Visual Performance

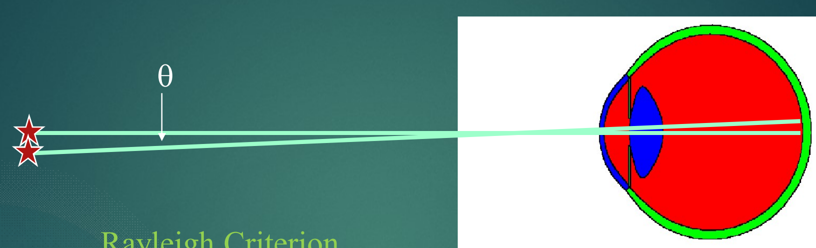
Aspects

- Resolution Limit
- Pattern Detection
- Pattern Recognition
- Contrast Level
- Color
- Temporal Response

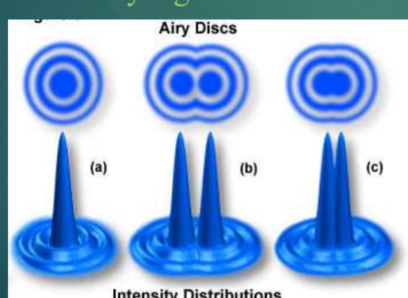
Conditions

- Illumination
- Monocular vs. Binocular
- Distance
- On-axis vs. Off-axis
- Single or multiple targets
- Literacy & Verbal ability

Theoretical Limit of Resolution



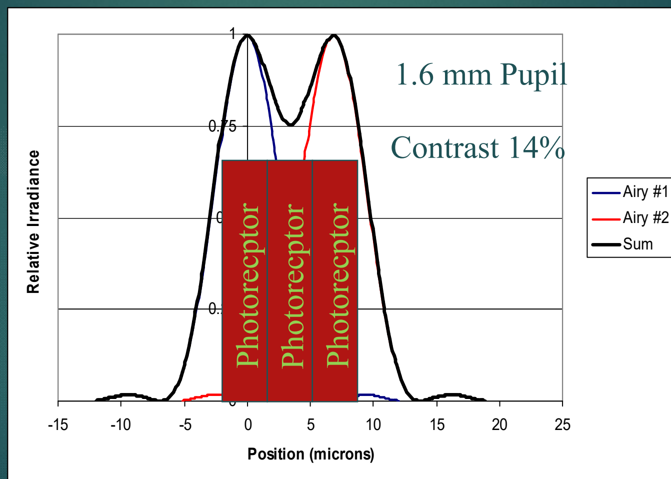
Rayleigh Criterion



$$\theta = \frac{1.22\lambda}{D} \text{ radians}$$

For $\lambda = 587.6$ nm
D ranges from 2 – 8 mm
$0.090 \le \theta \le 0.358$ mrad
$0.3 \le \theta \le 1.23$ minutes of arc

Rayleigh Criteria

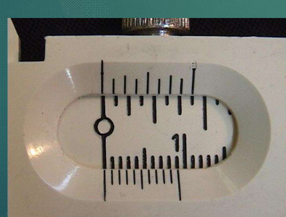


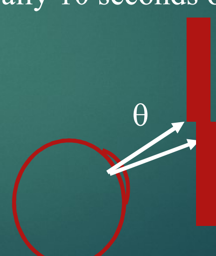
Visual Acuity

Visual Acuity is a measure of the smallest detail that can be resolved by the visual system. There are different types of acuity measures.

Point Acuity – "Binary Star" test – typically 1 arcmin resolution

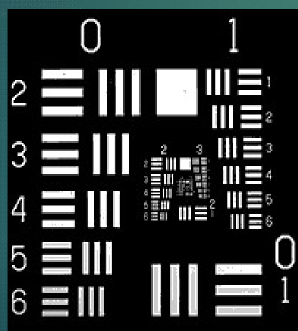
Vernier Acuity – Two lines slightly offset from each other. Finds smallest detectable offset – typically 10 seconds of arc

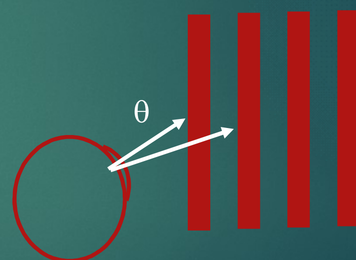




Visual Acuity

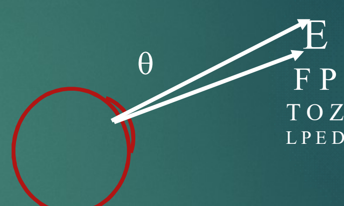
Grating Acuity – Sinusoidal or Square wave gratings are used to determine the smallest separation between peaks that can be resolved. Typically 2 arcmin.

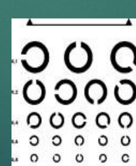


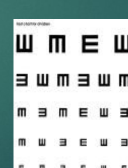


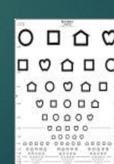
Visual Acuity

Letter Acuity – Different Letters or Symbols need to be recognized Typically 5 arcmin.



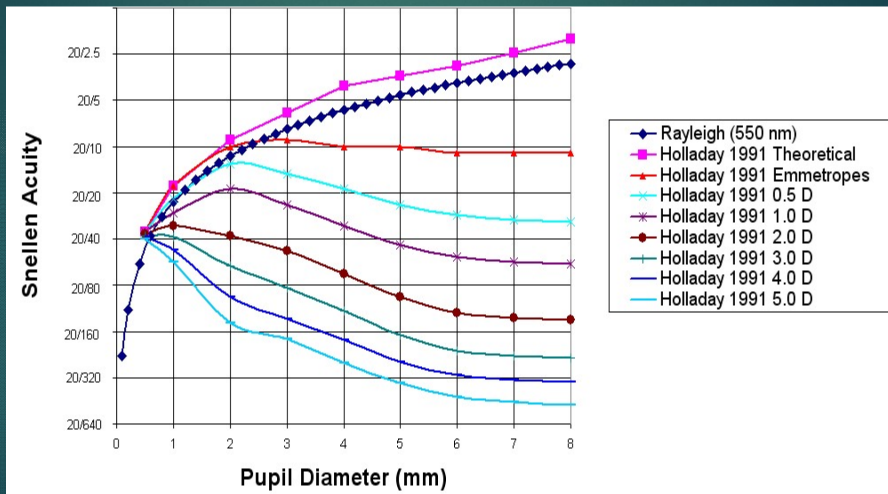




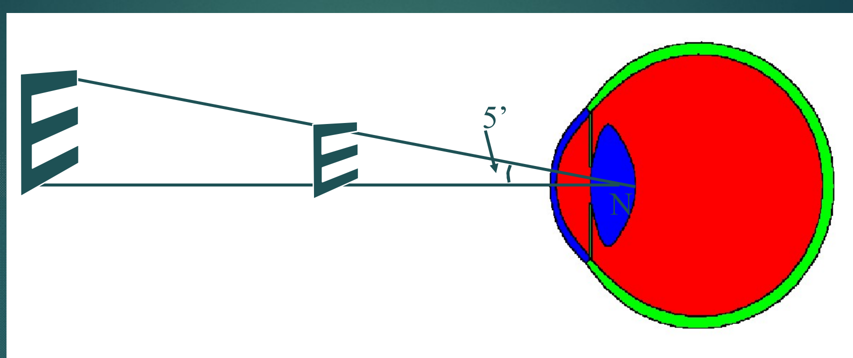


ETDRS Landolt C Tumbling Es Lea

Visual Acuity & Pupil Size



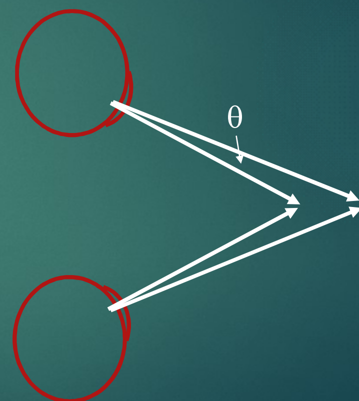
Visual Acuity Charts



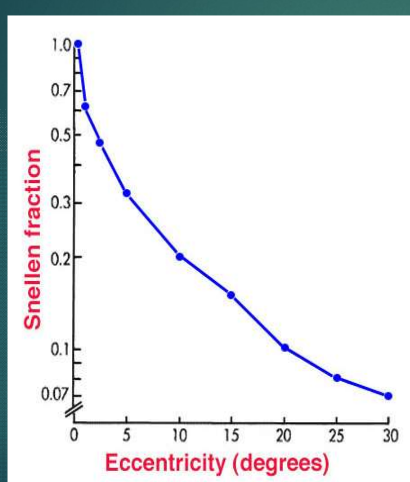
Visual Acuity Charts are designed so the 20/20 line subtends 5 arcmin.
20/40 subtends 10 arcmin
20/10 subtends 2.5 arcmin

Stereo Acuity

Given one object slightly closer than the other, find the smallest separation that is resolvable.
Typically - 5 seconds of arc



Visual Acuity vs. Field Angle



Visual Acuity rapidly decreases away from the fovea. Typically 20/20 in the fovea and 20/200 at a field angle of 20 degrees.

Spatial Summation

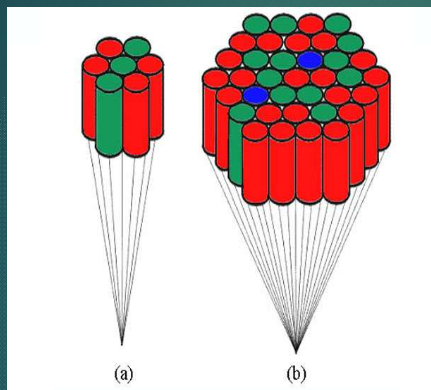


Figure 26. Schematic illustration of the size of receptive fields in (a) the parafoveal region (7^o eccentricity) and in (b) the peripheral retina (35^o eccentricity).

The loss in acuity is primarily due to Spatial Summation, where the output of multiple photoreceptors are tied to a single nerve fiber.

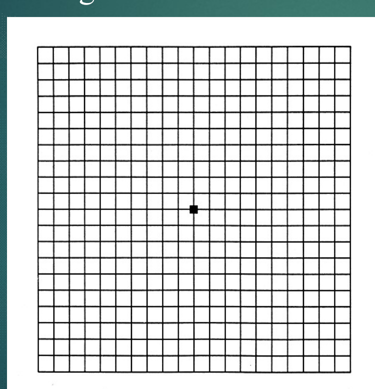
Acuity versus Field Angle

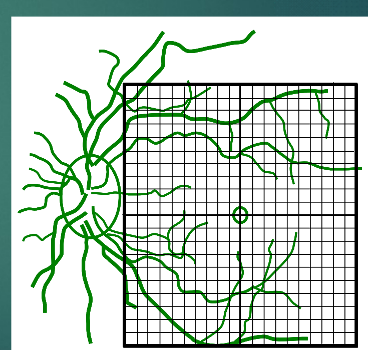
http://www.usd.edu/psyc301/images/acuity.GIF

Foveated Display

Amsler Grid

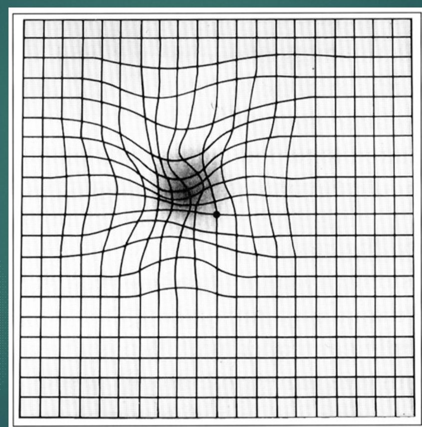
The Amsler Grid is a device used to rapidly assess visual field loss. It is composed of a grid of 20 by 20 squares, each 5 mm on a side. The grid is held at reading distance and subtends roughly 20° of visual angle.





National Eye Institute, National Institutes of Health

Amsler Grid



National Eye Institute, National Institutes of Health

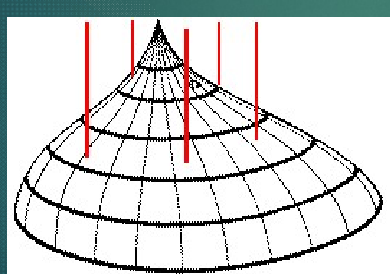
Visual Field Testing

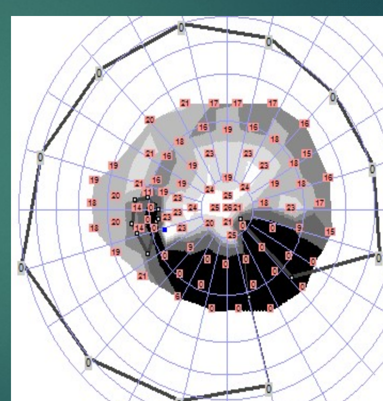
- Kinetic - Target moved from out of field of view towards center of field until it is perceived.
  - *Tangent Screen:* Objects of different sizes moved from perimeter until seen. Bigger bjects seen earlier.
  - *Goldmann Projection:* Objects of different brightness moved in from the perimeter until seen. Brighter objects seen sooner.
- Static - Dim light shines in retina and is slowly increased in brightness until perceived. Repeated for multiple locations on the retina.

Visual Field Testing

Visual Fields

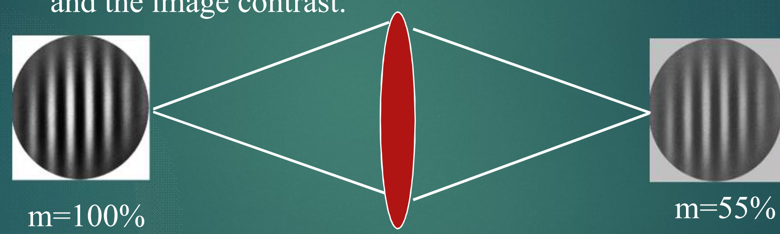
"Island of Vision"





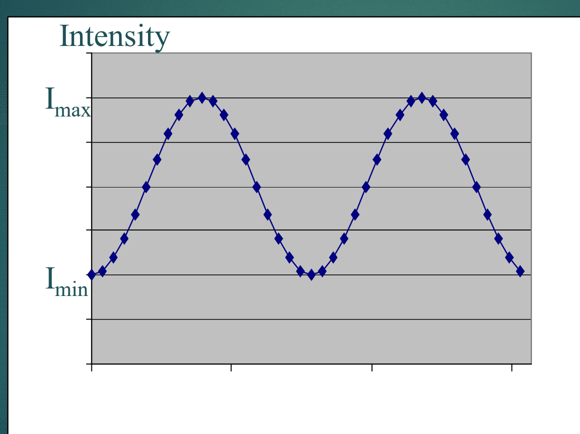
Modulation Transfer Function (MTF)

The MTF measures the loss in contrast in the image of a sinusoidal target. It is the ratio of the object contrast and the image contrast.



$$\text{MTF} = \frac{0.55}{1.00} = 0.55$$

Contrast

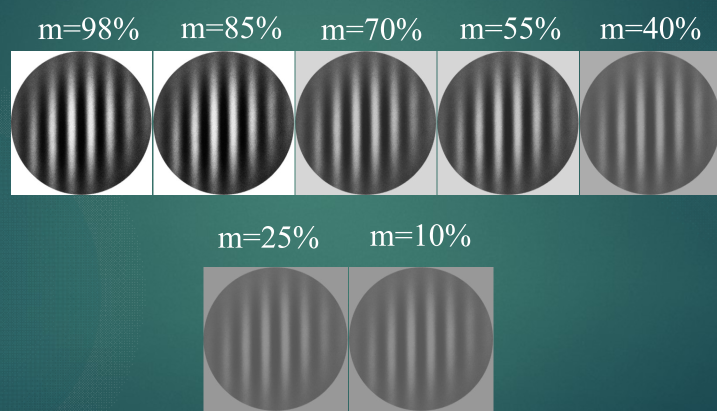


$$\text{Contrast } C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

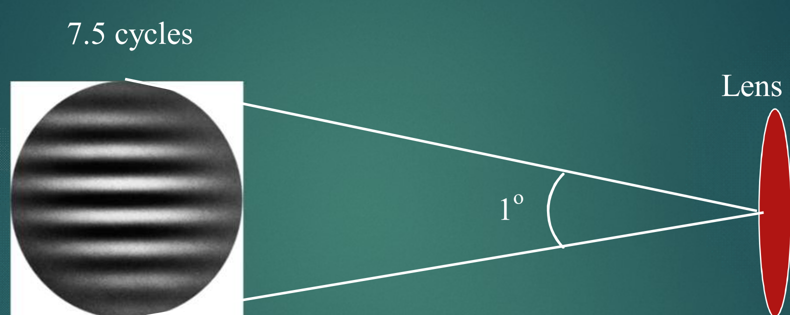
Contrast Sensitivity CS is the reciprocal of the minimum value of C that is detectable.

$$CS = \frac{1}{C_{min}}$$

Contrast Sensitivity

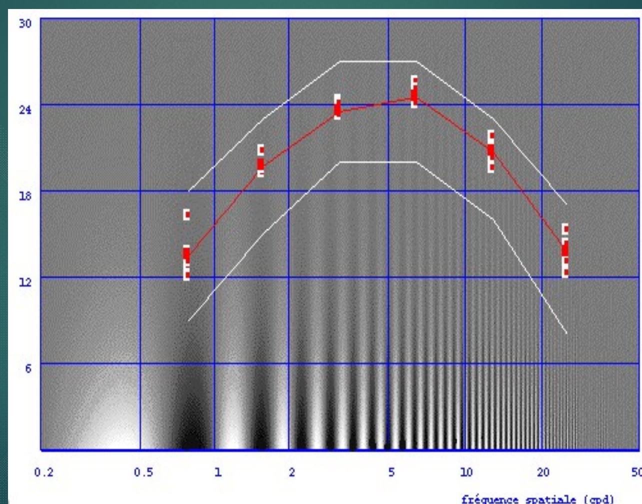


Spatial Frequency



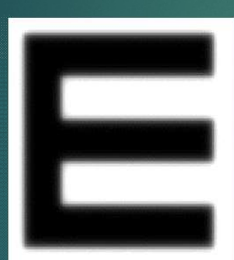
Spatial frequency is the number of cycles (1 black bar plus 1 white bar equals 1 cycle) subtending 1 degree.

Arden Grating



Spatial Frequency

20/20 Letter



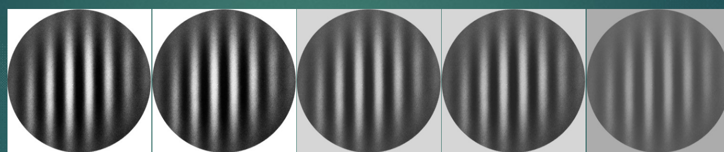
5 arcmin or 25 µm

$$\frac{1\text{ cycle}}{10\ \mu\text{m}}\left(\frac{1000\ \mu\text{m}}{1\text{ mm}}\right)=100\ \frac{\text{cycles}}{\text{mm}}\ (\text{on retina})$$

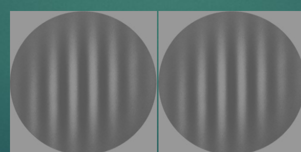
$$\frac{1\text{ cycle}}{2\text{ arcmin}}\left(\frac{60\text{ arcmin}}{1\text{ deg}}\right)=30\ \frac{\text{cycles}}{\text{deg}}$$

Aberrations & Contrast Sensitivity

m=98% m=85% m=70% m=55% m=40%



m=25% m=10%

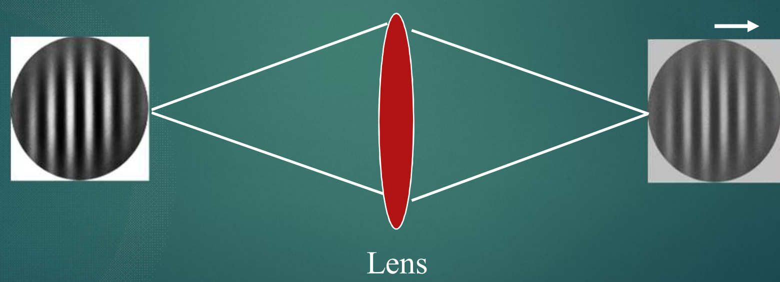


Point Spread Function

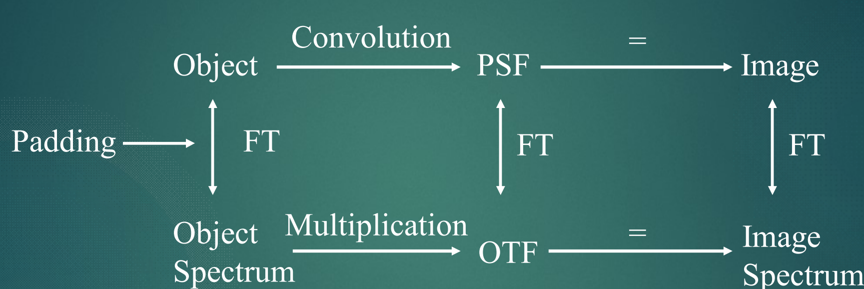
The Point Spread Function (PSF) is the image of a point source of light formed on the retina. It has a finite size due to aberrations and diffraction.

Optical Transfer Function (OTF)

The OTF is a complex function that measures the loss in contrast in the image of a sinusoidal target, as well as any phase shifts. The MTF is the amplitude (i.e. MTF = |OTF|) and the Phase Transfer Function (PTF) is the phase portion of the OTF.

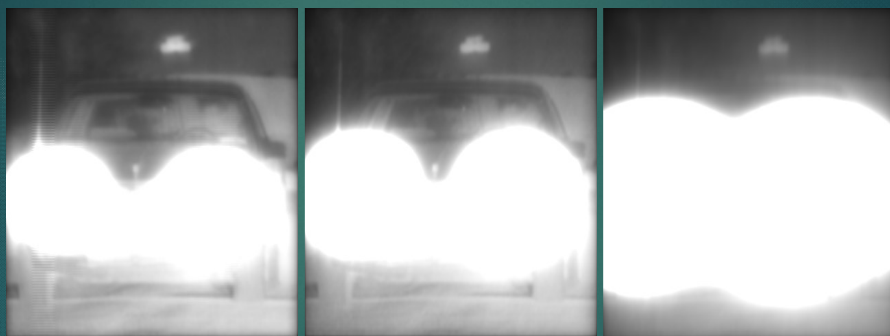


Fourier Theory



$$|FT\{P(x,y)\exp(i2\pi(\text{Wavefront Error})\}|^2 = PSF$$
$$FT\{PSF\} = OTF$$

Effects of Refractive Surgery



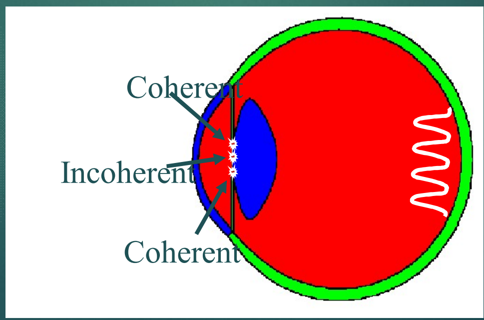
No Surgery -2.75 D PRK -7.00 D PRK

Retinal Image Quality

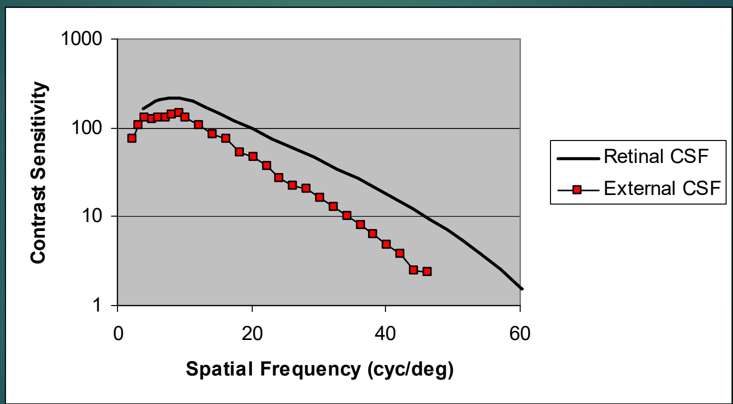
- Ideally, if the optics of the eye are known, then we can determine the quality of the image falling onto the retina.
- Need to measure the aberrations of the eye.
- Would like to measure wavefront error directly, but this has only recently become feasible.
- Early researchers settled for MTF (no phase information).
- More recently, the PSF was measured directly.

Campbell & Green Experiment

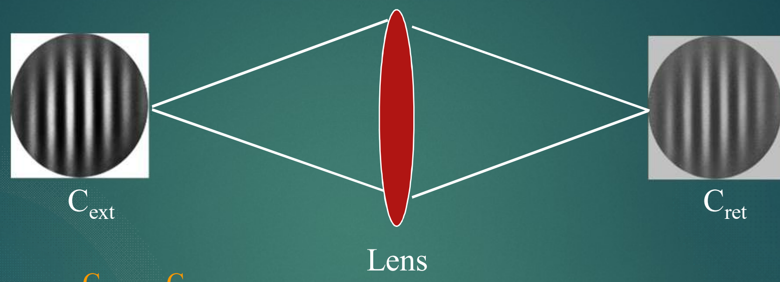
- Campbell & Green, "Optical and Retinal Factors Affecting Visual Resolution," J Physiology, vol 181, p.576-593 (1965).
- First, perform contrast sensitivity
- Second, perform contrast sensitivity when bypassing the optics of the eye.



Campbell and Green Experiment



MTF & Contrast Sensitivity



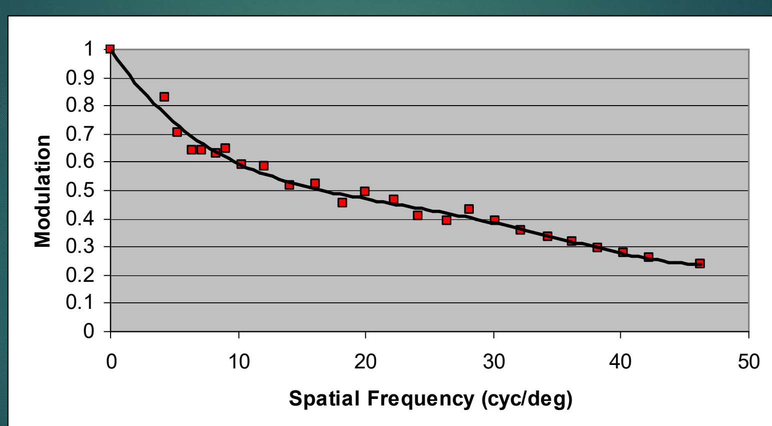
$$MTF = \frac{C_{ret}}{C_{ext}} \Rightarrow \frac{C_{ret\ min}}{C_{ext\ min}}$$

$$CS_{ext} = \frac{1}{C_{ext\ min}}$$

$$\text{Define} \quad CS_{ret} = \frac{1}{C_{ret\ min}}$$

$$MTF = \frac{CS_{ext}}{CS_{ret}}$$

Campbell and Green Experiment



Improving Vision

$$MTF = \frac{CS_{ext}}{CS_{ret}}$$

$$\Delta MTF = [C_{ret\ min}]\Delta CS_{ext}$$

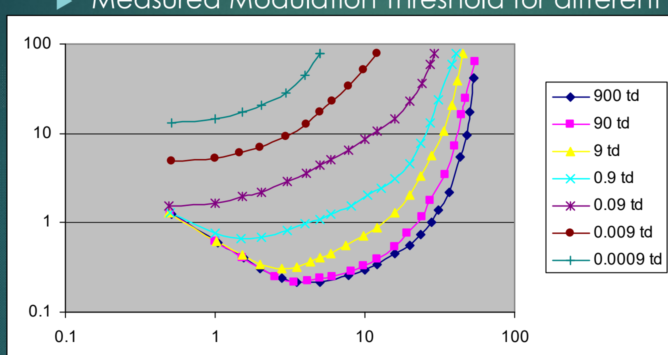
Changes to Optical System

Modulation Threshold
Under a given illumination, this is fixed by the retina & brain

Changes to Visual Performance

Van Nes & Bouman Experiment

- Van Nes & Bouman, J Opt Soc Am, vol. 57, p. 401-406 (1967).
- Measured Modulation Threshold for different illumination



Troland
td = 0.0035 lm/m^2

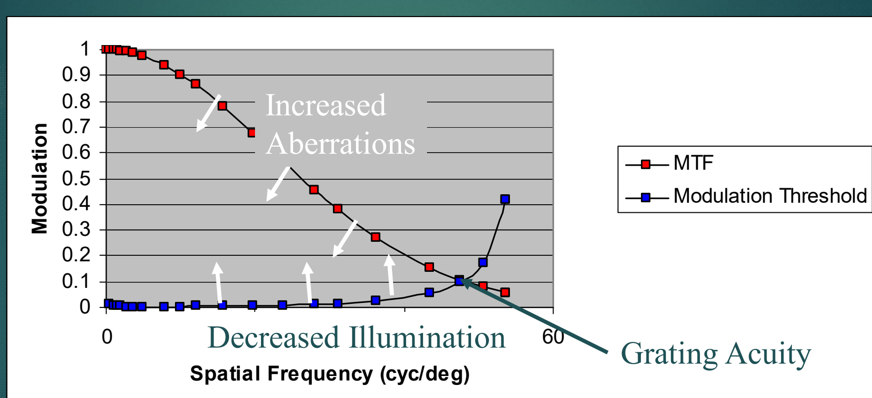
Higher contrast objects are needed for darker conditions
High spatial frequencies cannot be seen under dark conditions

Mitchell *et al*. Experiment

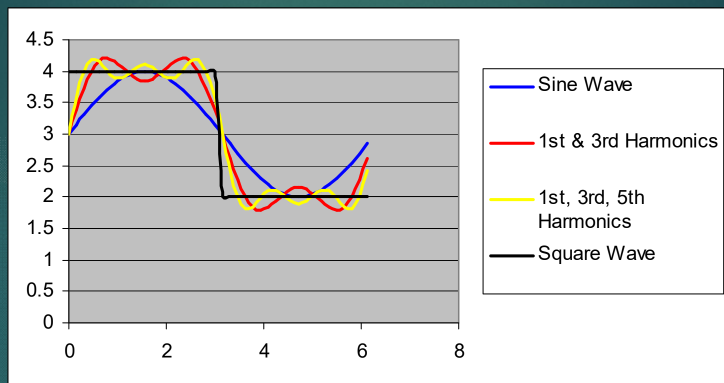
- Mitchell, Freeman & Westheimer, J Opt Soc Am, vol. 57, p. 246-249 (1966).
- Found modulation threshold is lowest for horizontal and vertical gratings and highest for gratings at ±45°

These gratings are easier to see… than these gratings

Grating Acuity

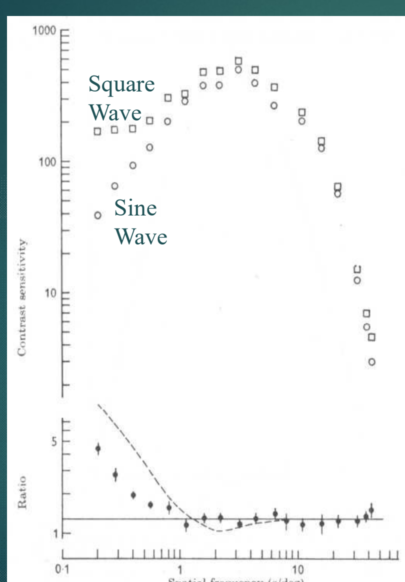


Square Wave Gratings



$$a_o + \frac{4a}{\pi}\left[\sin x + \frac{1}{3}\sin 3x + \frac{1}{5}\sin 5x + \ldots\right]$$

Square Wave Response



$$a_o + \frac{4a}{\pi}\left[\sin x + \frac{1}{3}\sin 3x + \frac{1}{5}\sin 5x + \ldots\right]$$

If a square wave pattern is used for contrast sensitivity testing in place of a sine wave, the sensitivity is higher. For spatial frequencies higher than 1 cyc/deg, the fundamental frequency is detected. For lower spatial frequencies, the harmonics are seen.