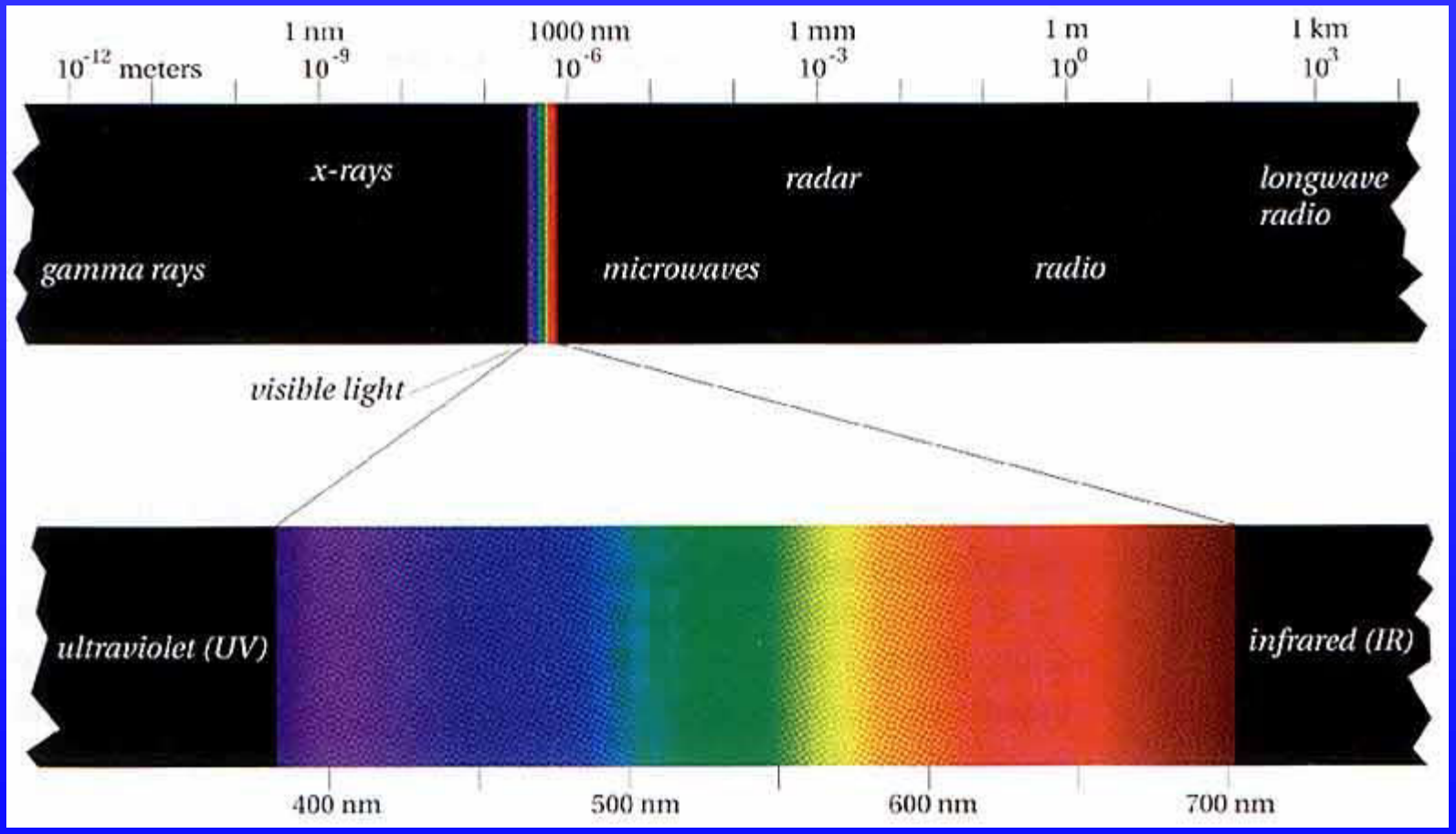
The Visual System and Visual Performance

The Visible Spectrum



Anatomy of the Eye

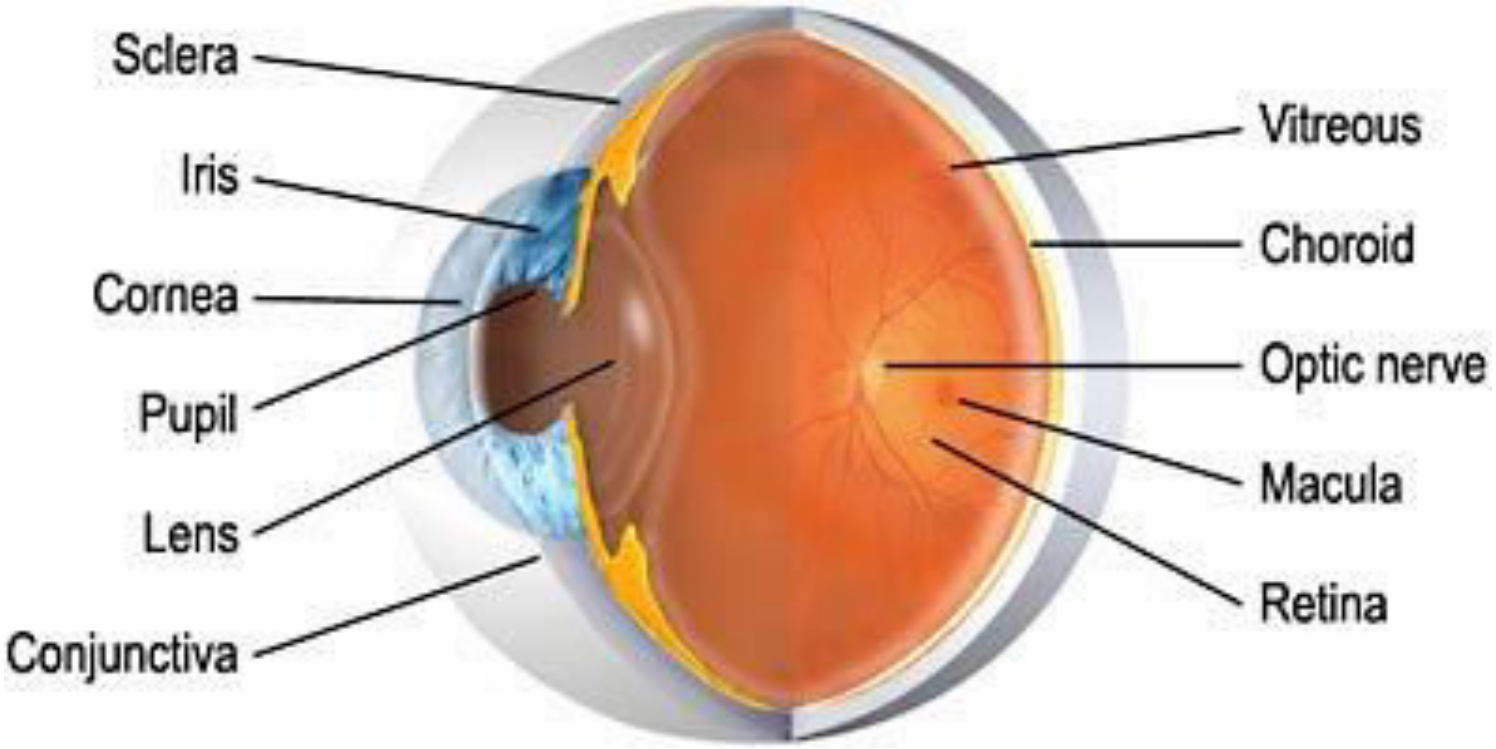


Illustration by Mark Ericksen, St. Luke's Cataract and Laser Center, StLukesEye.com

The Eye (2)

- Cornea
  - Protection
  - Focusing
- Aqueous Humor
  - Shape
  - Nutrition
- Iris
  - Light control
  - Focusing

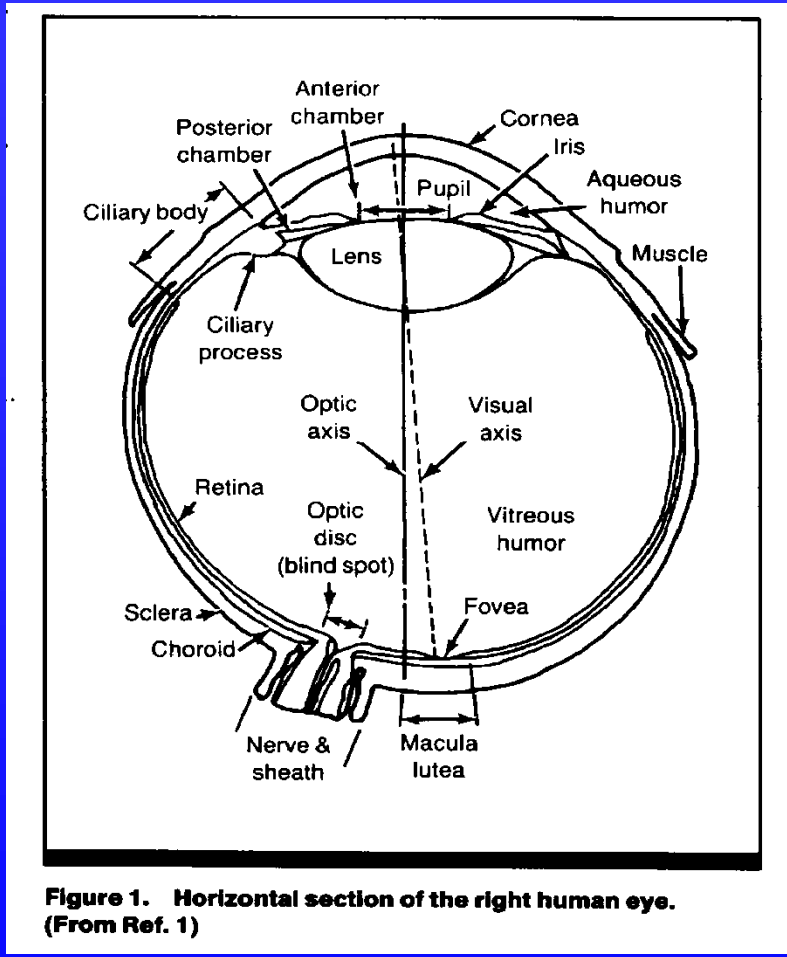


Figure 1. Horizontal section of the right human eye. (From Ref. 1)

The Eye (3)

- Lens
  - Focusing
  - Accommodation
- Vitreous Humor
  - Shape
- Retina
  - Rods: black & white, night vision
  - Cones: color, day vision
  - Fovea: sharpest vision (concentration of cones)

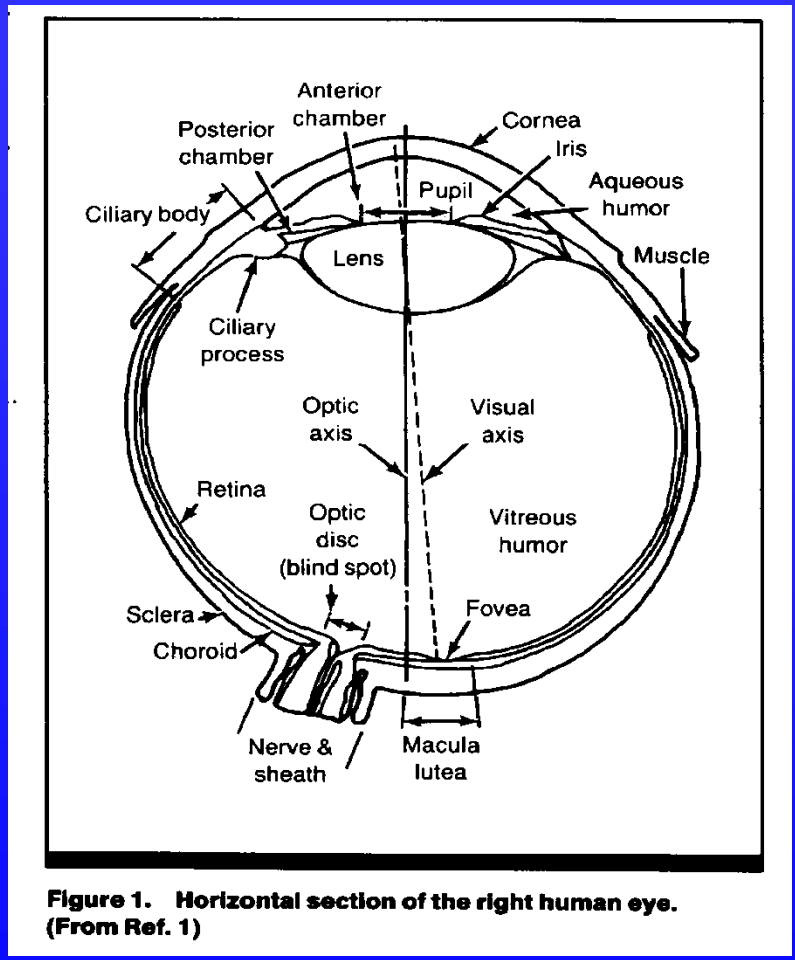


Figure 1. Horizontal section of the right human eye. (From Ref. 1)

The Eye (4)

- Optic Nerve
  - Nerve signals to brain
  - Optic Disk: blind spot
- Eye Muscles
  - Eye movement
  - Convergence

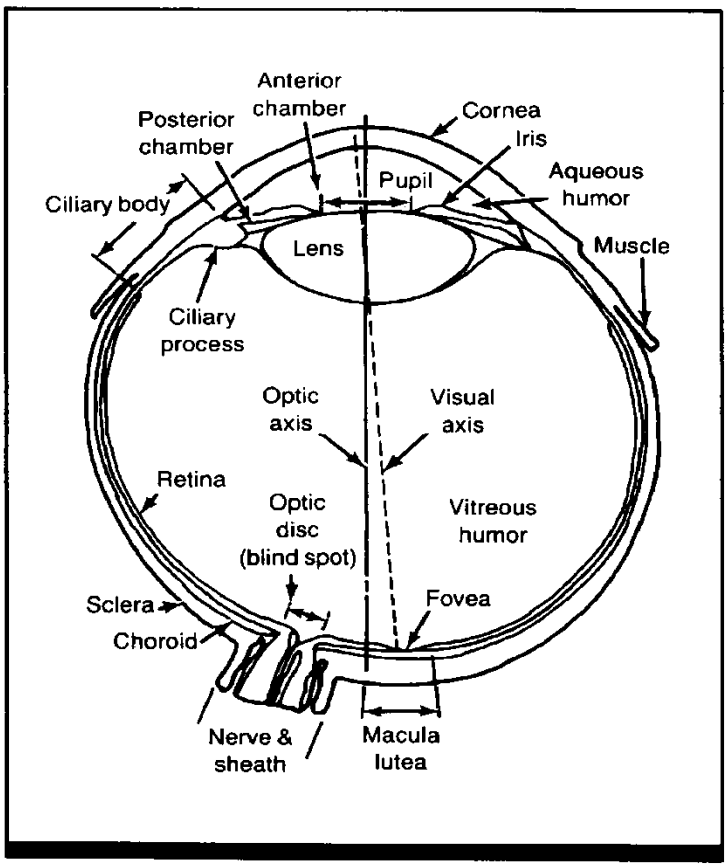


Figure 1. Horizontal section of the right human eye. (From Ref. 1)

NEAR AND FARSIGHTED EYE

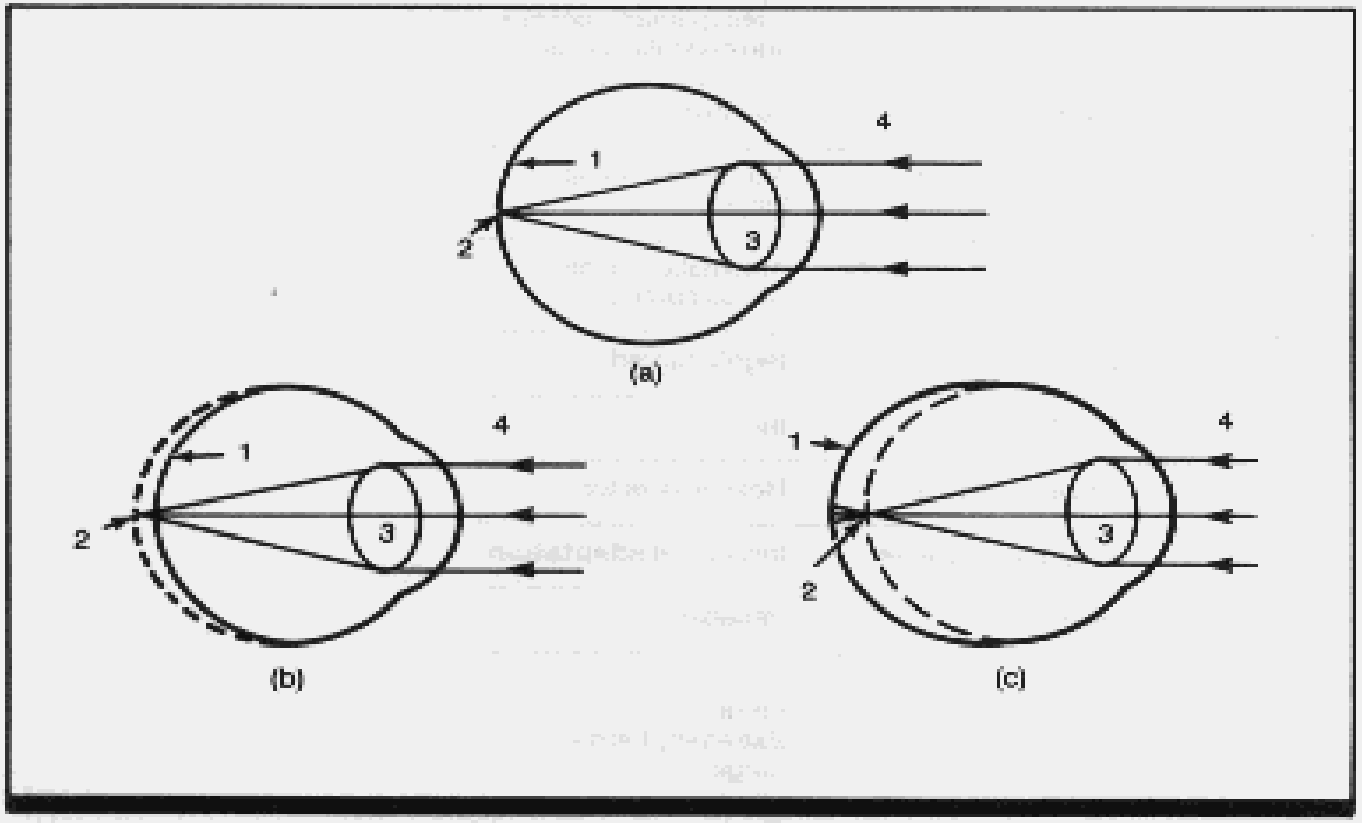
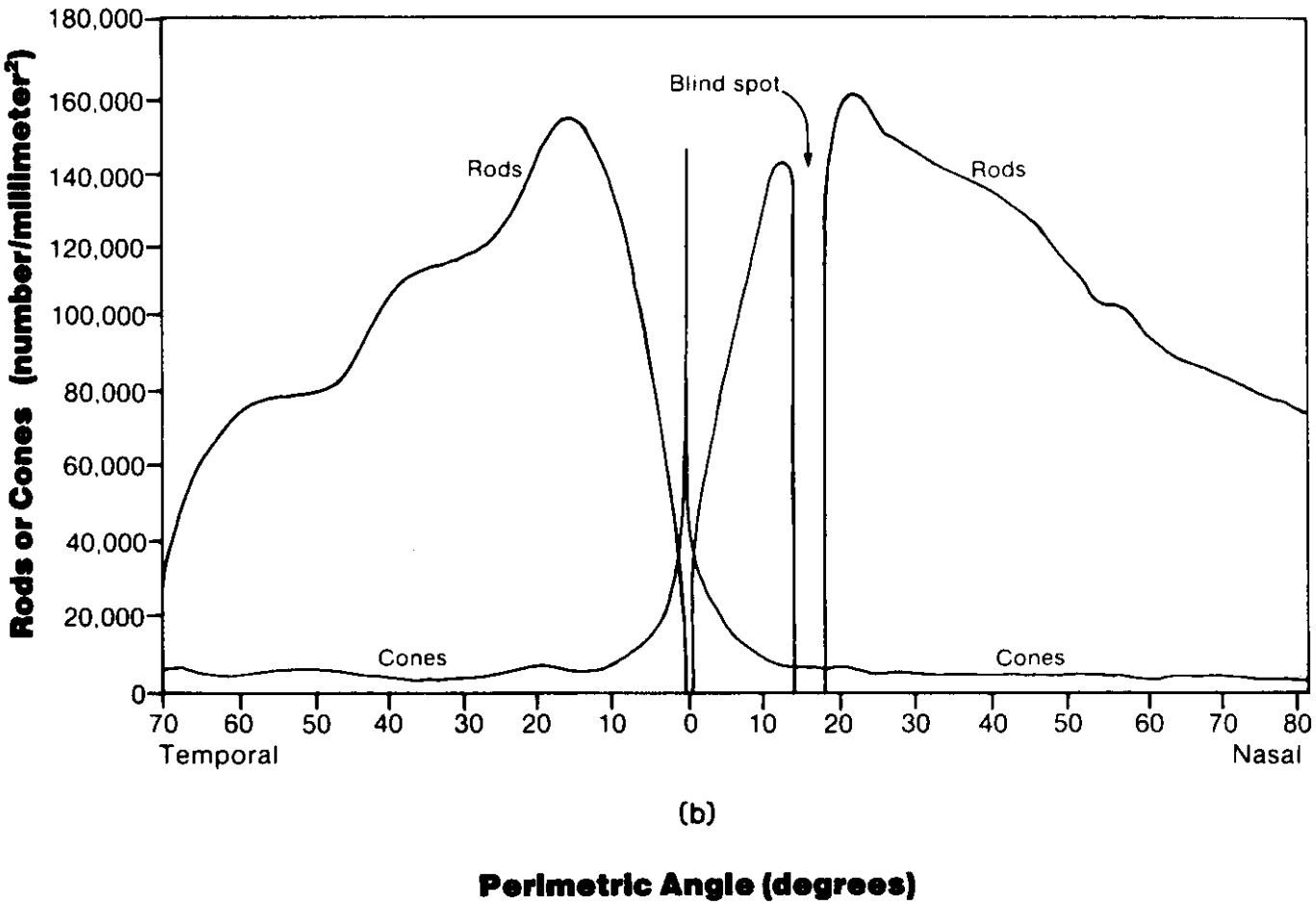


Figure 1. Refraction of light by the eye. (a) normal (emmetropic) eye; (b) farsighted (hyperopic) eye; (c) nearsighted (myopic) eye; (1 = retina; 2 = focal point; 3 = lens; 4 = incoming light). (From Ref. 3)

DENSITY OF RODS AND CONES



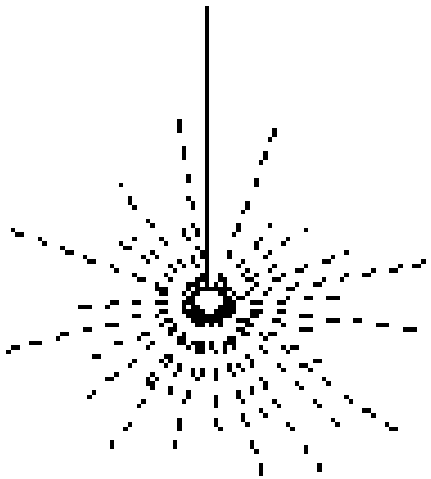
Visual Performance

- Brightness
- Visual Angle
- Visual Acuity
- Color
- Visual Field

Brightness

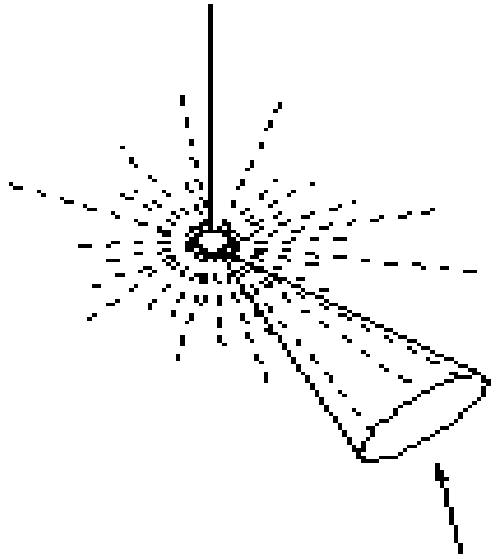
- Relative amount of light reflected from an object produces a sensation of lightness or brightness.
- Brightness is related to the luminance of light as well as a subjective response to color

Luminous Intensity



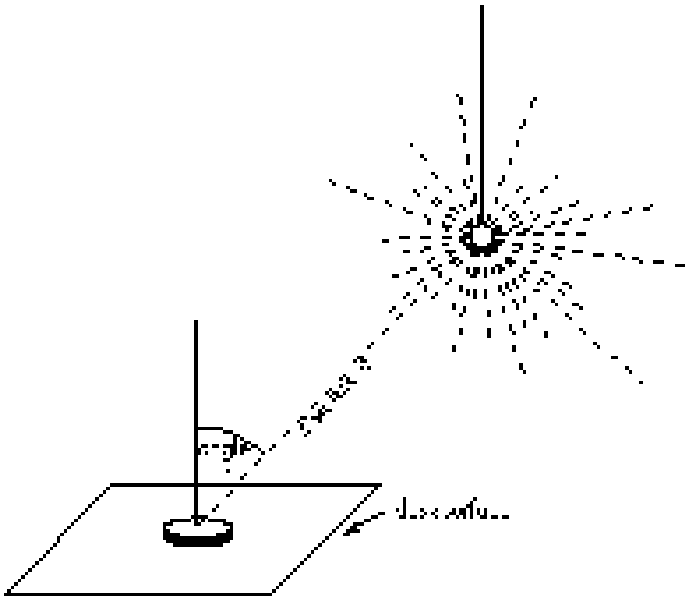
A point light source giving off photons equally in all directions, with a luminous intensity of x candelas

Luminous Flux



Luminous flux - for a solid angle of 1 steradian there will be x lumens

Illuminance



The photocell is placed flat on the desk, and is in effect counting the number of photons falling on it - i.e. measuring illuminance in lumens per square metre (LUX)

Illuminance v. Luminance

- Illumination/Illuminance: The amount of light striking any point on the inside surface of a sphere surrounding the light source (Luminous flux/unit area)
  - Foot candle: 1 lumen/square foot
  - Lux: 1 luman/square meter
- Luminance: The amount of light per unit area leaving (reflected from) a surface
  - Foot Lamberts: 1 lumen/square foot
  - Candelas/square meeter

Luminance

Luminance, milliLamberts (mL)	Example
1,000,000,000	sun's surface at noon
1,000,000	tungsten filament
10,000	white paper in sunlight
1,000	earth on clear day
100	earth on cloudy day
10	white paper in reading light
1	white paper 1 ft from candle
0.001	earth in moonlight
0.0001	white paper in starlight

Note: 1 foot-Lambert (ft-L) = 0.929 mL, so 1 ft-L ~ 1 mL.

Luminance (2)

- Threshold of detectability

  1×10^{-6} mL

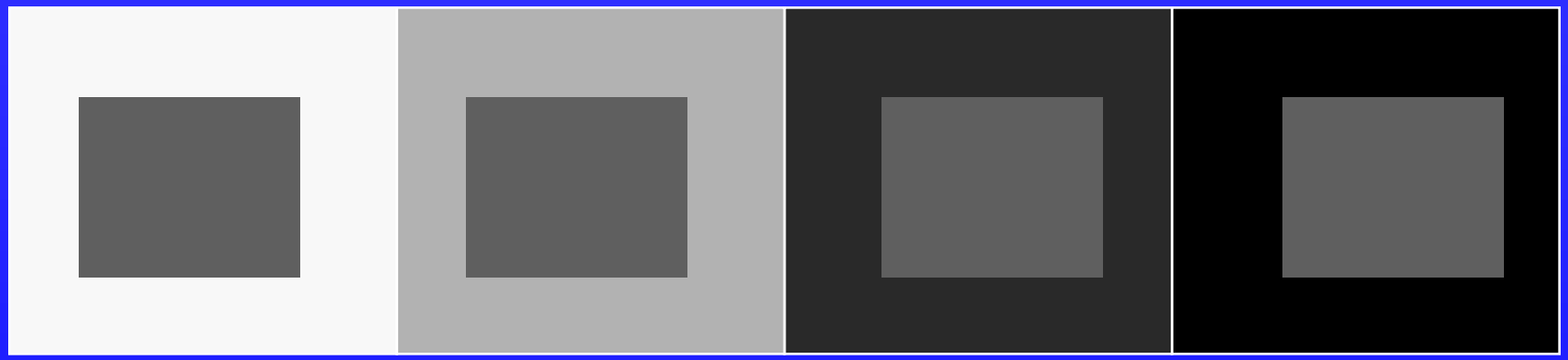
- Threshold of pain

  3×10^{4} mL

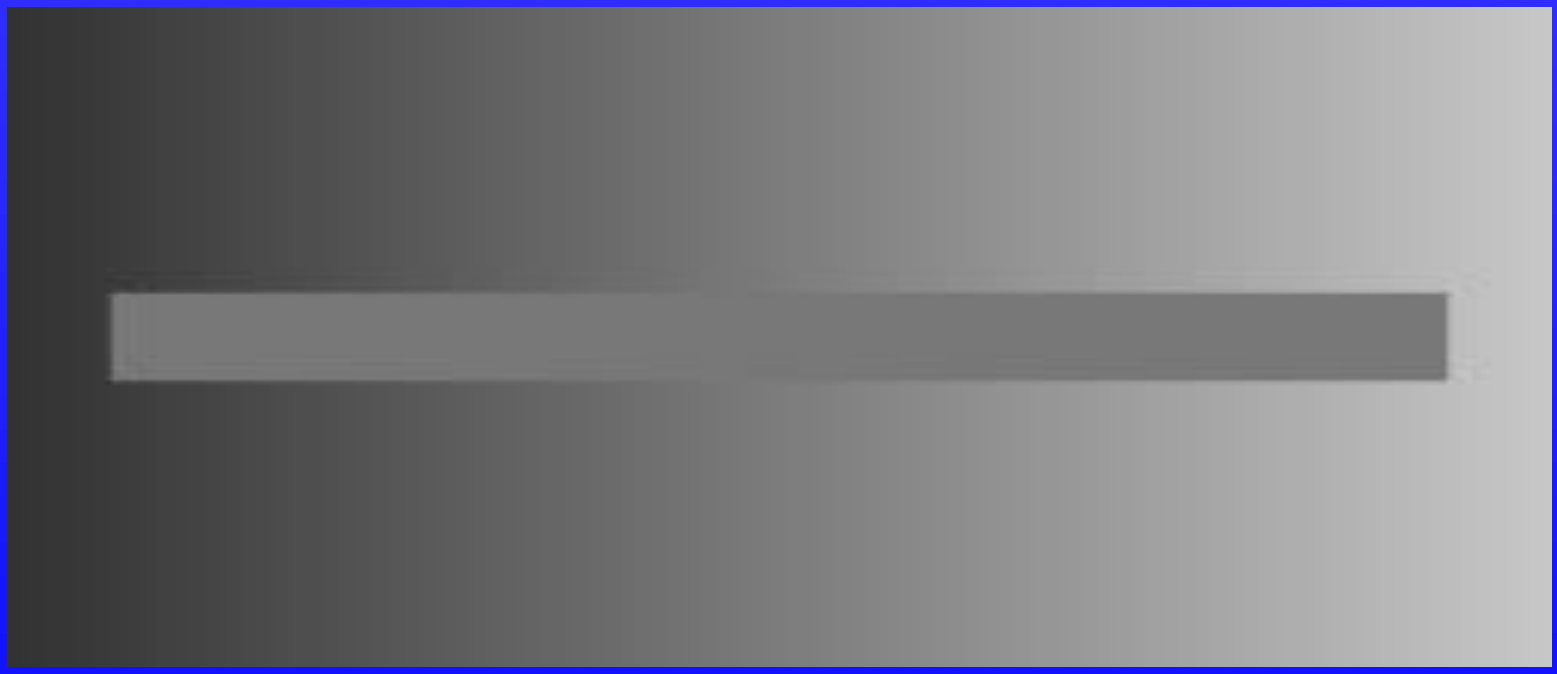
- Limits to discriminability

  3 - 4 levels

Lightness

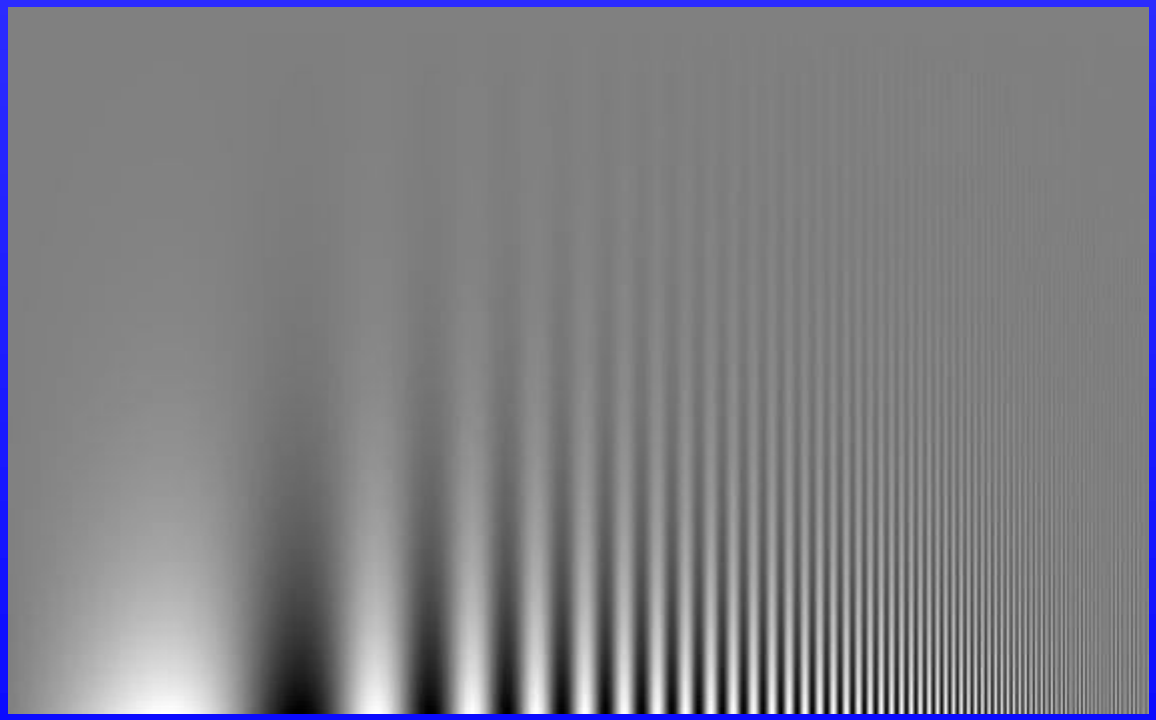


Lightness

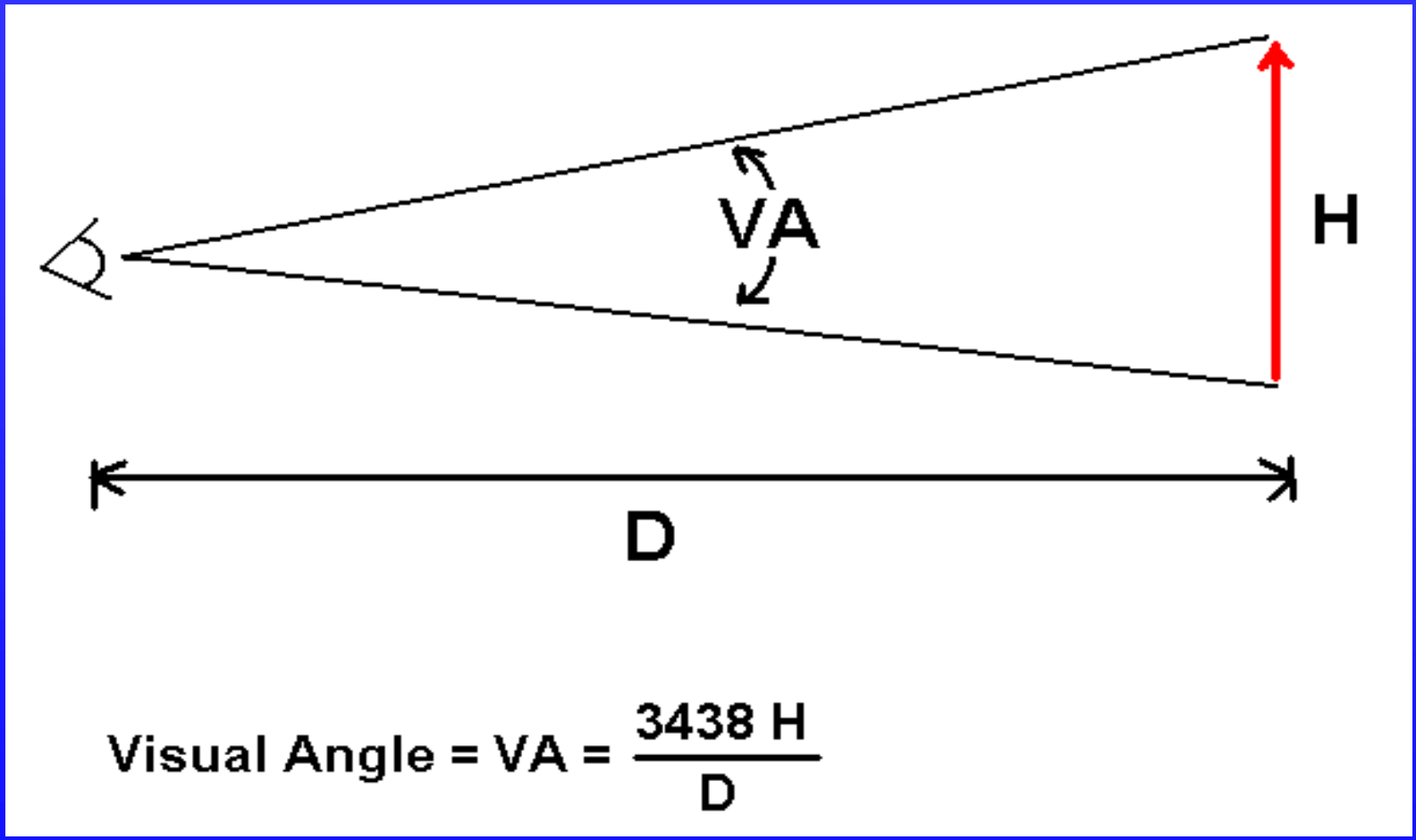


Contrast Sensitivity

the luminance of pixels is varied sinusoidally in the horizontal direction. The spatial frequency increases exponentially from left to right. The contrast also varies logarithmically from 100% at the bottom to about 0.5% at the top. The luminance of peaks and troughs remains constant along a given horizontal path through the image. If the detection of contrast was dictated solely by image contrast, the alternating bright and dark bars should appear to have equal height everywhere in the image. However, the bars seem to be taller in the middle of the image.



Visual Angle (minutes of arc)

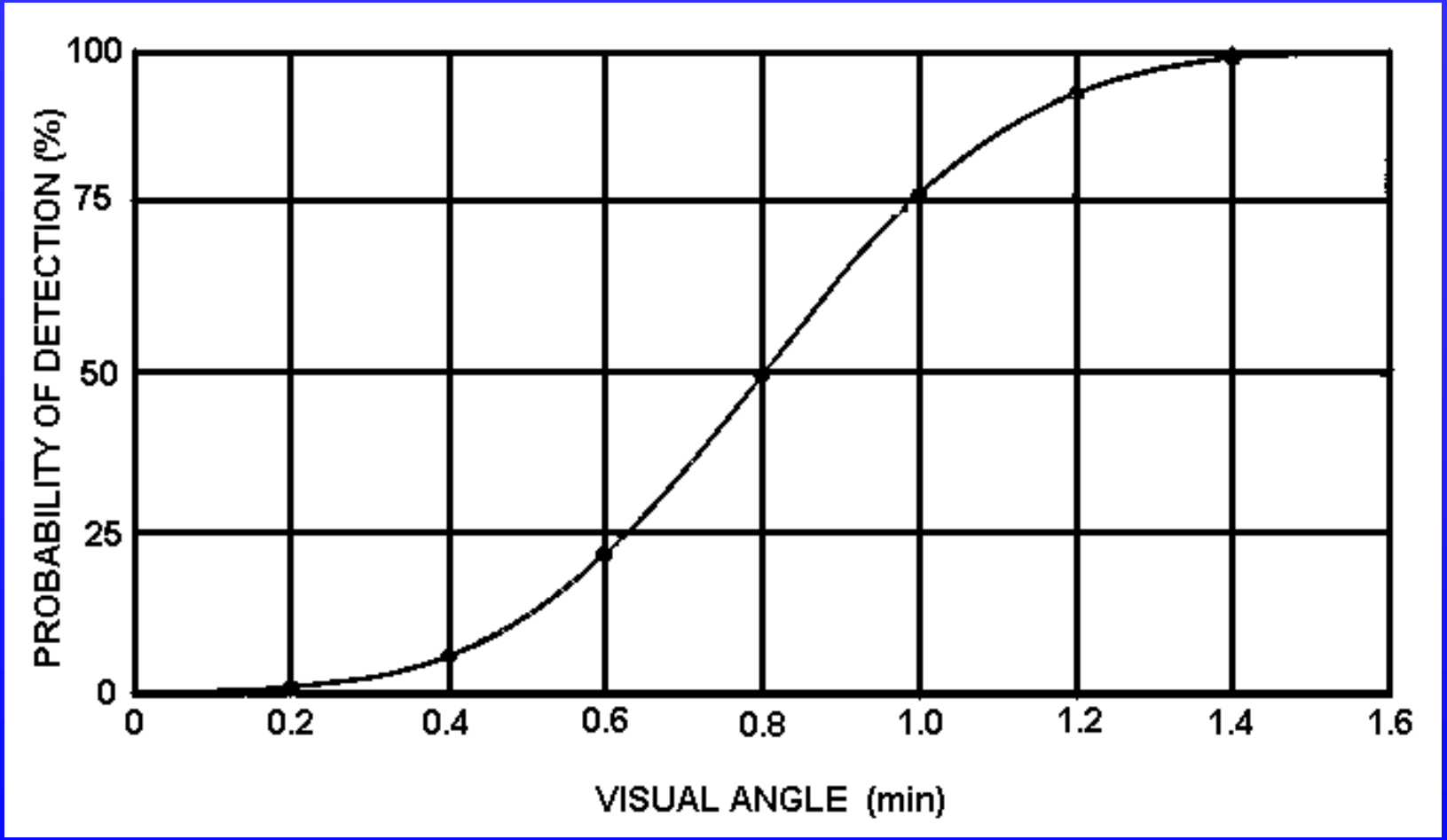


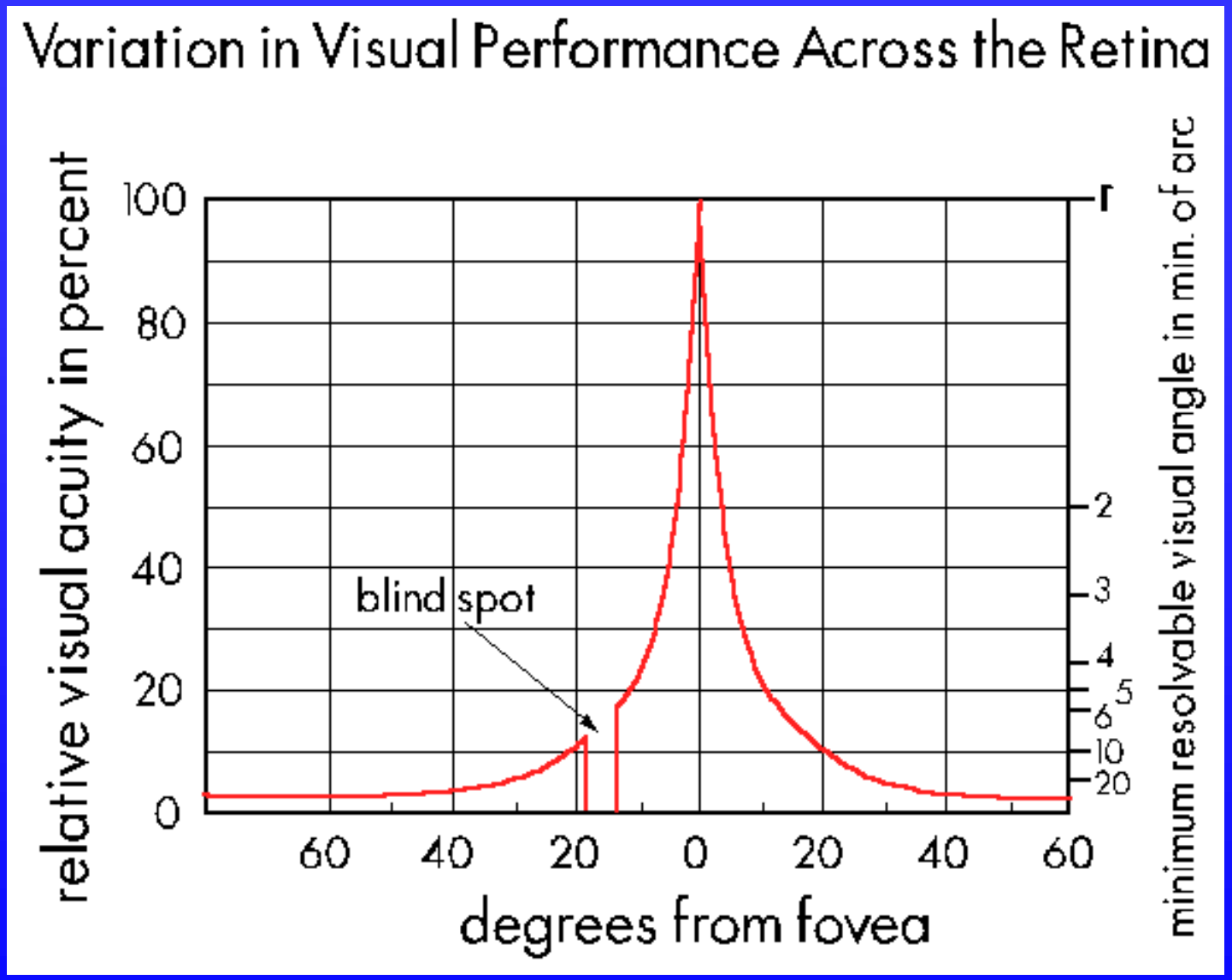
Visual Angle = $\tan^{-1}$ H/D

Visual Angle of Familiar Objects

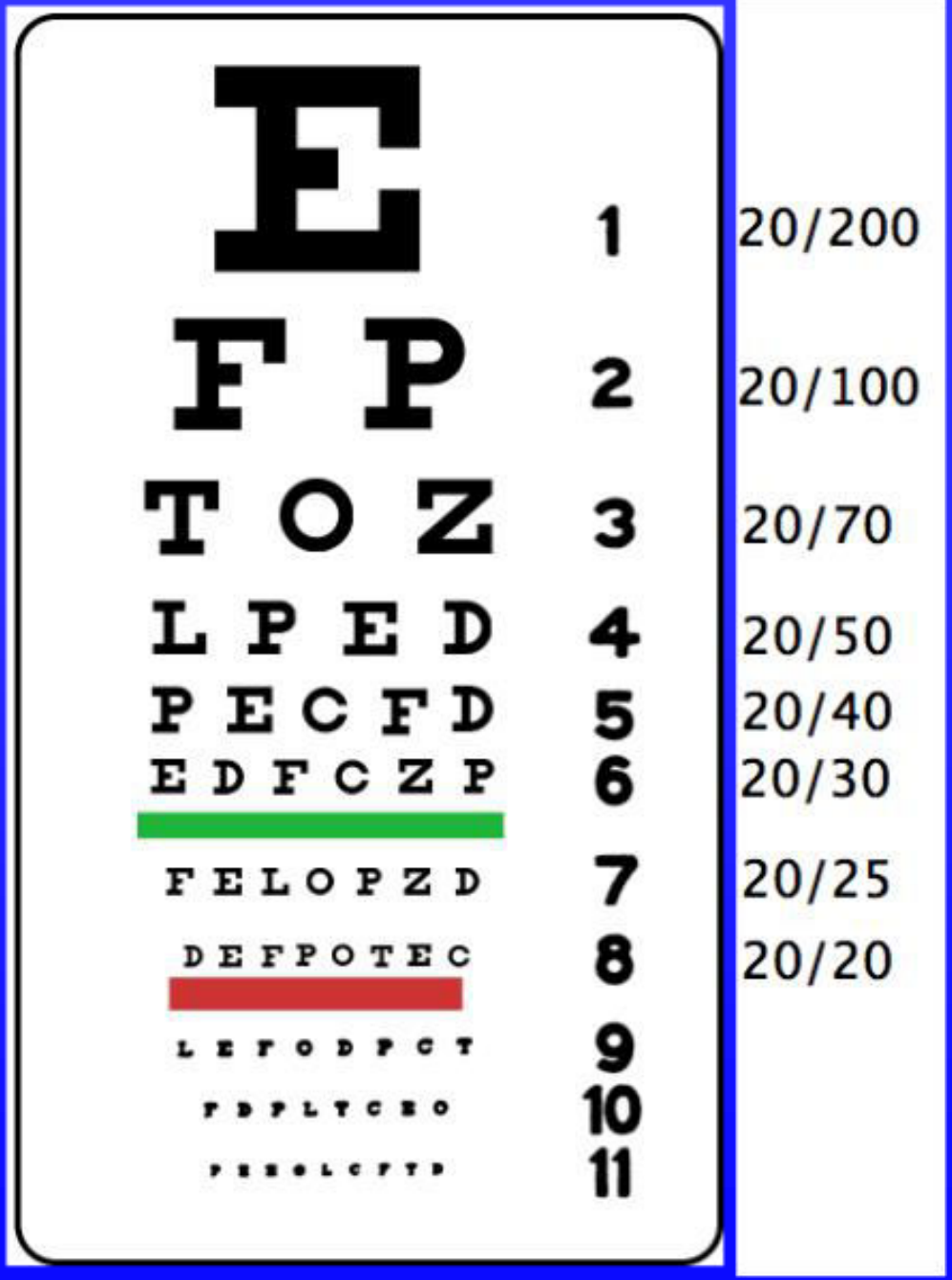
Object	Distance	Visual Angle
Sun	93,000,000 mi	30’
Moon	240,000 mi	30’
Quarter	arm’s length	2°
Quarter	90 yd	1’
Quarter	3 mi	1”
Lowercase pica type	reading distance	13’

Cumulative Probability of Detection



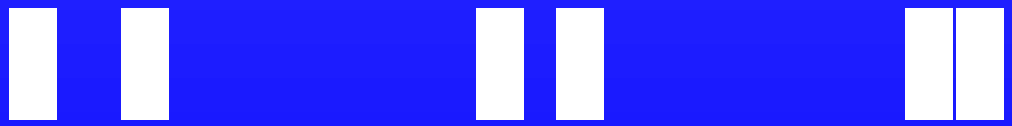

Variation in Visual Performance Across the Retina
relative visual acuity in percent
100
80
60
40
20
0
blind spot
60
40
20
0
20
40
60
degrees from fovea
minimum resolvable visual angle in min. of arc
1
2
3
4
5
6
10
20

Acuity

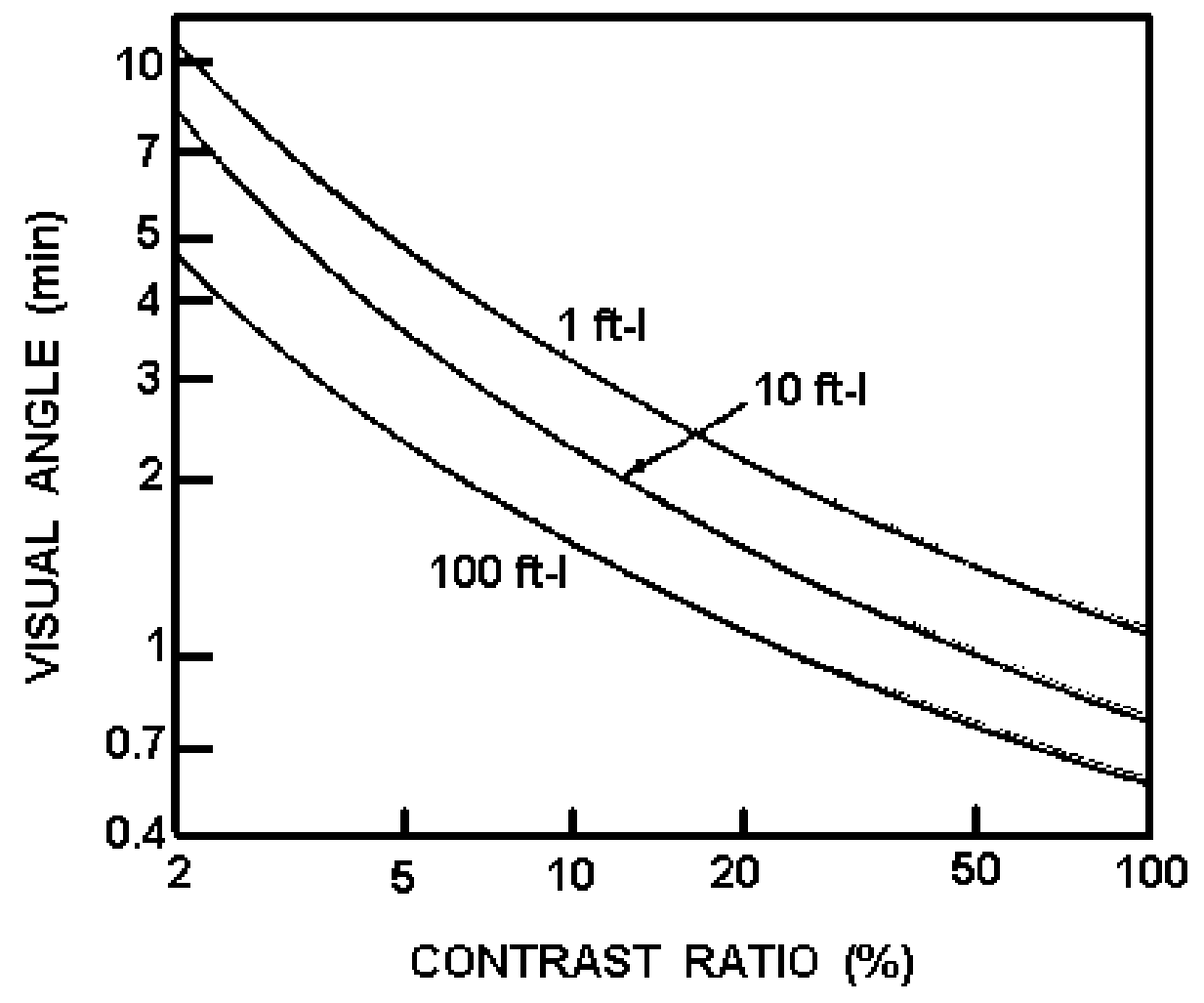

E
F P
T O Z
L P E D
P E C F D
E D F C Z P
F E L O P Z D
D E F P O T E C
L E F O D P C T
F D P L T C E O
P E C O L C F T D
1
2
3
4
5
6
7
8
9
10
11
20/200
20/100
20/70
20/50
20/40
20/30
20/25
20/20

Minimum Separable Acuity

- Also called gap resolution
- Smallest space eye can detect between parts of a target (visual object).

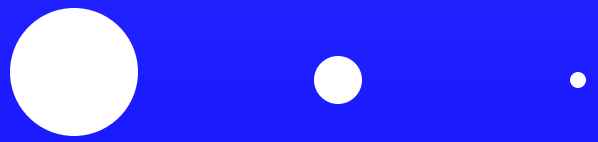


Minimum Separable Acuity as Function of Contrast

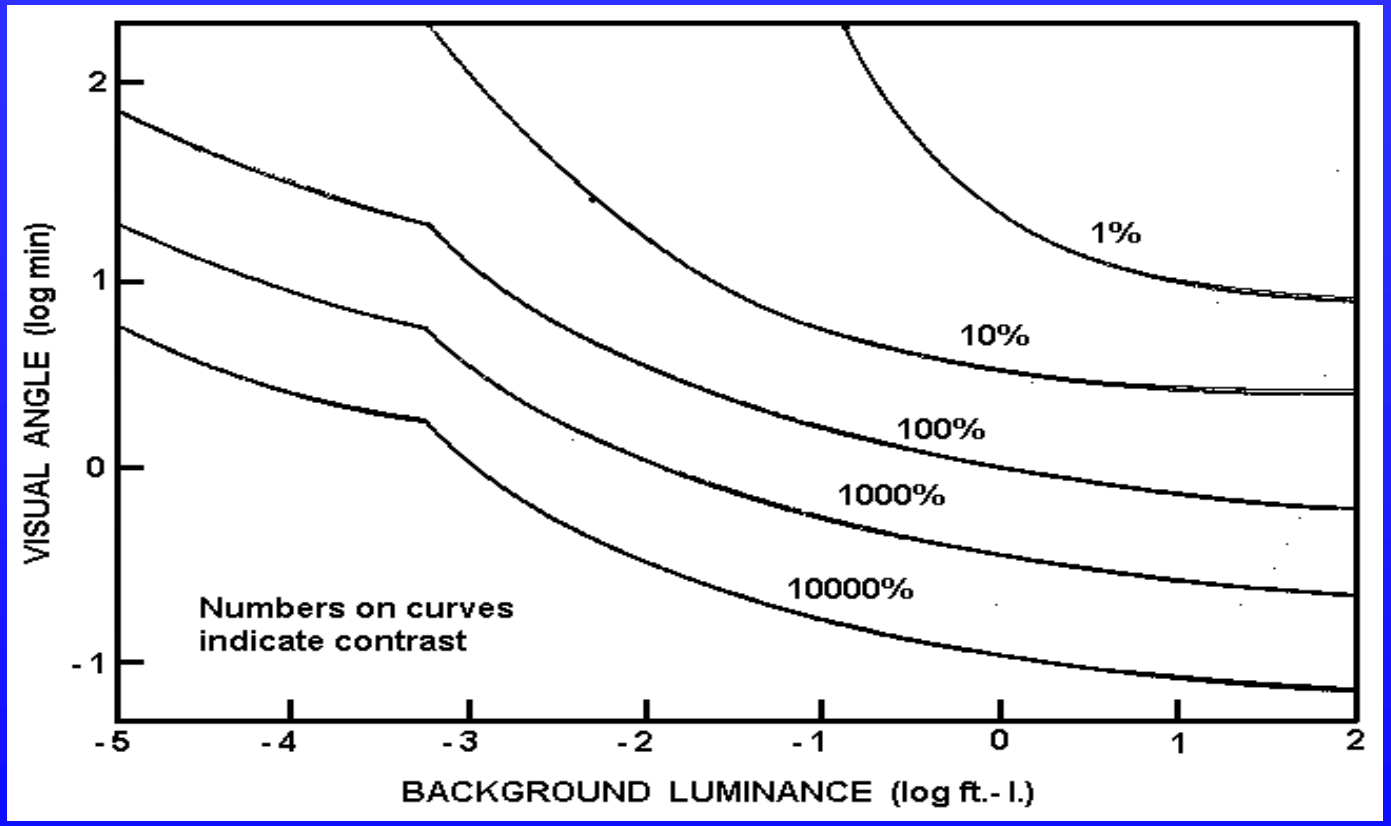


Minimum Perceptible Acuity

- Also called spot detection.
- Eye's ability to detect smallest possible target.

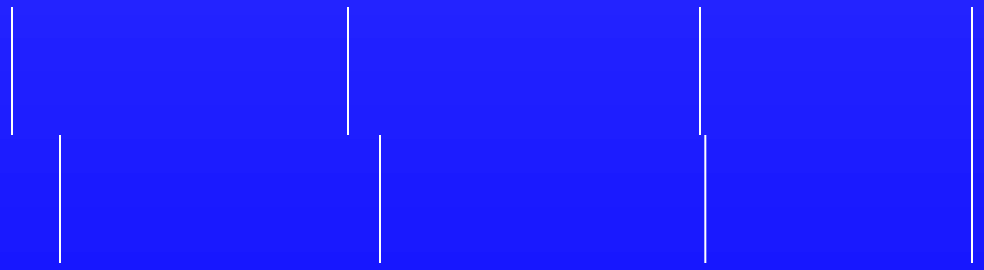


Minimum Perceptible Acuity as Function of Contrast and Background Luminance

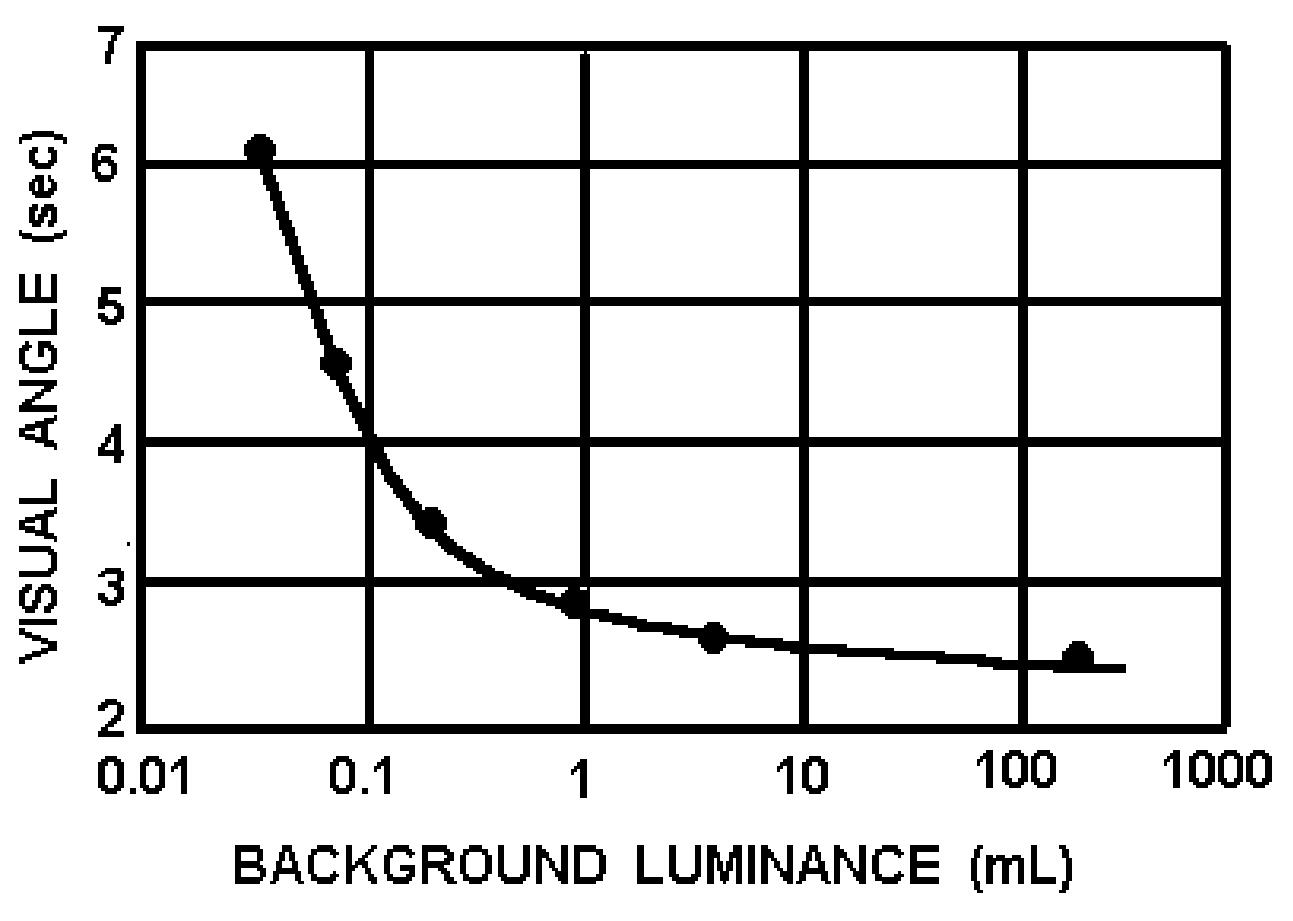


Vernier Acuity

- Smallest lateral displacement of one line from another that can be detected.



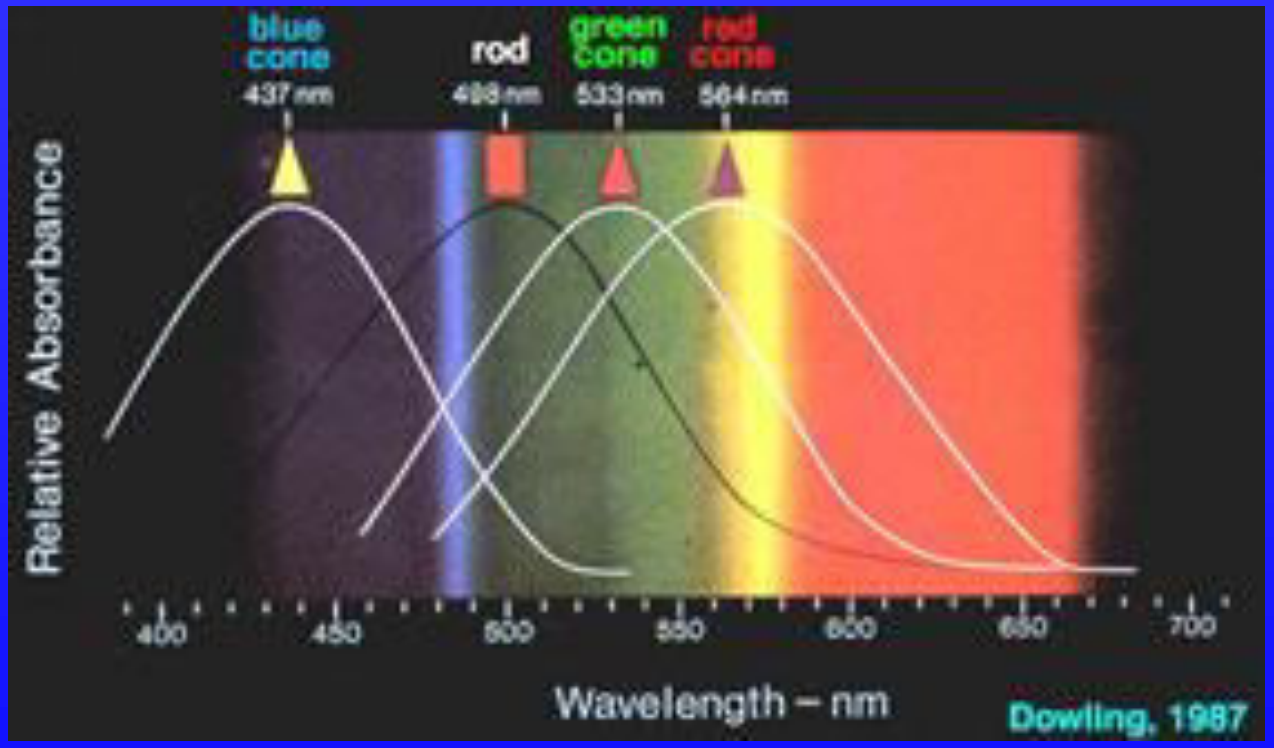
Vernier Acuity as Function of Background Luminance



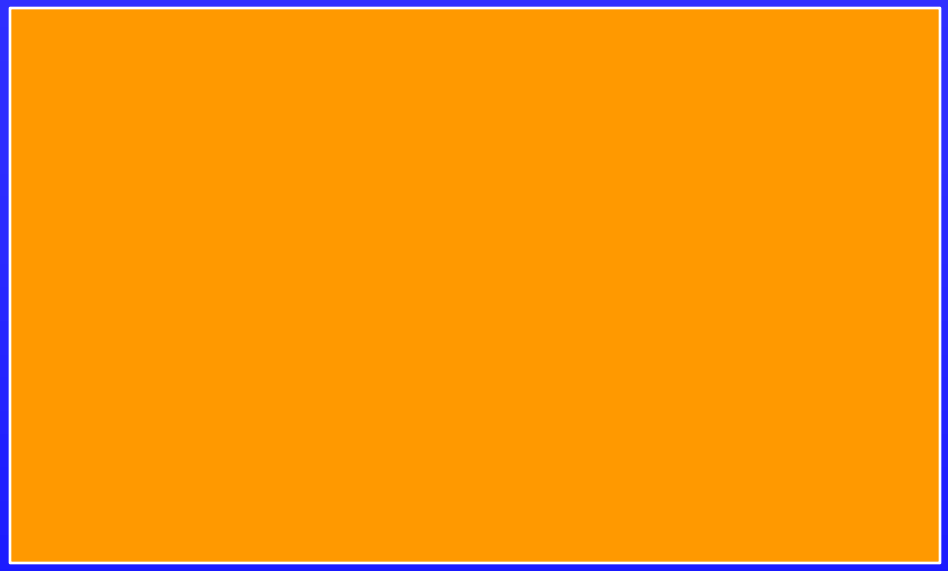
Color

- Attributes
  - hue: red, green, blue …
  - saturation: vividness of hue
  - brightness: luminance
- Relative discrimination
  - thousands of distinct colors
- Absolute discrimination
  - 24 distinct colors
  - recommended: 9

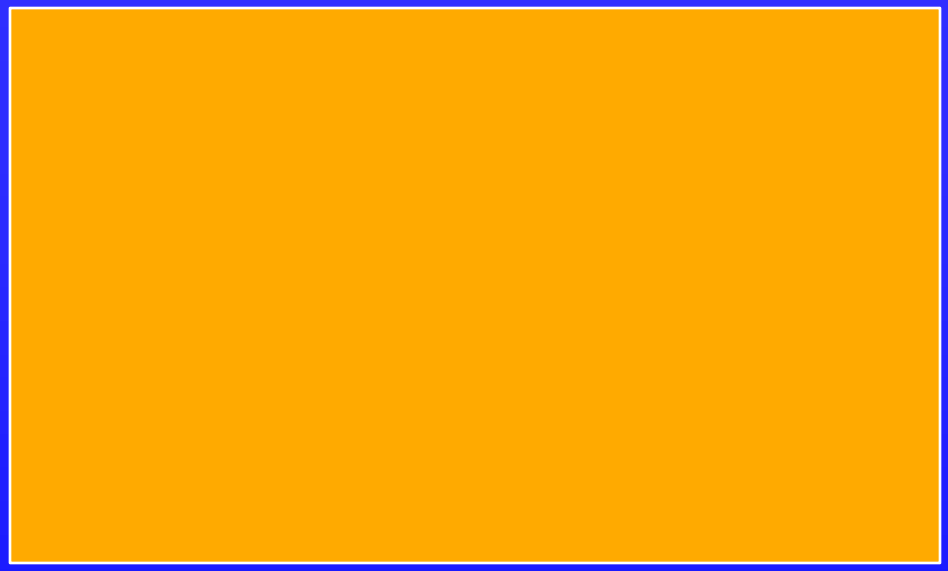
HUE


blue cone
437 nm
rod
498 nm
green cone
533 nm
red cone
564 nm
Relative Absorbance
400
450
500
550
600
650
700
Wavelength – nm
Dowling, 1987

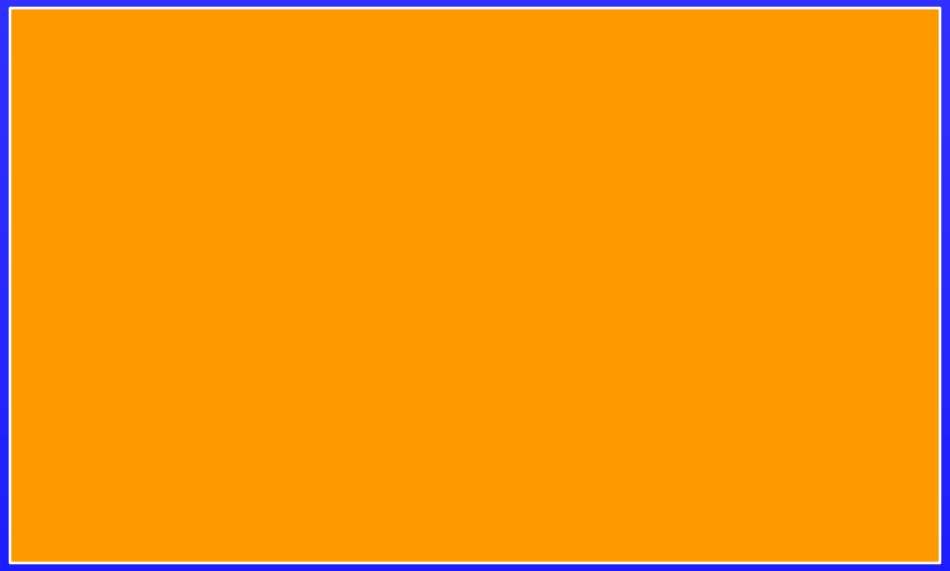
Absolute discrimination 0



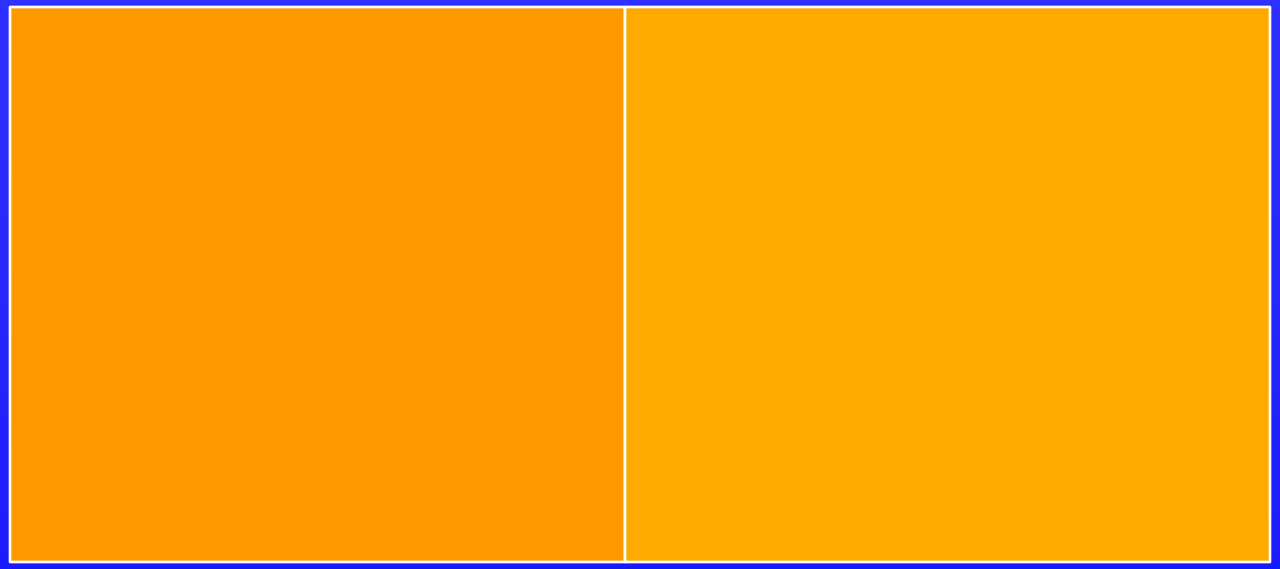
Absolute discrimination 1



Absolute discrimination 2



Relative discrimination

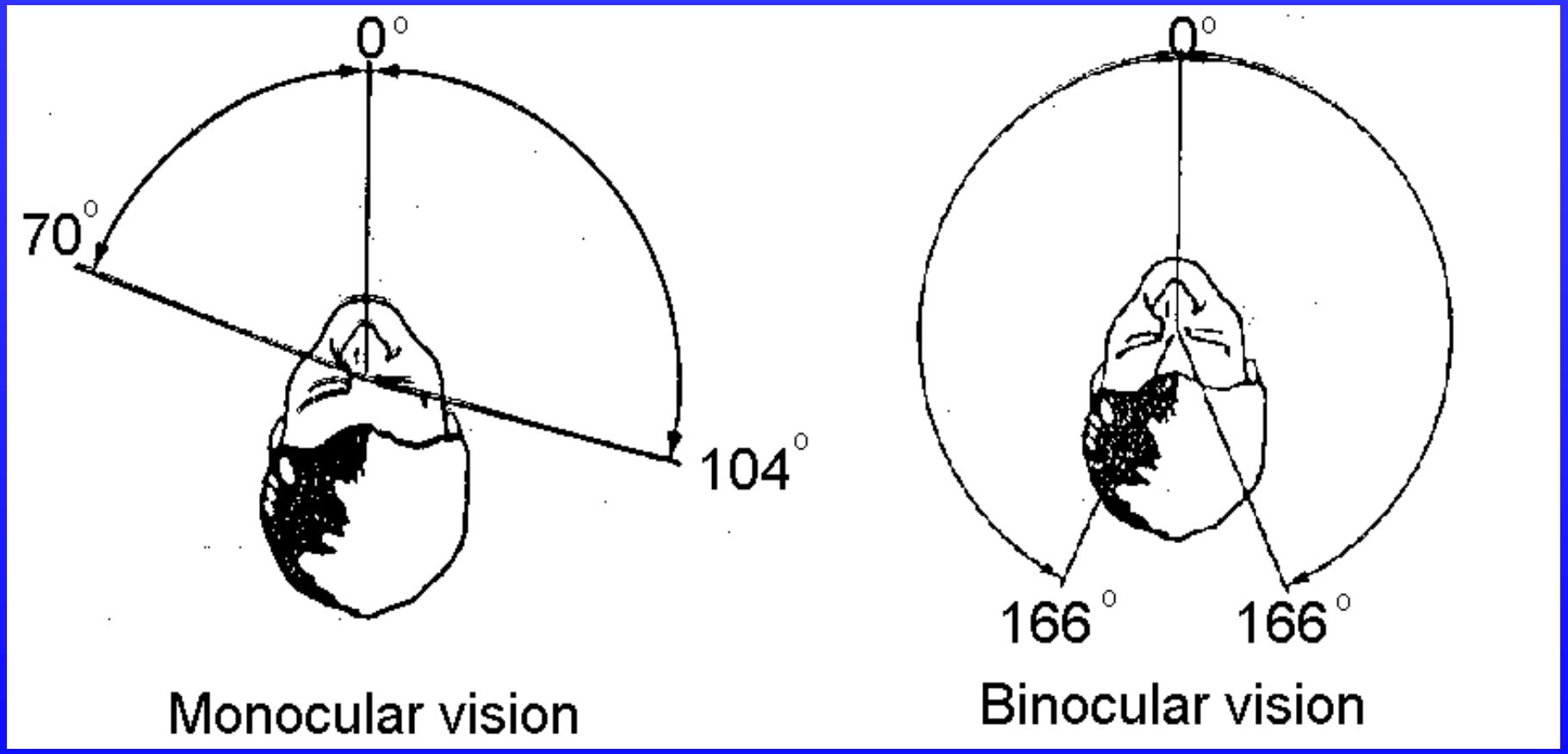


List of colors

- http://en.wikipedia.org/wiki/List_of_colors

					Shades of blue							
Alice blue	Azure	Baby blue	Blue	Cerulean	Cerulean blue	Chinese blue	Cobalt blue	Columbia blue	Cornflower blue	Dark blue	Denim	Dodger blue
Indigo	International Klein Blue	Light blue	Midnight blue	Navy blue	Periwinkle	Persian blue	Powder blue	Prussian blue	Royal blue	Sapphire	Steel blue	Ultramarine
Air Force blue	Egyptian blue	Electric blue	Maya Blue	Medium blue	Sky blue							

Visual Field



Visual Impairments

Myopia :	Nearsightedness
Hyperopia :	Farsightedness
Presbyopia :	Loss of accommodation
Night Blindness :	Reduced rod vision
Color Blindness :	Inability to discriminate
Tunnel Vision :	Reduced field of view

Other Factors Affecting Visual Performance

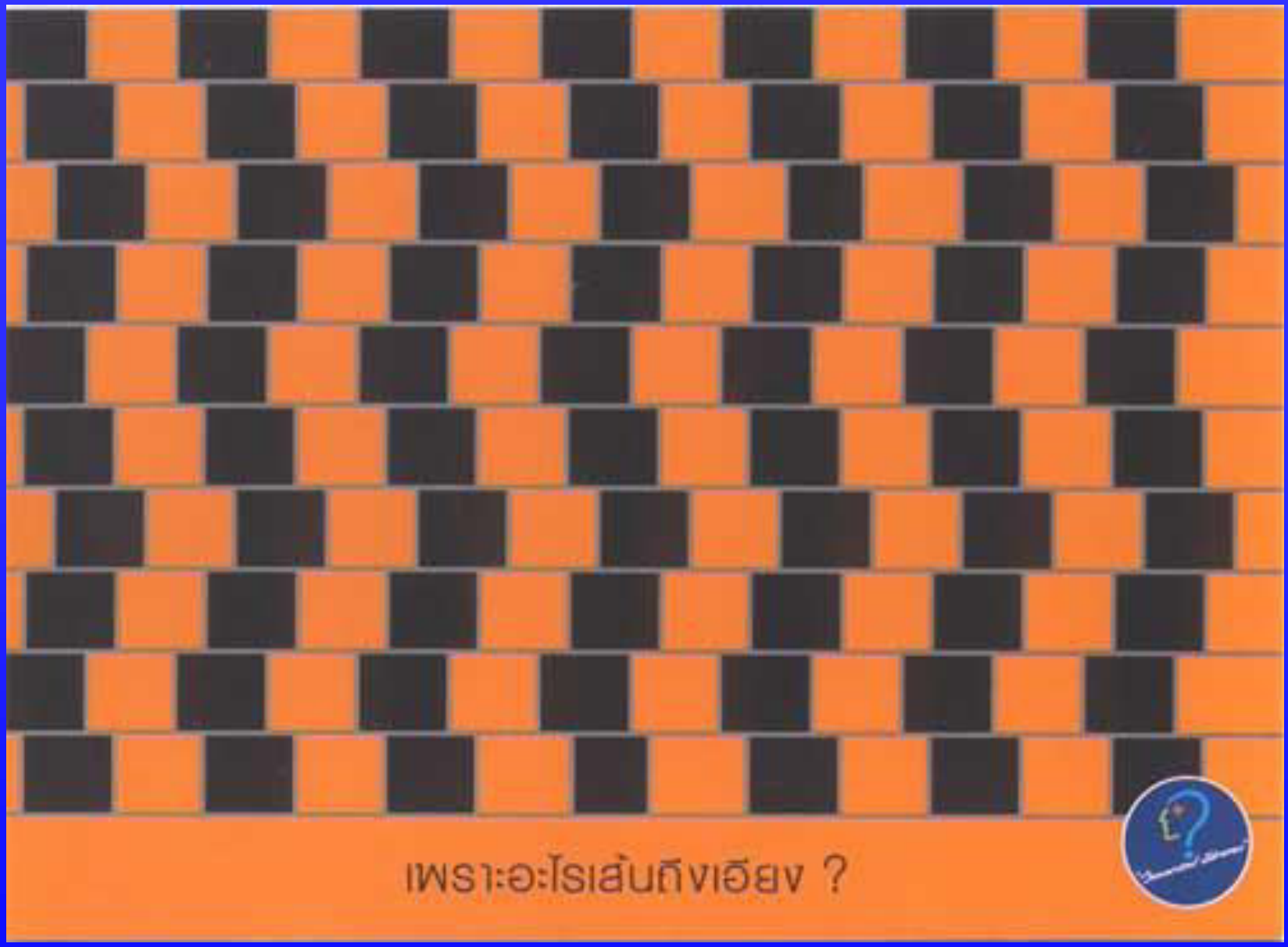
- Contrast: optimum level exists

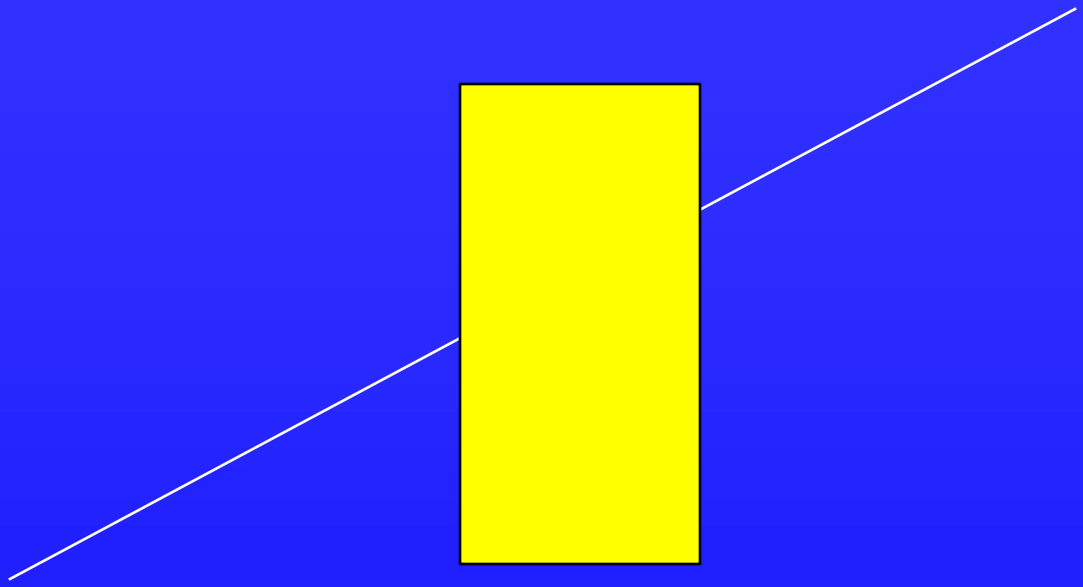
$$\text{Contrast} = \frac{B1 - B2}{B1} \times 100$$

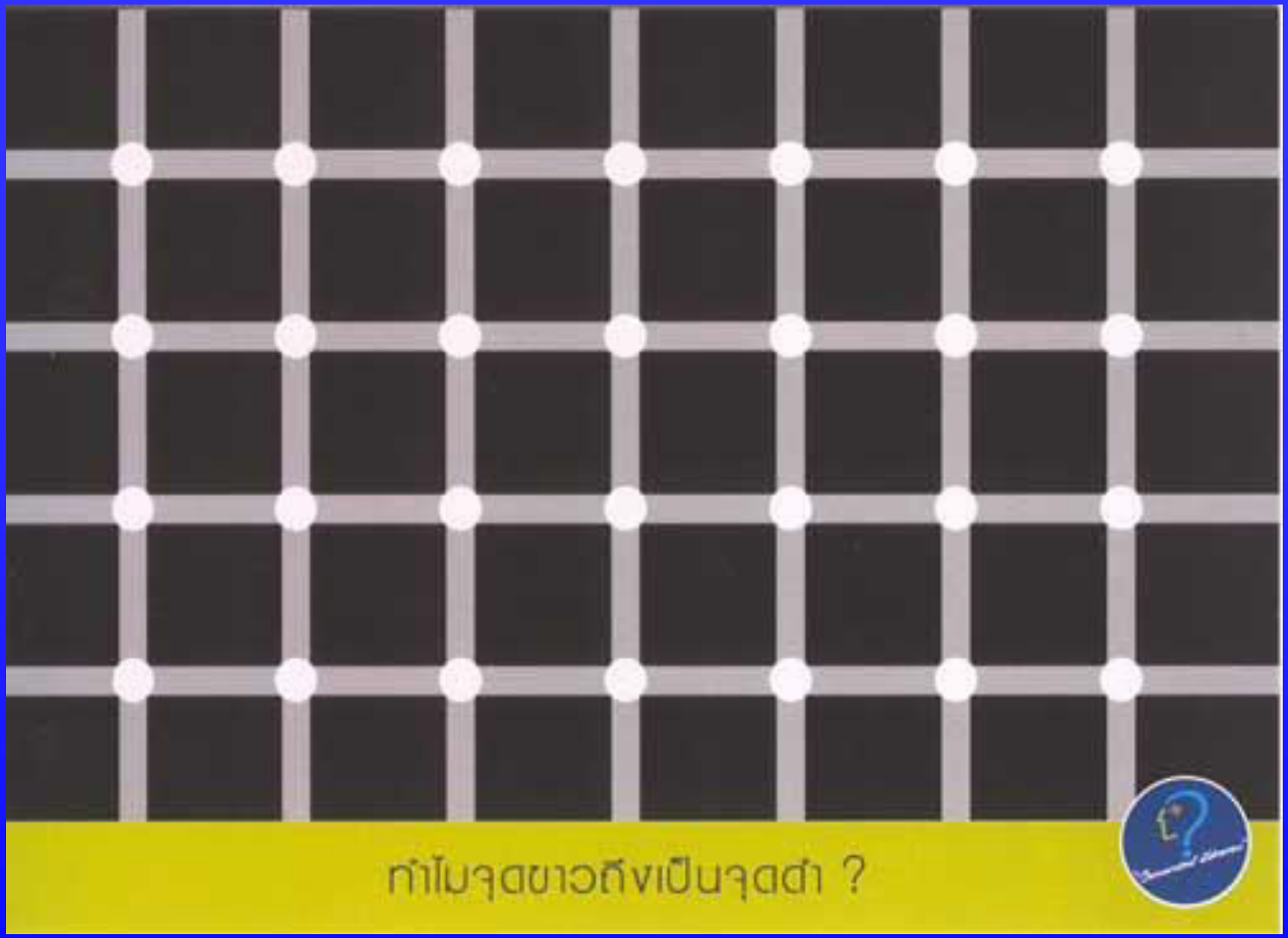
- Illumination: optimum level exists
- Time: positive relationship
- Luminance Ratio: see contrast

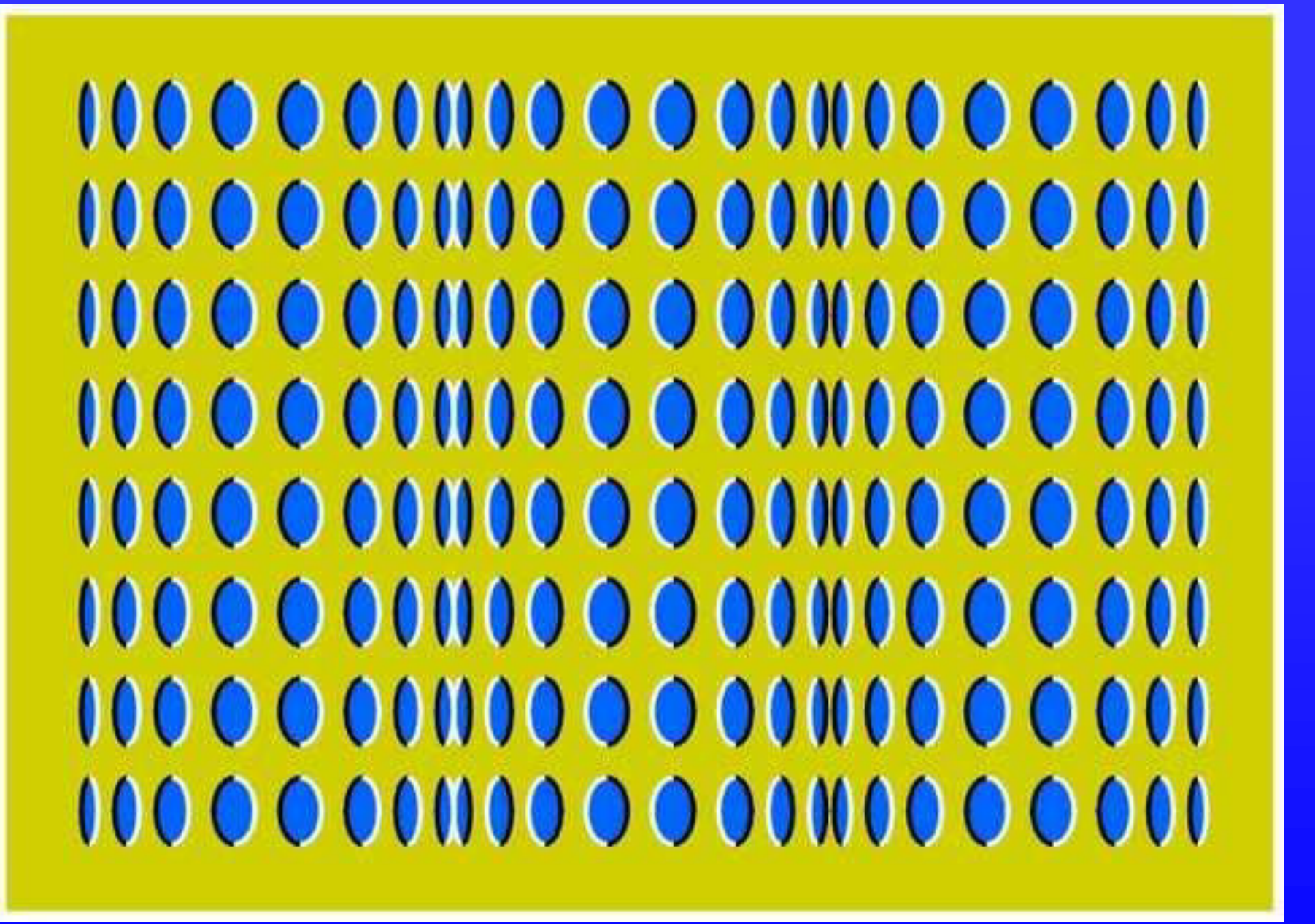
Other Factors Affecting Visual Performance (2)

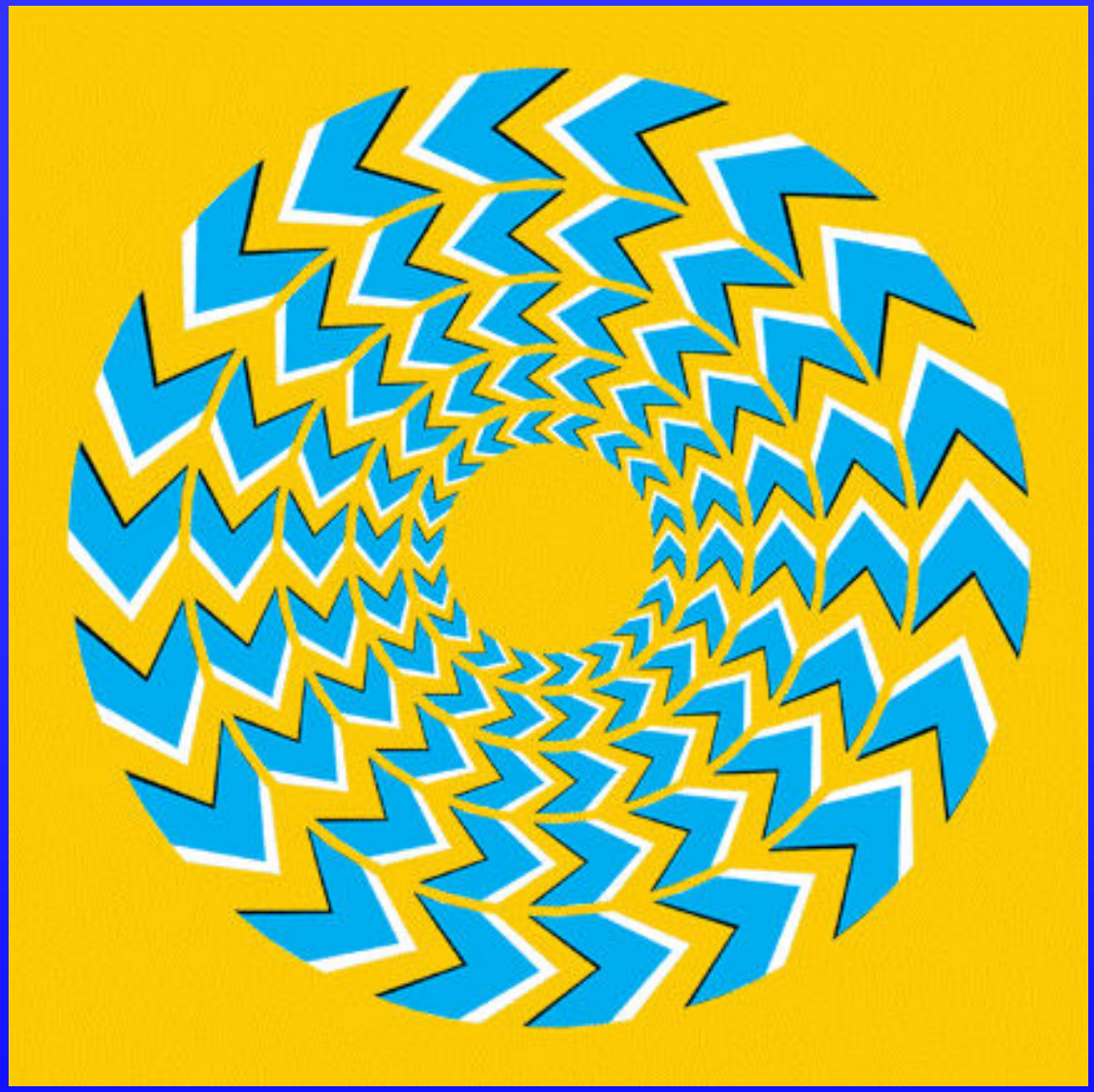
- Glare: negative relationship
- Movement: negative relationship
- Age: negative relationship
- Drugs: some drugs impair vision


เพราะอะไรเส้นถึงเอียง ?



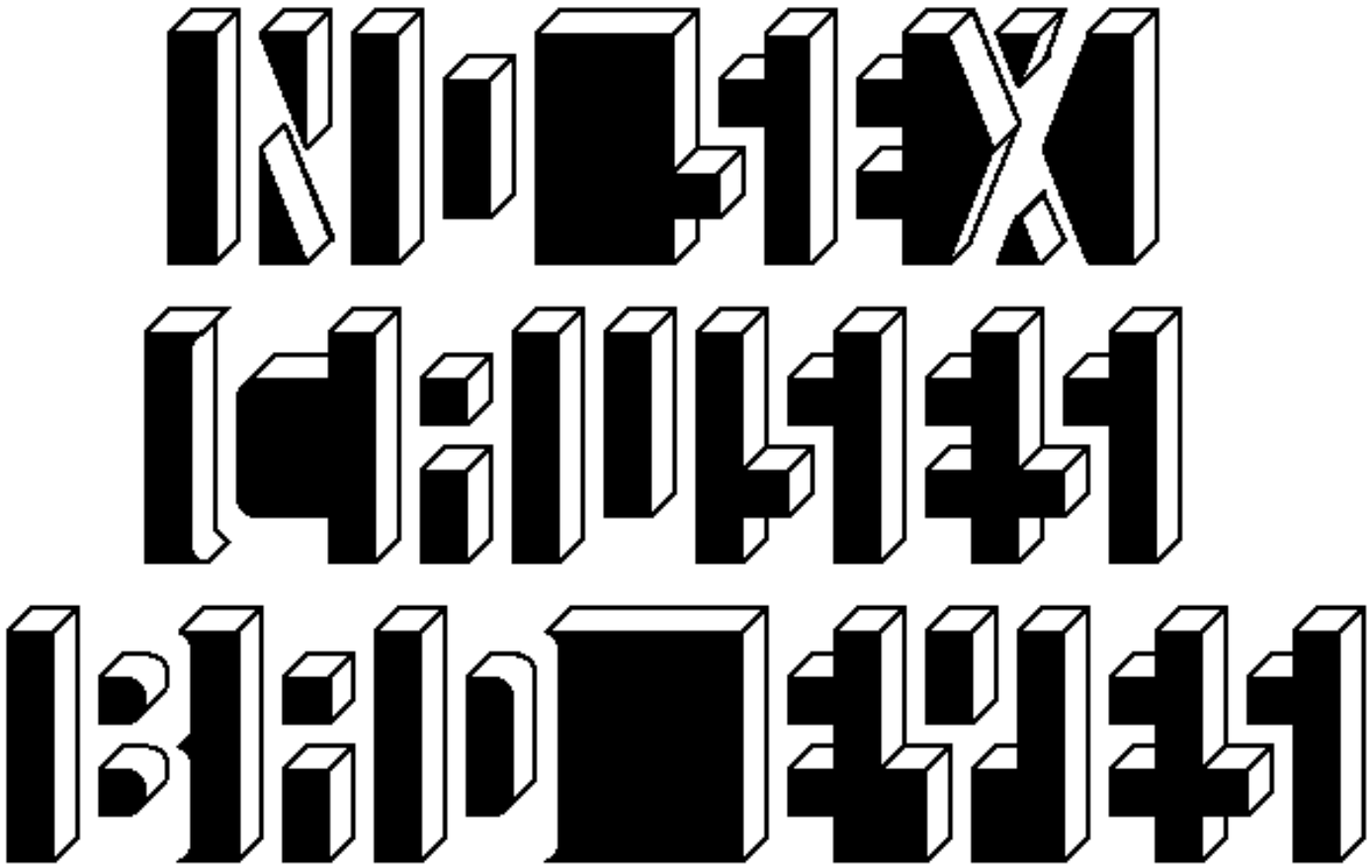

ทำไมจุดขาวถึงเป็นจุดดำ ?





Eye Examination Chart

Increase distance from chart until it is readable




ถ้าอ่านไม่ออก ลองถอยห่างออกไปเรื่อยๆ