# King Saud University

# College of Engineering

# IE – 341: “Human Factors Engineering”

# Spring – 2024 (2nd Sem. 1445H)

***Human Capabilities***

***Part – A. Vision (Chapter 4)***

***Part 1: Visual Capabilities – Visual Discrimination***

**Prepared by: Ahmed M. El-Sherbeeny, PhD**

# Lesson Overview: Vision

Part 1 (this part):

- Process of Seeing (Vision)
- Visual Capabilities
    - Accommodation
    - Visual Acuity
    - Convergence
    - Color Discrimination
    - Adaptation
    - Perception
- Factors Affecting Visual Discrimination
    - Luminance Level
    - Contrast
    - Exposure Time
    - Target Motion
    - Age
    - Training

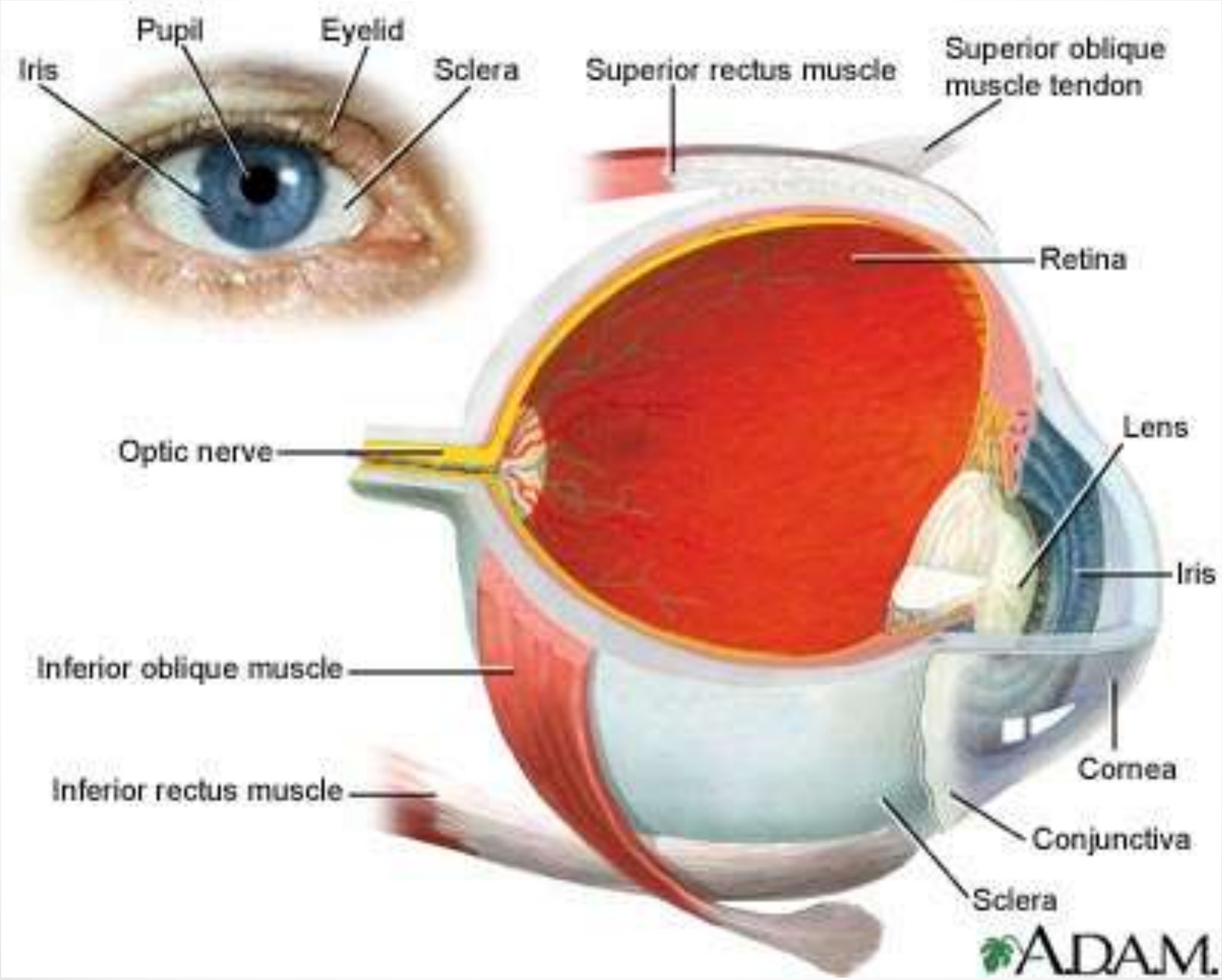
# Cont. Lesson Overview: Vision

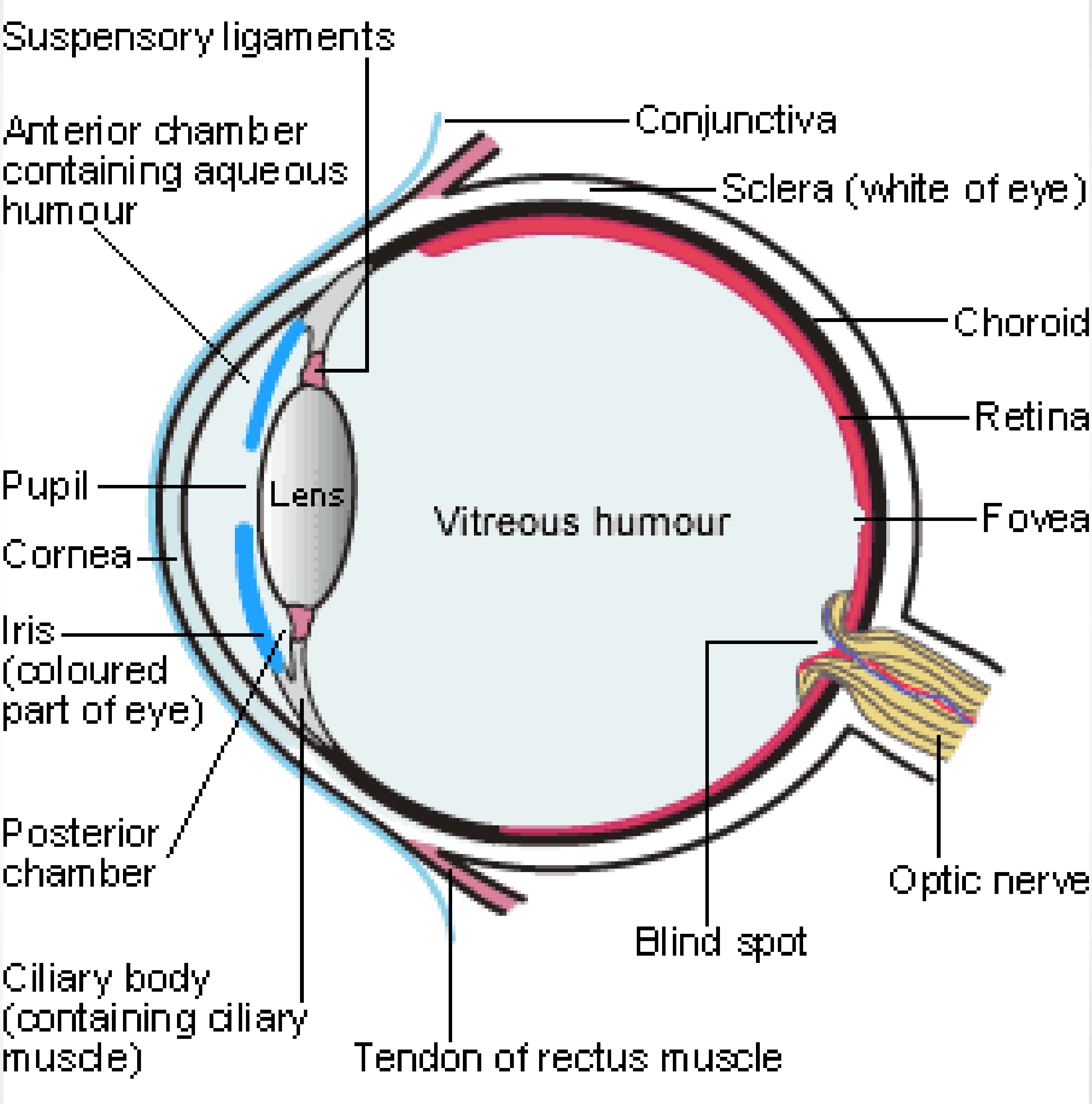
Part 2:

- Alphanumeric Displays
  - Characteristics
  - Typography
  - Typography Features
    - Hardcopy
    - Visual Display Terminals (VDT)
- Graphic Representations
- Symbols
- Codes

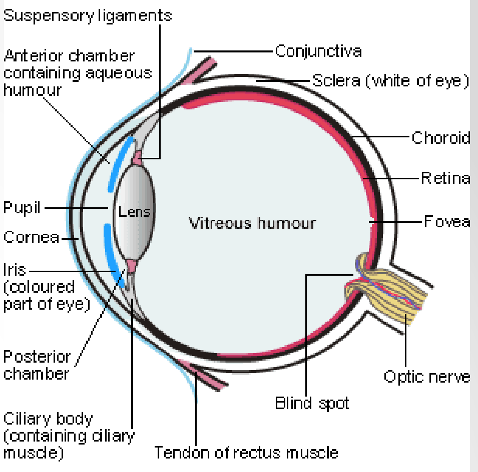
# Process of Seeing (Vision)

# Process of Seeing (Vision)



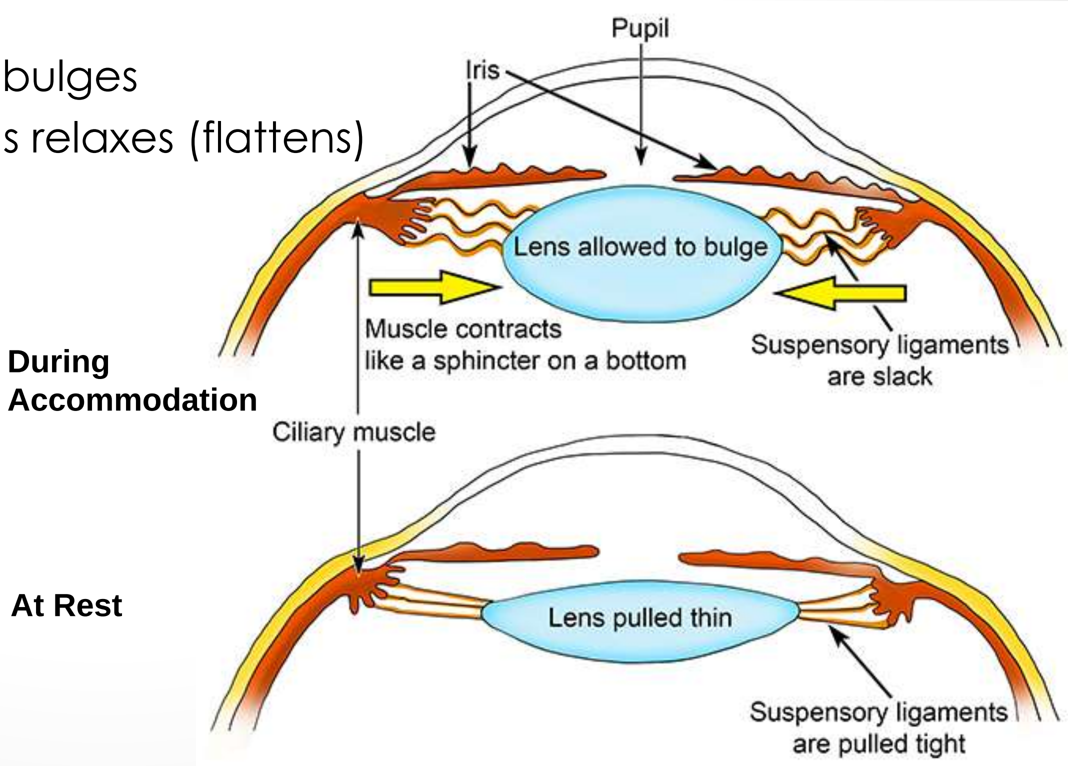

Suspensory ligaments
Anterior chamber containing aqueous humour
Conjunctiva
Sclera (white of eye)
Choroid
Retina
Fovea
Pupil
Lens
Vitreous humour
Cornea
Iris (coloured part of eye)
Posterior chamber
Blind spot
Optic nerve
Ciliary body (containing ciliary muscle)
Tendon of rectus muscle

# Process of Seeing (Vision)



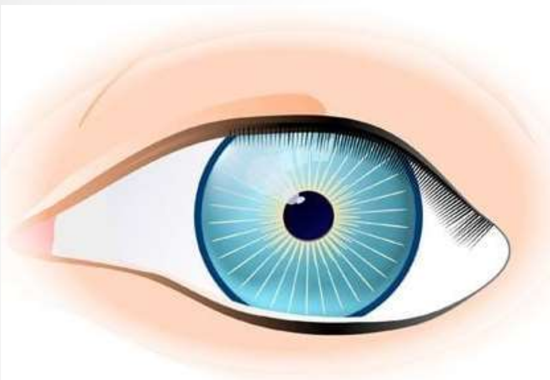

- The human **eye** works like a camera.
- Light rays reflected from object
  - enter the transparent **cornea**
  - pass through:
    - clear fluid (**aqueous humor**) that fills the space between the cornea
    - and the **pupil** (a circular variable aperture)
    - and adjustable **lens** behind the cornea (light rays are transmitted and focused)
      - close objects: lens bulges
      - distant objects: lens relaxes (flattens)

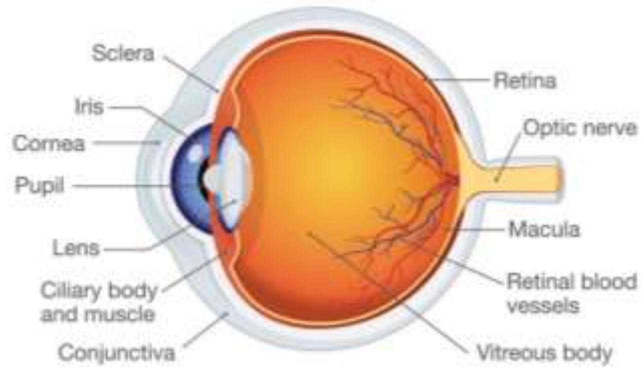

- **The eye adjusts the amount of light entering it like the aperture of a camera**

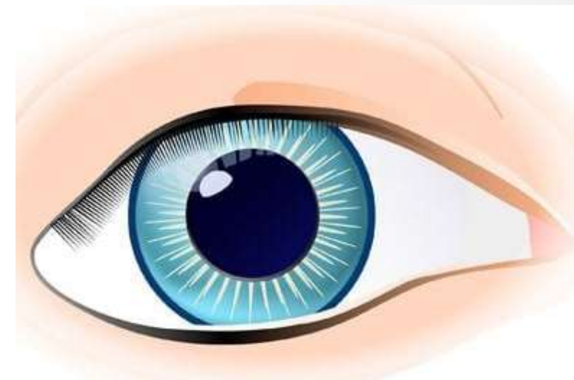


# Cont. Process of Seeing (Vision)

- Muscles of the **iris** change size of pupil:
  - larger in the dark (about 8 mm diameter; dilation),
  - smaller in bright conditions (2 mm; constriction)

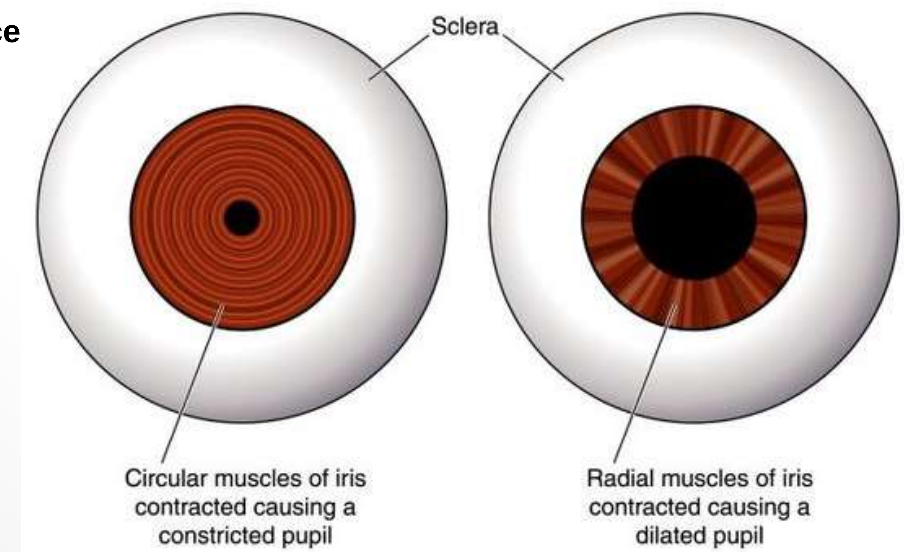




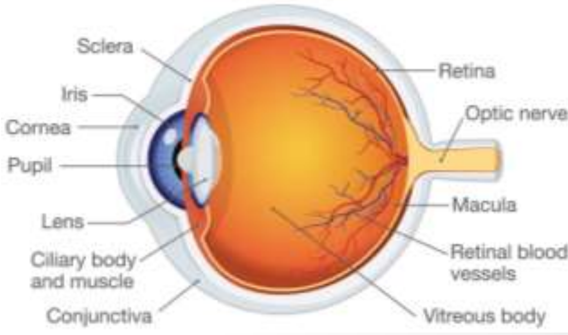
**In a Brightly Lit Place**

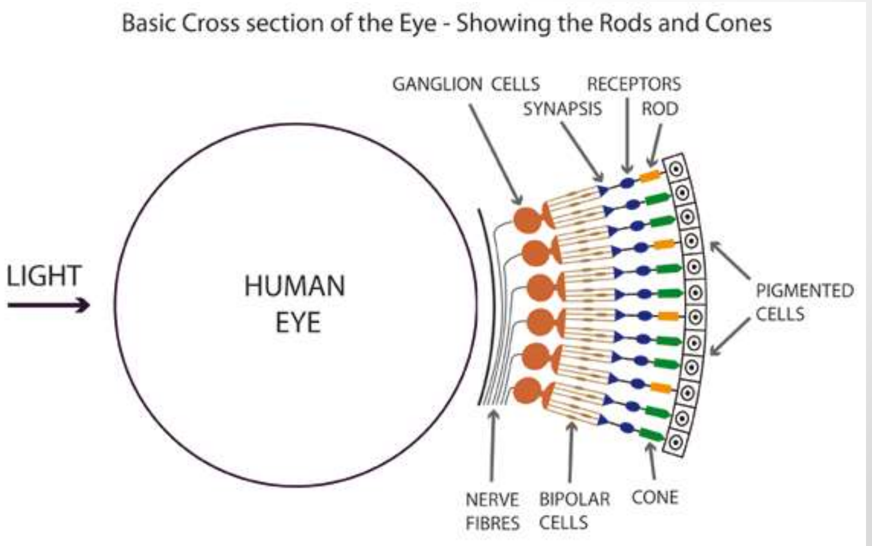
**In the Dark**

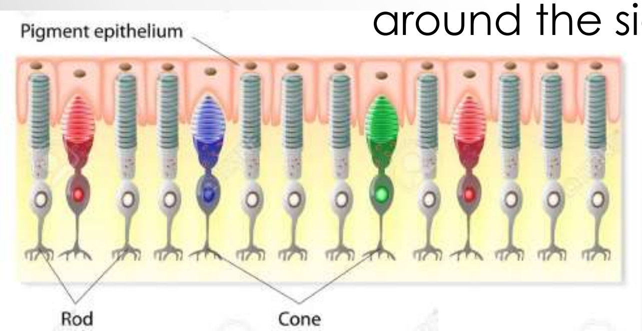


# Cont. Process of Seeing (Vision)

- Light rays transmitted through pupil to lens
  - refracted by adjustable lens
  - then transverse the **vitreous humor** (a clear jellylike fluid filling the eyeball, behind the lens)
- In normal or corrected vision persons
  - light rays are focused exactly on the sensitive **retina**
- The retina consists of
  - about 6 to 7 million **cones**
    - receive daytime, color vision
    - concentrated near center of retina (fovea)
  - and about 130 million **rods**
    - rods important in dim light, night
    - distributed in the outer retina, around the sides of the eyeball



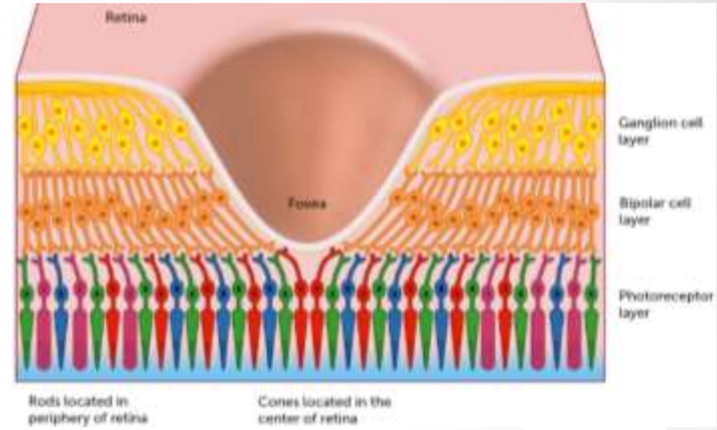




Structure of the Retina

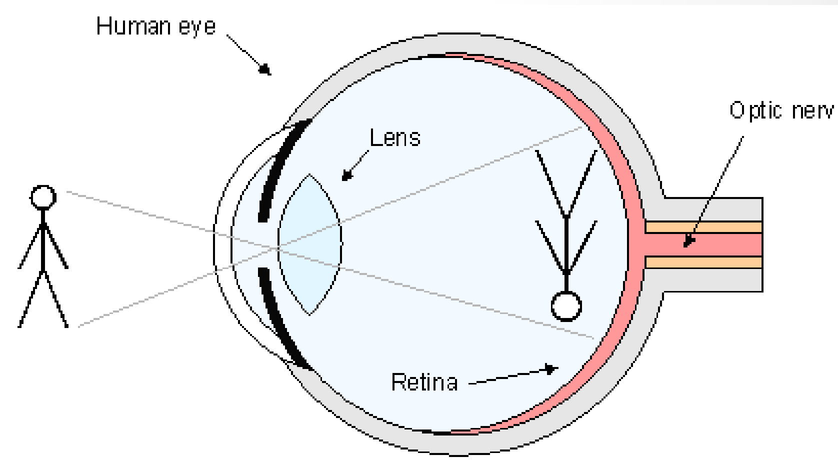
# Cont. Process of Seeing (Vision)

- Greatest sensitivity is in the **fovea**
  - the "dead center" of the retina
  - for clear vision, the eye must be directed so that the image of the object is focused on the fovea
  - see more details about the fovea, rods, and cones on the following slide



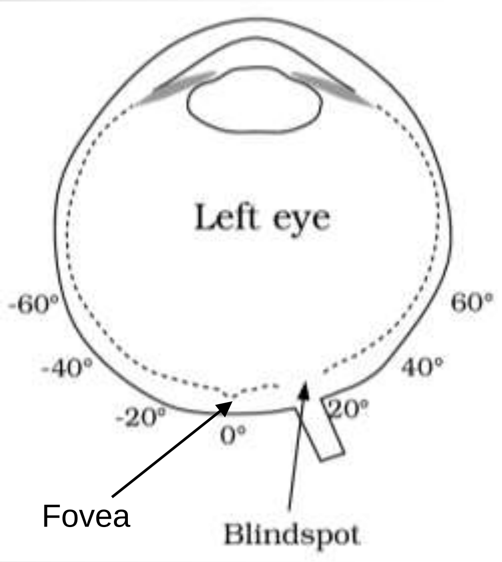

- The image on the retina is *inverted*
- Cones and rods connected to **optic nerve**
  - transmits neural impulses to the **brain** which integrates impulses, giving visual impression of object
  - process also corrects inverted image on the retina
  - more information about vision and human eye:

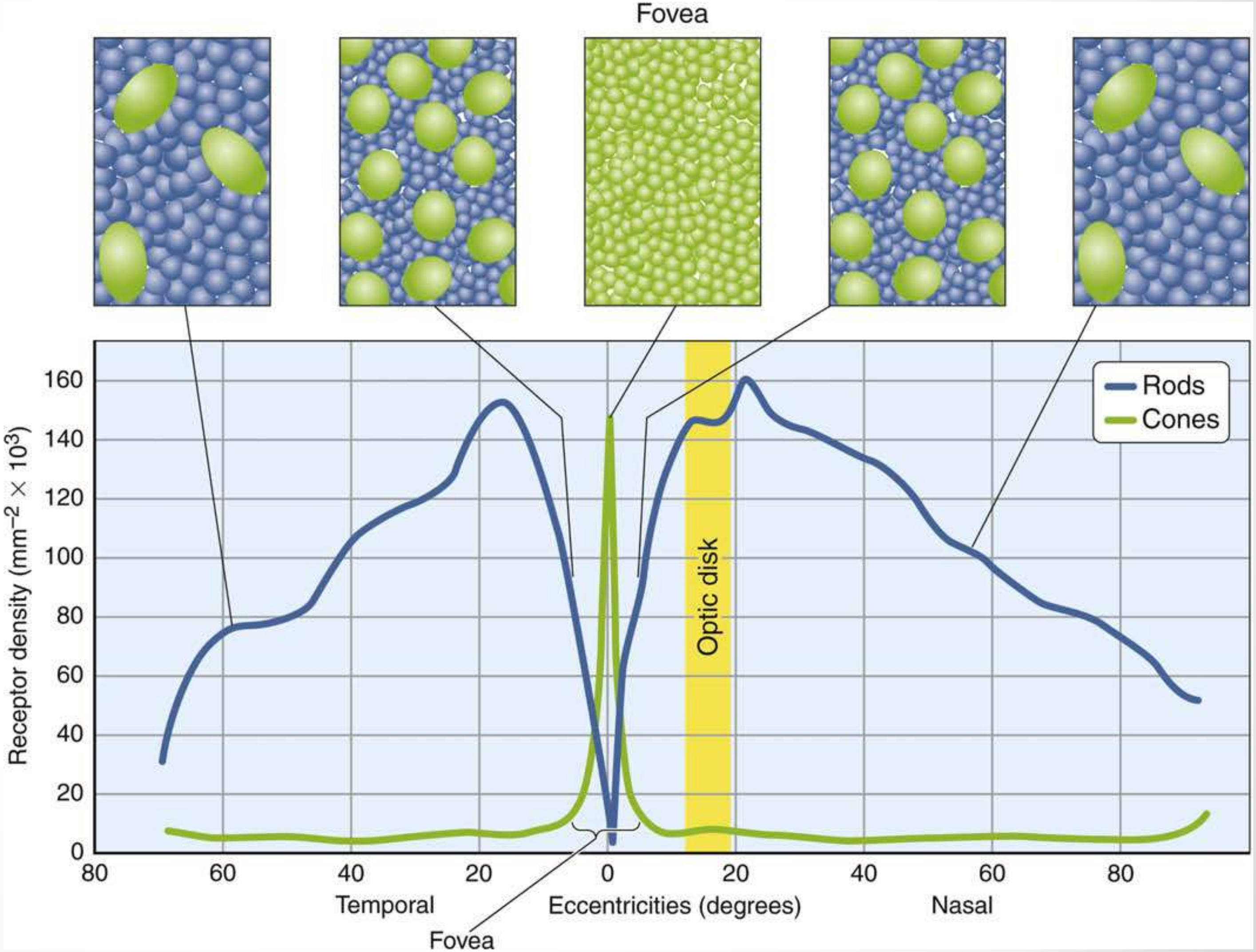
https://youtu.be/nbwPPcwknPU




Images are inverted on their way to the retina at the back of the eye

# Cont. Process of Seeing (Vision)




- **Distribution of photoreceptors in the eye relative to the fovea**
- **Rods outnumber cones by a ratio of ~20:1.**
- **However, in the fovea, the cone density is the highest and is correlated with visual acuity**

# Visual Capabilities

# Visual Capabilities

- Visual Capabilities
  - visual capabilities exist as a result of the visual system
  - these capabilities have important implications for the design of visual displays:

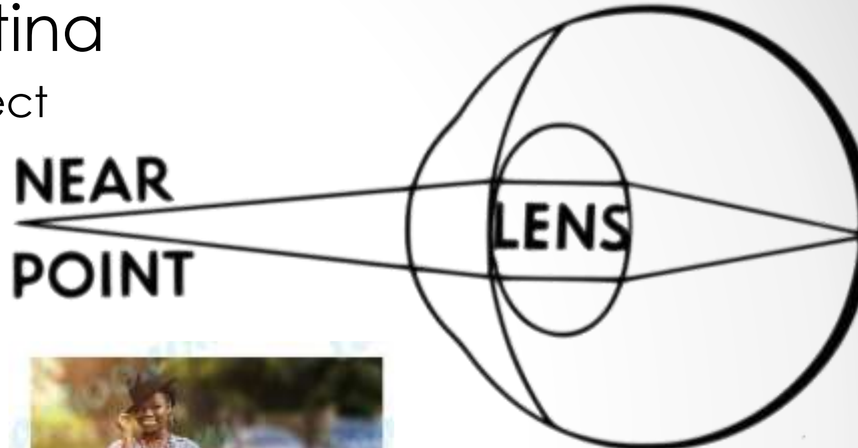
1. Accommodation
2. Visual Acuity
3. Convergence
4. Color Discrimination
5. Adaptation
6. Perception

# Visual Capabilities: 1. Accommodation

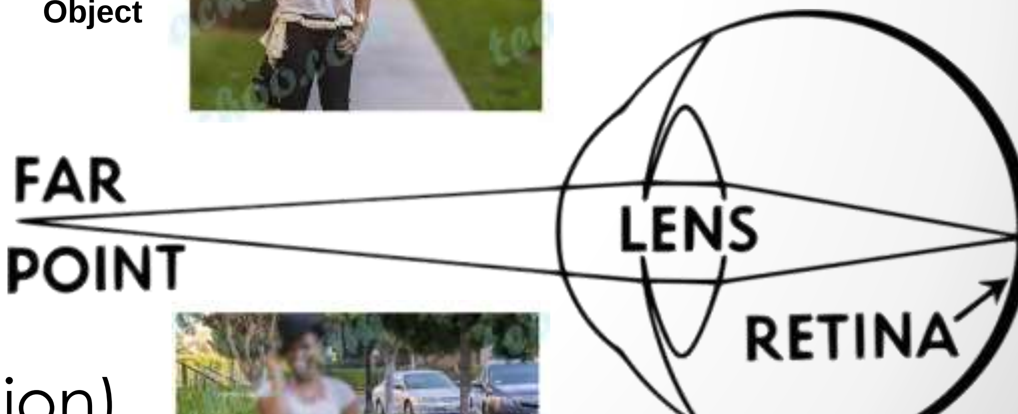
- Accommodation (aka focus): ability of the lens to focus light rays on the retina
  - this allows us to see details of an object

- Near point: closest distance possible for focus (i.e. any closer will be blurry)

- Far point: farthest distance for focus (usu. = ∞ for normal vision)



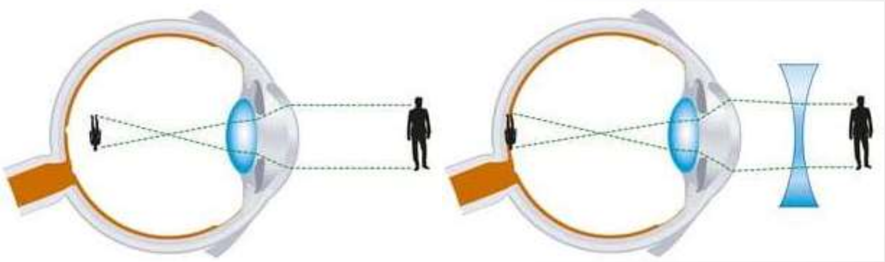

**Nearby Object**



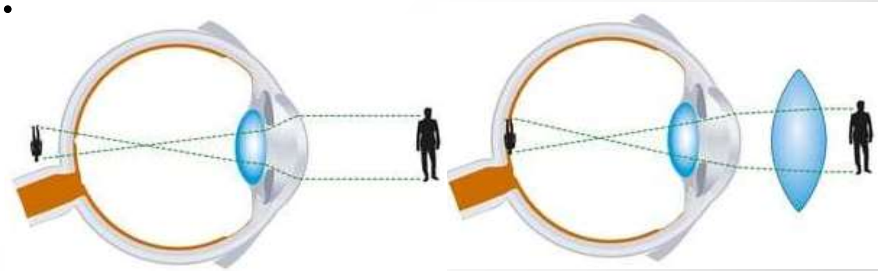

**Object at infinity**

# Visual Capabilities: 1. Accommodation

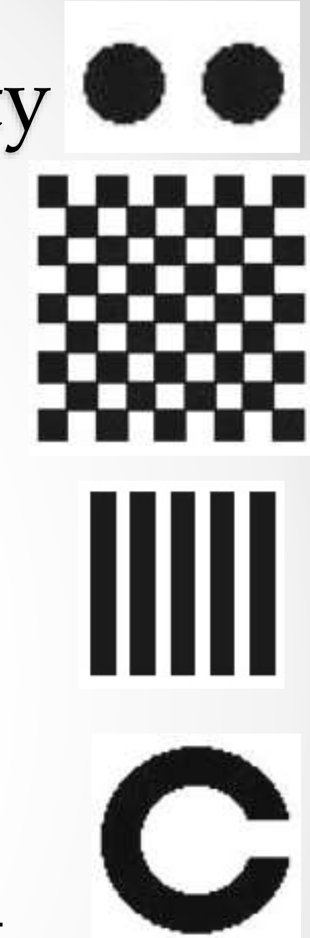
- Diopter: measure of focus (for eye, camera)
  - Diopter [D] = 1 / target distance [*m*]
  - e.g. 1D = 1 m; 2D = 0.5 m; 3D = 0.33 m; 0D = ∞
  - More powerful lens ⇒ higher diopters
- Dark focus: eye accommodation in dark
  - = 1D (for normal vision)
- Nearsightedness (myopia):
  - far point = too close
  - i.e. lens remains bulged with far objects



- Farsightedness (hyperopia):
  - near point = too far
  - i.e. can't see close objects;
  - lens: flat for close objects
  - both conditions can be corrected using corrective lenses (as shown)



# Visual Capabilities: 2. Visual Acuity



- Visual Acuity:
  - ability of eye to discriminate fine details
  - depends largely on accommodation
- Minimum separable acuity:
  - most common measure of visual acuity (see figure 4-2)
  - Def$^{n}$: smallest feature or space between the parts of a target (e.g. letter '**E**' below) that eye can detect
- Visual angle (< ~10°):
  - $H$ = stimulus height
  - $D$ = dist. from eye
  - $H$,$D$: same units (e.g. *ft.*, *mm*)
  - Normal VA = 1.0 *min*.
  - Note, 1° = 60 *min*.

$$\text{VA (minutes)} = \frac{3438 \cdot H}{D}$$

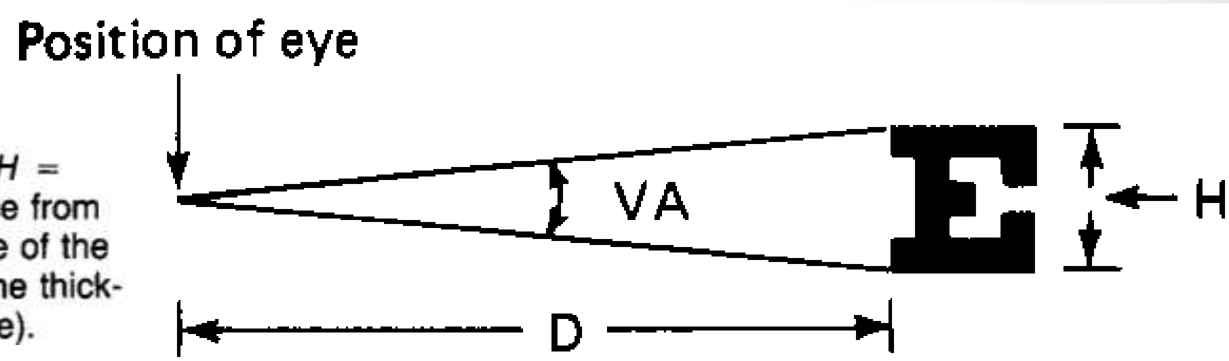



**FIGURE 4-3**
Illustration of the concept of visual angle; $H$ = height of visual stimulus, and $D$ = distance from the eye. In this illustration, the visual angle of the specific elements of $E$ could be derived (the thickness of the elements would be the $H$ value).

# Visual Capabilities: 2. Visual Acuity

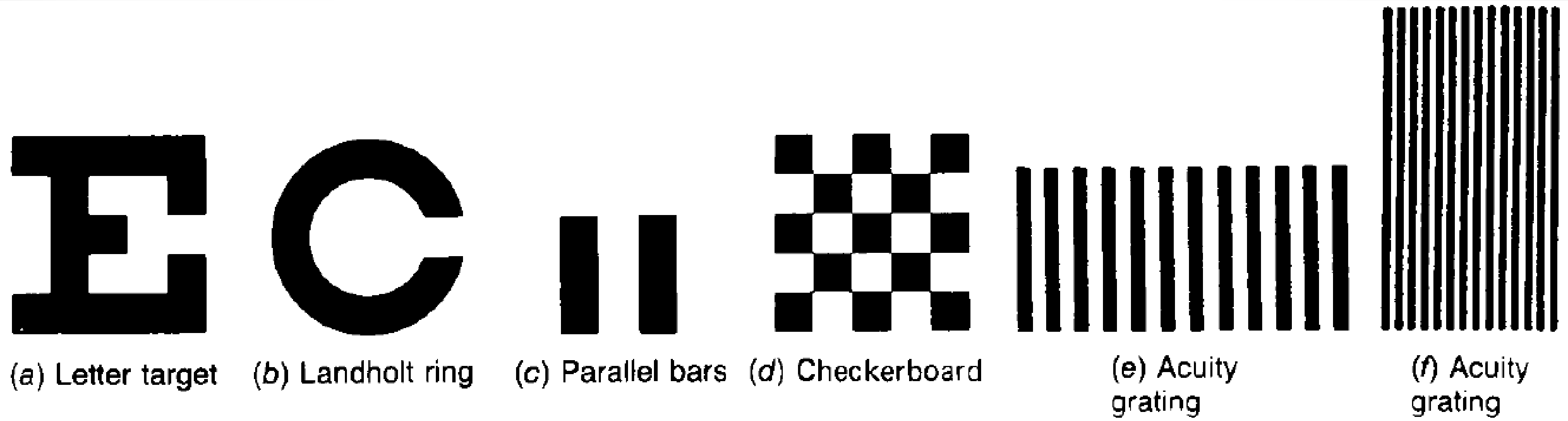



**FIGURE 4-2**
Illustrations of various types of targets used in visual acuity tests and experiments. The features to be differentiated in targets a, *b*, c, and *d* are all the same size and would, therefore, subtend the same visual angle at the eye. With target a the subject is to identify each letter; with c, e, and *f* the subject is to identify the orientation (such as vertical or horizontal); and with *b* the subject is to identify any of four orientations. With target *d* the subject is to identify one checkerboard target from three others with smaller squares.

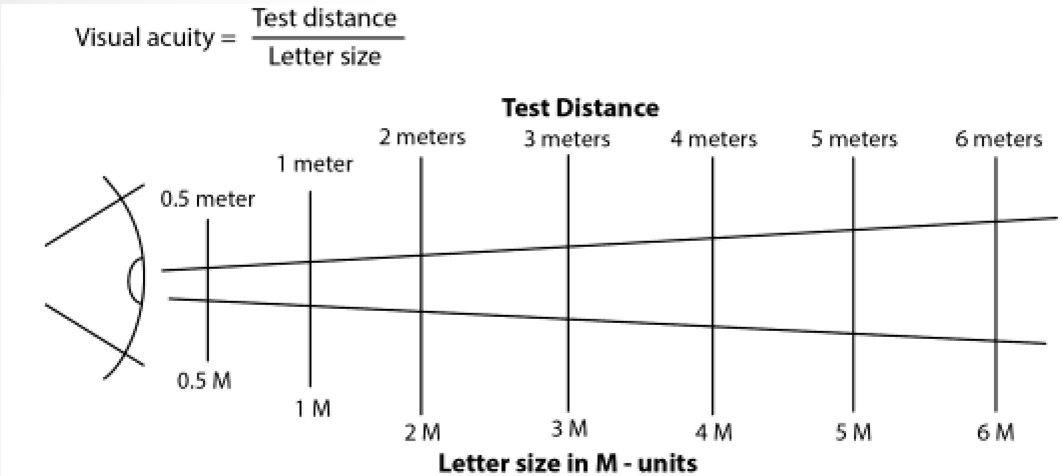
# Visual Capabilities: 2. Visual Acuity

- Cont. Visual angle (VA):
  - *reciprocal* of VA (for smallest detail that eye can see) is used as measure for visual acuity
  - i.e. Visual **Acuity** = [1 / **VA**]
    - e.g. VA = 1.5 *min*. ⇒ acuity = 0.67
    - e.g. VA = 0.8 *min*. ⇒ acuity = 1.25
    - Note, as acuity ↑ ⇒ detail that can be resolved is ↓
  - Clinical testing: *D* = 20 ft (i.e. 6 m) from chart (next 2 slides)
    - e.g. ***Snellen* acuity**: 20/30 (6/9) ⇒
      person *barely* reads @ 20 *ft*.
      what normal (20/20) person reads @ 30 *ft*.
    - e.g. 20/15 (6/4.5) ⇒
      person reads @ 20 *ft*
      what normal person must bring to 15 *ft*. to read
      (far- or near-sightedness?*)
    - e.g. 20/20 (6/6) ⇒ resolving 1 *min*. arc of detail @ 20 *ft*. (normal vision)
    - e.g. Given VA = 1.75 *min*. ⇒ Snellen acuity = 1 / VA = 20 / x
      i.e. x = (20) (1.75) = 35 ⇒ Snellen acuity = 20 / 35

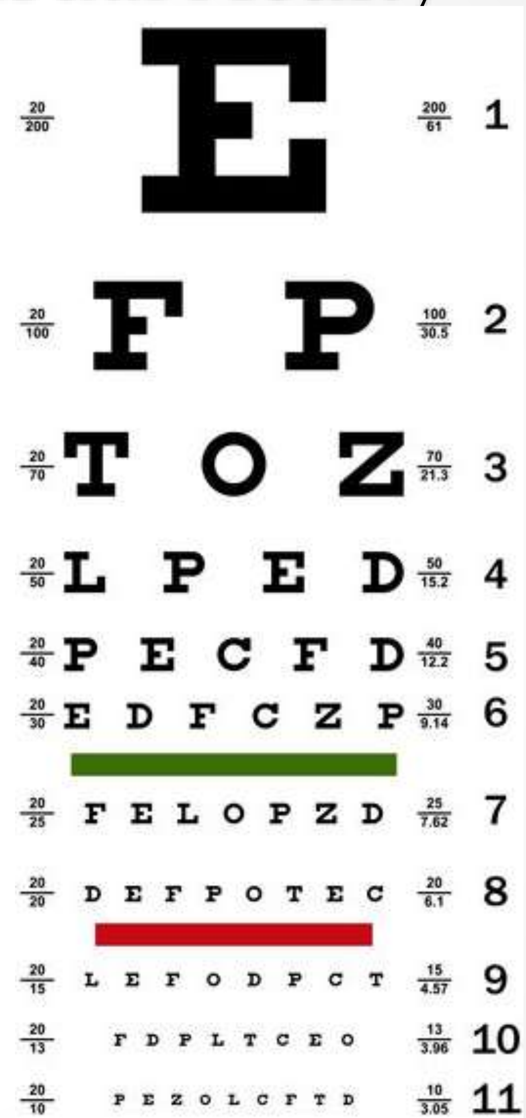

$$\text{Visual acuity} = \frac{\text{Test distance}}{\text{Letter size}}$$

**Herman Snellen**
**Dutch**
**Ophthalmologist**
**1834 - 1908**

# Visual Capabilities: 2. Visual Acuity

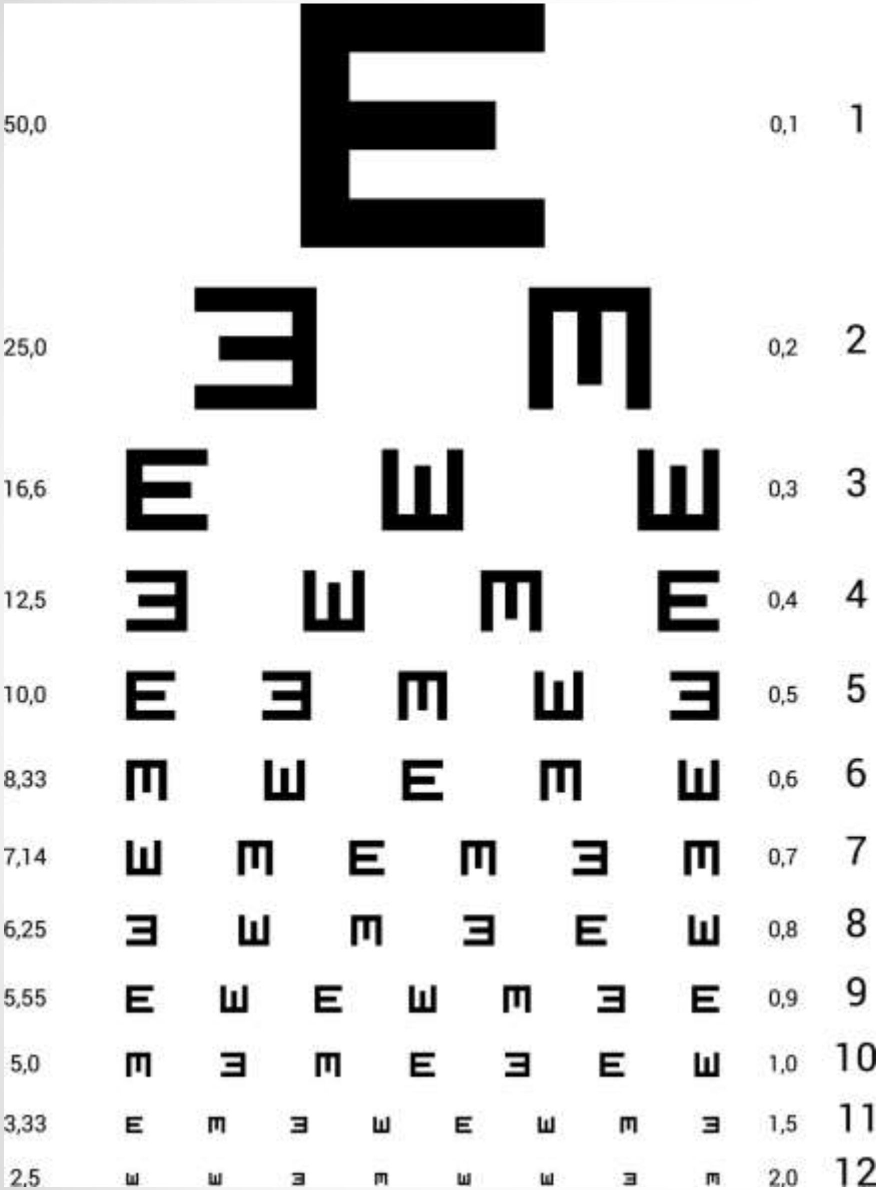



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Snellen fraction | 0.5/0.5 | 1/1 | 2/2 | 3/3 | 4/4 | 5/5 | 6/6 |
| Decimal equivalent | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Snellen equivalent | 20/20 | 20/20 | 20/20 | 20/20 | 20/20 | 20/20 | 20/20 |

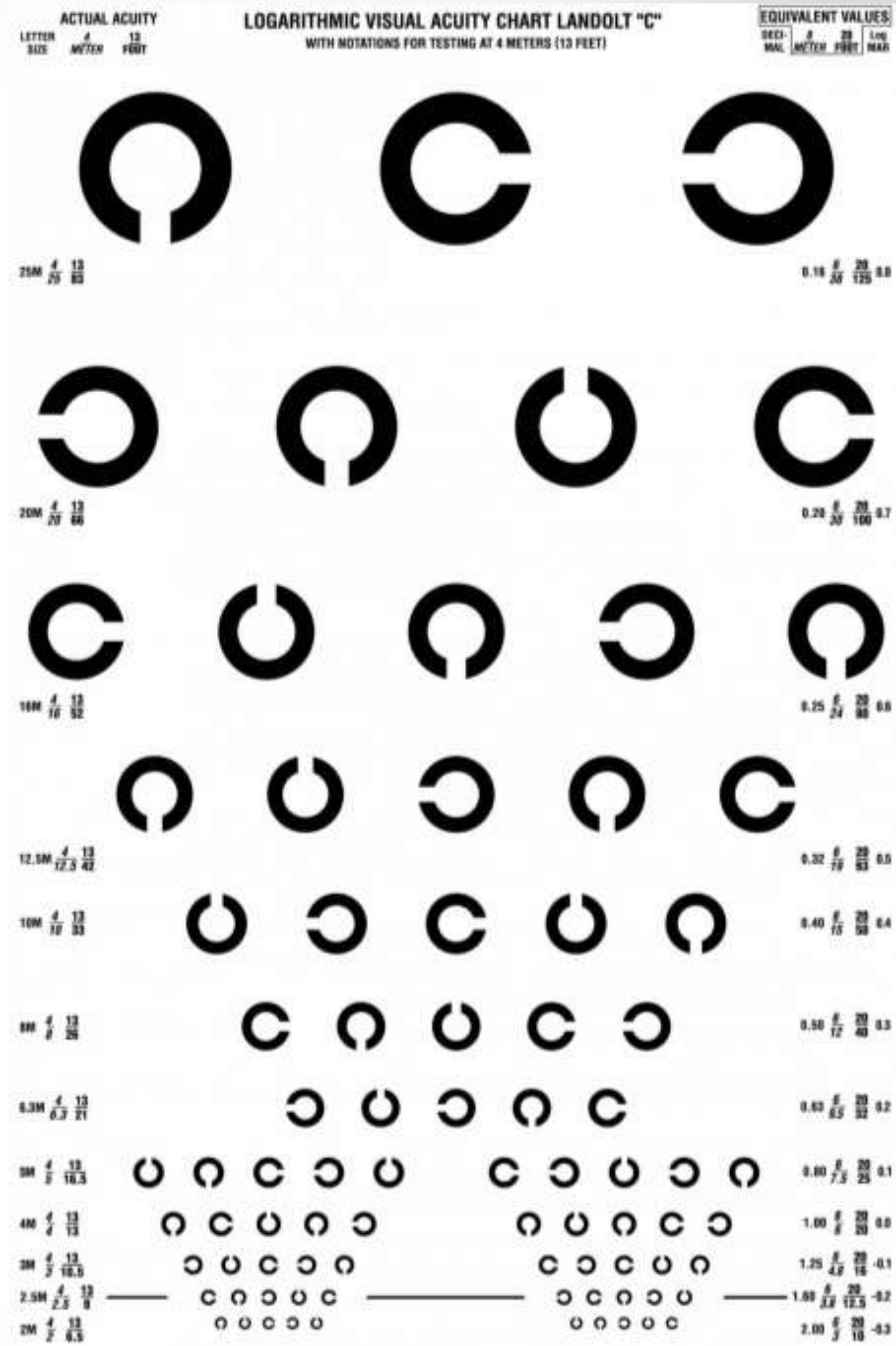



**Sample Snellen "Letter" Chart**

- Watch more about visual acuity: https://youtu.be/ovuyPrffiqg



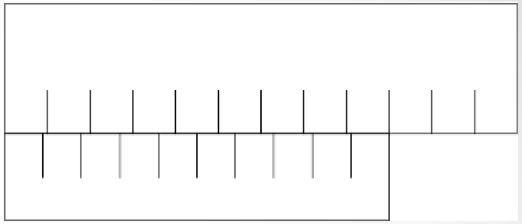

Snellen Letter 'E' Chart



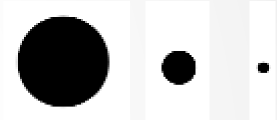

Snellen Landolt 'C' Chart

# Visual Capabilities: 2. Visual Acuity

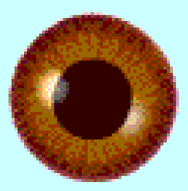
- Other types of visual acuity measures:
  - Vernier acuity: smallest lateral displacement (i.e. offset) of one line that can be detected from another line



  - Minimum perceptible acuity: ability to detect a spot from its background; test: find the smallest target, such as a dot, that the eye can detect



  - Stereoscopic acuity: ability to differentiate different images received by the retinas of the two eyes of a single object with depth (i.e. converting 2D → 3D).
    - Most difference is when the object is near the eyes.
    - Try the following game to see if you have **Stereo vision**
      - Center your nose over the brown eye and focus on the eye
      - Put a free thumb in front of your nose
      - Continue to focus on the eye
      - If both eyes are on, you see two thumbs framing one eye
      - Now, switch your focus to your thumb
      - You should see two eyes framing one thumb
      - **Source:** http://www.vision3d.com/frame.html



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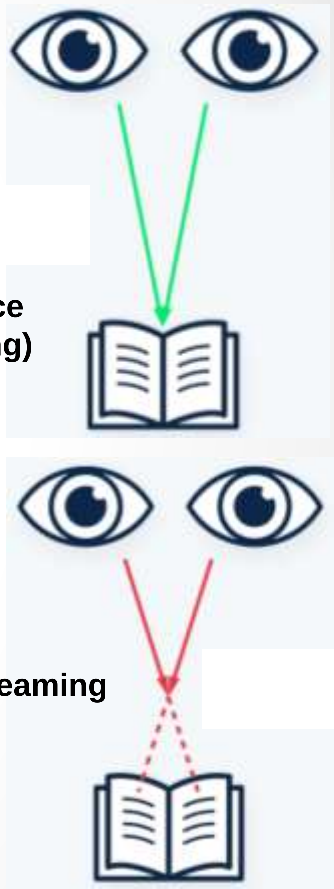
# Visual Capabilities: 3. Convergence

- Two eyes must converge on an object ⇒
  - images of the object on the two retinas are in corresponding positions to get the impression of a single object (the images are **fused**) aka “binocular vision”

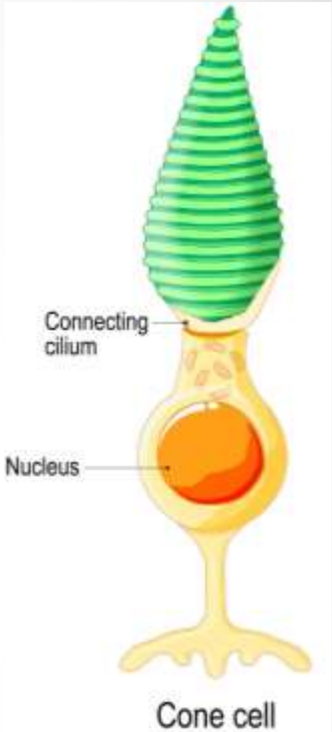


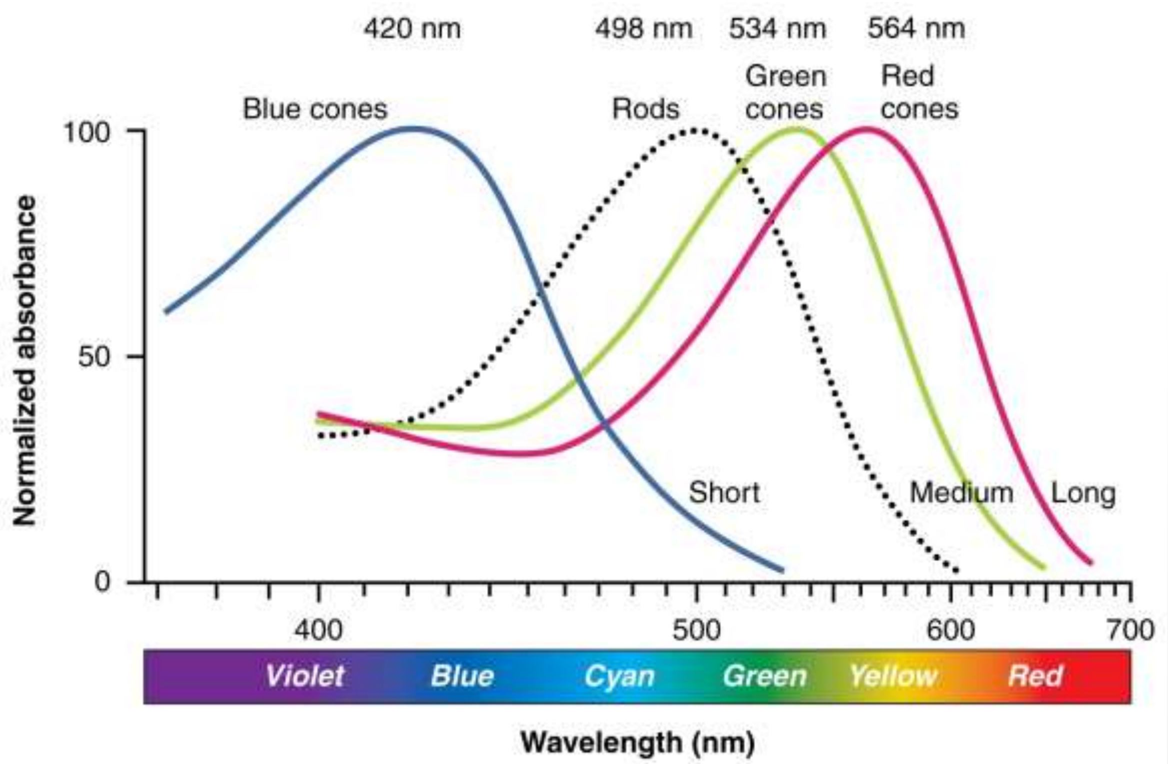

- Convergence is controlled by muscles surrounding the eyeball.
  - some individuals converge too much
  - others tend not to converge enough
  - these two conditions are called **phorias**
  - this cause double images which are visually uncomfortable and may cause muscular stresses and strains

- Orthoptics:
  - aims to strengthen eye muscles to correct common eye problems (e.g. convergence insufficiency)

# Visual Capabilities: 4. Color Discrimination

- Cones
  - located in fovea (center of retina)
  - basis for color discrimination
    (i.e. responsible for color perception)
  - 3 types of cones, each sensitive to light wavelengths corresponding to primary colors (as shown below): **Red**, **Green**, **Blue** (reaching up to 10 million hues!)
  - In dark: cones not activated ⇒ no color is visible



# Visual Capabilities: 4. Color Discrimination

- Color vision:
  - **Tri**chromats: people distinguishing different colors
  - Color vision deficiency (CVD); aka color blindness:
    - **Mono**chromats: non-color vision (v. v. rare!)
    - **Di**chromats: deficiency in red or green cones (aka anomalous trichromats)
      - inherited or acquired (e.g. accident or disease)
      - existent in ~ 8% males and 0.5% females
      - poorer performance in practical tasks vs. trichromats (e.g. traffic signals, color-coded components)

  - Click here to test your color vision strength, and learn more about CVD

The way a mammalian trichromat (three cones) would see a scene

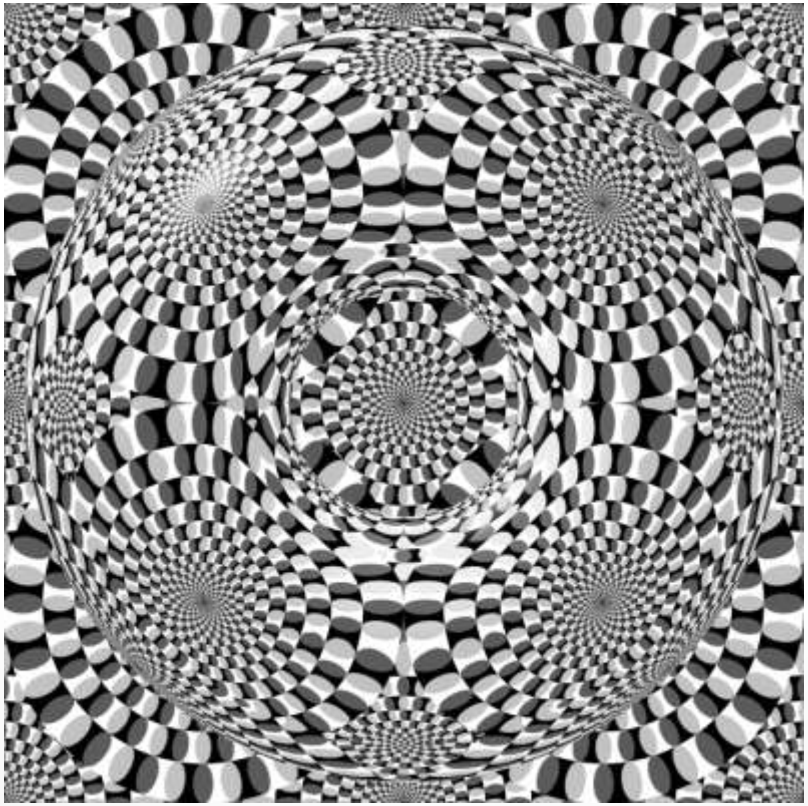
The way a mammalian dichromat (two cones) would see the same scene

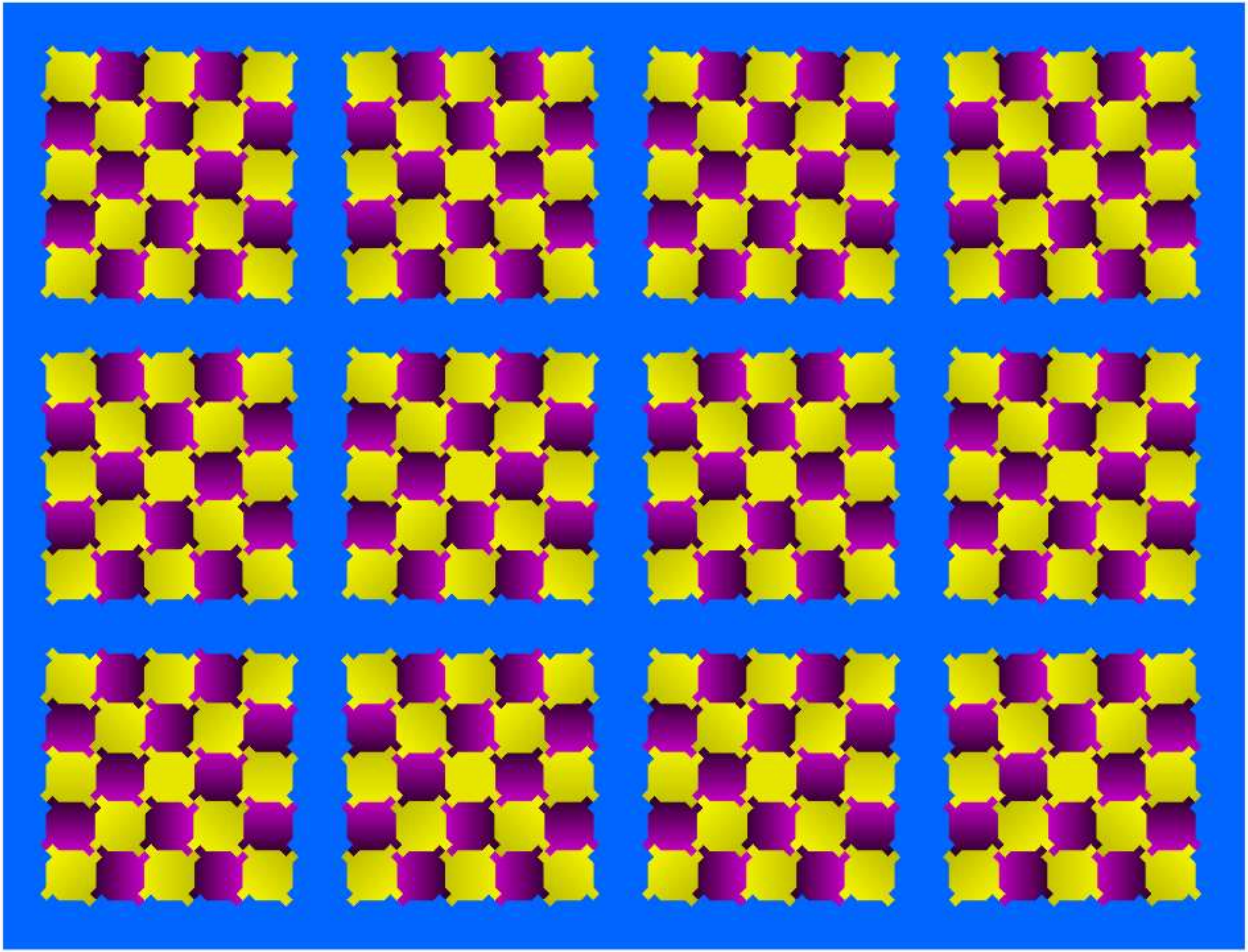
# Visual Capabilities: 4. Color Discrimination

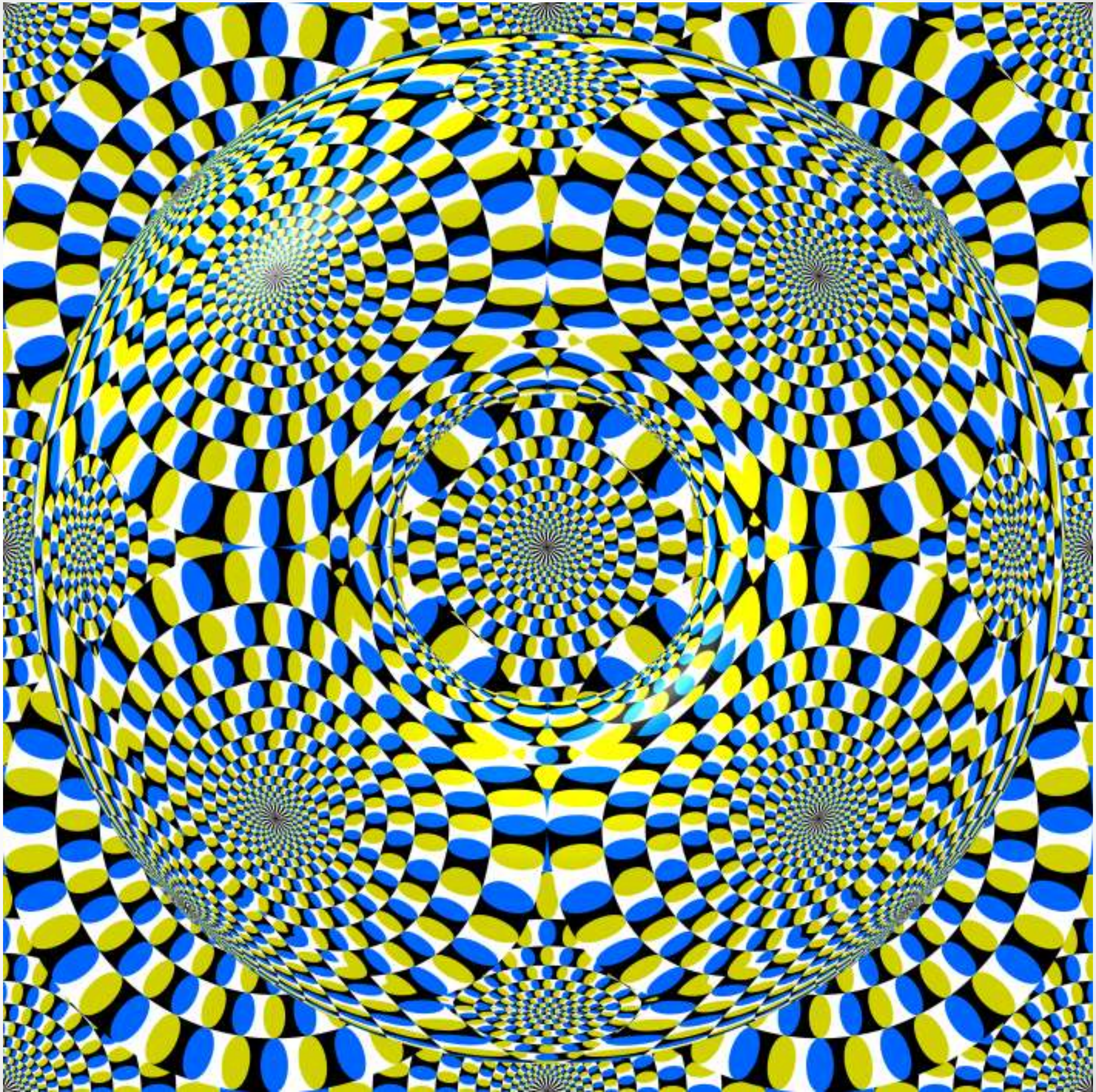
- Cont. Color vision:

  Just for fun, consider the next 2 slides:

  - "rotating turtles"
  - "doughnut of rotating snakes"
  - are these "optical illusions" static or dynamic?
  - and how/why does this work even with grayscale images (as shown below)?

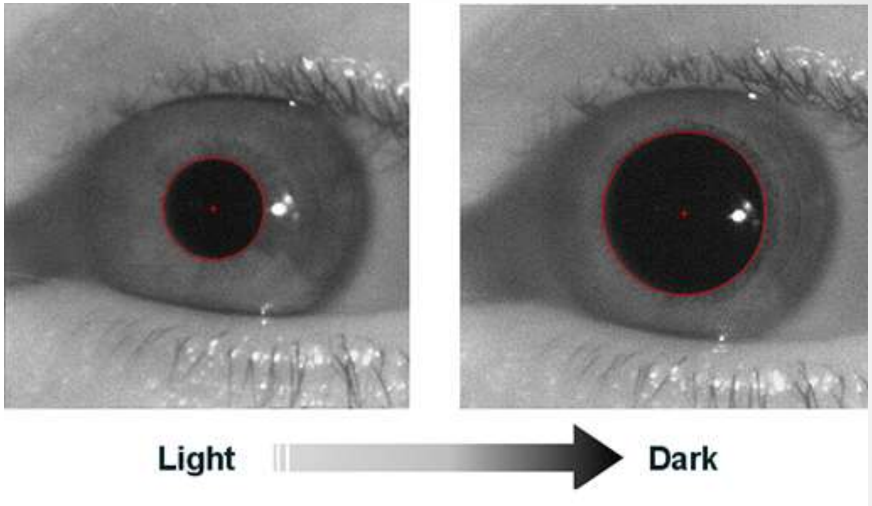




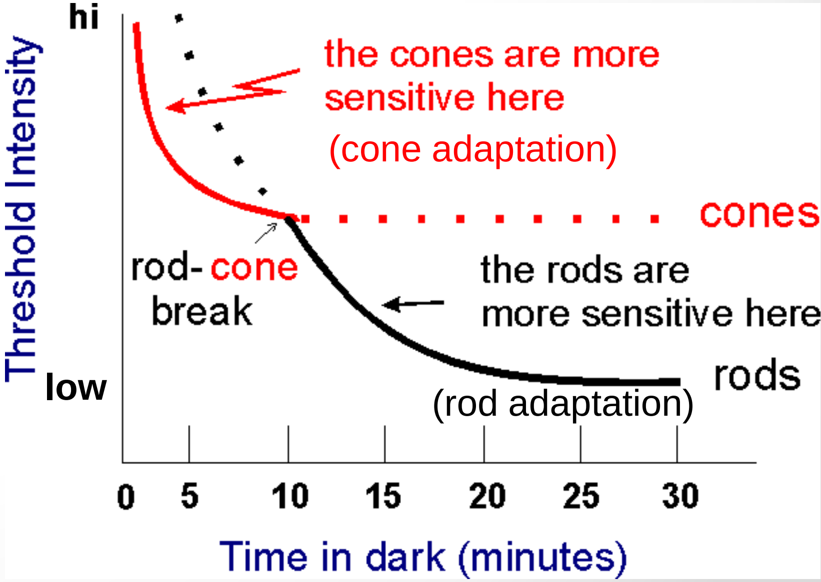


# Visual Capabilities: 5. Adaptation

- Adaptation: changes in sensitivity to light



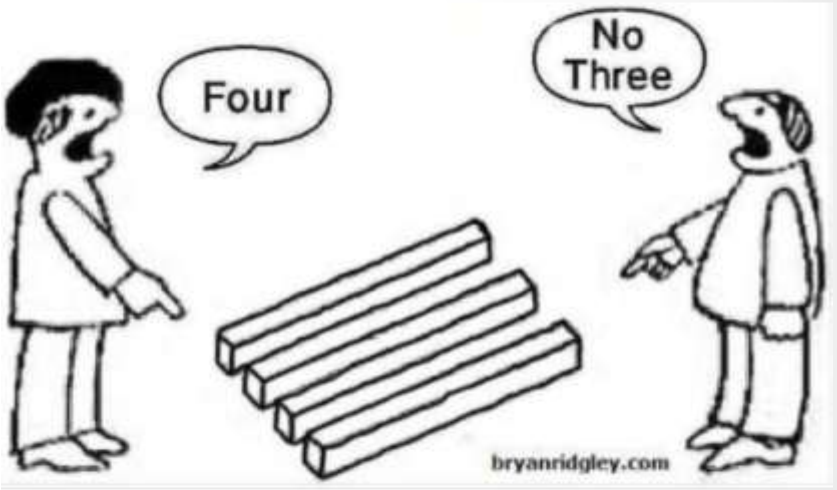

- Entering dark room:
  - this is *dark* adaptation
  - pupil increases in size
    ⇒ more light enters eyes
  - sensitivity of eye ↑ gradually
  - this occurs in two phases (as shown)
  - requires up to 30-35 min.
  - cones lose most sensitivity
    in dark (mostly rods)

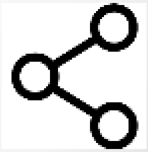

- Exiting dark room to light
  - this is *light* adaptation
  - pupil contracts (aka constriction) to limit light entering eyes
  - adaptation requires ~1 min. (why faster?)
  - more light ⇒ cones are activated

# Visual Capabilities: 6. Perception

- When viewing visual displays
  - viewing/seeing features on visual displays (e.g. on traffic sign; scale) may not be enough to make appropriate decisions
  - meaning of displayed information must also be understood




- Perception*: interpreting sensed information
- The interpretation process
  - sometimes straightforward
  - most displays: depends on previous learning (experience or training); e.g. with road signs, color codes; abbreviations

- Visual displays design must meet 2 objectives:
  - display must be seen clearly (and without distortion, as shown above)
  - design must help viewer to correctly perceive/understand meaning of display

# Factors Affecting Visual Discrimination

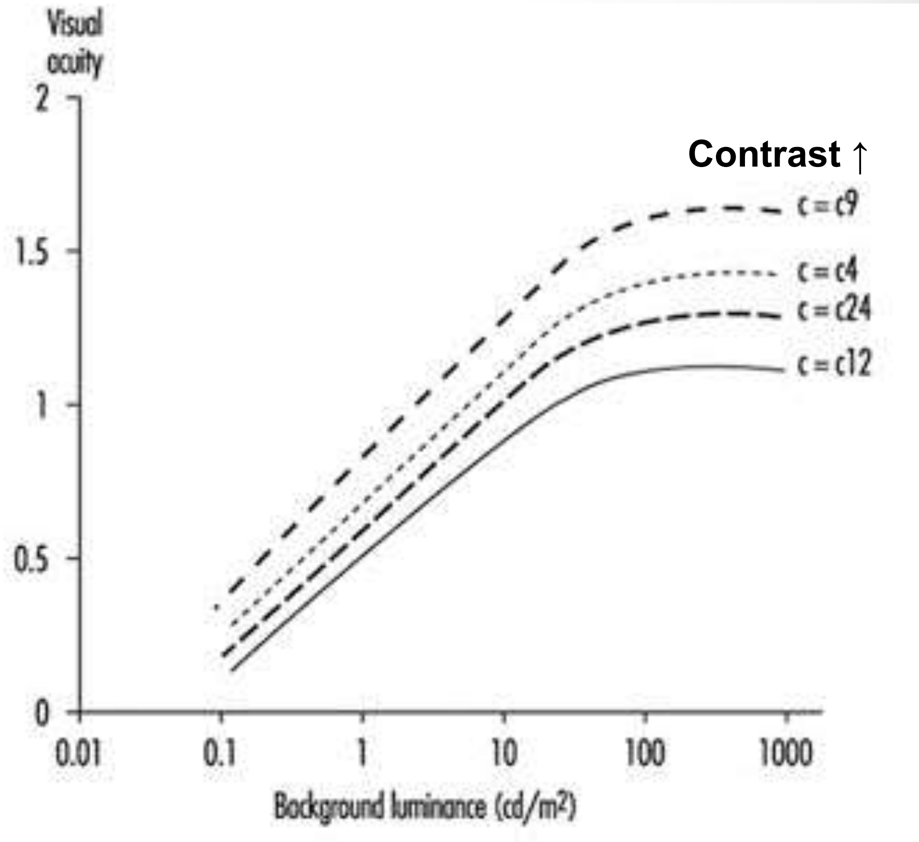
# Factors Affecting Visual Discrimination

1. Luminance Level
2. Contrast
3. Exposure Time
4. Target Motion
5. Age
6. Training

# Factors Affecting Visual Discrimination

- Visual discrimination depends mostly on visual acuity
- Some factors external to the individual that affect visual discrimination:

1. Luminance Level:
   - as light or background light levels ↑
   - ⇒ cones are activated
   - ⇒ visual acuity ↑
   - then levels off (as shown here)
   - best efficiency: large light background and dark object
   - this is required for complex, intricate tasks

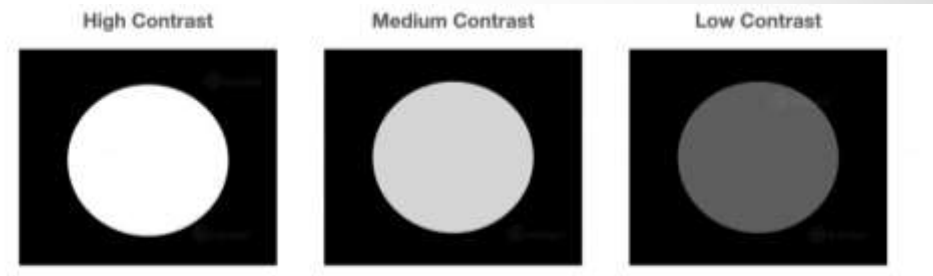



Relationship between acuity of a dark object perceived on a background receiving increasing illumination for four contrast values (Adrian, 1993)

# Factors Affecting Visual Discrimination

## 2. Contrast (AKA brightness contrast):

- refers to difference in luminance of viewed objects
- most important consideration: difference in luminance between object (target) and background
- **threshold contrast**: contrast level at which you can barely see the target
- when contrast is low, target must be larger to be equally discriminable to target with greater contrast (see example below)




Low Contrast

High Contrast

Low Contrast

# Factors Affecting Visual Discrimination

2. Cont. Contrast:

- Measure # 1: ***Michelson* Contrast**: measures deviation above and below a mean luminance
  - $L_{MAX}$: max. luminance in pattern
  - $L_{min}$: min. luminance in pattern
  - Note, MC varies bet. 0 and 1

$$MC = \frac{L_{MAX} - L_{min}}{L_{MAX} + L_{min}}$$

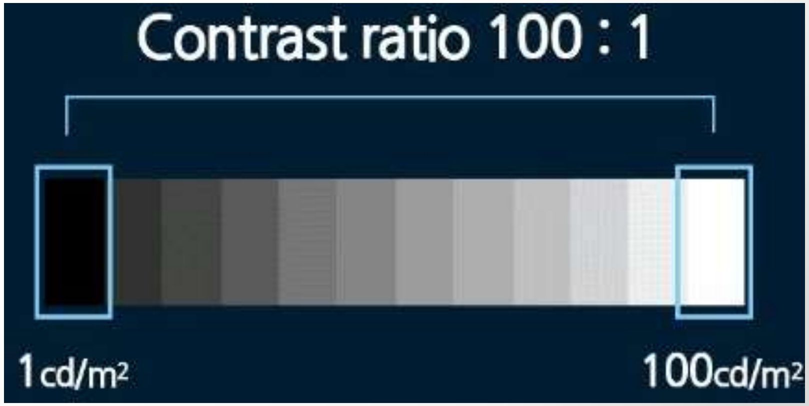
- Measure # 2: **Luminous Contrast**:

$$LC = \frac{L_{MAX} - L_{min}}{L_{MAX}}$$

- Measure # 3: **Contrast** (or luminance) **Ratio**:
  - it's recommended to have CR:
  - 3:1 for target: adjacent surrounding
  - 10:1 for target: remote darker area
  - 1:10 for target: remote lighter area

$$CR = \frac{L_{MAX}}{L_{min}}$$

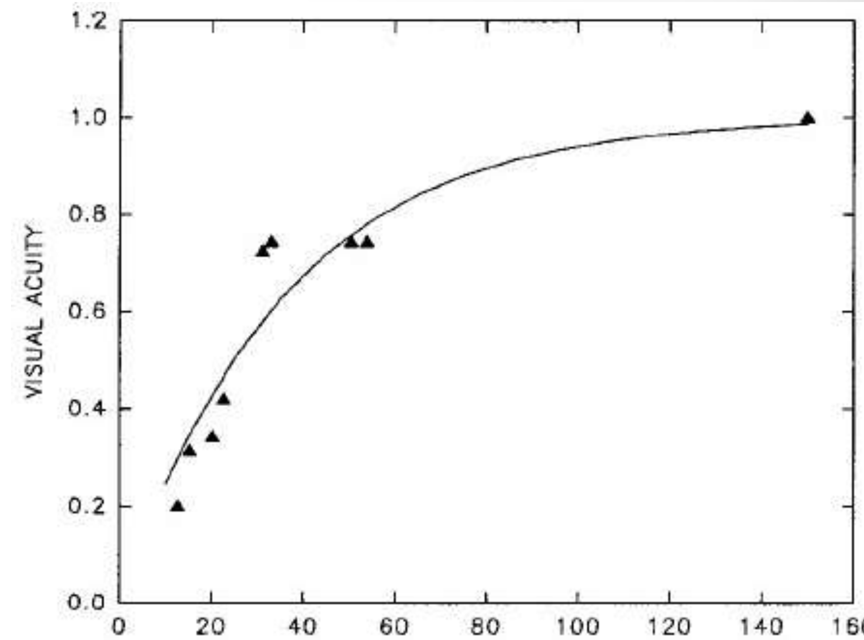
- Note, Can you show the mathematical relation between each of these 3 formulae?



# Factors Affecting Visual Discrimination

## 3. Exposure Time:

- Under high illumination:
  - As exposure time ↑ ⇒ Acuity ↑ for first 100-200 ms.
  - After that acuity levels off




Exposure Time [*ms*]

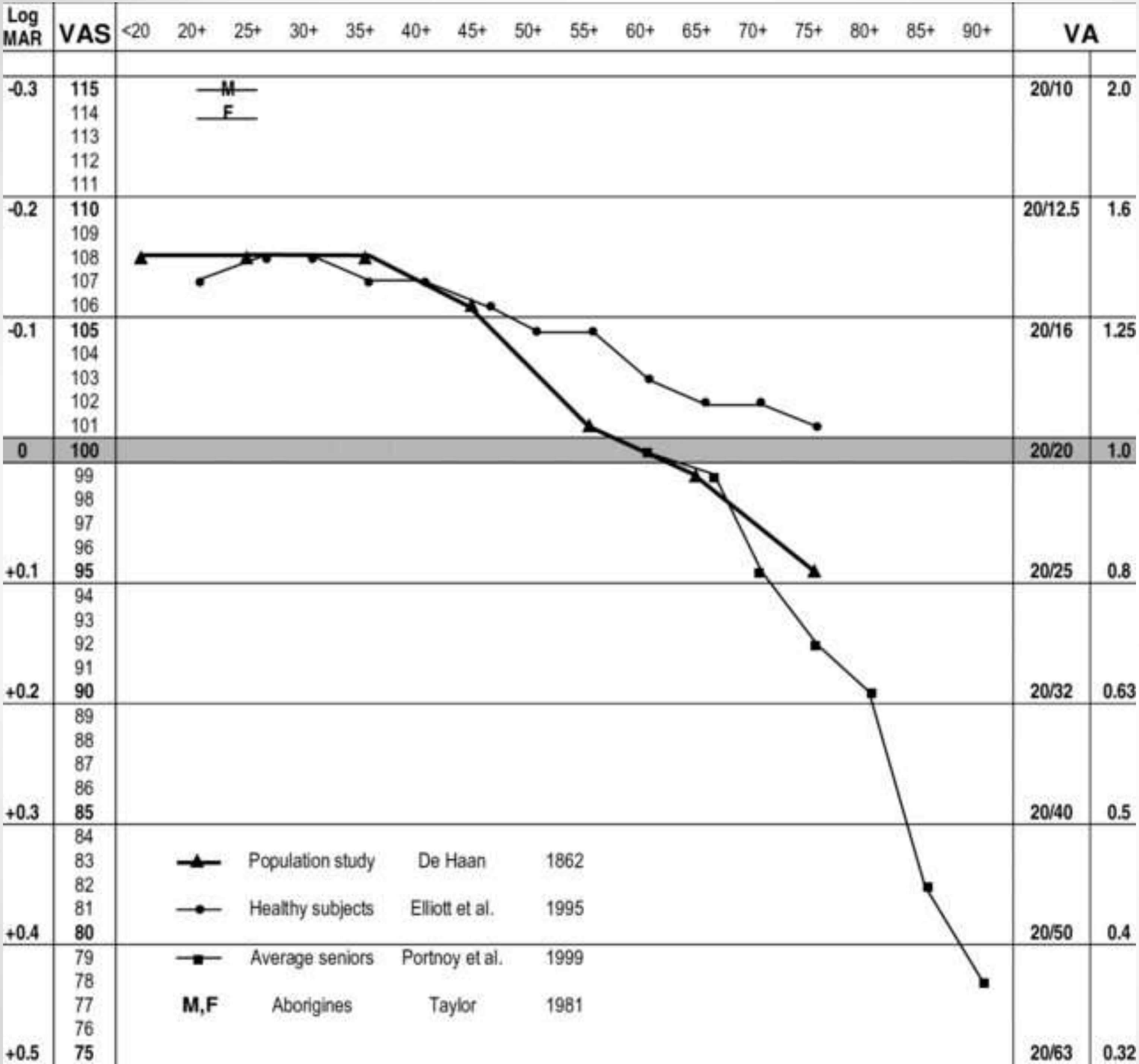
## 4. Target Motion:

- Acuity ↓ with motion of:
  - Target
  - Observer
  - or Both
- Dynamic visual acuity:
  - Ability to make visual discriminations under such conditions (e.g. driver looking at objects on sidewalk)
  - This acuity rapidly ↓ as rate of motion ↑

# Factors Affecting Visual Discrimination

5. Age:
   - visual acuity, **contrast sensitivity** (ability to see details at low contrast levels) ↓ with age
     (note, the higher the threshold contrast, the lower the contrast sensitivity)
   - decline starts at age 40 (see next slide)
   - at age 75: acuity = 20/30
   - ⇒ visual displays for old people must provide:
     - large targets
     - adequate illumination

6. Training:
   - Besides contacts, glasses, eye surgery, vision can be improved by:
   - Training to improve focus:
     - Improves Snellen acuity by 14%
     - Improves contrast sensitivity by 32%
   - Dynamic visual acuity can be improved with practice




Visual acuity changes with age (several studies)

# References

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  - ***Human Factors in Engineering and Design***. Mark S. Sanders, Ernest J. McCormick. 7th Ed. McGraw: New York, 1993. ISBN: 0-07-112826-3.
- **More Optical Illusions Sites**
  - http://upload.wikimedia.org/wikipedia/commons/6/60/Grey_square_optical_illusion.PNG
  - http://www.illusion-optical.com/Optical-Illusions/Circles.php