Visual Performance

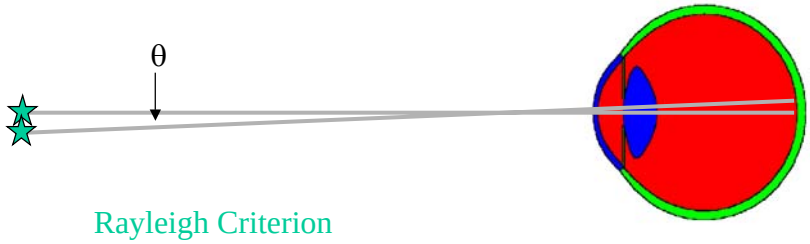
Aspects

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

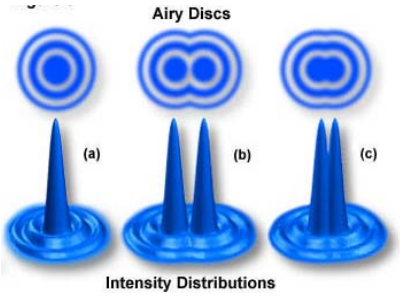
Conditions

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

Theoretical Limit of Resolution



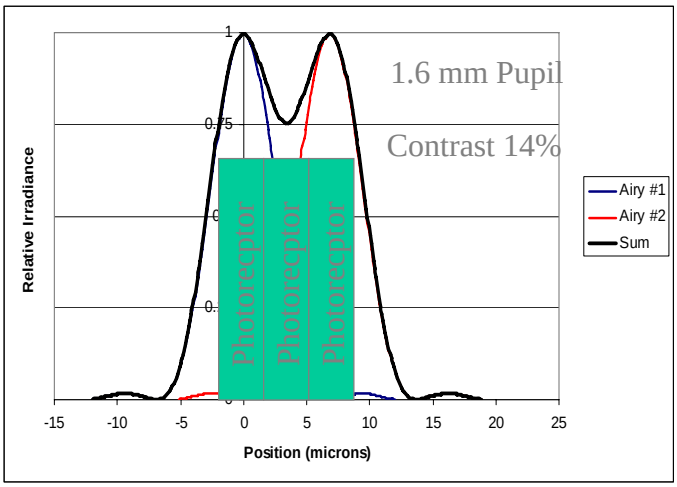
Rayleigh Criterion



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

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

Rayleigh Criteria

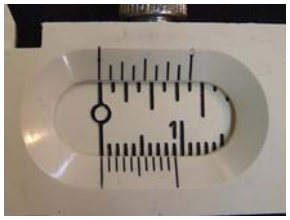


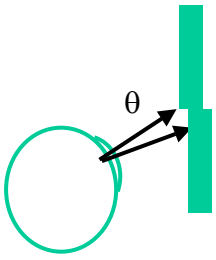
Visual Acuity

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

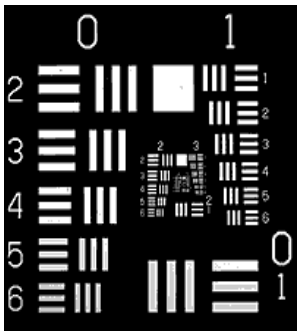
Vernier Acuity – Two lines slightly offset from each other. Finds smallest detectable offset – typically 10 seconds of arc

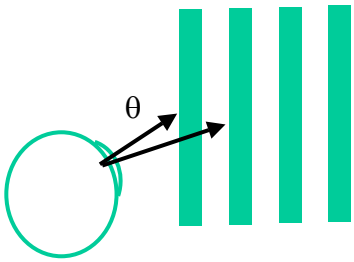




Visual Acuity

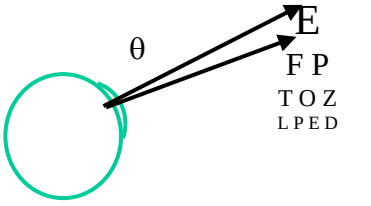
Grating Acuity – Sinusoidal or Square wave gratings are used to determine the smallest separation between peaks that can be resolved. Typically 2 arcmin.

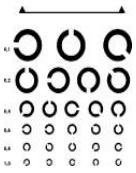


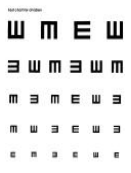


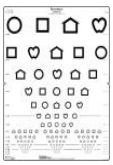
Visual Acuity

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



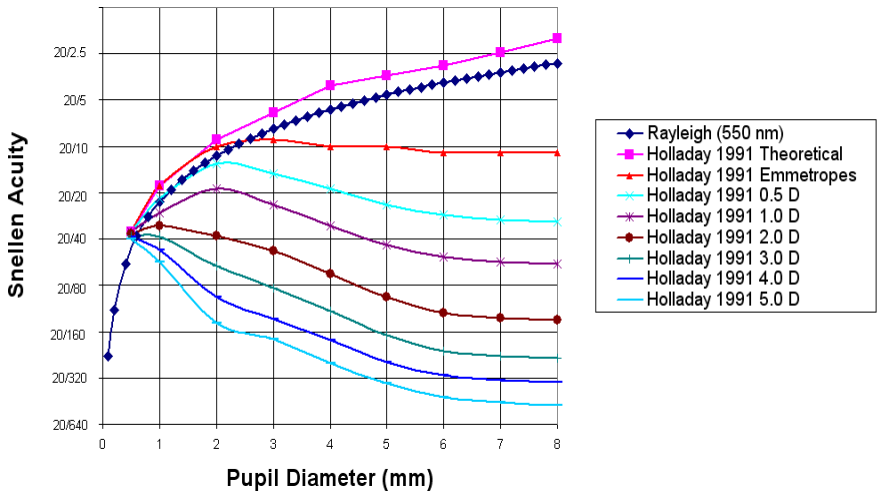




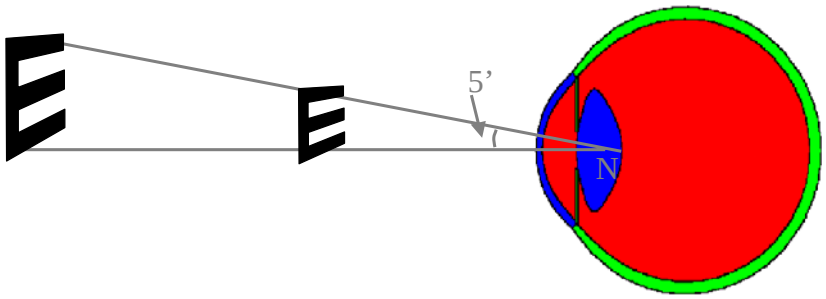


ETDRS Landolt C Tumbling Es Lea

Visual Acuity & Pupil Size



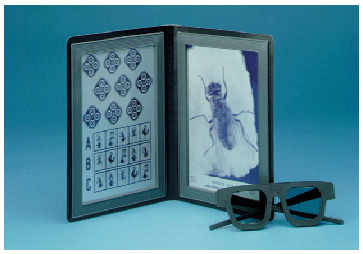
Visual Acuity Charts

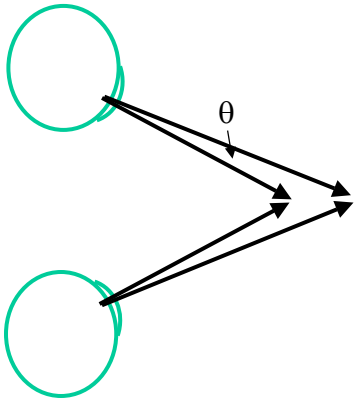


Visual Acuity Charts are designed so the 20/20 line subtends 5 arcmin.
20/40 subtends 10 arcmin
20/10 subtends 2.5 arcmin

Stereo Acuity

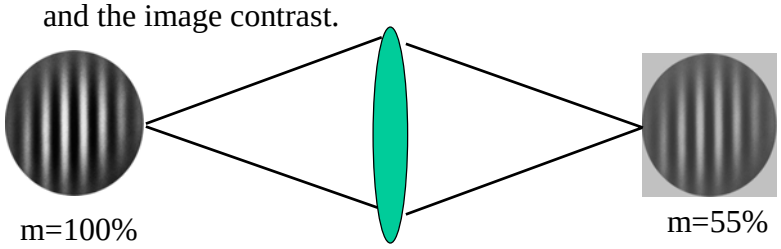
Given one object slightly closer than the other, find the smallest separation that is resolvable.
Typically - 5 seconds of arc





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.



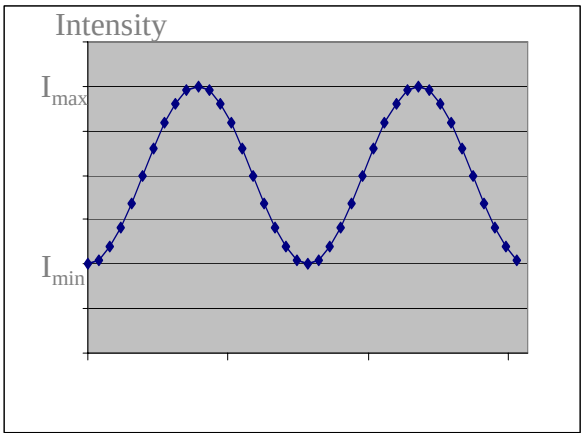
m=100%

m=55%

Lens

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

Contrast

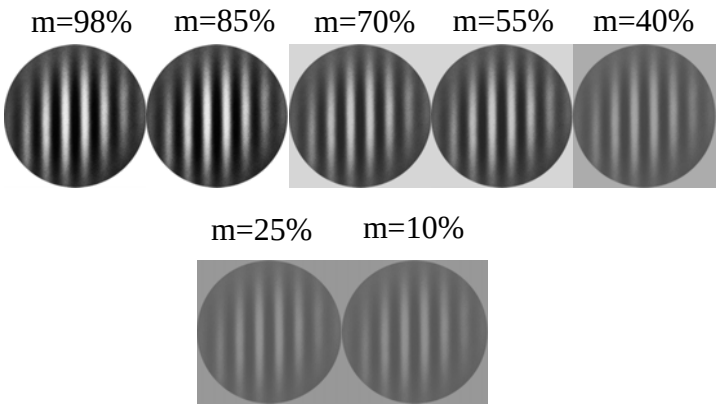


$$\text{Contrast } C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

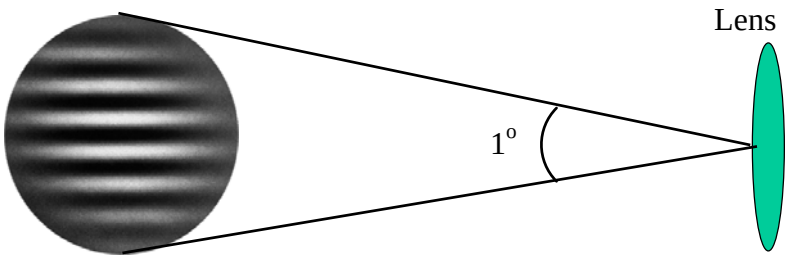
Contrast Sensitivity CS is the reciprocal of the minimum value of C that is detectable.

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

Contrast Sensitivity

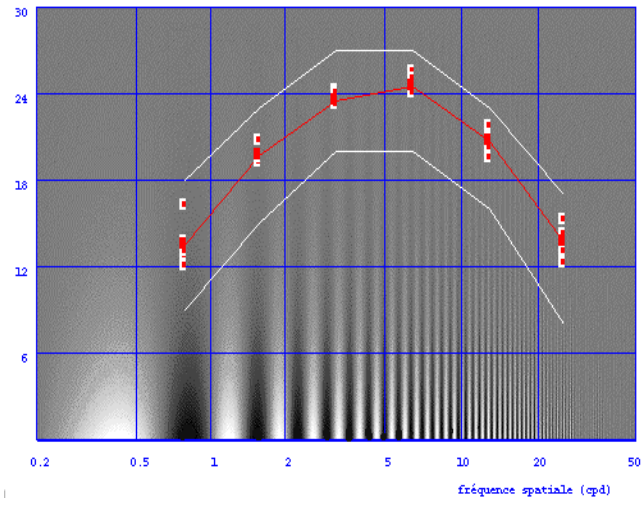


Spatial Frequency



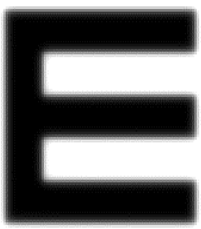
Spatial frequency is the number of cycles (1 black bar plus 1 white bar equals 1 cycle) subtending 1 degree.

Arden Grating



Spatial Frequency

20/20 Letter



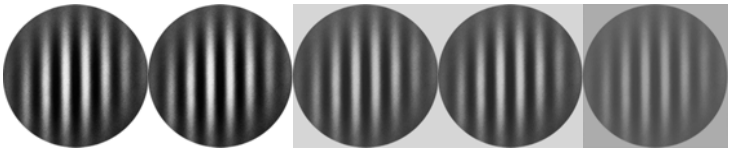
5 arcmin
or
25 μm

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

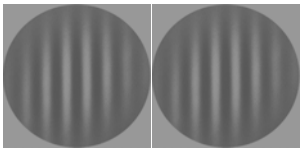
$$\frac{1\,\text{cycle}}{2\,\text{arcmin}}\left(\frac{60\,\text{arcmin}}{1\,\text{deg}}\right)=30\,\frac{\text{cycles}}{\text{deg}}$$

Aberrations & Contrast Sensitivity

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



m=25% m=10%

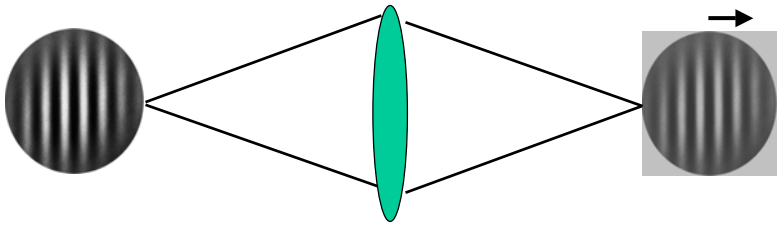


Point Spread Function

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.

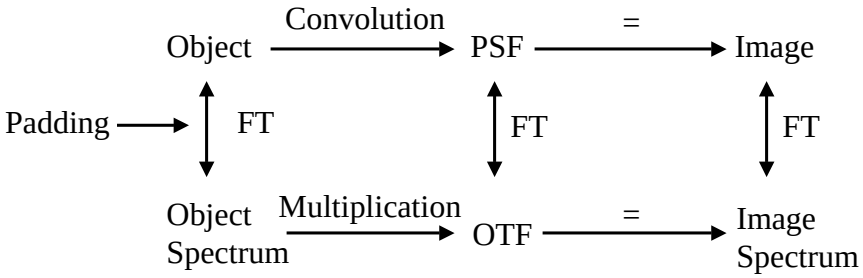
Optical Transfer Function (OTF)

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.



Lens

Fourier Theory



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

$FT\{PSF\} = OTF$

Effects of Refractive Surgery

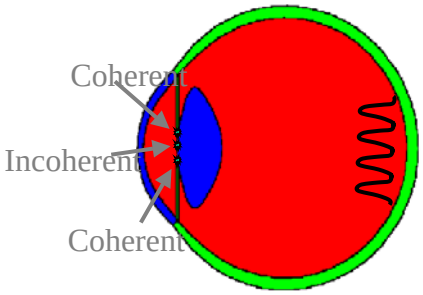
No Surgery | -2.75 D PRK | -7.00 D PRK

Retinal Image Quality

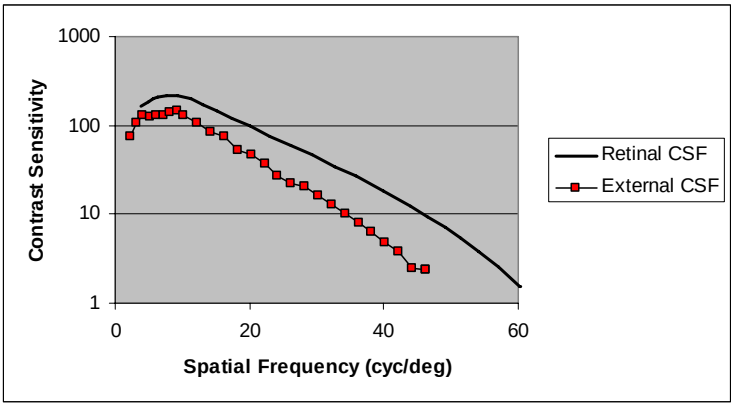
- Ideally, if the optics of the eye are known, then we can determine the quality of the image falling onto the retina.
- Need to measure the aberrations of the eye.
- Would like to measure wavefront error directly, but this has only recently become feasible.
- Early researchers settled for MTF (no phase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

Campbell & Green Experiment

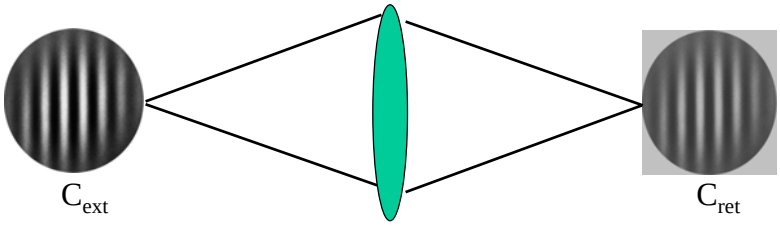
- Campbell & Green, "Optical and Retinal Factors Affecting Visual Resolution," J Physiology, vol 181, p.576-593 (1965).
- First, perform contrast sensitivity
- Second, perform contrast sensitivity when bypassing the optics of the eye.



Campbell and Green Experiment



MTF & Contrast Sensitivity



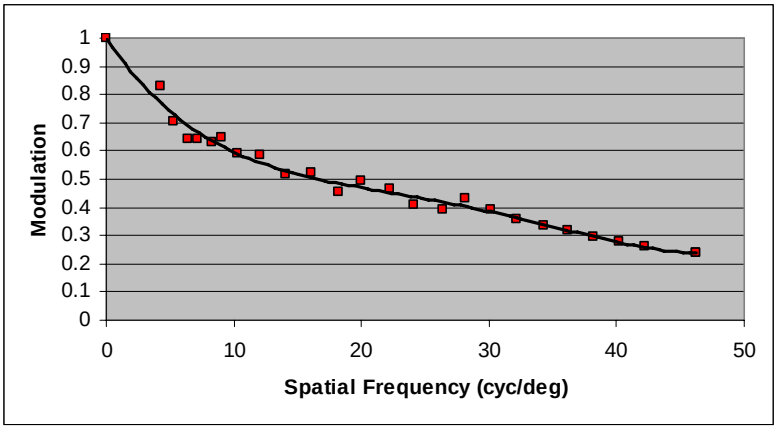
$$MTF = \frac{C_{ret}}{C_{ext}} \Rightarrow \frac{C_{ret\ min}}{C_{ext\ min}}$$

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

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

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

Campbell and Green Experiment



Improving Vision

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

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

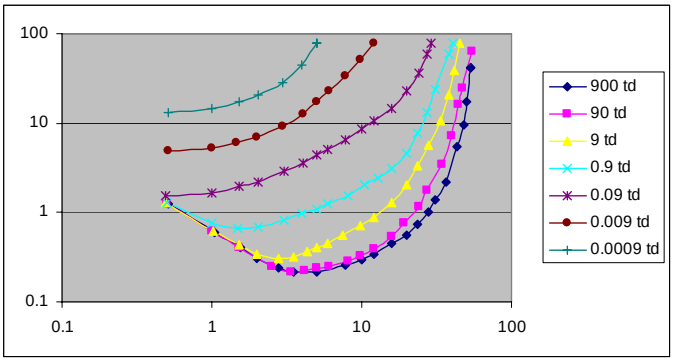
Changes to Visual Performance

Changes to Optical System

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

Van Nes & Bouman Experiment

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



Troland
td = 0.0035 lm/m^2

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

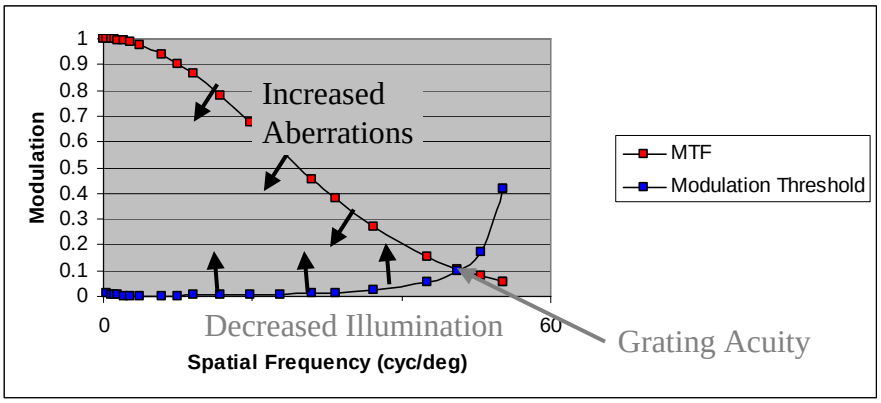
Mitchell *et al*. Experiment

- 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°

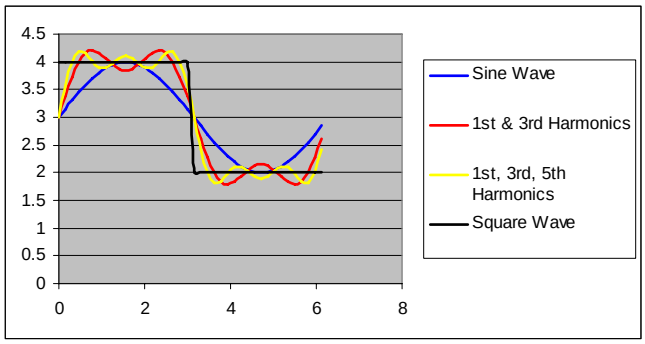
These gratings are easier to see…

than these gratings

Grating Acuity

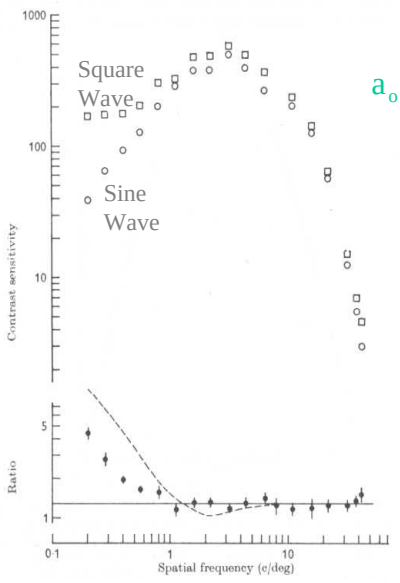


Square Wave Gratings



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

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.