What is the best metric for retinal exposure?–

THE IMPORTANCE OF FIELD-OF-VIEW In Circadian and Melanopic Effects

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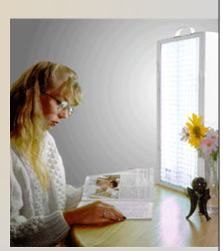
Retinal Exposure Dosimetry – What are the Appropriate Metrics?

- Retinal exposure rate (irradiance) (and illumination) is directly related to the ***radiance*** (and ***luminance***) of the light source but ***NOT*** directly related to measured corneal irradiance (or illuminance)! A TWA

- Historically, illuminance (in lux) introduced at a meeting held at NIH (USA) in the early days of SAD light therapy ~1983 for a line-of-sight fixed source – for simplicity and because of available instrumentation.

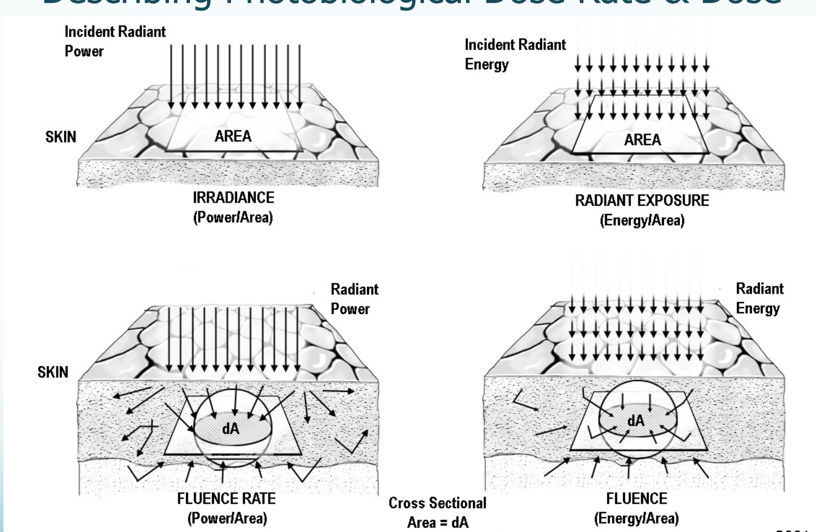


- While this was possible for the same type of large source, it can introduce errors and lack of reproducible results in research today.

Introduction and Background

- From the viewpoint of a vision scientist, retinal anatomy, physiology and visual functions are always of primary interest.
- My particular interest in retinal light exposure dosimetry has stemmed largely from efforts to assess potential hazards from both acute and chronic light exposure.
  - The importance of wavelength
  - ***The importance of the spatial distribution of light***
  - Also important to ipRGC sensitivity and functions

To Review: CIE Radiometric Quantities for Describing Photobiological Dose Rate & Dose



2001

Corresponding photometric quantity of illumination – *illuminance* **in lux**

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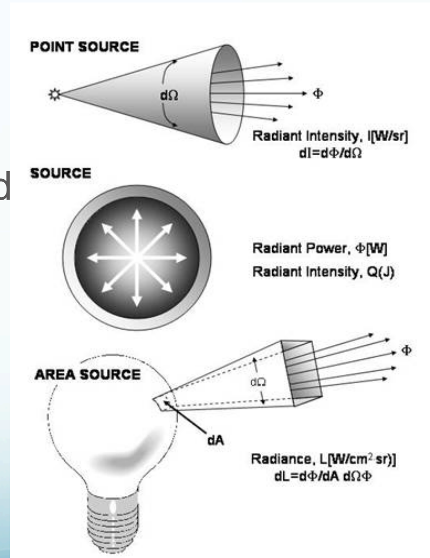
To Review:

CIE Standardized Radiometric Terms

Describing a Source:

- Provided in the CIE International Lighting Vocabulary and ISO and IEC standards
- Radiometric quantities, units and symbols are standardized.
- *Retinal irradiance* is directly proportional to *radiance*



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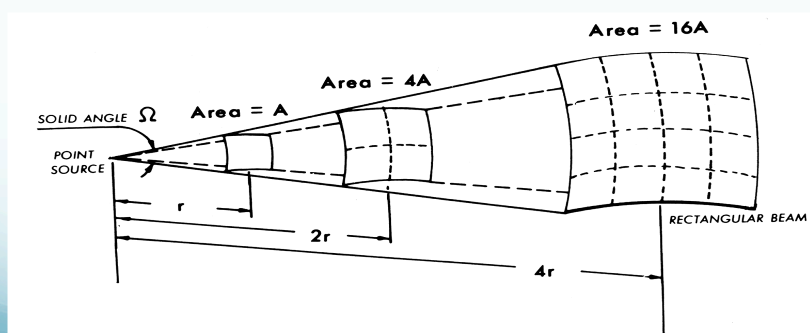
Is Illuminance or Irradiance an appropriate metric?

- Irradiance and illuminance decrease with distance
  - At distances r much greater than the source dimension the irradiance decreases inversely as the square of the distance – **THE INVERSE-SQUARE LAW**



Sliney & Wolbarsht, Figure 2-20 (1980)

To explain to psychiatrists and medical professionals, I have found this example useful:

Consider this light source
of brightness L ➘

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We measure Irradiance E:

At 1.0 meter – E = 1 μW/cm^2 (or 2 lx)

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Consider this light source of brightness L ➘

We measure Irradiance E:

At 1.0 meter – E = 1 µW/cm^2 (or 2 lx)

At 2.0 meters – E = 1/4th µW/cm^2 (0.5 lx)

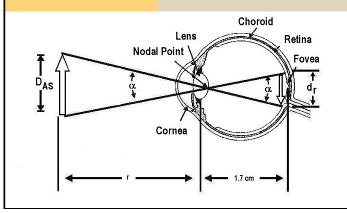
At 3.0 meters – E = 1/9th µW/cm^2 (0.22 lx)

At 4.0 meters – E = 1/16th µW/cm^2 (0.13 lx)

But, the luminance (& radiance) remains the same – **retinal image size decreases**

Calculating Retinal Exposures

- Retinal irradiance is directly proportional to the radiance (brightness) of the source being viewed.
- The retinal irradiance E_r in $W \cdot cm^{-2}$ is:
- $$E_r = 0.27\, L \cdot \tau \cdot d_e^2$$
  - where L is the radiance in $W \cdot cm^{-2} \cdot sr^{-1}$
  - and τ is the transmittance of the ocular media
- Retinal illuminance in Trolands (td) is L ($cd \cdot m^{-2}$) multiplied by square of the pupil diameter (in mm).



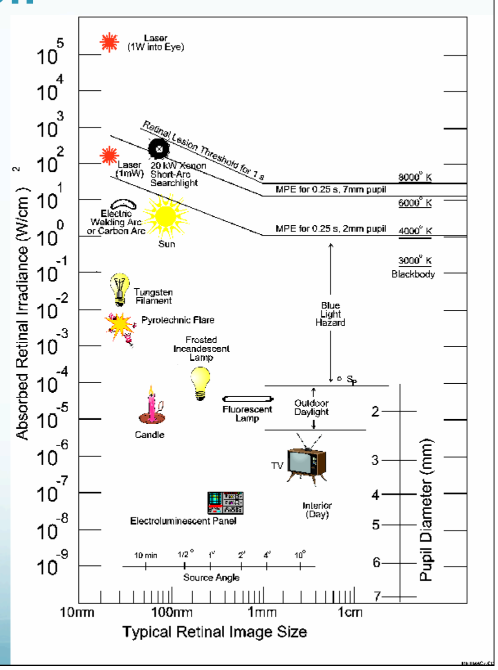
- Unusual case: for Ganzfeld, $L = E/\pi$

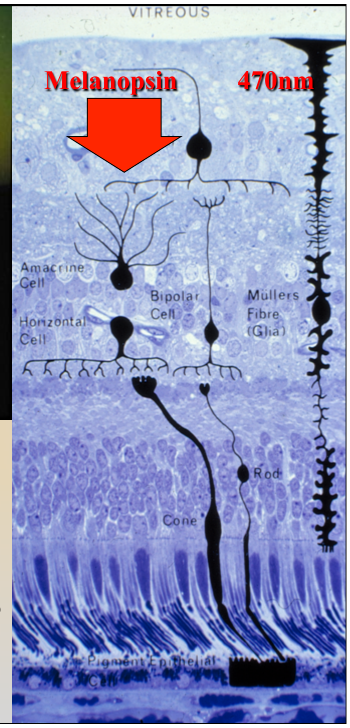
(See Sliney and Wolbarsht, 1980)

Retinal Illumination

- The ambient outdoor illumination of the retina is of the order of 0.02-0.1 mW/cm^2 and these levels are just comfortable to view
- Retinal illuminance outdoors is ~ 5×10^5 td
- The sun's image is a million times greater

D Sliney 1980





Then…What about spatial Distribution of Ganglion Cell Receptors?

ipRGCs – Berson et al, Science 295,2002

The importance of spatial stimuli

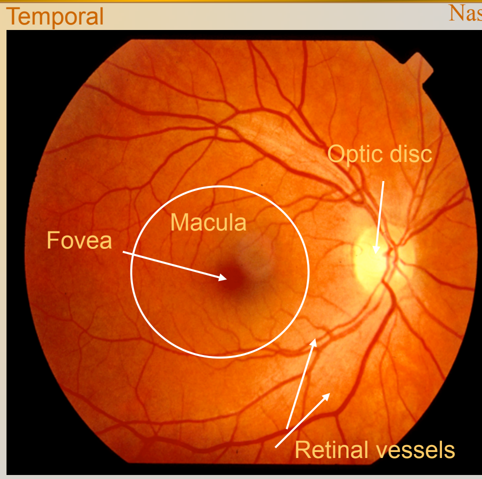
The Normal Human Eye

Retinal Ganglion Cells

- Absent in fovea
- In peripheral macula and peripheral retina
- Highest density at ~5° from center of fovea

-Curcio CA, Allen KA. Topography of ganglion cells in human retina. Journal of *Comp. Neurol*. 300(1):5–25 (1990).
-Watson AB, A formula for human retinal ganglion cell receptive field density as a function of visual field location, *J. Vis*ion 14(7):14, 1–17 (2014).

Temporal Nasal



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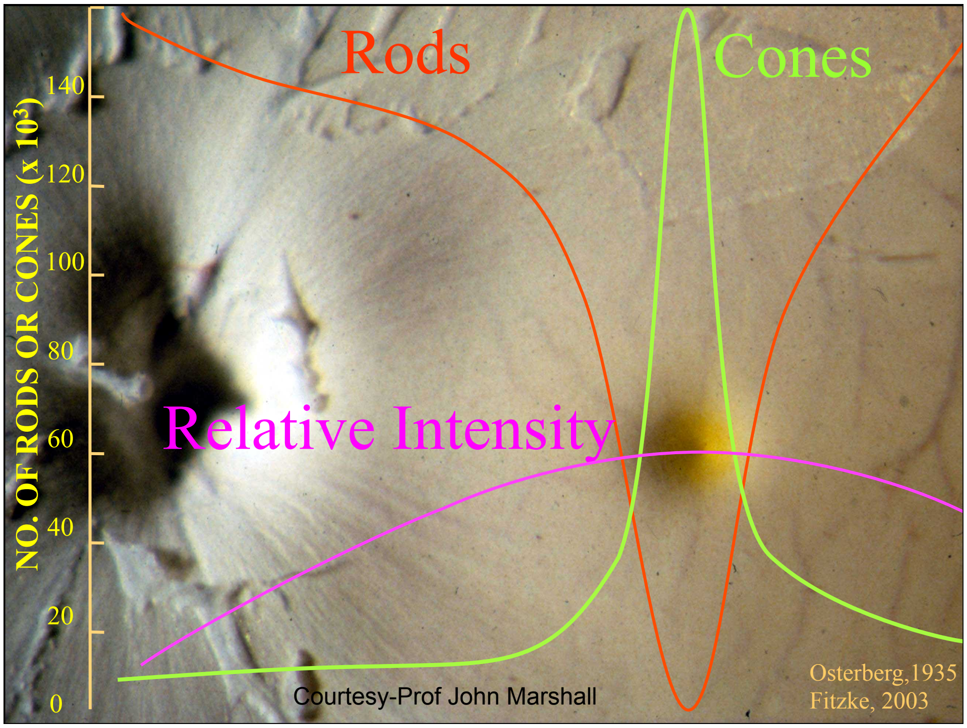
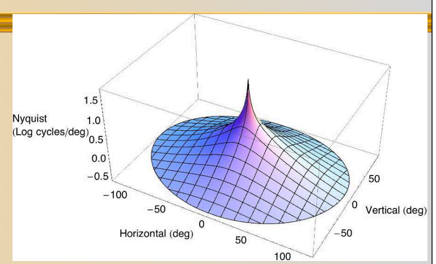
Retinal Fundus Schematic – Courtesy, Aiello

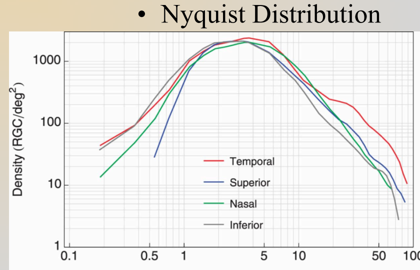


RGCs – Their location across the retina

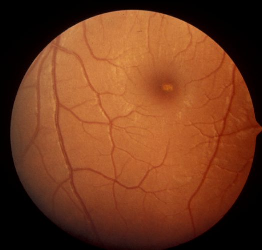
- Distribution of RGCs
  - Watson, Cumulative total number of RGC along four meridians. *J Vision* 14(7):14, 1–17(2014) .
  - Curcio C. A. Allen K. A. Topography of ganglion cells in human retina. *J Comp Neurol*, 300 (1), 5–25(1990).
- And the ipRGCs?



- Nyquist Distribution

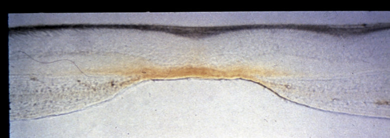


The Macula Lutea - Lutein Pigment

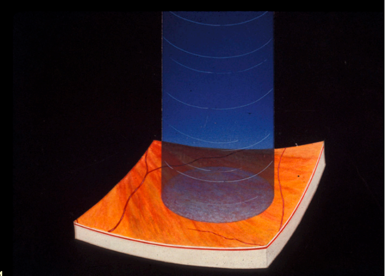


In the inner and outer plexiform layers

Thought to minimize BLH



Highest concentration in fovea



D Sliney 2001

Our normal FOV – up to 45º-50º

– Good lighting design to reduce glare will position luminaires above the normal FOV out of sight

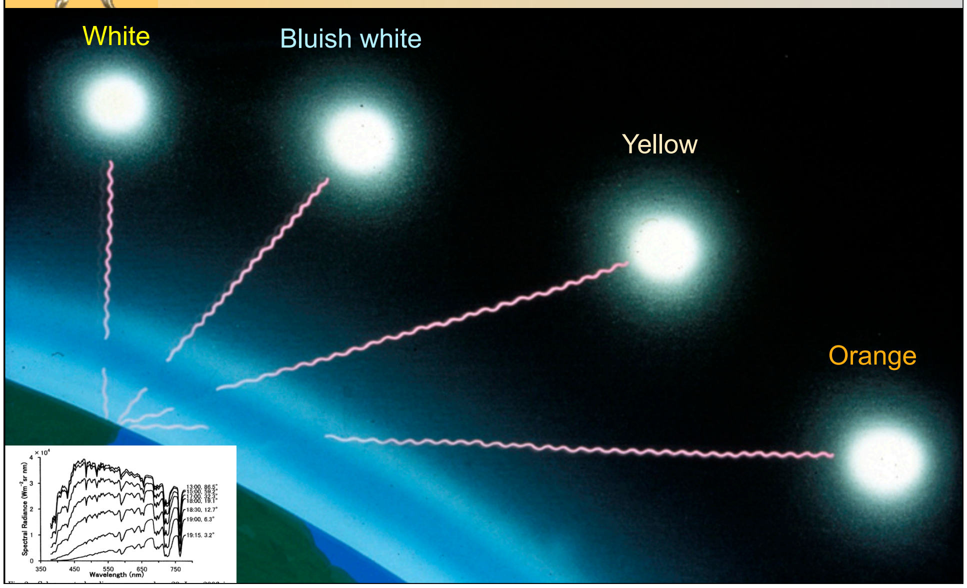
Indoors:

Look up to see direct light; look ahead and glare is reduced

- **Conclusion** – Use limited FOV to measure the retinal stimuli

Changing atmospheric pathlengths

- and changing spectral appearance of solar disc

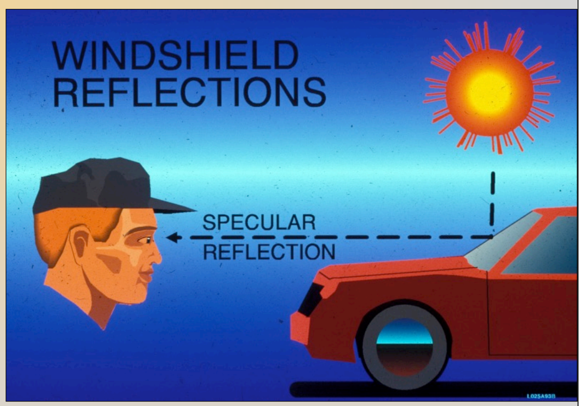


UVR and blue light are scattered out of the direct image making the yellow-to-red sun safe to view directly at sunset, but staring at the sun at midday produces photomaculopathy

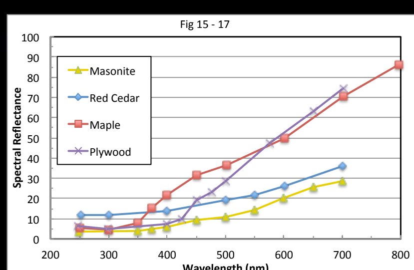
D Sliney 2006

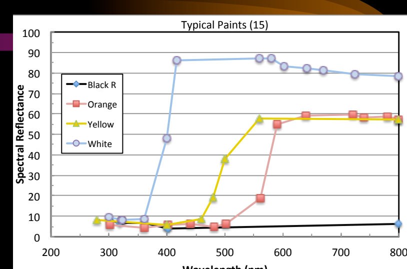
In nature the retina is not directly exposed to intense bluish-white light from the solar disc. But today – from tilted glass…

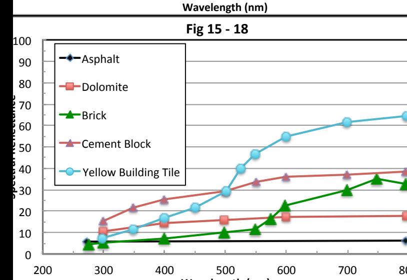
- Performed measurements with spot photometer and spectroradiometer
- Assessed potential blue-light hazard and safe viewing times
- An unfinished study



Reflectance of natural surfaces & in built environments: low in blue-violet





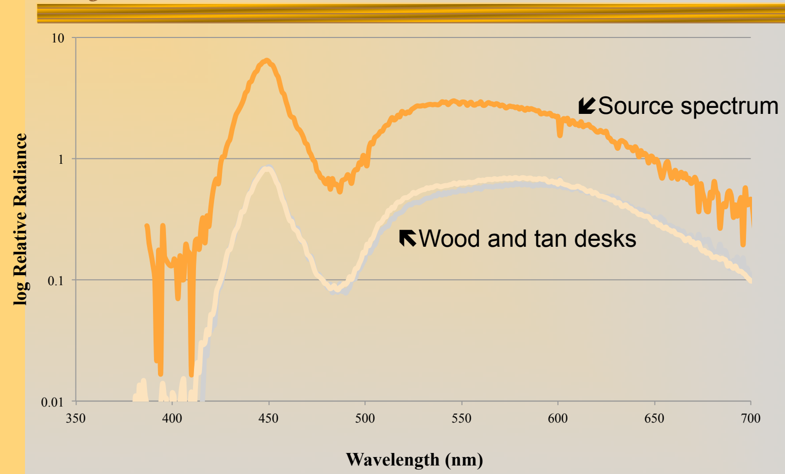


- The spectral reflectance of most materials below 500 nm is lower than longer wavelengths
- Exceptions are snow or white paint! …or blue paint!

From Sliney & Wolbarsht book, Chap 15, 1980

Radiance Reflected in FOV

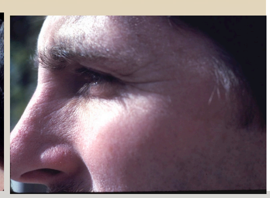
Spectral Radiance Distributions of Objects illuminated with "White" LED

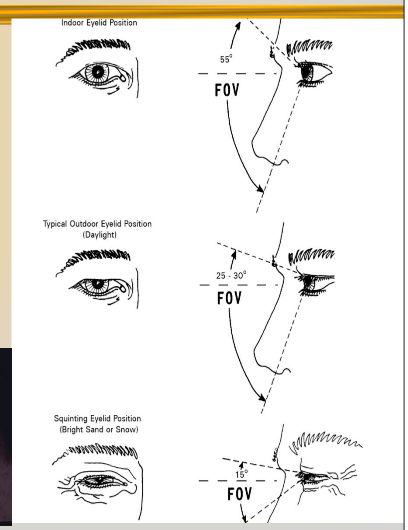


Note that the blue-fraction is reduced twice as much in reflected spectra compared to the yellow-orange-red part of the spectrum

***Outdoors**: Lid Position depends on scene brightness (luminance)*

Studies of lid opening by Deaver & Sliney showed that upper limit of FOV reduces with increasing scene luminance

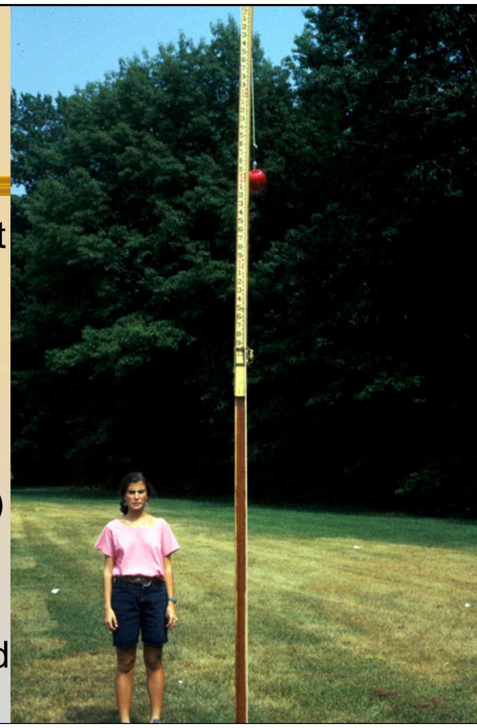




Lid Position

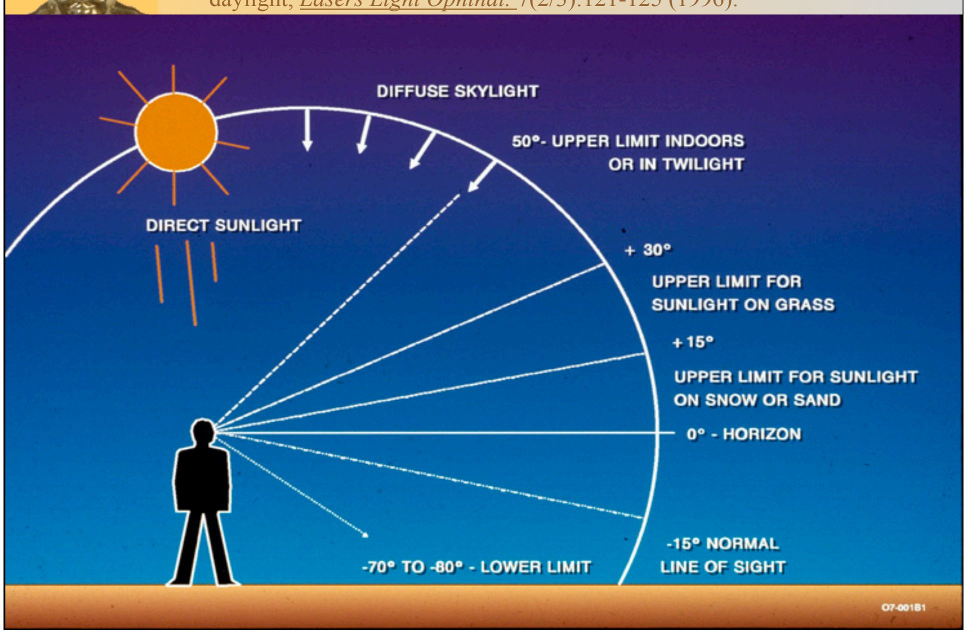
- Lid position measured at USACHPPM under sunlight by measuring upper limit of visual field for changes in outdoor luminance (Deaver et al., *Lasers & Light*,1993)
- Luminance (brightness) in field of view measured

LPA 25



Summary of Findings

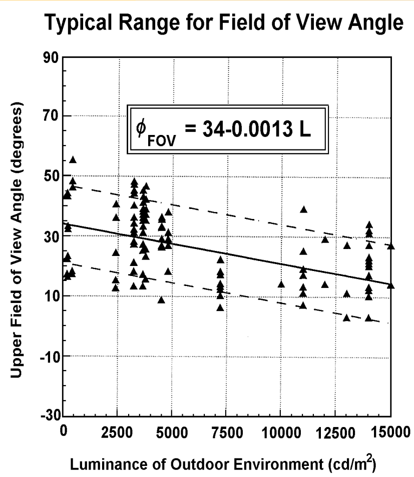
(Deaver DM, Davis J, Sliney DH, Vertical visual fields-of-view in outdoor daylight, <u>Lasers Light Ophthal.</u> 7(2/3):121-125 (1996).

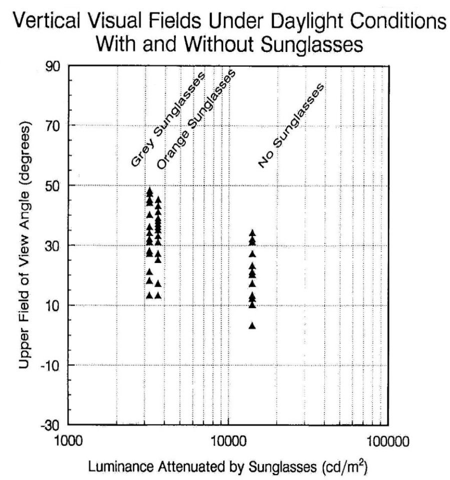


Lid Shading Experiments

- Large variation among individuals

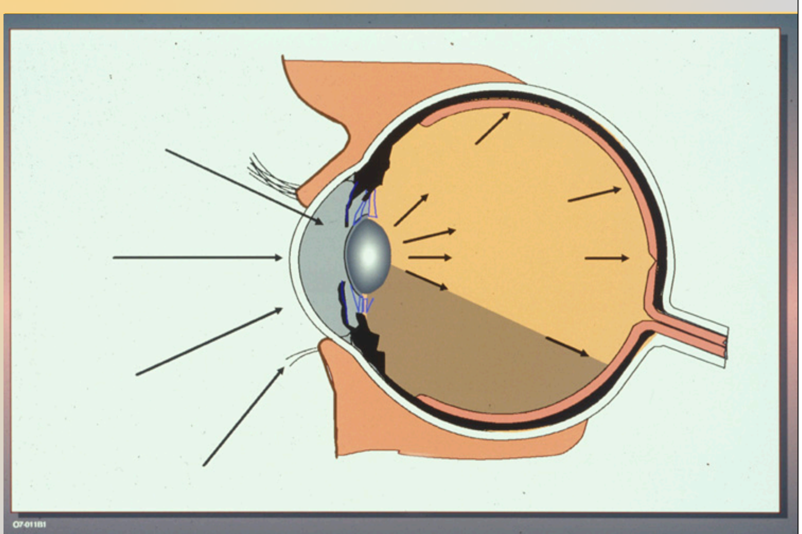
Upper FOV limit was: $f(k_1 - 0.0013\ L)$





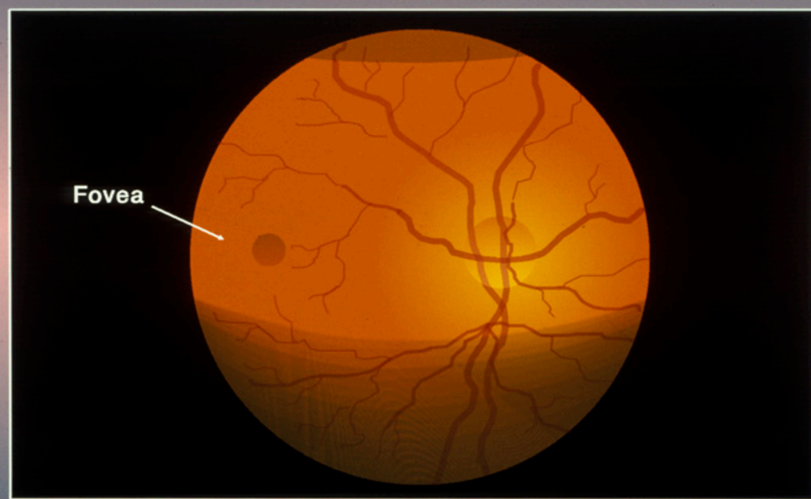
Retinal Exposure in Sunlight

(inferior retina is not exposed)



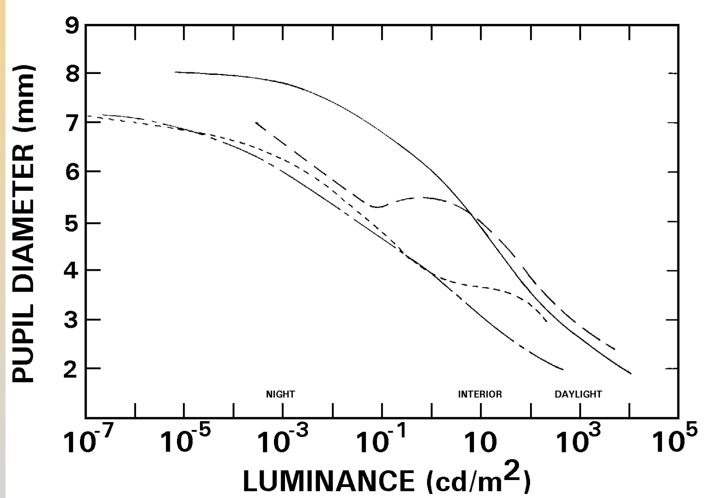
Glickman-2003 – ipRGCs in inferior retina were more sensitive

RETINAL ILLUMINATION

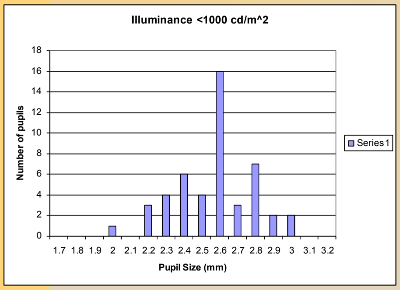


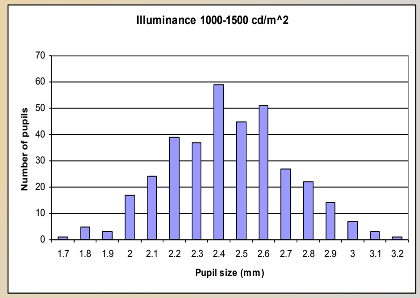
Inferior retina is ‘in the dark.’ Regardless of ambient light levels, the macula is always exposed; signs of ageing, such as lipofuscin clumps appear in superior retina (Beaver Dam study results)

The** **area** **of the pupil aperture determines the total light entering the eye, but there is a wide individual variability — low-n samples from classical studies



Pupil Size also varies:
Some Data Plotted by Frequency

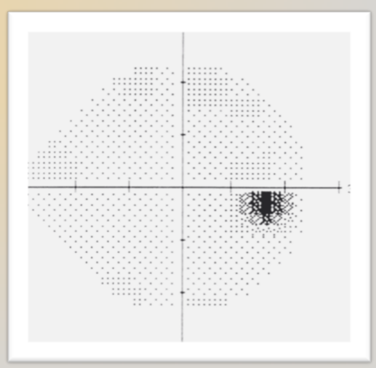




- **CONCLUSION:** For any given setting, two persons may have differing pupil areas as great as 2.6-fold — This individual variability limits the precision of any dose-response curve.

Ophthalmic Clinical Perimetry

- Clinical Perimetry measures the visually important visual field ~ +/- 30^{o} (60^{o} full angle)

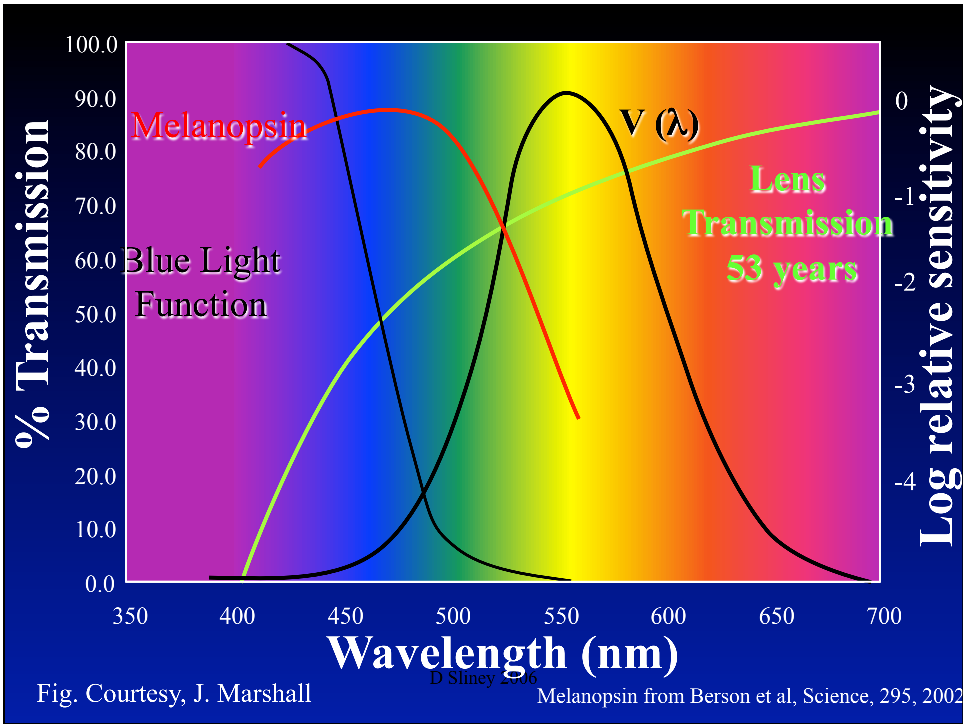


CONCLUSIONS

- Measurement of overhead sunlight or overhead artificial lighting luminaires is not highly related to retinal illumination!
- Vertical illuminance is a metric that is really only relevant to light boxes within direct FOV
- Reflectance of natural or built materials in the lower FOV dominates retinal illumination
- Ignoring this viewing/exposure geometry may result in false negative experimental results!

Sliney's Hypothesis to Test…

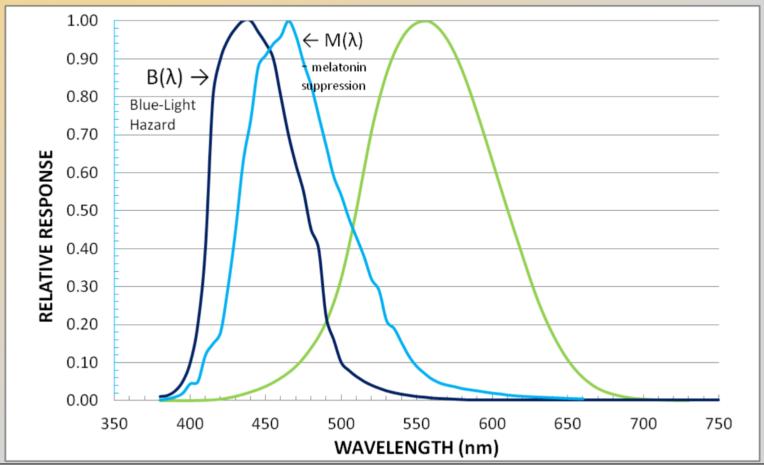
- There is a subset of the general population who have a reduced ipRGC/melanopsin-mediated response compared to the normal physiologic response to bright light (pupil and lid reduction of retinal illumination).
- Finding that subset could show an increased incidence of AMD if there really is any link.
- Linking two Research Areas – neurological ipRGC research and ophthalmic epidemiology!



Practical Dosimetry – Illuminance?

- Photometric quantity, *illuminance (lux)*, or the radiometric quantity, irradiance (W/cm^2 and W/m^2) used successfully used to describe exposures from single phototherapy light source.
- More applicable measurement quantities are **luminance** ("brightness") and **radiance**,
  - Extent of illumination (i.e., source size or reflected scene area).
  - Retinal illumination is directly proportional to the luminance and radiance of a viewed light source or scene.
  - To evaluate potential retinal hazards of bright light, the limits are set in radiance along with spectral weighting (e.g., for blue-light hazards).
- But radiance or luminance must be averaged over appropriate fields-of-views (FOVs).
  - For the same corneal illuminance/irradiance, the retinal irradiance from a relatively small source will be far greater than from a much larger light source. **Is this important?**

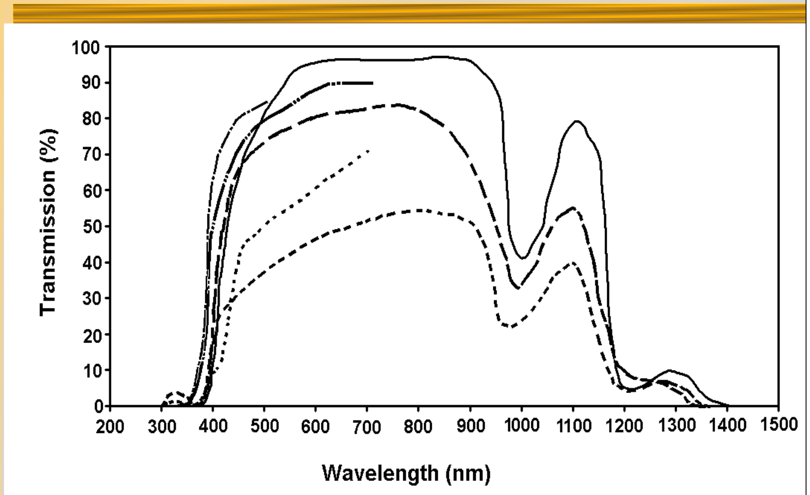
Action Spectra of Interest – Visible Radiant Energy (the known)



Individual Variability

- Frequently ignored factor
- Individual's pupil size
- Individual's sun-avoidance behavior
- Individual lid opening – really!?
- Individual's lens/corneal spectral transmission – varies with age, latitude
- Potential photophobia
  - How big a factor can each of these be?

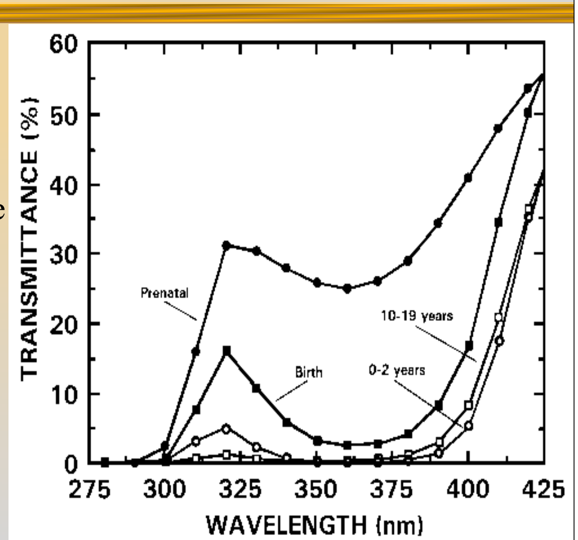
Spectral Transmission to the Retina

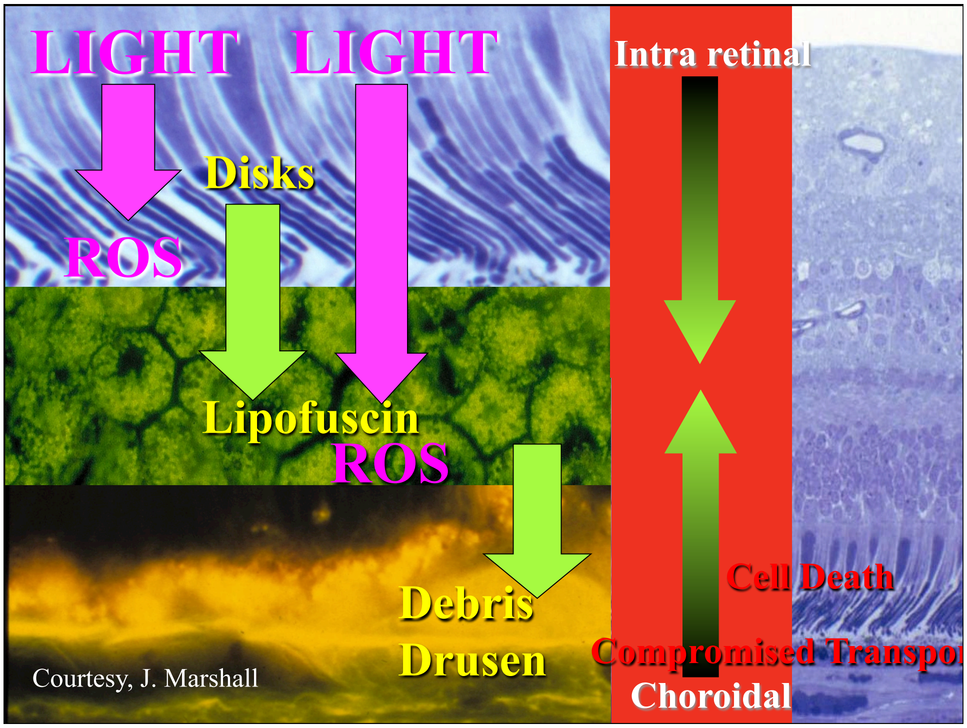


The UV/violet Spectral transmission diminishes in the ageing eye

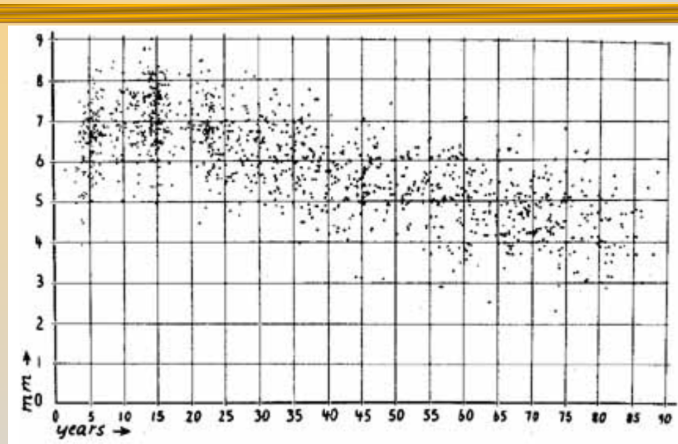
For very small children, small amounts of 295-325 nm UV reach the retina

- ***Childhood*** sunlight exposure frequently overlooked
- UV/violet Spectral Transmittance of the Human Lens (Data of Barker & Brainard)
- UV-A absorbing chromophores have fascinated biochemists – some lenticular fluorophores



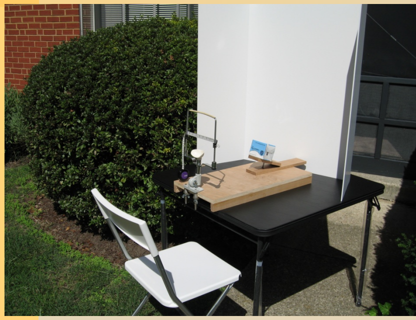


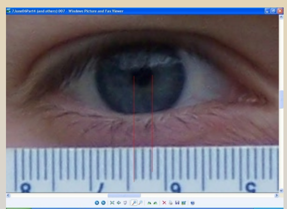
Pupil Size Decreases with Age



Note the spread of pupil sizes for low indoor light

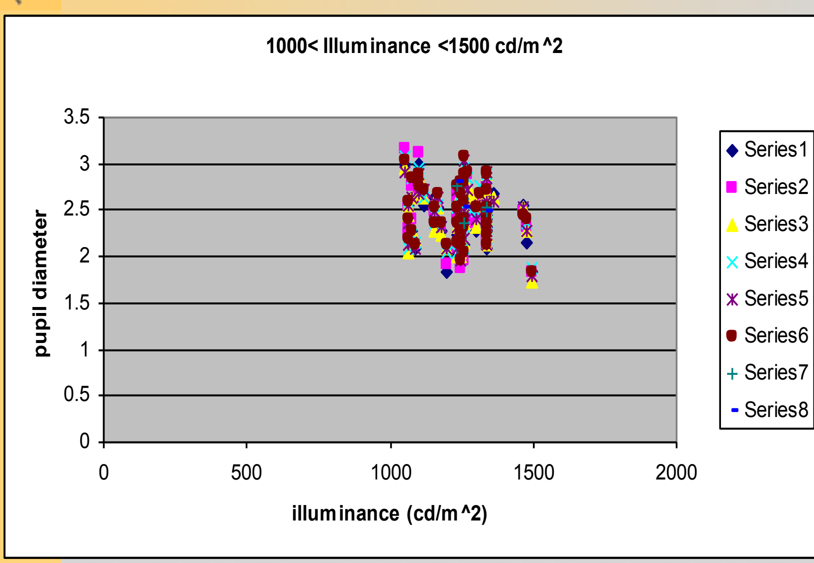
Pupil-Size Measurement in Sunlight – King–Sliney Studies



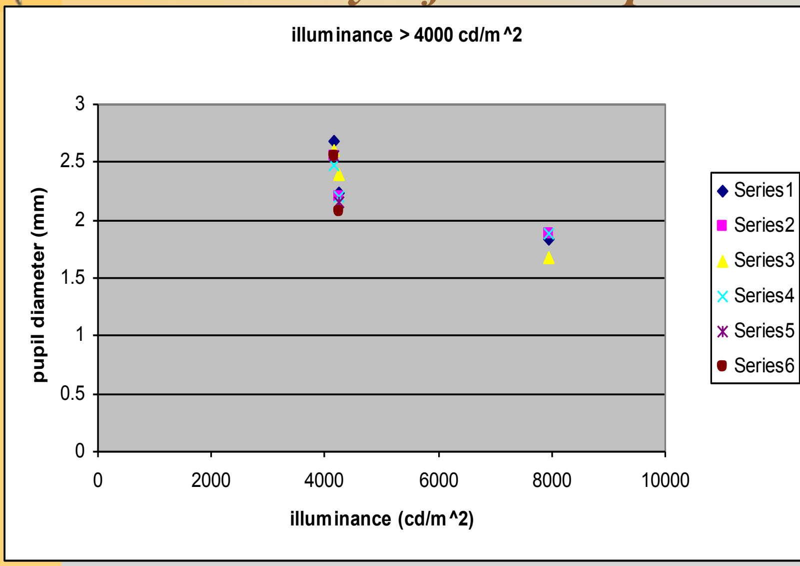


- Pupil size out of doors is not well studied
- Past laboratory studies were limited in luminance
- USUHS student (Stephanie King) study to photograph pupils of military personnel in outdoor daylight
- 1.4-2.0 mm range in brightest light
- 2.39 mm average found during overcast skies

Moderate Daylight, mostly cloudy (Area > 2x variation)



Higher Daylight Luminance Values – only a few data points



Results and Data Analysis of USUHS Pupil Measurement Study

Overcast, cloudy day so this was a conservative study of outdoor daylight pupil sizes when lid openings were somewhat greater

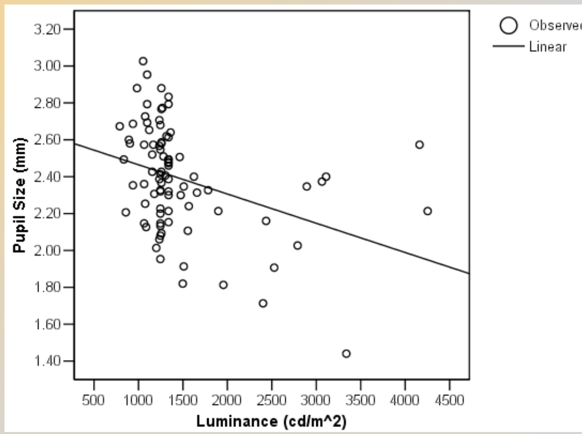
N	Mean (mm)	Std Dev	Min (mm)	Max (mm)	95% CI for Mean LB	95% CI for Mean UB
86	**2.39**	0.29	1.44	3.03	2.33	2.45

- Across all luminance measurements
- One point at 7957 cd/m^2, 1.82mm — a sunny day!
- Key QUESTION What causes the pupil variation?

Pupil Size in Outdoor Daylight – King & Sliney

Overall Results

- Relationship between pupil size and luminance
  - F-test statistic for linear regression (0.001 test stat)
- ***Conclusion*** – large variation is pupil area
- Sunglass-wear will increase pupil area



An Example…Retinal illuminance increases as the square of the pupil diameter Consider photometric units (Trolands):

- What is the luminance of the screen in this room?
- Using the Minolta Luminance meter, we would likely measure about 350 cd m^{-2}
- The retinal illuminance in Trolands is then:
  - ~ 3,150 Td for a 3-mm pupil
  - ~ 8,750 Td for a 5-mm pupil
  - ~ 17,200 Td for a 7-mm pupil
- But this photometric measure is rarely used except in vision-science experiments!

One CONCLUSION:

Individual Pupil Size

— the Variability

- Remember that the intrinsically photosensitive retinal ganglion cells (ipRGCs) play a key role in maintaining the pupil size in the outdoor environment! Is this the explanation?

- Now let us look at the lids—also presumably largely controlled by ipRGC and the role of the upper lid in determining ocular exposure!