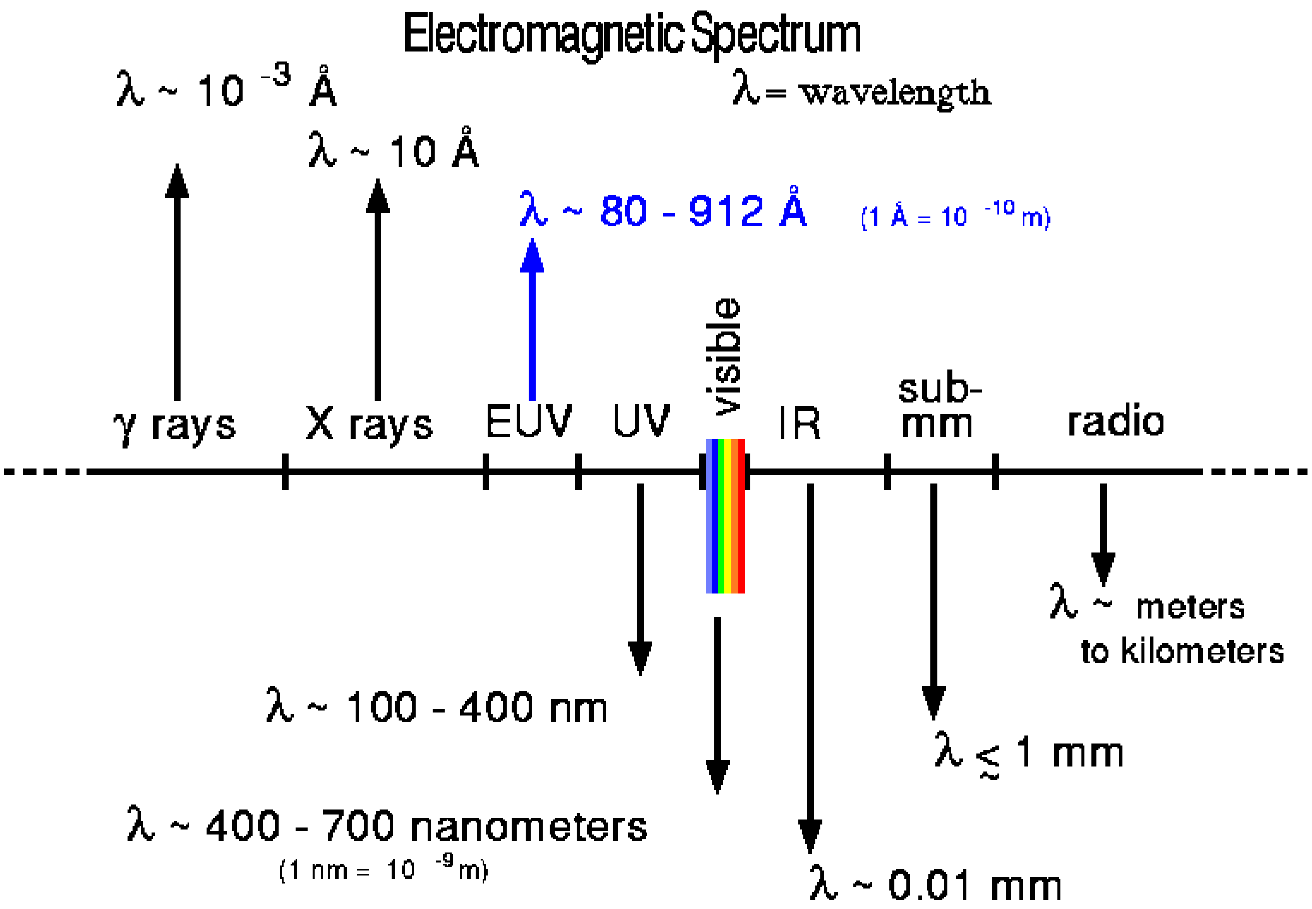
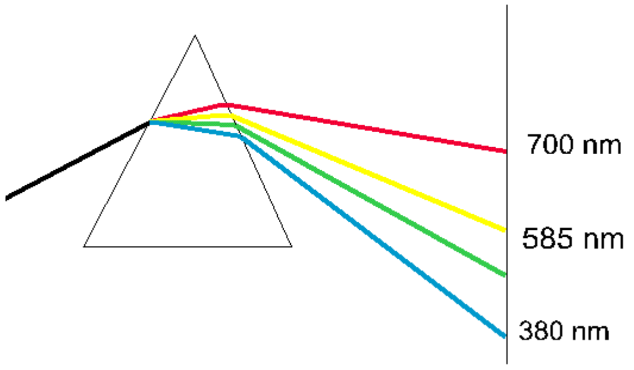
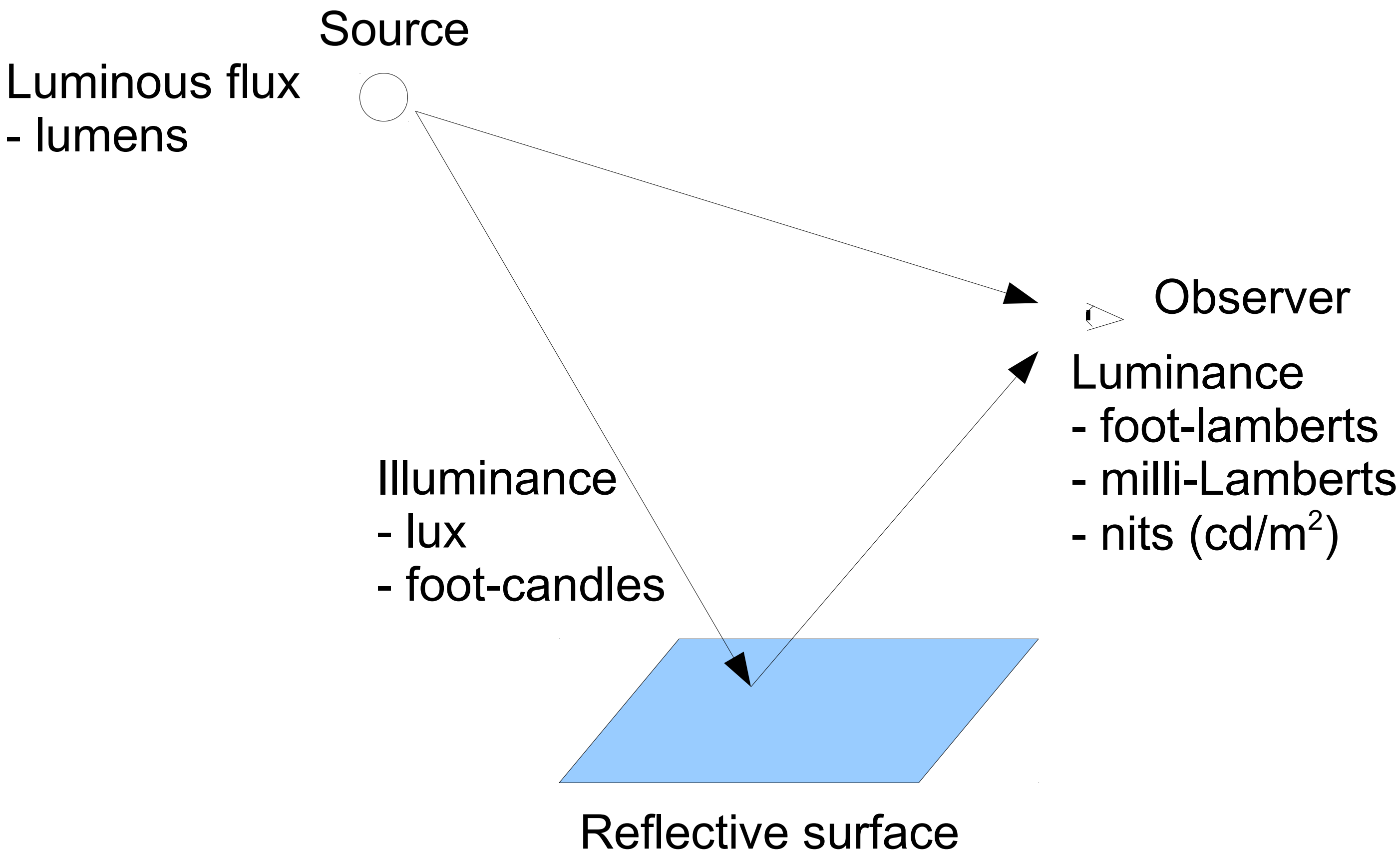
The Visual System and Visual Performance

Photometry: Electromagnetic Spectrum



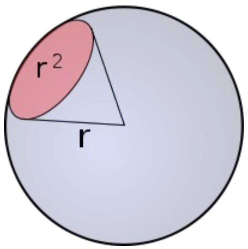


Photometry: Basic Concepts



Photometry: Concepts and Units

- Luminous intensity
  - Luminous power / unit solid angle
  - SI units: candelae/candelas (cd)
  - Candle emits ~1cd
- Luminous flux
  - Power of light perceived by human eye (visible light)
  - vs radiant flux (total power)
  - SI units: lumens (lm)
  - 1 lm = 1 cd·sr
- Illuminance
  - Luminous flux reaching a surface per unit area
  - Units
    - SI: lux (lx) = lm / m^2
    - Non-SI: footcandles (fc) = lm / ft^2
- Luminance
  - Luminous flux leaving (reflected from) a surface
  - Units
    - SI: cd / m^2 = “nits”
    - Non-SI: footlamberts(fL) = lm / ft^2
- Contrast: luminance ratio
- Reflectance: % reflected
- Brightness: perception



1 steradian (sr)
Source: Wikimedia commons, http://upload.wikimedia.org/wikipedia/commons/thumb/9/98/Steradian.svg/200px-Steradian.svg.png

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 footlambert (ft-L) = 0.929 mL, so 1 ft-L ~ 1 mL.

Luminance (2)

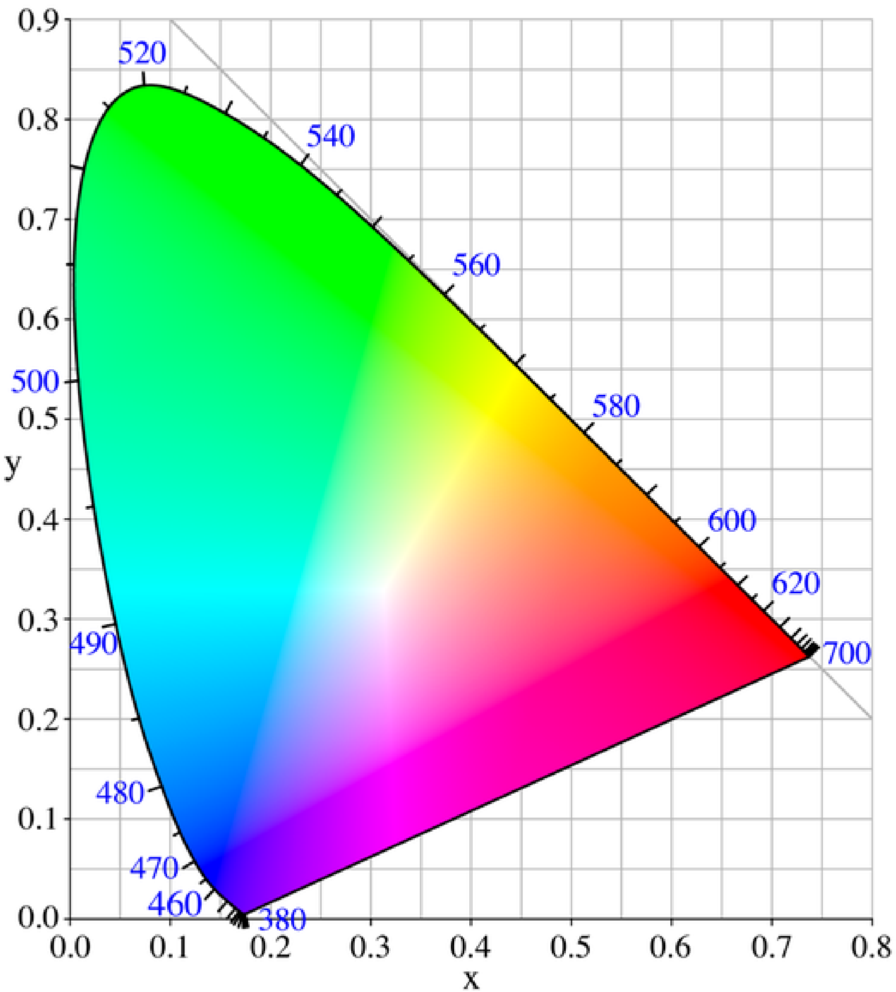
- Threshold of detectability
  1×10^{-6} mL

- Threshold of pain
  3×10^{4} mL

- Limits to discriminability
  3 - 4 levels

The CIE Color System

(*Commission Internationel de L'Elairage*: International Commission on Illumination)



- System, developed in 1931, to specify colors
- Based on experiments conducted in 1920s
- Idea: any color specified by combination of 3 primaries, e.g., red, green, blue (RGB)
- x & y axes represent proportions of two "imaginary" colors, "red" (r) and "green" (g), which determine remaining proportion of "blue" (b):

$$x = \frac{r}{r+g+b}$$

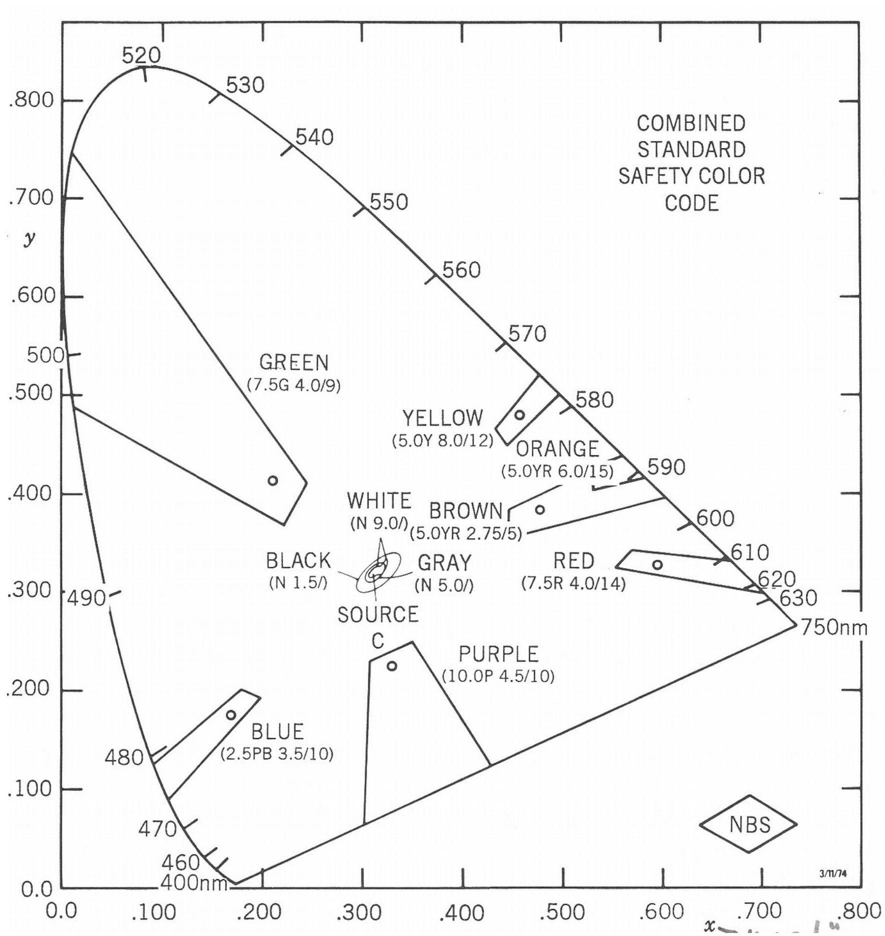
$$y = \frac{g}{r+g+b}$$

sources: Wikimedia Commons, http://en.wikipedia.org/wiki/File:CIExy1931.png
Chapanis, A. (1996). *Human Factors In Systems Engineering*, New York: Wiley, 224.

The CIE Color System

(<u>C</u>ommission <u>I</u>nternationel de L'<u>E</u>lairage: International Commission on Illumination*)*

sources: Wikimedia Commons, http://en.wikipedia.org/wiki/File:CIExy1931.png
Chapanis, A. (1996). *Human Factors In Systems Engineering*, New York: Wiley, 224.



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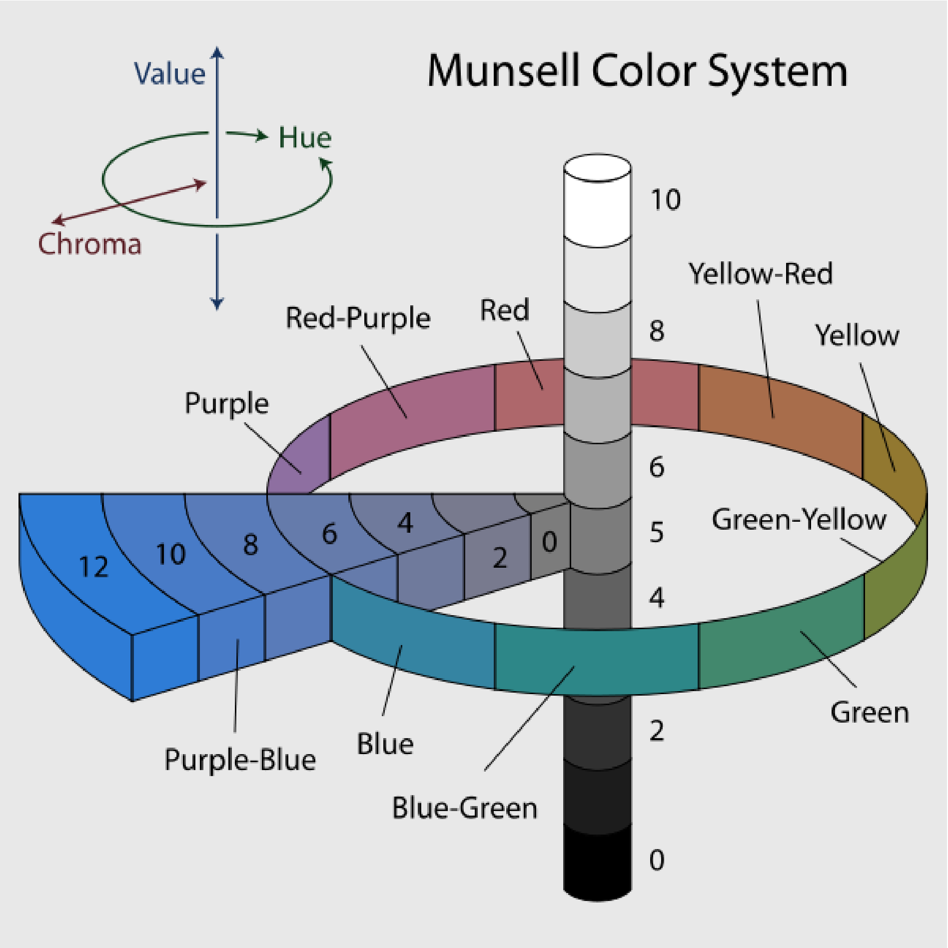
$$x = \frac{r}{r+g+b}$$

$$y = \frac{g}{r+g+b}$$

•“Safety” colors indicated

Munsell Color System

- Developed in early 1900s
- Early use was for soil research
- Specifies color in terms of
  - Lightness/Value
  - Hue ("color")
  - Saturation/Chroma



source: Wikimedia Commons, http://en.wikipedia.org/wiki/File:Munsell-system.svg

Federal Standard 595C - Colors Used in Government Procurement FED-STD-595

- Color description & communication system
- Developed 1956 by US government
- Means of specifying colors to contractors, vendors
- Federal Standard 595 Color Server: http://www.colorserver.net/

Reds

31086	31090	31105	31120	31136
31140	31158	31302	31310	31328
31350	31400	31433	31575	31630
31638	31643	31667	31668	31669
31670				

Oranges

32144	32160	32169	32190	32197
32199	32203	32215	32243	32246
32276	32300	32356	32473	32510
32516	32519	32544	32555	32563
32630	32648	32684		

Anatomy and Physiology: The Eye

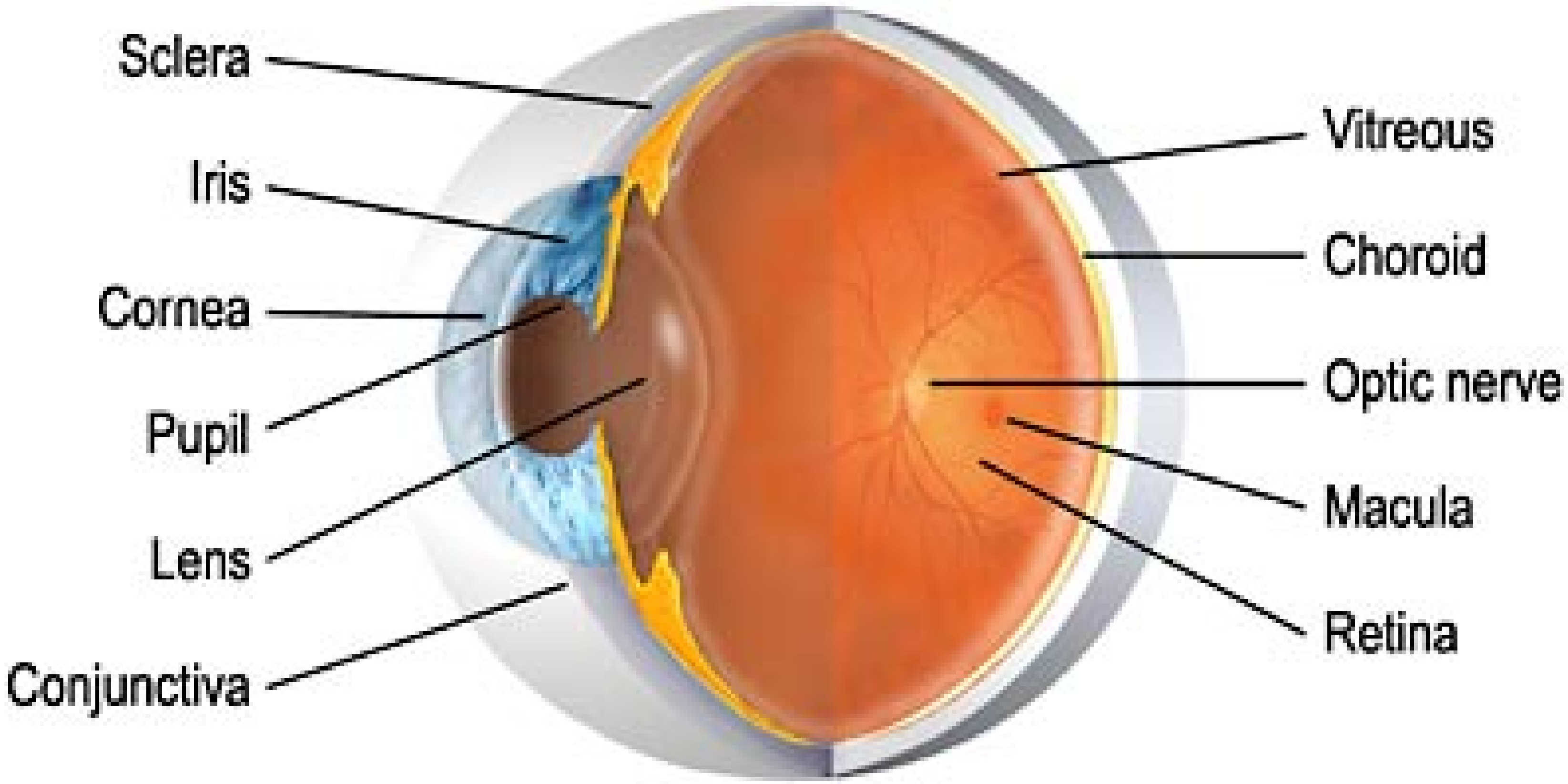
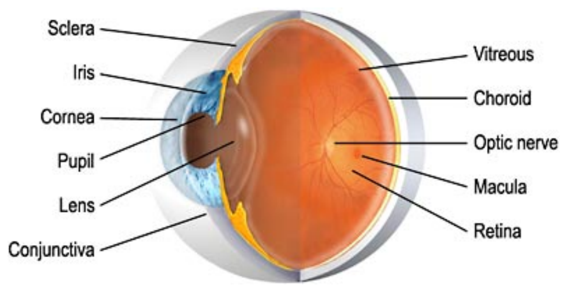


Illustration by Mark Ericksen, St. Luke's Cataract and Laser Center, StLukesEye.com

Anatomy and Physiology: The Eye (2)

- Sclera: white of the eye, fibrous, protective
- Iris
  - Light control
  - Focusing
- Cornea
  - Protection
  - Focusing
- Pupil: opening
- Lens
  - Focusing (ciliary muscles)
  - Accommodation
- Conjunctiva: clear, covers sclera, lines eyelids
- Aqueous Humor (cornea-lens chamber)
  - Shape
  - Nutrition



- Vitreous Humor (lens-retina chamber)
  - Shape
- Choroid: vascular layer, connective tissue between sclera and retina
- Optic Nerve
  - Nerve signals to brain
  - Optic Disk: blind spot
- Retina
  - Rods: black & white, night vision
  - Cones: color, day vision
  - Macula: area of greater acuity
  - Fovea: greatest actuity (highest concentration of cones)
- Eye Muscles
  - Eye movement
  - Convergence

Rod and Cone Cells

	Rods	Cones
Location	periphery	macula/fovea
Acuity	- (lower density)	+ (higher density)
Sensitivity	+ (scotopia)	- (photopia)
Color	-	+
Adaptation	rapidly lose sensitivity	little affected by intensity
Wavelengths sensed	insensitive to red	

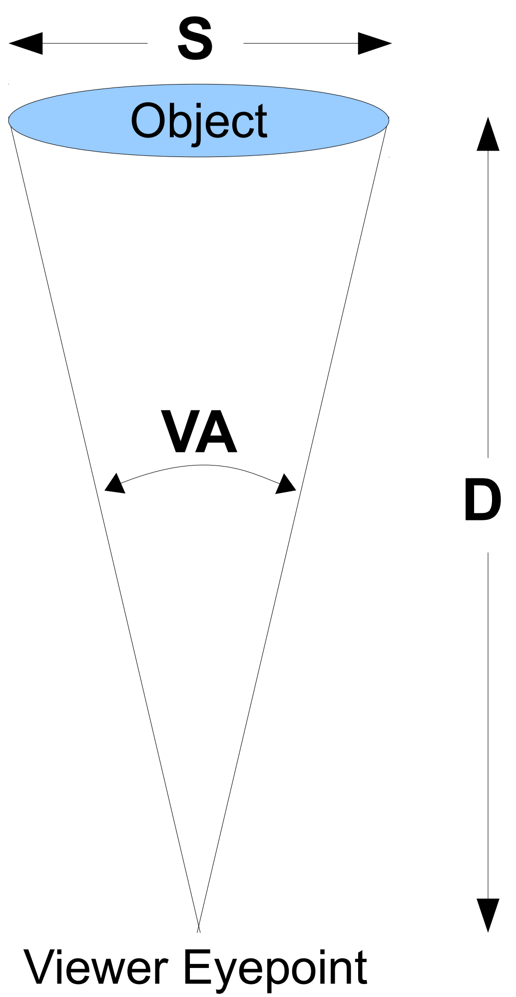
Visual Performance

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

Brightness

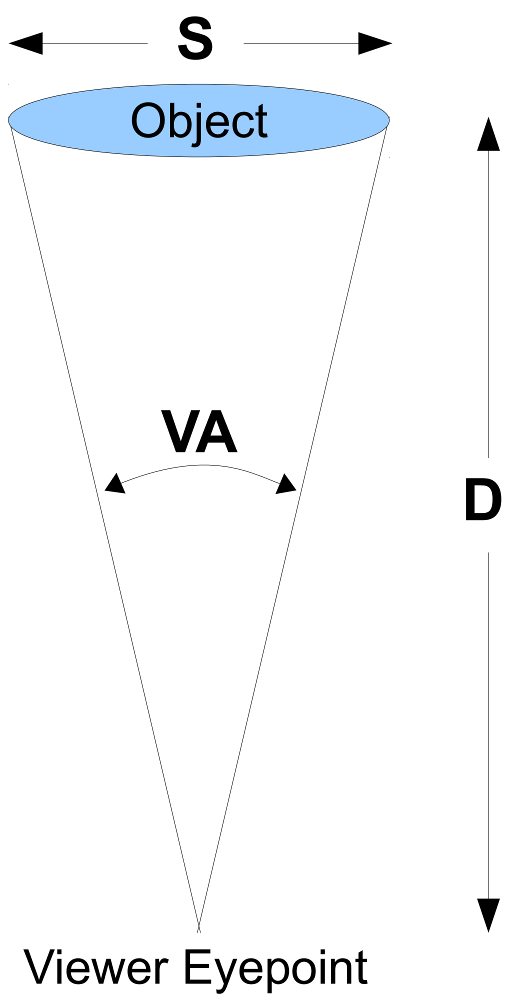
- Relative amount of light reflected from an object produces a sensation of lightness or brightness.
- Brightness is related to the luminance of light as well as a subjective response to color

Visual Angle (VA)



VA = 2 arctan (S/2D)

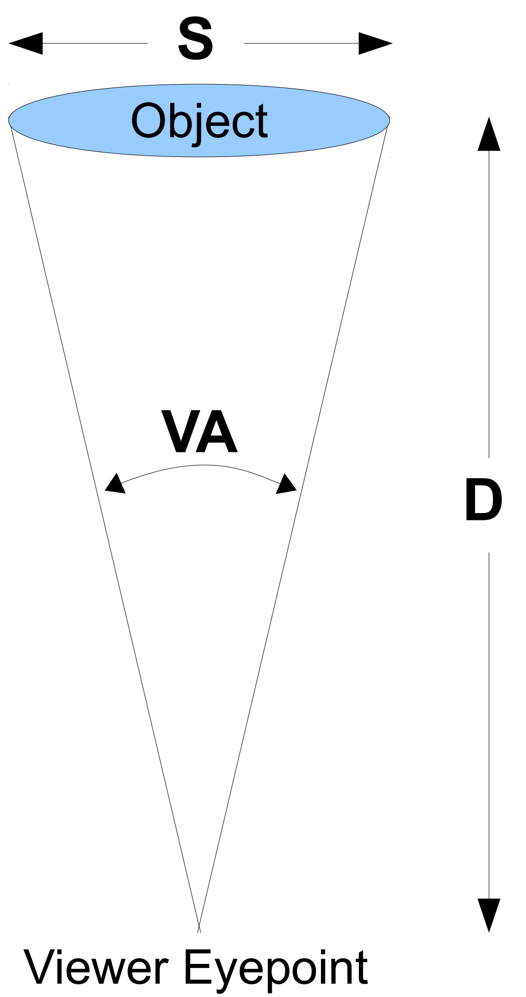
Visual Angle (VA)



$$VA = 2 \arctan (S/2D)$$

Object	VA (degrees)
Quarter at arms length	2.3
Quarter at 10 ft	0.5
Toyota Corolla at 100 yd	2.9
100 ft Douglas Fir @ 300 yd	6.4

Visual Angle (VA)



VA = 2 arctan (S/2D)

Object	VA (degrees)
Quarter at arms length	2.3
Quarter at 10 ft	0.5
Toyota Corolla at 100 yd	2.9
100 ft Douglas Fir @ 300 yd	6.4
Mt Jefferson at 72 mi (H)	0.4
Mt Jefferson at 72 mi (W)	1.6
Cell Tower Pole at 300 yd (dia)	0.3
Cell Tower Antennae at 300 yd (H)	3.9
180 ft Cell Tower at 300 yd (H)	11.4

Mt. Jefferson/Cell Tower Comparison

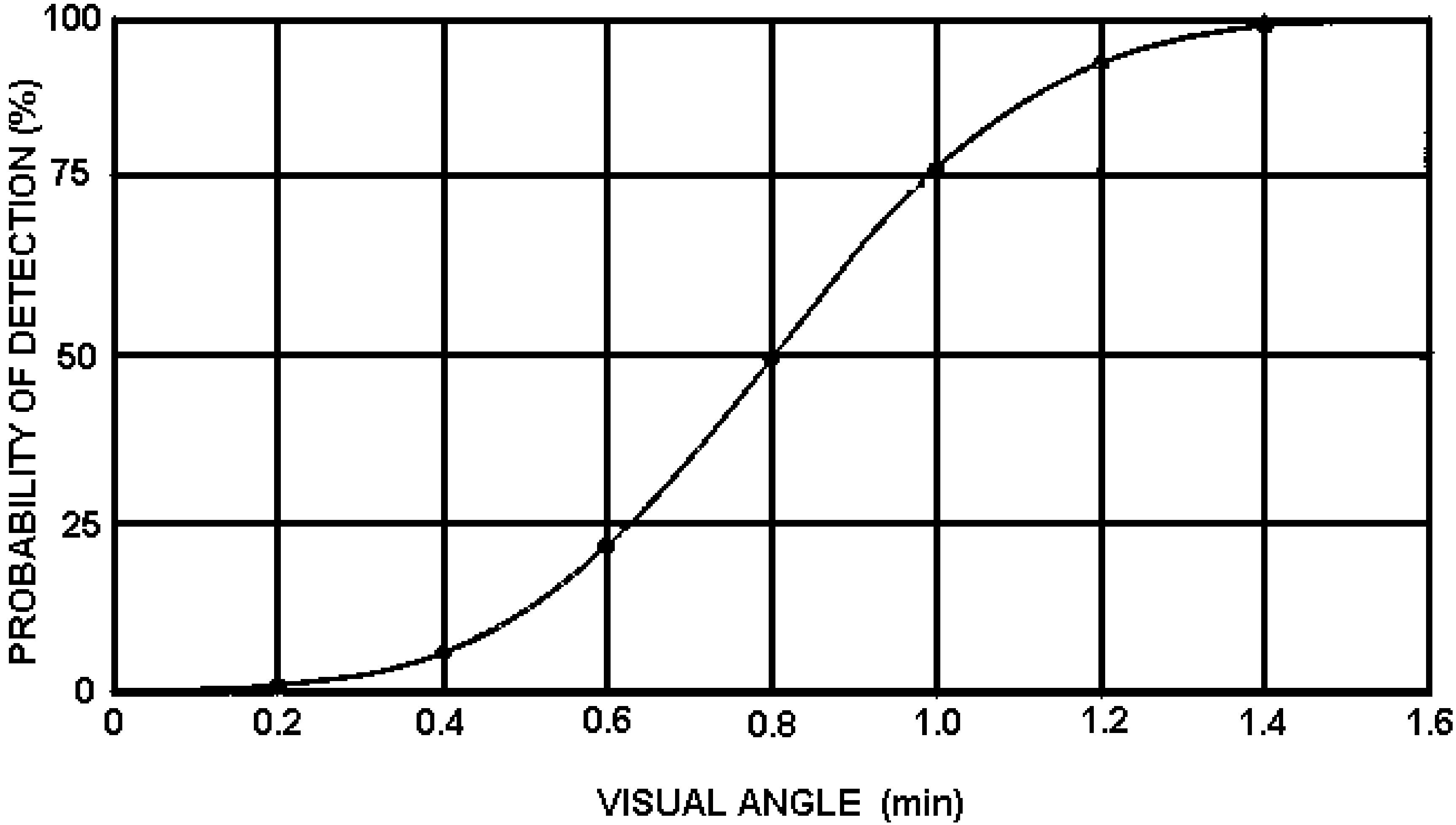
NB: lower portion of tower clipped by bottom of photo

Mt. Jefferson/Cell Tower Comparison

Object	VA (degrees)
Mt Jefferson at 72 mi (H)	0.4
Cell Tower Antennae at 300 yd (H)	3.9
Cell Tower Antennae > 9x Mt Jefferson	
180 ft Cell Tower at 300 yd (H)	11.4
180 ft Cell Tower > 28x Mt Jefferson	

NB: lower portion of tower clipped by bottom of photo

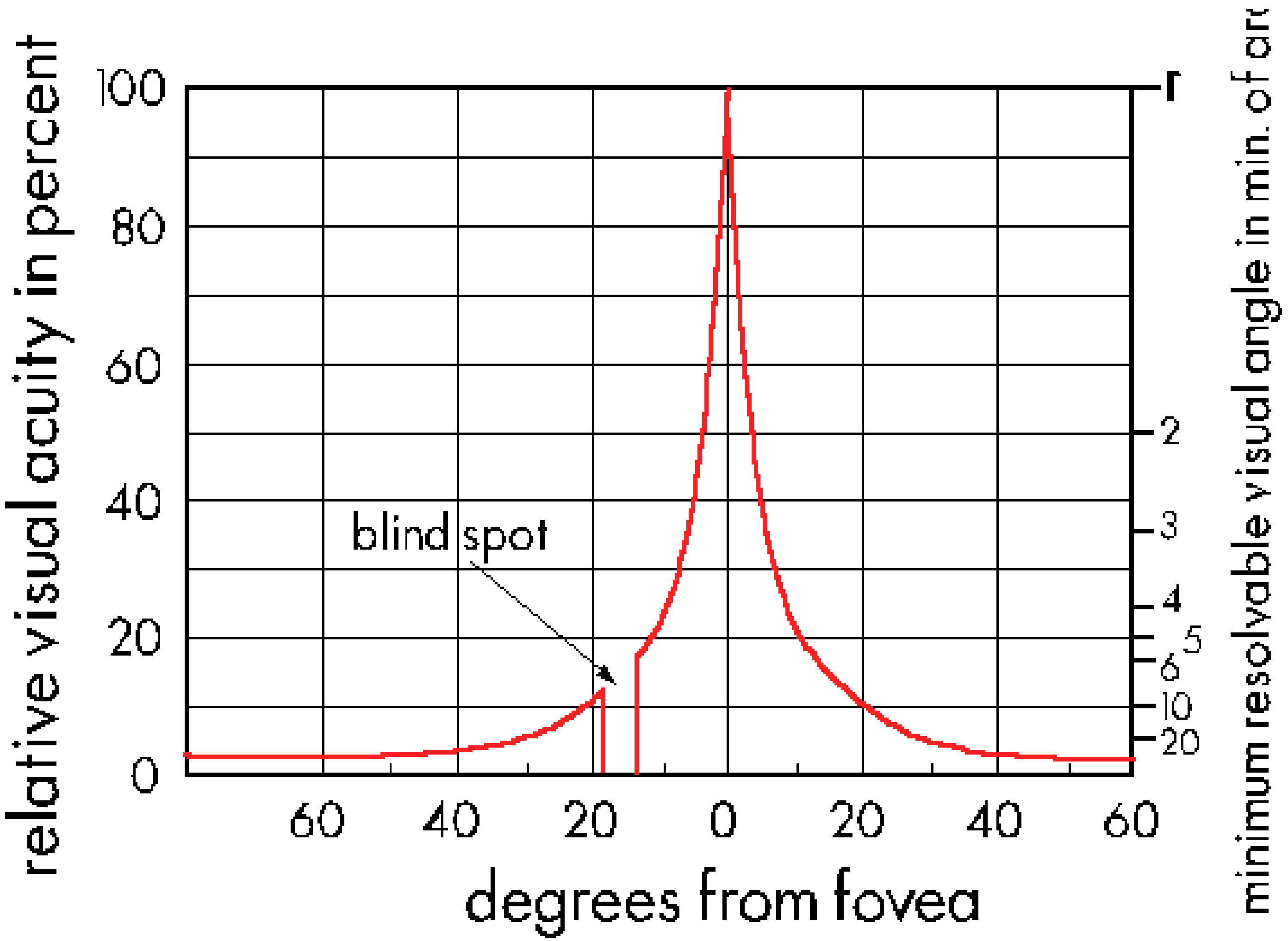
Cumulative Probability of Detection



Visual Acuity

- Ability to resolve detail
- Often, inverse of smallest visual angle (in minutes) that can be resolved
- e.g., Acuity = 1
  - Observer can resolve/detect a feature of 1 minute VA

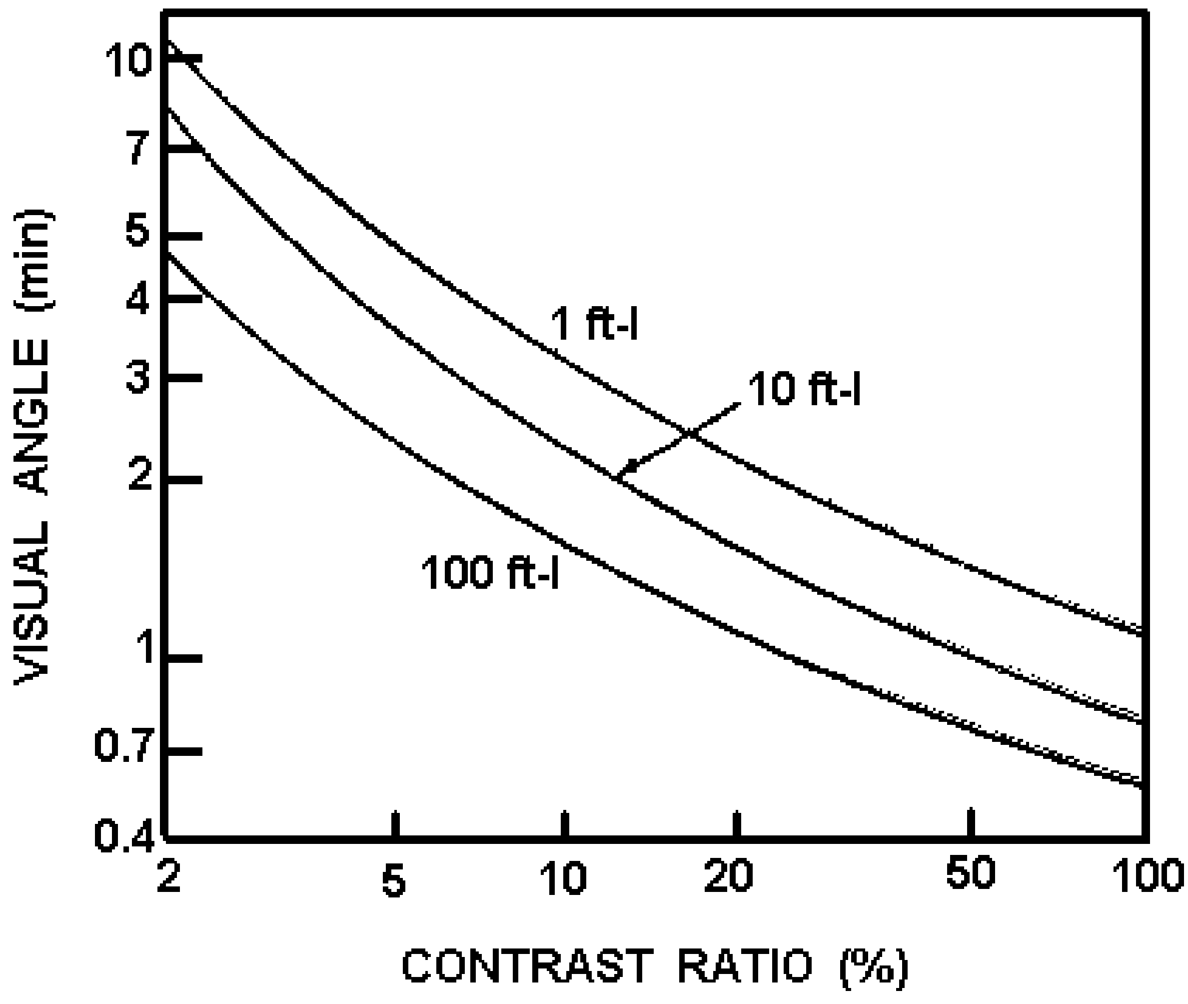
Variation in Visual Performance Across the Retina



Minimum Separable Acuity

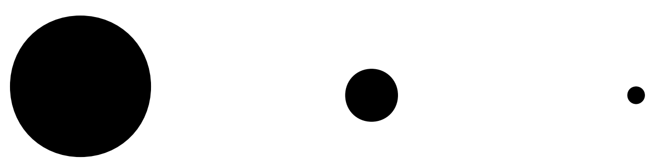
- Also called gap resolution
- Smallest VA eye can detect between parts of a target (visual object).

Minimum Separable Acuity as Function of Contrast

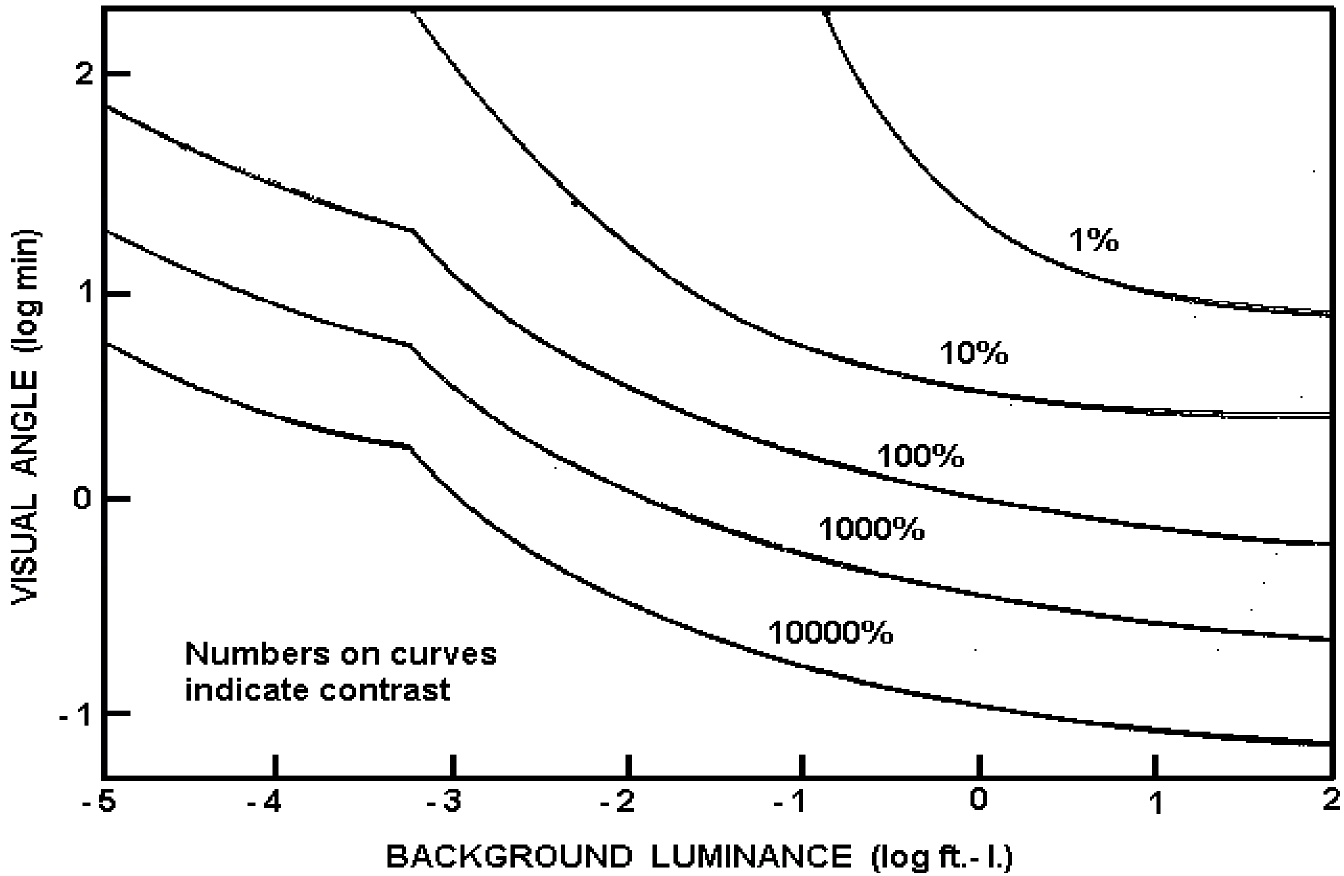


Minimum Perceptible Acuity

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

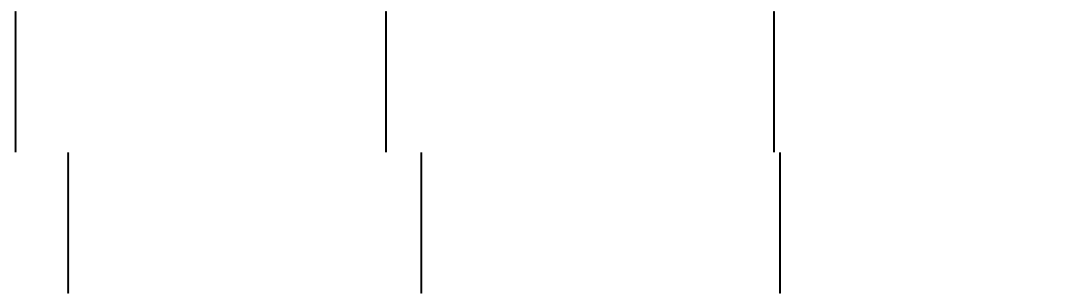


Minimum Perceptible Acuity as Function of Contrast and Background Luminance

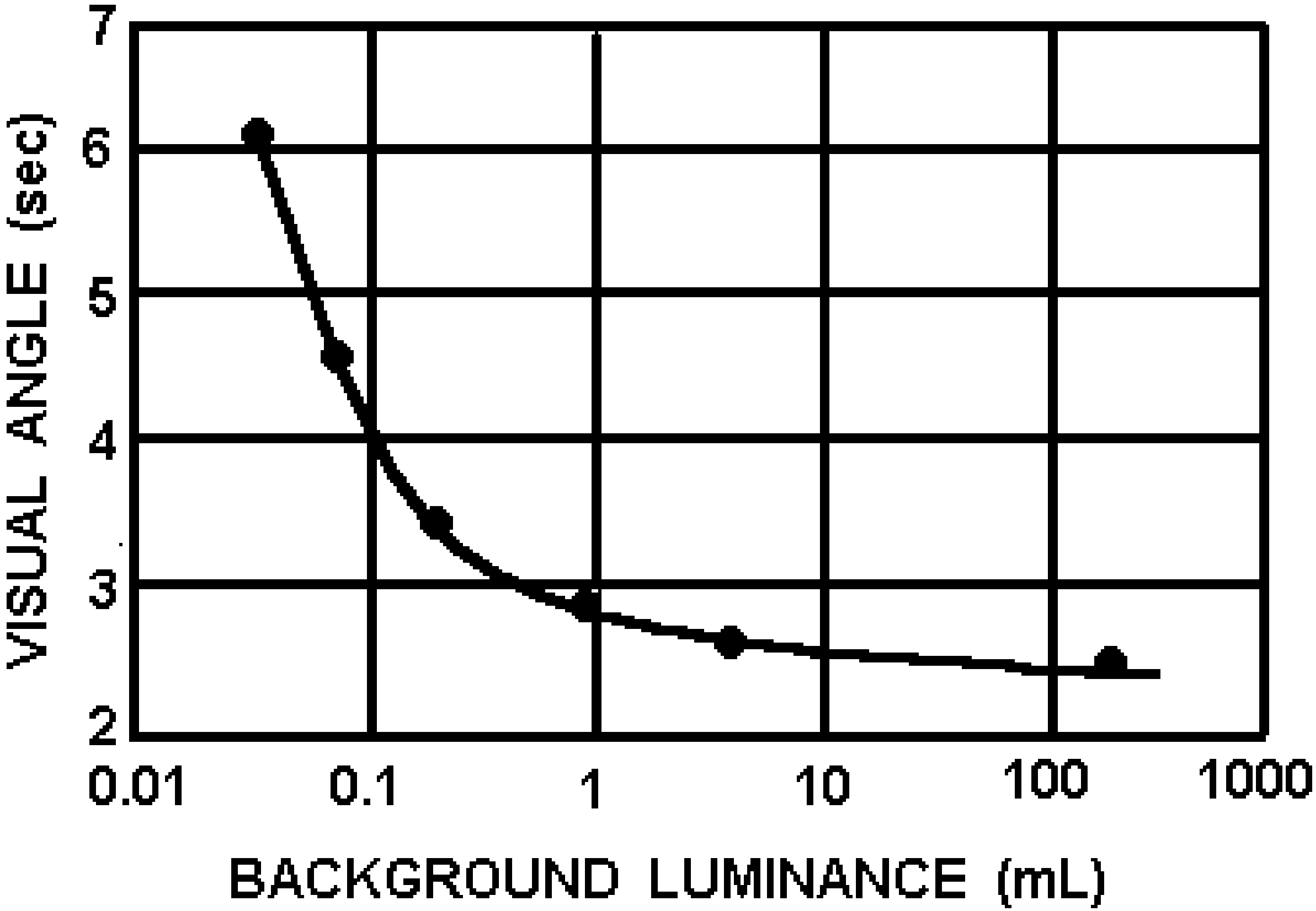


Vernier Acuity

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



Vernier Acuity as Function of Background Luminance



Landolt Ring / Landolt C

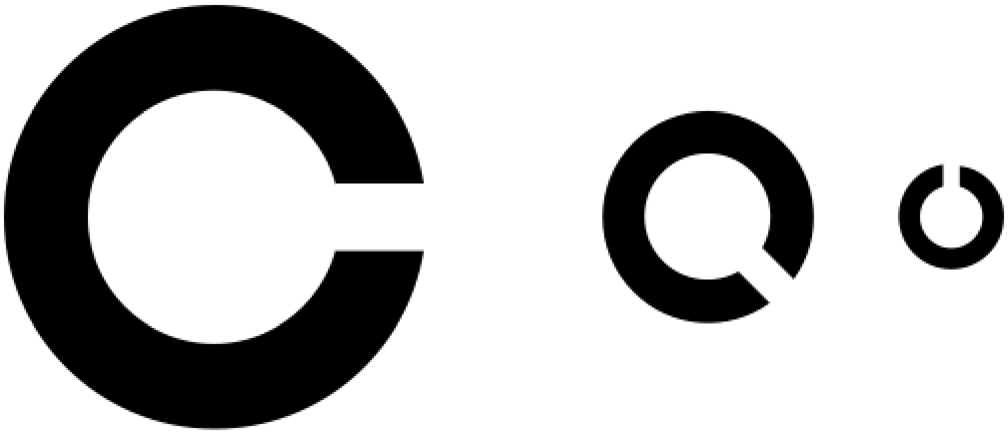
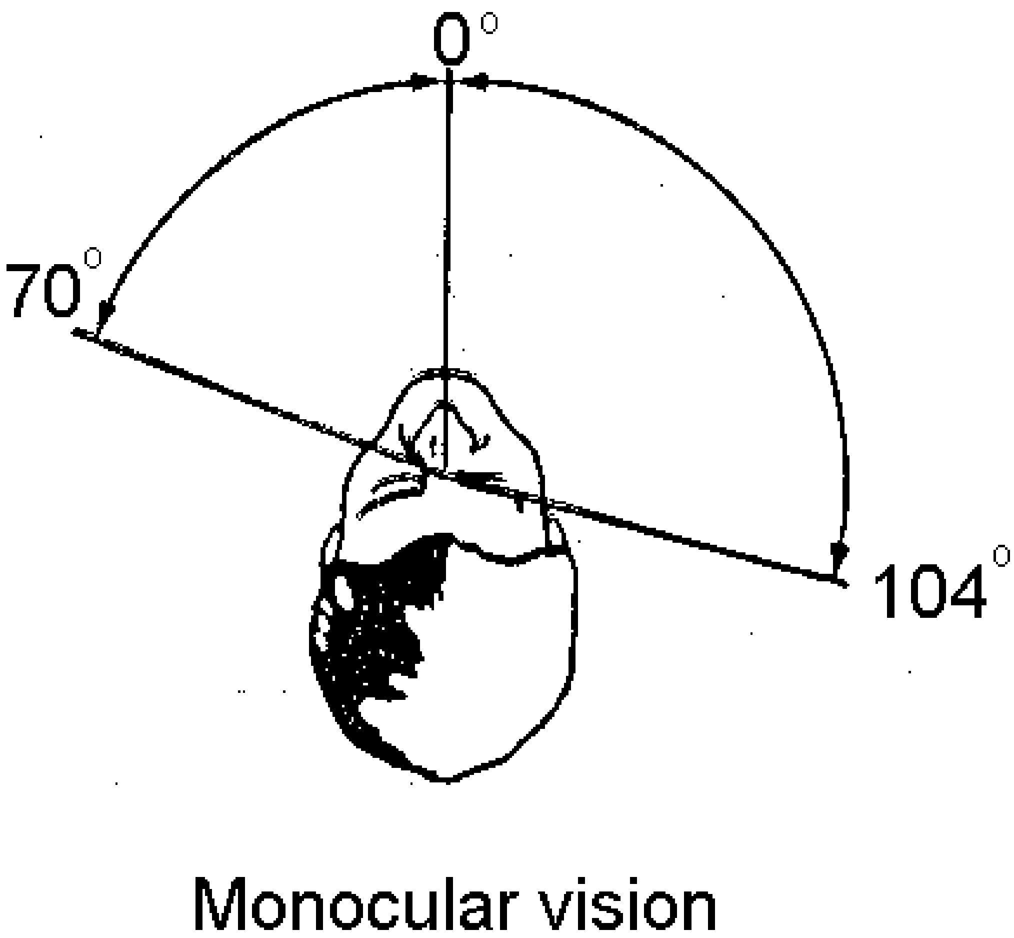


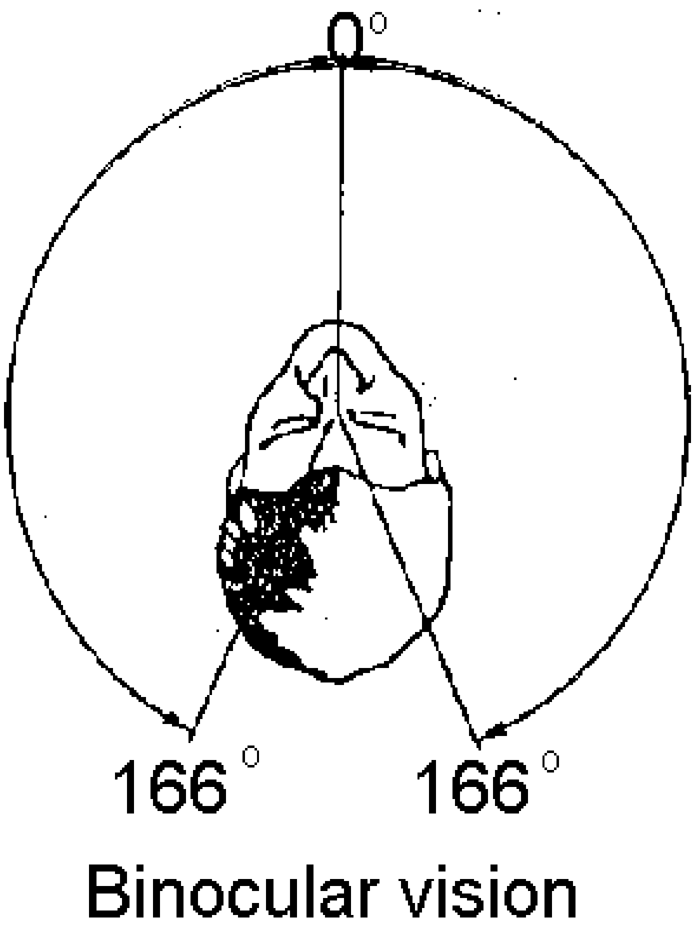
Image source: http://upload.wikimedia.org/wikipedia/commons/thumb/a/ab/Landolt_C.svg/500px-Landolt_C.svg.png

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

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: contrast

Other Factors Affecting Visual Performance (2)

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

Signal Detection Theory

True State of World

Observer Response

	Signal Present	Signal Absent
"Yes"	Hit	False Alarm
"No"	Miss	Correct Rejection (Quiet)

- Sensitivity
- Response Bias
  = P("Yes")
  = f(expectancies, costs/payoffs)
- Influences
  - costs/payoffs
  - false signals (intentional & not)
  - incentives
  - rate
  - signal amplification
  - rest breaks
  - memory aid/"template" of signal
  - experience
  - redundancy
- Interventions
  - instruction
  - exhortation
  - training

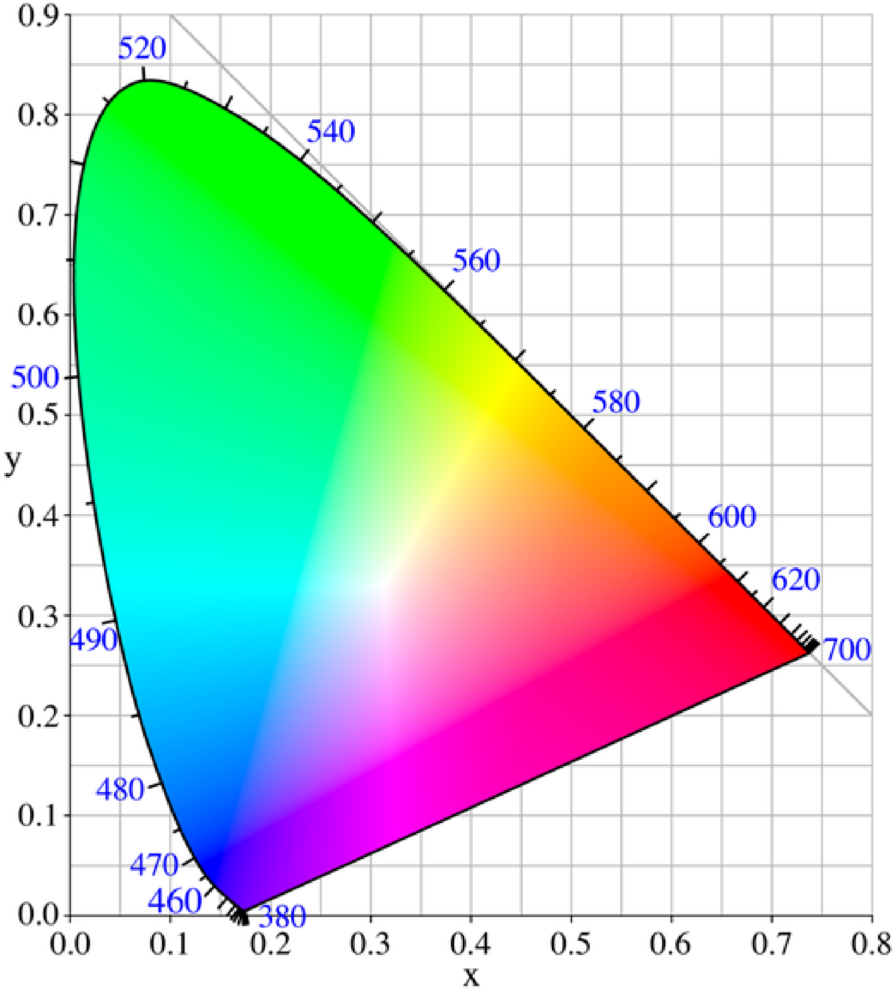
Discrimination

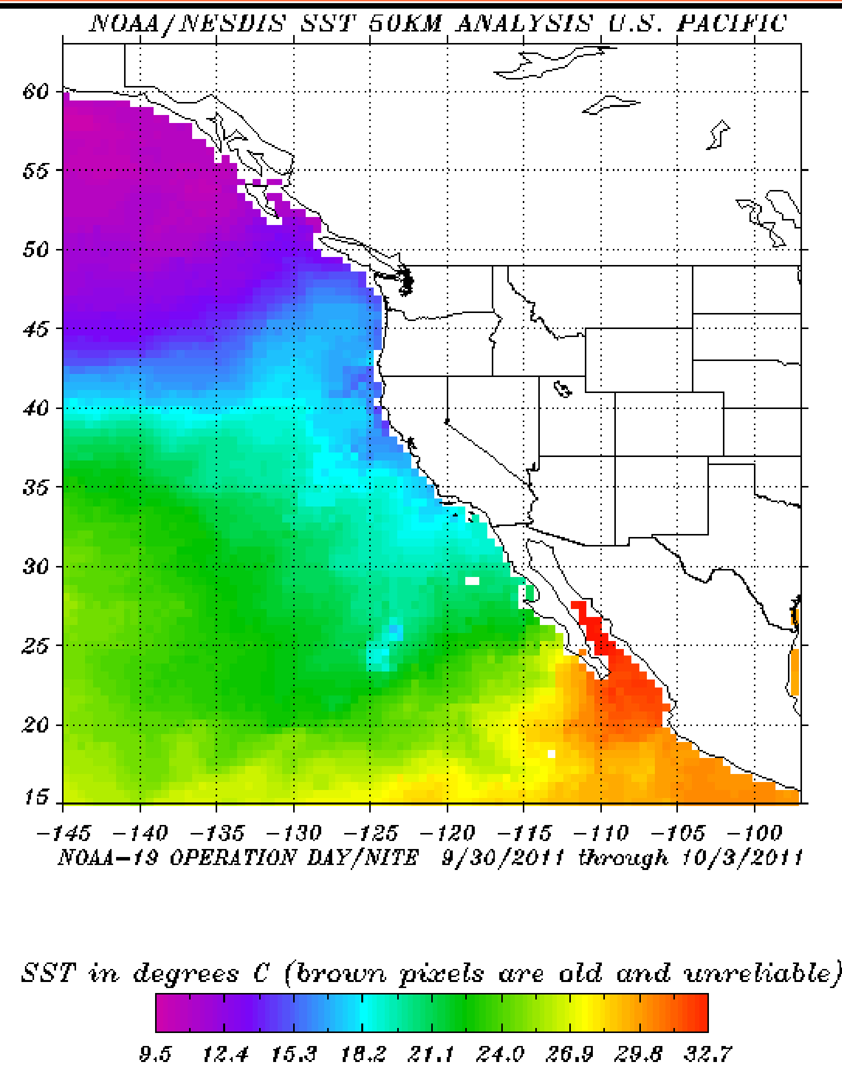
- Discrimination vs detection
- Just-Noticeable Difference (JND)
- Weber's Law

$$k = \frac{\Delta I}{I}$$

- where:
  - k = constant, specific to sensory continua (brightness, loudness, etc.)
  - I = intensity
  - Δ I = difference in intensity between two stimuli, just noticeable
- (Applies to non-sensory dimensions as well, e.g., cost.)

Color Discrimination

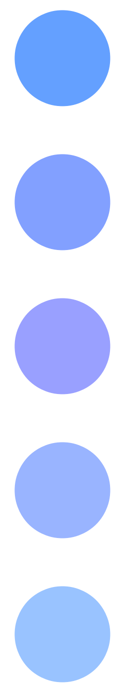




Source: NOAA Sea Surface Temperature (SST) Contour Charts
http://www.osdpd.noaa.gov/ml/ocean/sst/contour.html

Absolute Judgment
Color Codes 1

Subsystem Status



4

3

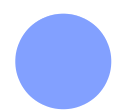
2

1

0

Absolute Judgment
Status Display 1

Subsystem
Status

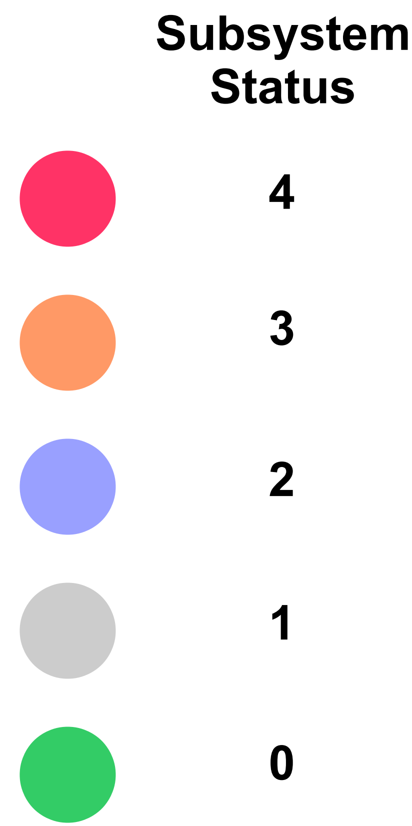


Absolute Judgment
Status Display 1

Subsystem Status

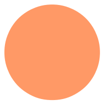
3

Absolute Judgment
Color Codes 1



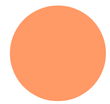
Absolute Judgment
Status Display 1

Subsystem Status



Absolute Judgment
Status Display 1

Subsystem Status



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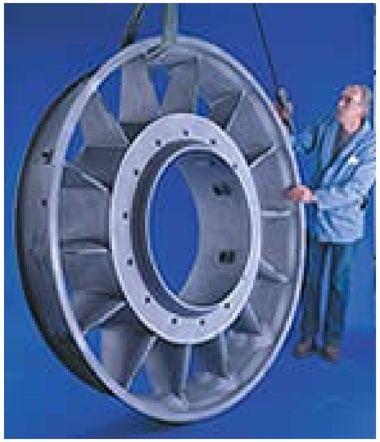
Visual Search: Visual Inspection



Source: http://www.pccstructurals.com/

Subtasks In Visual Inspection

Wang, M. J. and Drury, C. G. (1989). A method of evaluating inspector's performance difference and job requirement, *Applied Ergonomics*, 20, 181–190.

Subtask	Sub-task description	Major skill	Mental attributes required
Present	(1) Orient the item	Manual	—
Search	(2) Search the item	Cognitive	Attention, perception, memory
	(3) Detect the flaws	Cognitive	Detection, recognition, memory
Decision	(4) Recognize/classify the flaws	Cognitive	Recognition, classification, memory
	(5) Decide about the item	Cognitive	Judgment, classification, memory
Action	(6) Dispatch the item	Manual	—
	(7) Record the information about the item	Manual and Cognitive	Memory

Factors Affecting Visual Inspection Performance

Jiang, X., Gramopadhye, A., & Melloy, B. (2004). Theoretical issues in the design of visual inspection systems. *Theor. Issues In Ergon. Sci., 5*(3), 232–247.

- **Subject factors**
  - visual lobe (central area)
  - visual acuity
  - color vision
  - discriminability
  - search strategy
  - fixation time
  - number of fixations
  - memory standards
  - cost/value structure
  - decision criterion
- **Physical and environmental factors**
  - lighting
  - illumination
  - noise
- **Task factors**
  - fault conspicuity
  - fault probability
  - fault mix
  - viewing area
  - pacing
  - physical standards
  - detection probability
- **Organizational factors**
  - number of inspectors
  - feedback training
  - feedforward training
  - knowledge of results

Some Representative Standards for Visual Inspection

- Limited inspection time (e.g., ≤ 2 hours)
- No photochromic or tinted lenses
- Even white light illumination
- Adequate level of illumination (see next slide)
- Appropriate equipment
  - High intensity light sources
  - Borescopes
  - Magnifiers
  - Microfinish comparators
  - Profilometers

Recommended Levels Of Illumnation

TABLE 16-3
RECOMMENDED ILLUMINATION LEVELS FOR USE IN INTERIOR LIGHTING DESIGN

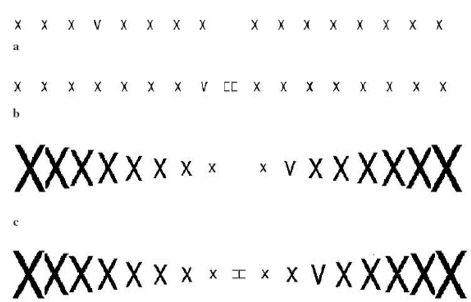
Category	Range of illuminances, lx (fc)	Type of activity
A	20–30–50* (2–3–5)*	Public areas with dark surroundings
B	50–75–100* (5–7.5–10)*	Simple orientation for short temporary visits
C	100–150–200* (10–15–20)	Working spaces where visual tasks are performed only occasionally
D	200–300–500† (20–30–50)†	Performance of visual tasks of high contrast or large size: e.g., reading printed material, typed originals, handwriting in ink and good xerography; rough bench and machine work; ordinary inspection; rough assembly
E	500–750–1000† (50–75–100)†	Performance of visual tasks of medium contrast or small size; e.g., reading medium-pencil handwriting, poorly printed or reproduced material; medium bench and machine work; difficult inspection; medium assembly
F	1000–1500–2000† (100–150–200)†	Performance of visual tasks of low contrast or very small size: e.g., reading handwriting in hard pencil on poor-quality paper and very poorly reproduced material; highly difficult inspection
G	2000–3000–5000‡ (200–300–500)‡	Performance of visual tasks of low contrast and very small size over a prolonged period: e.g., fine assembly; very difficult inspection; fine bench and machine work
H	5000–7500–10,000‡ (500–750–1000)‡	Performance of very prolonged and exacting visual tasks: e.g., the most difficult inspection; extra fine bench and machine work; extra fine assembly
I	10,000–15,000–20,000‡ (1000–1500–2000)‡	Performance of very special visual tasks of extremely low contrast and small size: e.g., surgical procedures

* General lighting throughout room.
† Illuminance on task.
‡ Illuminance on task, obtained by a combination of general and local (supplementary) lighting.
Source: RQQ, 1980, Table 1.

Sanders, S. & E.J. McCormick (1976). *Human Factors In Engineering and Design, 7th Edition*, New York: McGraw-Hill, 530.

Recommendations For Improving Visual Inspection

- Hong, K., Nagarajah, R., Iovenitti, P., & Dunn, M. (2007). A sociotechnical approach to achieve zero defect manufacturing of complex manual assemblies. *Human Factors and Ergonomics in Manufacturing, 17*(2), 137–148.
  - Use 100% successive checks.
  - Inspectors should be key elements in the development of defect reducing methods.
  - Provide inspectors with sufficient training.
- Tetteh, E., Jiang, X., Mountjoy, D., Seong, Y., & McBride, M. (2008). Evaluation of a job-aiding tool in inspection systems. *Human Factors and Ergonomics in Manufacturing, 18*(1), 30–48.
  - Job-aids.
  - Systematic search strategies.
- Chan, A. H., & Ma, R. C. (2006). Improving target detection with nonlinear magnification in visual inspection. *Int J Adv Manuf Technol, 28*, 362–369.
  - Nonlinear magnification equilibrated the performance at the center and peripheral areas of the UFOV.



Other Vision Topics For Discussion

- Eye Movement (pursuit vs. saccadic)
- Color Sensation (e.g, color deficiencies, color “blindness”)
- Night Vision (glare, age effects)
- Bottom-Up vs Top-Down Processing