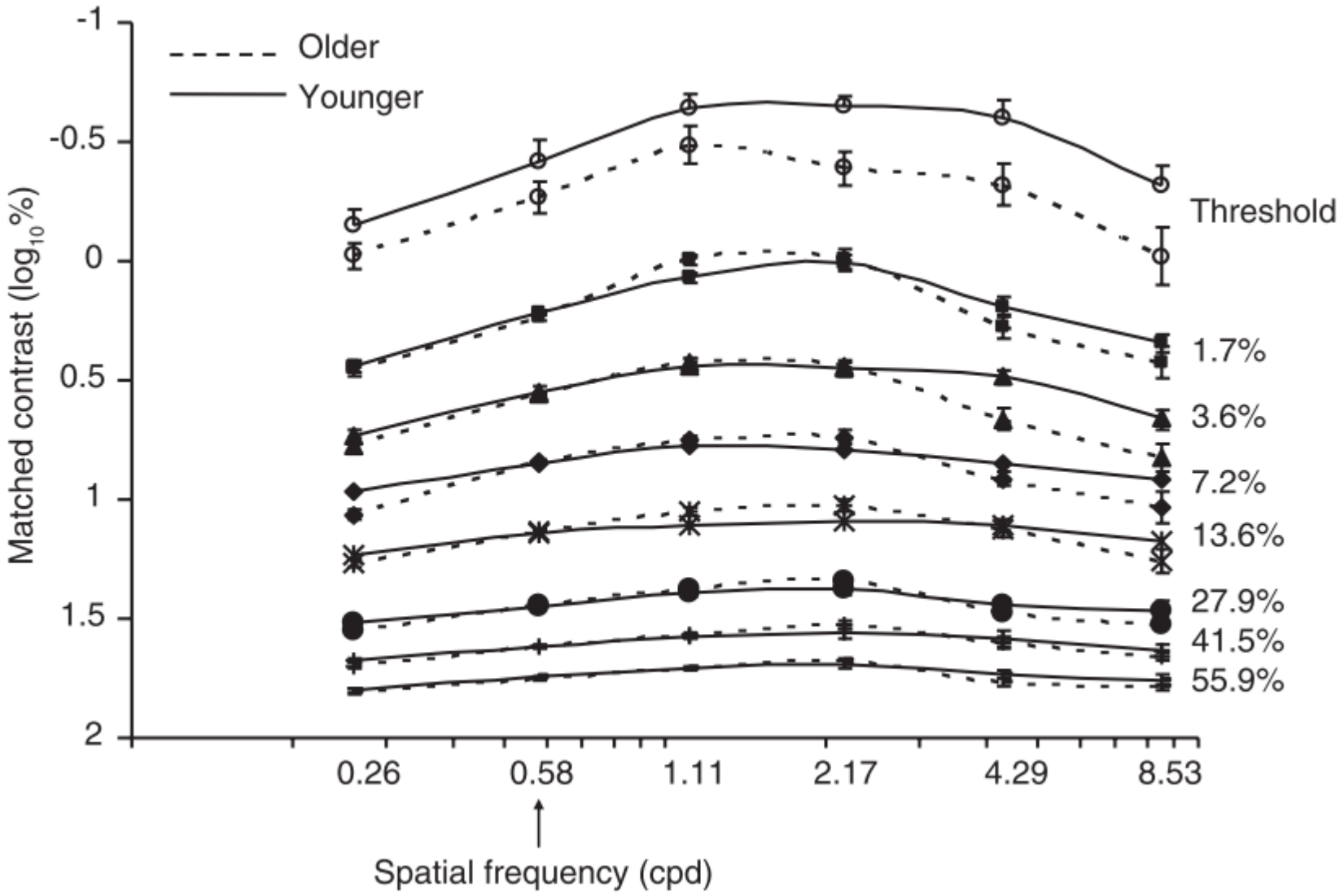


Figure Source: Mei, M., Leat, S. J., & Hovis, J. (2007). Supra-threshold contrast matching and the effects of contrast threshold and age. *Clinical and Experimental Optometry*, 90(4), 272–281. https://doi.org/10.1111/j.1444-0938.2007.00162.x

SUMMARY

- Both chromatic and achromatic contrast sensitivities are reduced as we age
- The effect of age varies at different luminance levels and spatial scales
- Reduction in retinal illumination play a large part in CSF changes (RMSE reduced from 0.3 to 0.14 log units)
- Differences between contrast vision of young and old observers diminish at suprathreshold levels

Thank you

Sophie Wuerger

Rafal Mantiuk

Jasna Martinovic