King Saud University

College of Engineering

IE – 341: “Human Factors”

Human Capabilities
Part – II. Vision (Chapter 4)

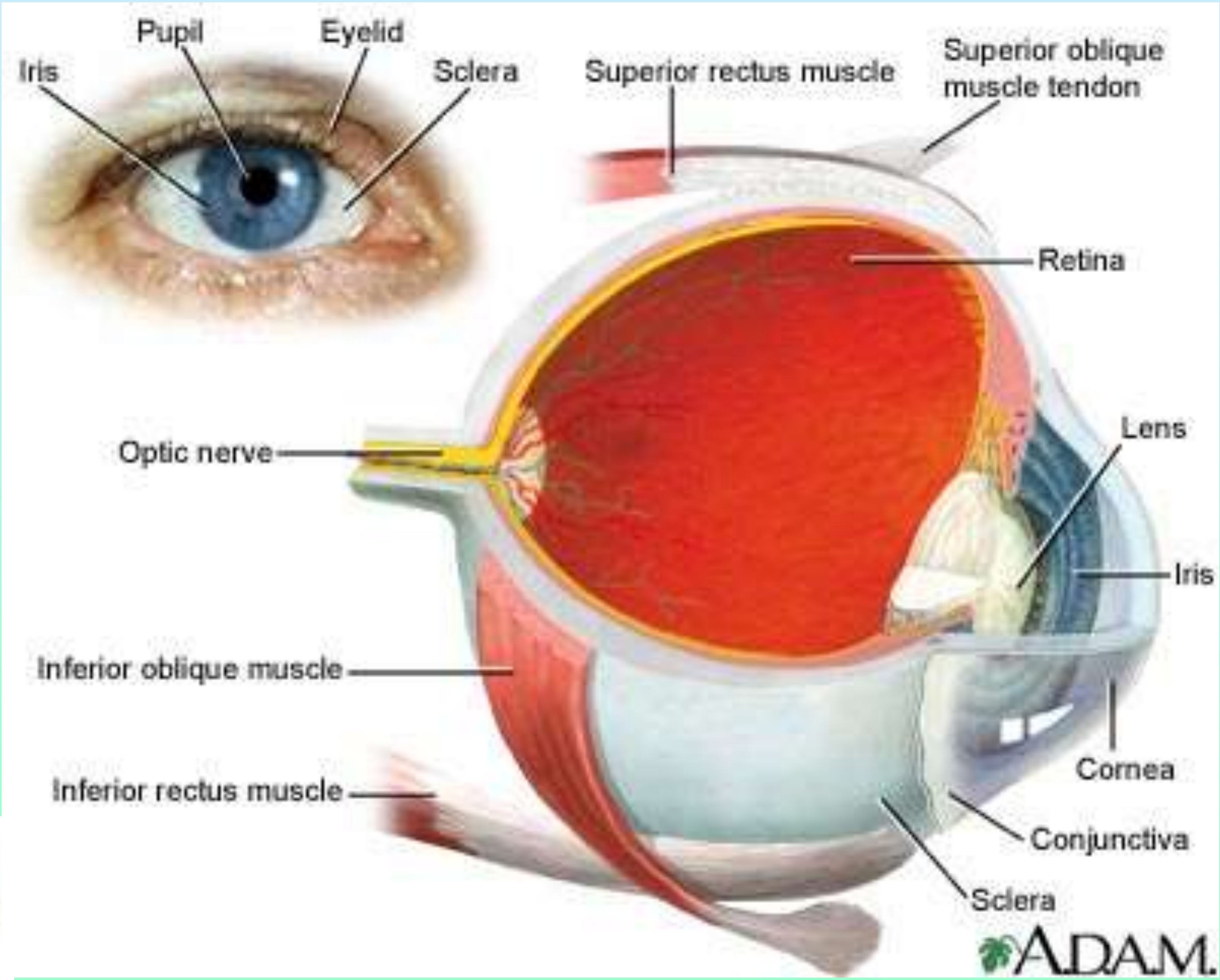
Lesson Overview: Vision

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

Cont. Lesson Overview: Vision

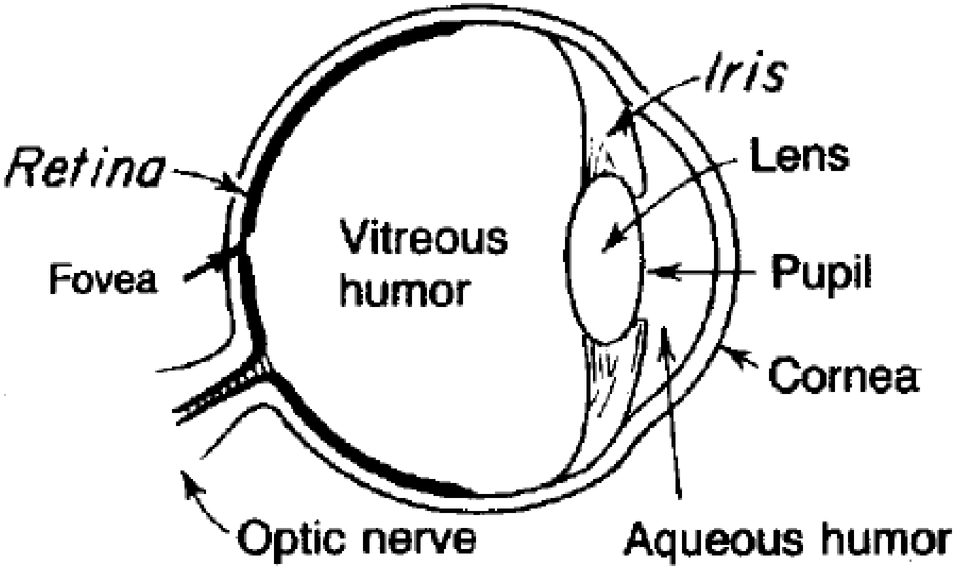
- Alphanumeric Displays
  - Characteristics
  - Typography
  - Typography Features
    - Hardcopy
    - Visual Display Terminals (VDT)
- Graphic Representations
- Symbols
- Codes

Process of Seeing (Vision)



Anatomy of the eye

- Eye and conversion of light to image
  - Cornea
  - Aqueous humor
  - Lens
  - Vitreous humor
  - Photoreceptors
  - Optic nerve, brain



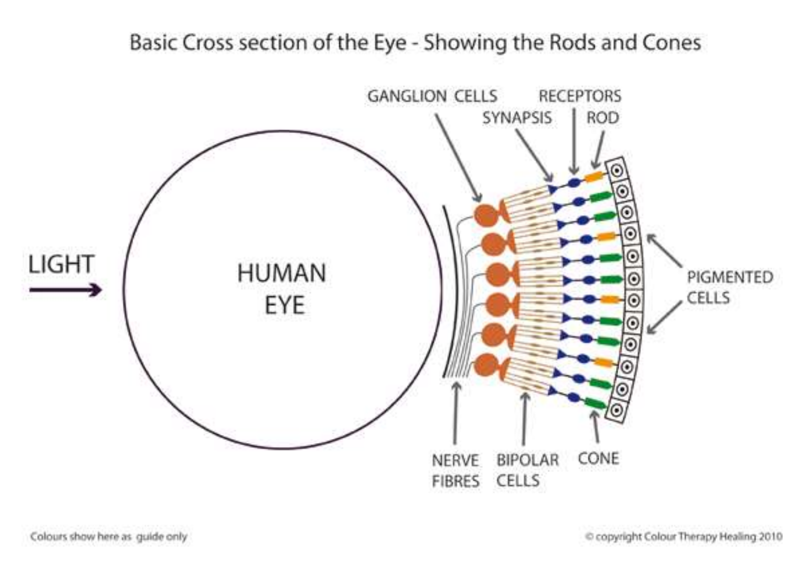
- Blind spot (no photoreceptors)

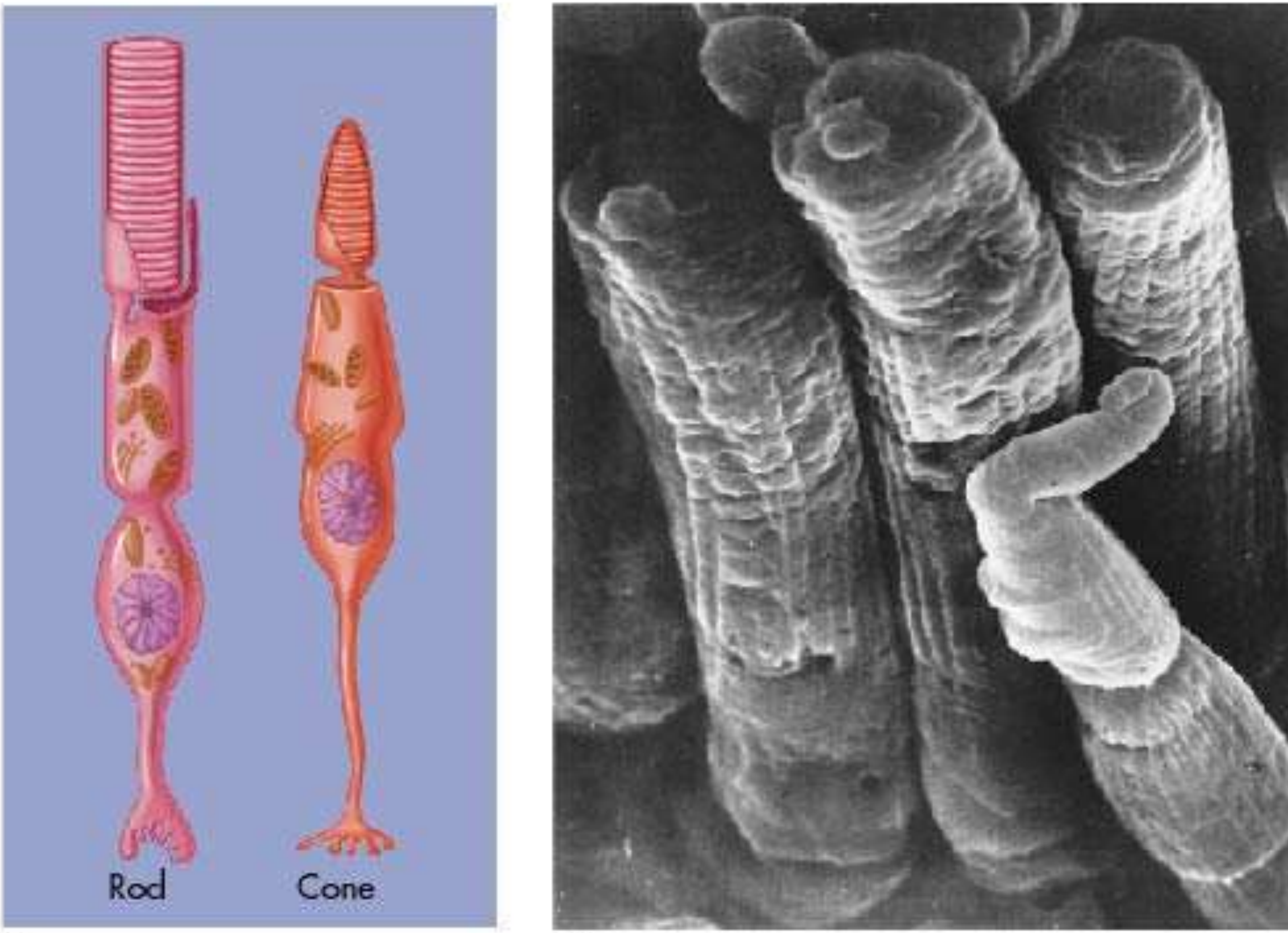
Process of Seeing (Vision)

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

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.

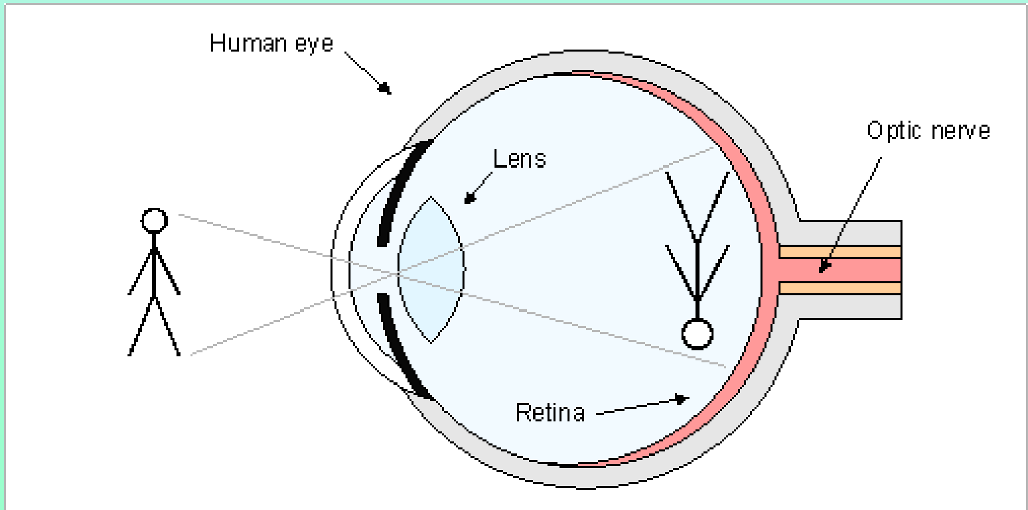




(a) (b)

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.
- 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.

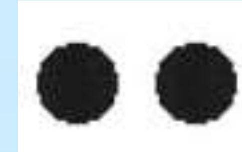


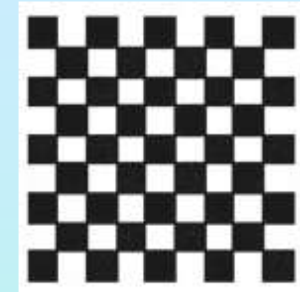
Images are inverted on their way to the retina at the back of the eye

Visual Capabilities: 1. Accommodation

- **Accommodation**: ability of the lens to focus light rays on the retina
- **Near point**: closest distance possible for focus (i.e. any closer will be blurry)
- **Far point**: farthest dist. for focus (usu. = ∞)
- **Diopter:** measure of focus (for eye, camera)
  - Diopter [D] = 1 / target distance
  - e.g. 1 D = 1 m; 2 D = 0.5 m; 3 D = 0.33 m; 0 D =∞
  - More powerful lens ⇒ higher diopters
- **Dark focus**: eye accommod. in dark (=1D)
- **Nearsightedness** (myopia):far point: too close; i.e. lens remains bulged with far objects
- **Farsightedness**: near point: too far (i.e. can't see close objects); lens: flat for close objects

Visual Capabilities: 2. Visual Acuity

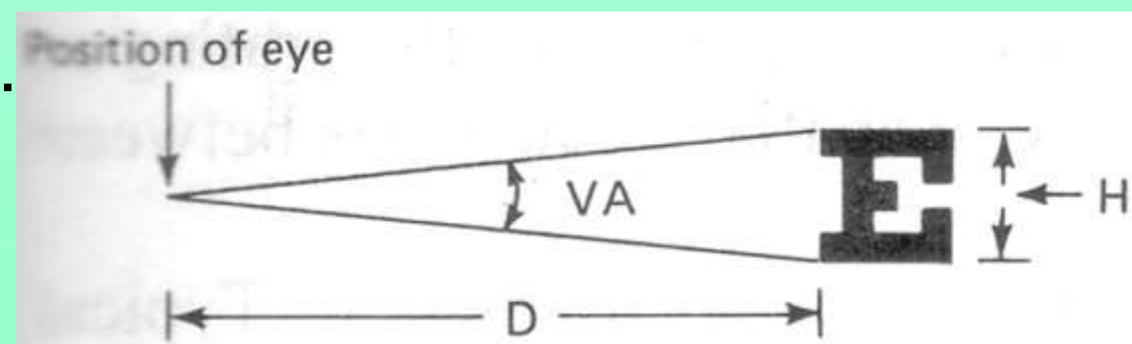




- **Visual Acuity**:
  - ability of eye to discriminate fine details
  - depends largely on accommodation
- **Minimum separable acuity**:
  - most common measure of VA
  - Def^{n}: smallest feature or space between the parts of a target (e.g. letter '**E**' below) that eye can detect

- **Visual angle**: (<10°):
  - H = stimulus height
  - D = dist. from eye
  - H, D: same units
  - Normal VA = 1 min.
  - Note, 1° = 60 min.

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



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
    - e.g. ***Snellen*** acuity: 20/30 (6/9) ⇒ person barely reads @ 20 ft what normal (20/20, 6/6) person reads @ 30 ft
    - e.g. 20/10 ⇒ person reads @ 20 ft what normal person must bring to 10 ft to read (far- or near-sightedness?)
    - e.g. 20/20 ⇒ resolving 1 min. arc of detail @ 20 ft (normal vision)
    - e.g. Given VA = 1.75 min. ⇒ Snellen Acuity = 20 / x i.e. x = (20) (1.75) = 35 ⇒ Snellen Acuity = 20 / 35

Visual Capabilities: 2. Visual Acuity

- **Other types of visual acuity measures**:
  - **Vernier acuity**: ability to differentiate the lateral displacement of one line from another
  - **Minimum perceptible acuity**: ability to detect a spot from its background

  - **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

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).
- 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

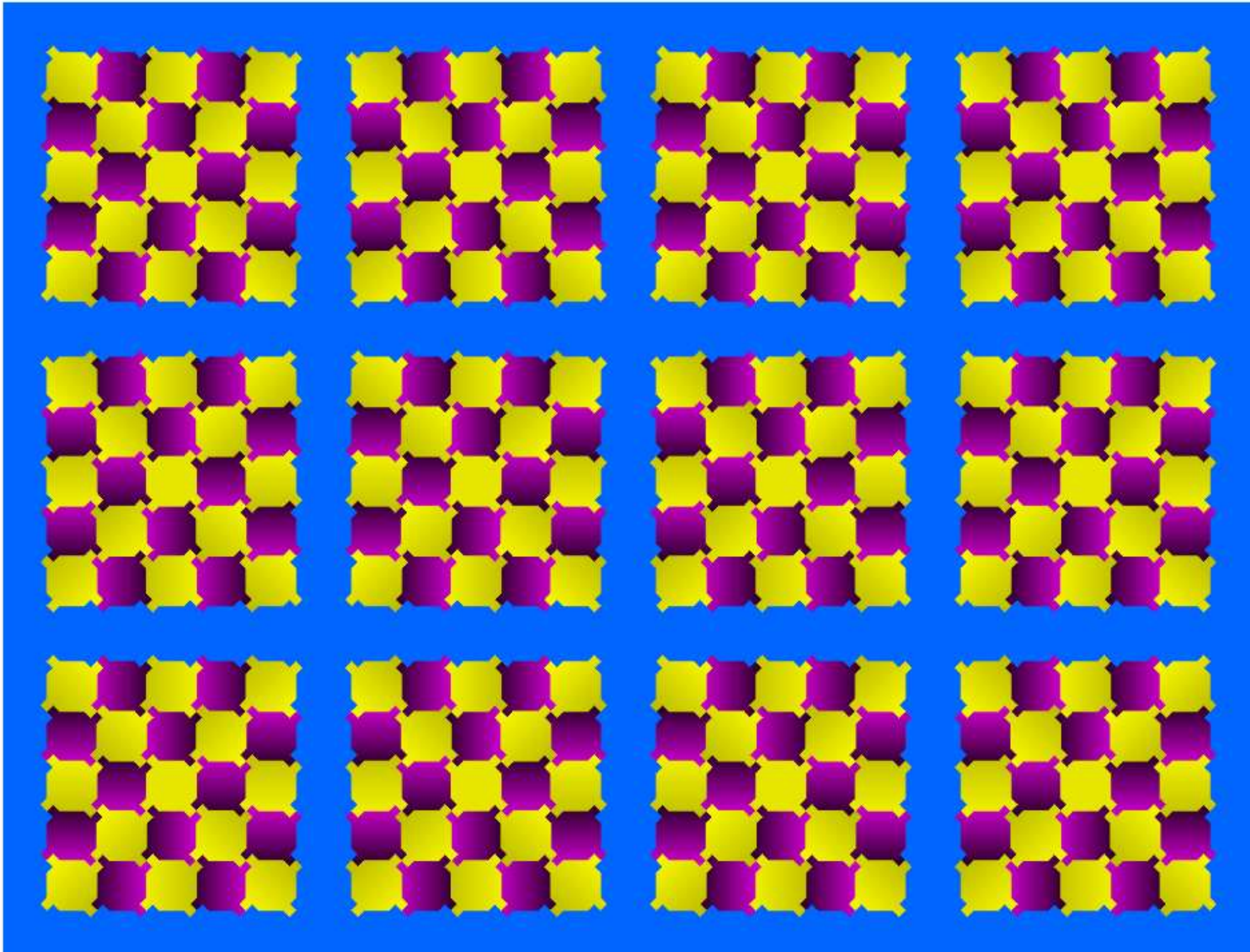
- Cones
  - Located in fovea (center of retina)
  - basis for color discrimination
  - 3 types of cones, each sensitive to light wavelengths corresponding to primary colors: Red, Green, Blue
  - In dark: cones not activated ⇒ no color is visible
- Color vision:
  - **Tri**chromats: people distinguishing different colors
  - Color deficiency (color blind):
    - **Mono**chromats (v. v. rare): non-color vision
    - **Di**chromats: deficiency in red or green cones
      - Inherted 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)

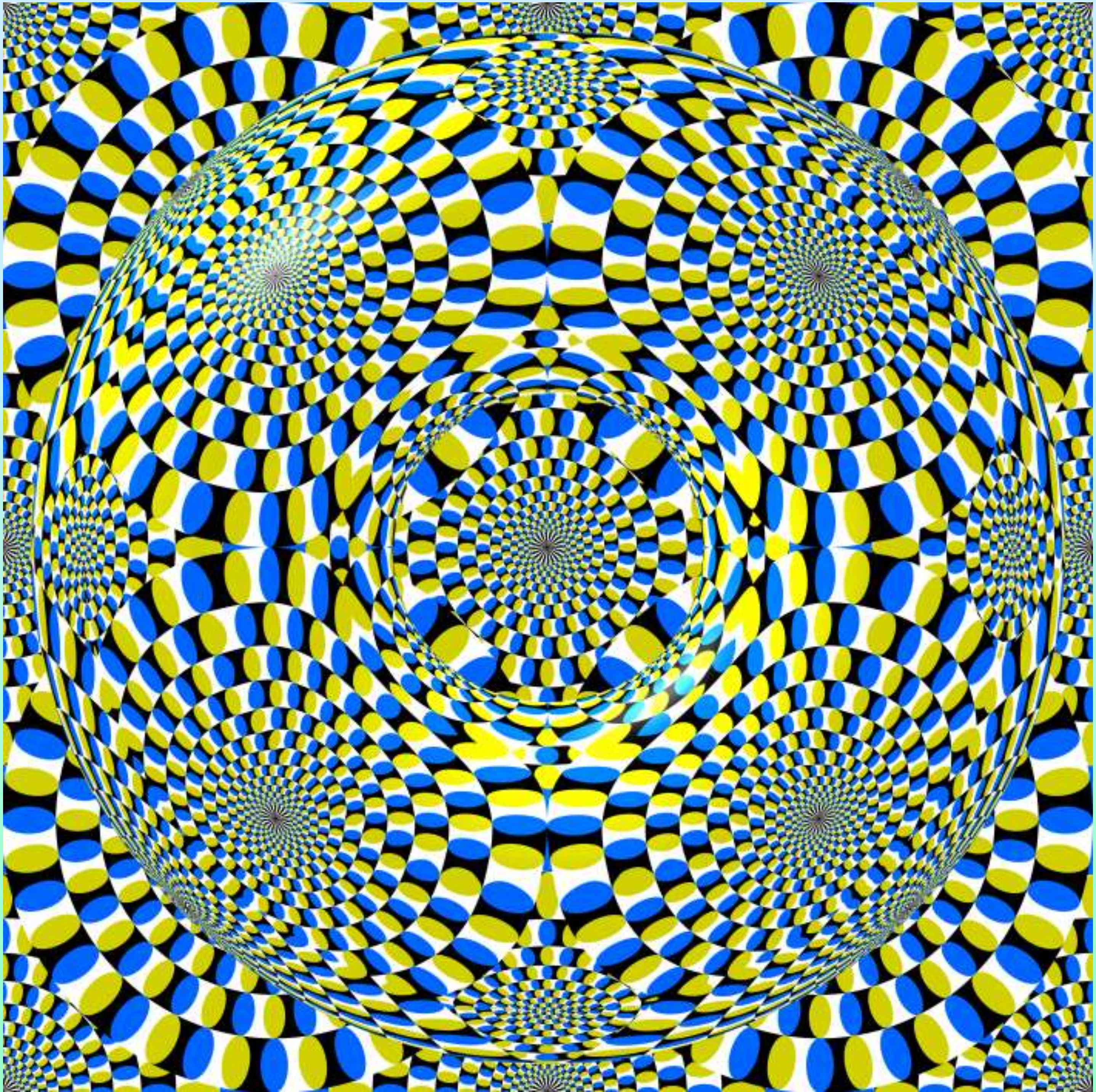
Visual Capabilities: 4. Color Discrimination

- Color Images:
  - This slide: trichromat vs. dichromat
  - Optical Illusions
    - Next slide: "rotating turtles"
    - Slide 17: "doughnut of rotating snakes"
    - Note slides 16, 17: static -not dynamic- images! (how?????)
    - Source (much more fun): www.diycalculator.com/sp-cvision.shtml

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: 5. Adaptation

- Adaptation: changes in sensitivity to light
- Entering dark room:
  - This is *dark* adaptation
  - Pupil increases in size ⇒ more light enter eyes
  - Sensitivity of eye ↑ gradually (up to 30-35 mins.)
  - Cones lose most sensitivity in dark (mostly rods)
- Exiting dark room to light
  - This is *light* adaptation
  - Pupil contracts to limit light entering eyes
  - Adaptation requires about 1 min. (why faster?)
  - More light ⇒ cones are activated

Visual Capabilities: 6. Perception

- When viewing visual displays
  - Displayed features and information 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)
- Visual displays design must meet 2 objectives
  - display must be seen clearly
  - design must help viewer to correctly perceive/understand meaning of display

Factors Affecting Visual Discrimination

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

1. Luminance Level:
   - As light or background light levels ↑
   - ⇒ cones are activated ⇒ visual acuity ↑
   - This is required for complex, intricate tasks
2. Contrast (AKA brightness contrast):
   - Refers to difference in luminance of viewed objects
   - Most important consideration: difference in luminance between: *object* (target) and *background*
   - When contrast is low, target must be larger to be equally discriminable to target with greater contrast

Cont. Factors Affecting Vis. Discrimin.

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 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?

Cont. Factors Affecting Vis. Discrimin.

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

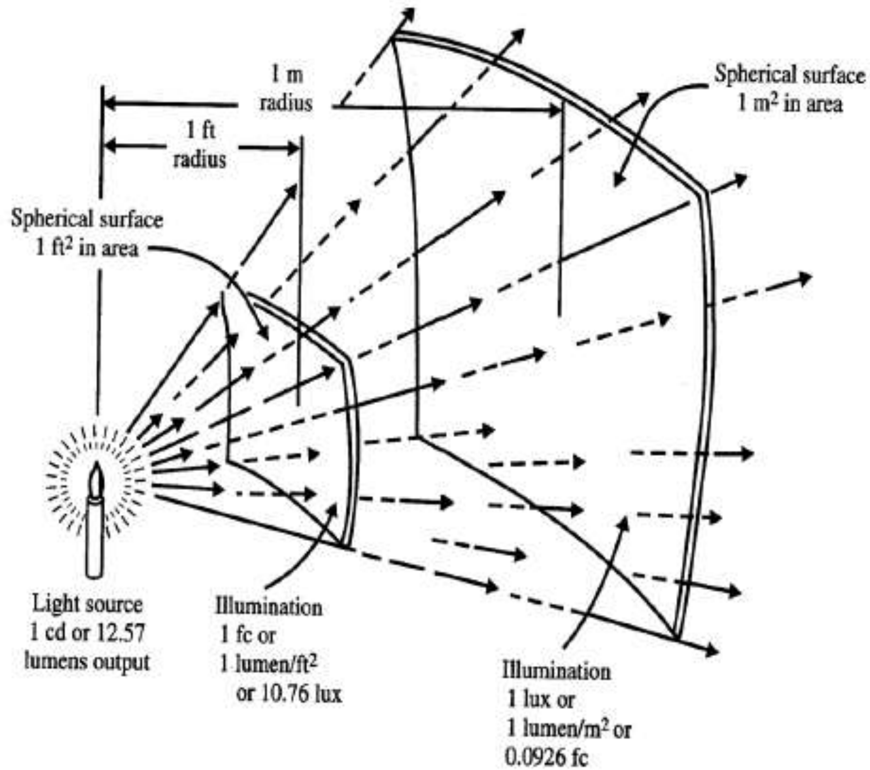
4. Target Motion:
   - Acuity ↓ with motion of:
     - Target
     - Observer
     - or Both
   - Dynamic visual acuity:
     - Ability to make visual discriminations under such conditions (e.g. driver looking at objects on sidewalk)
     - This acuity rapidly ↓ as rate of motion ↑

Cont. Factors Affecting Vis. Discrimin.

5. Age:
   - Visual acuity, contrast sensitivity (ability to see details at low contrast levels) ↓ with age
   - Decline starts at age 40
   - 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

Measurement of Light

- Illumination (fc) $= \text{intensity}/d^2$
- Luminance (fL) = ill (fc) x reflect
- Reflectance = $\frac{0.9 \times \text{test-lum}}{\text{white-lum}}$

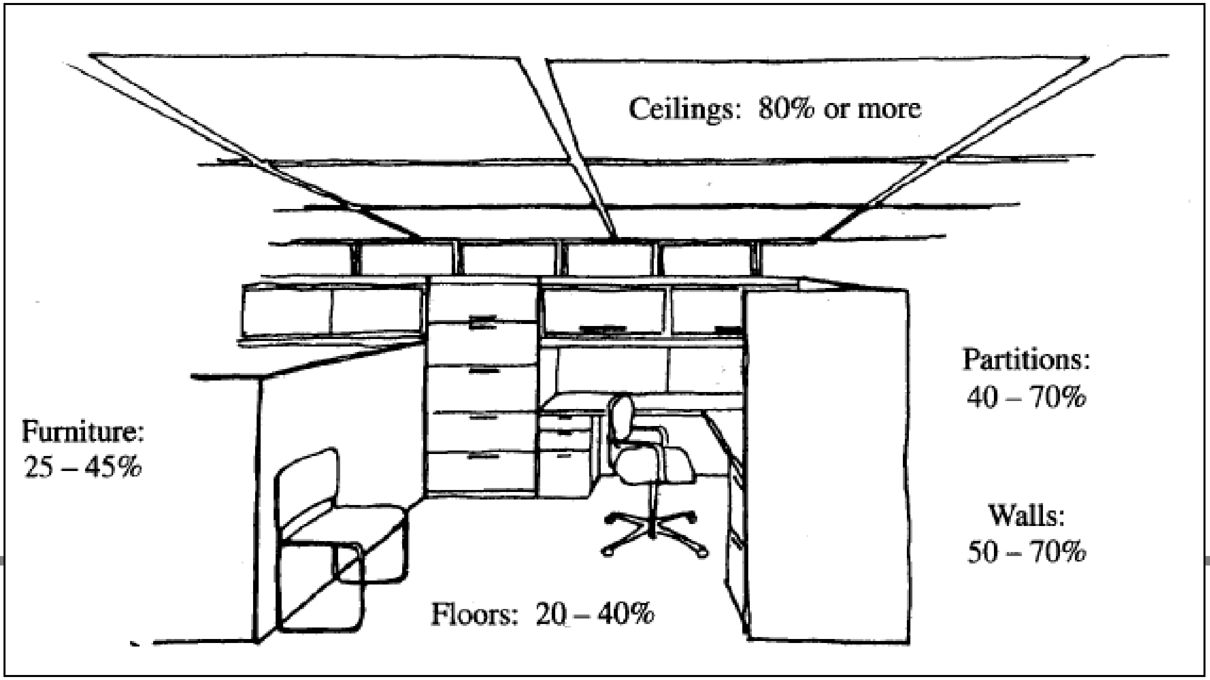


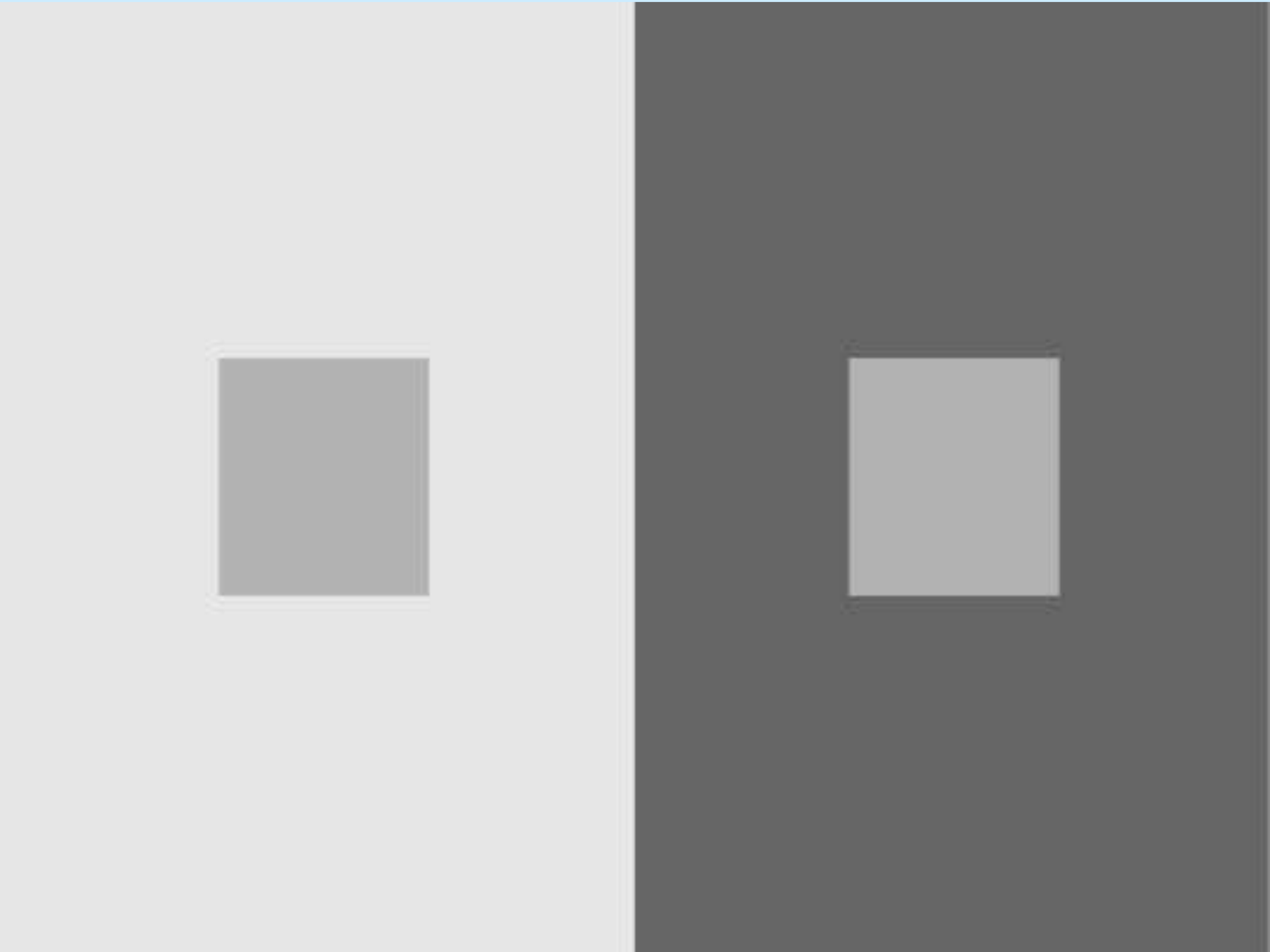
Illuminance v. Luminance

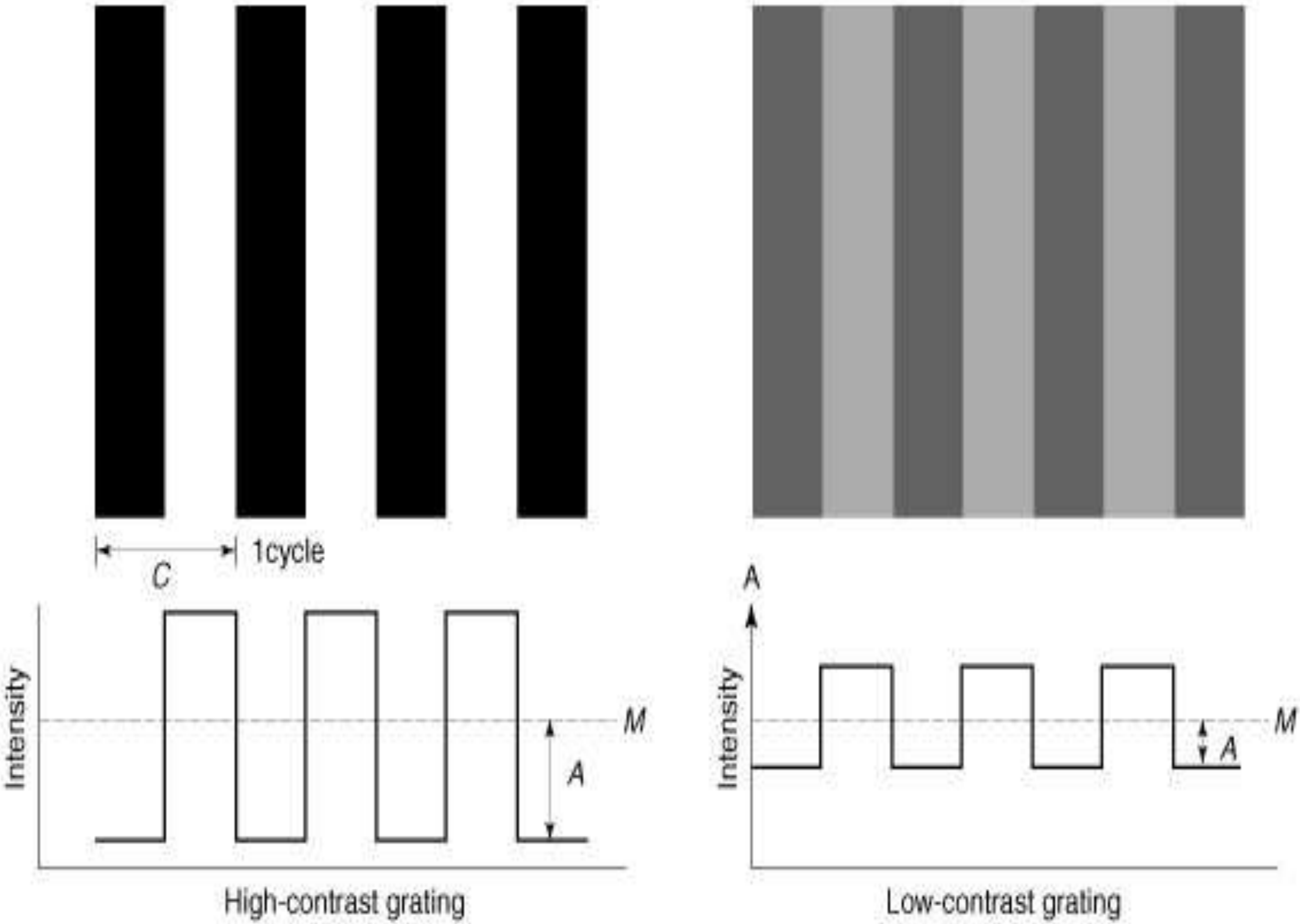
- Illumination/Illuminance: The amount of light striking any point on the inside surface of a sphere surrounding the light source (Luminous flux/unit area)
  - Foot candle: 1 lumen/square foot
  - Lux: 1 luman/square meter
- Luminance: The amount of light per unit area leaving (reflected from) a surface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

Reflectance and contrast

- Contrast ratio = $(L_{max}-L_{min}/L_{min})$
  - (Task:adjacent < 3:1, task:remote < 10:1)

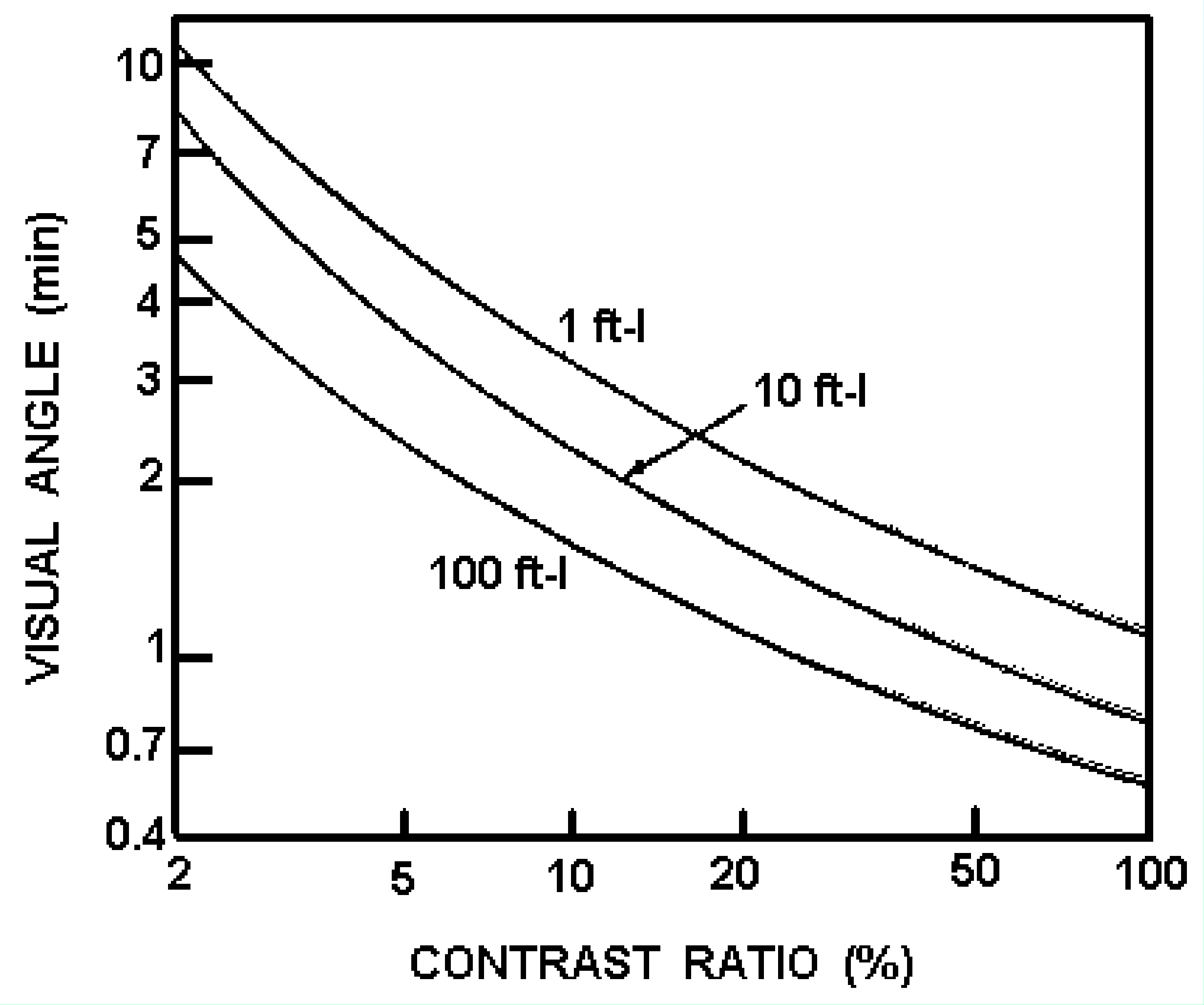




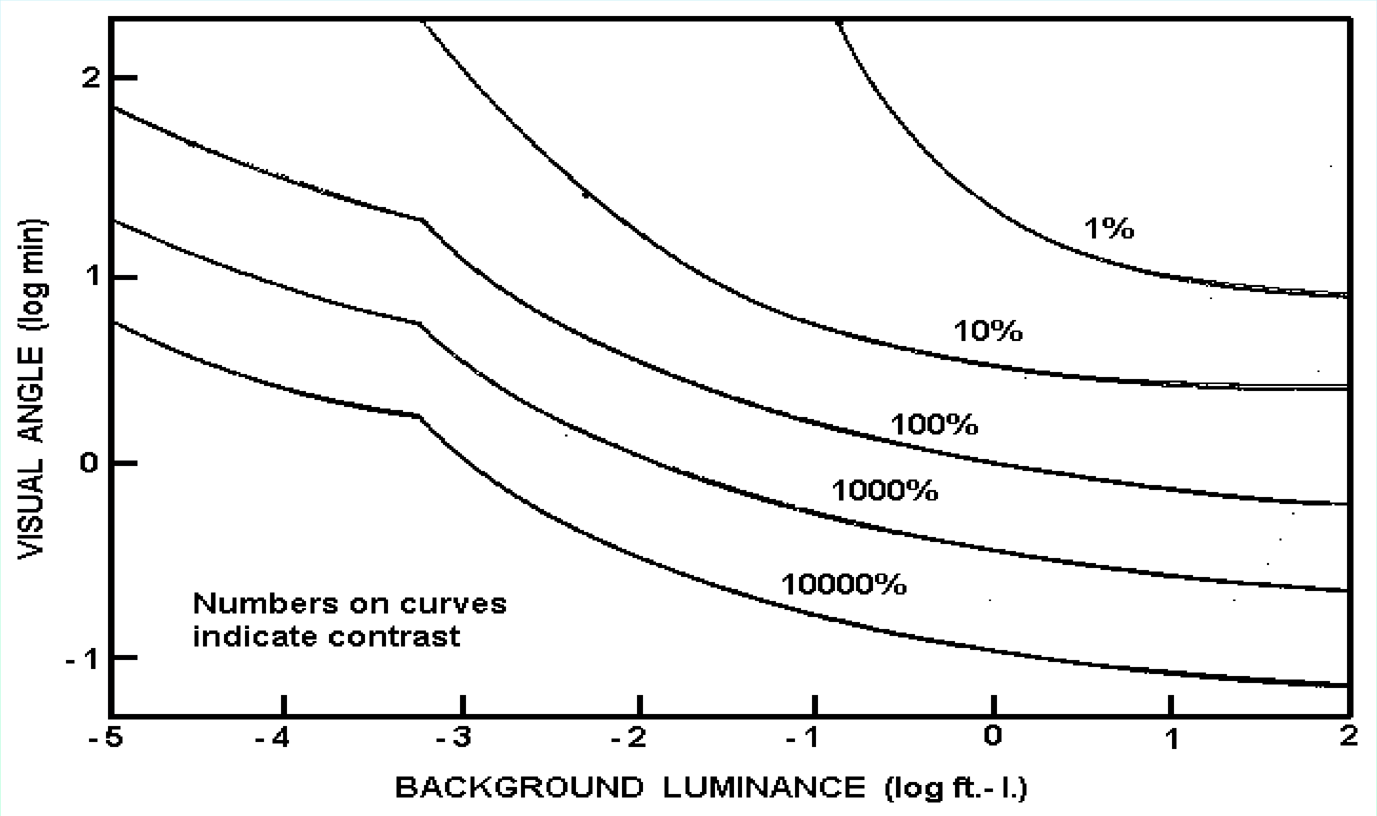


1cycle
C
Intensity
M
A
High-contrast grating
A
Intensity
M
A
Low-contrast grating

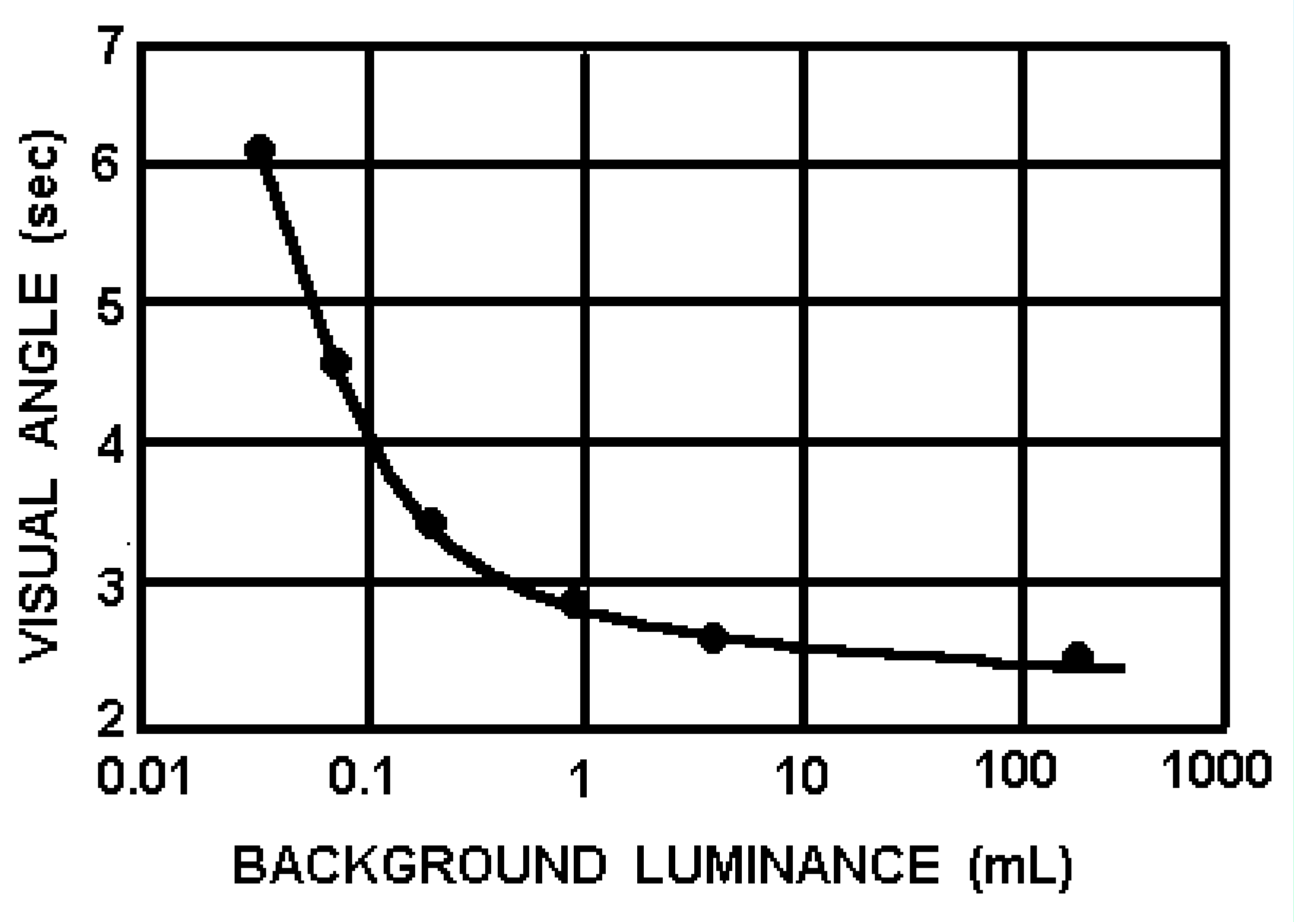
Minimum Separable Acuity as Function of Contrast



Minimum Perceptible Acuity as Function of Contrast and Background Luminance



Vernier Acuity as Function of Background Luminance




SEKONIC
125 16.0
POWER
MODE
MEMORY
FLASH MASTER
L-358

292
POWER
EL-1000
RANGE
OFF ON
LINE SEIKI

Recommended illumination

- Pick general category based on activity
- Adjust for three factors:
  1) Worker age
  2) Reflectance of task/background
  3) Speed/accuracy of task

Weighting Factors to be Considered in Selecting Specific Illumination Levels Within Each Category of Table 6–2

Task and Worker Characteristics	Weight −1	Weight 0	Weight +1
Age	< 40	40-55	> 55
Reflectance of task/surface background	> 70%	30-70%	< 30%
Speed and accuracy (only for categories D - I)	Not important	Important	Critical

Recommended Illumination Levels for Use in Interior Lighting Design

Category	Range of Illuminance (fc)	Type of Activity	Reference Area
A	2-3-5	Public areas with dark surroundings.	General lighting throughout room or area.
B	5-7.5-10	Simple orientation for short temporary visits.	
C	10-15-20	Working spaces where visual tasks are performed only occasionally.	
D	20-30-50	Performance of visual tasks of high contrast or large size, e.g., reading printed material, typed originals, handwriting in ink and xerography; rough bench and machine work; ordinary inspection; rough assembly.	Illuminance on task.
E	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	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.	

Recommended Illumination Levels for Use in Interior Lighting Design

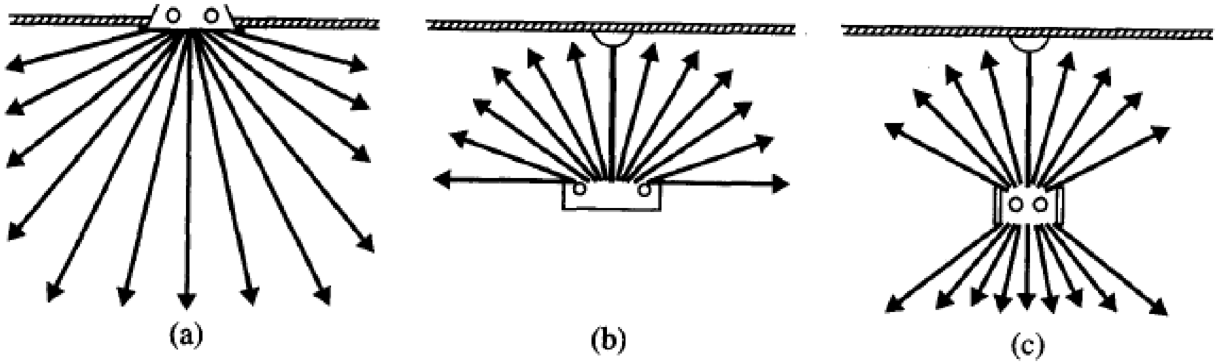
Category	Range of Illuminance (fc)	Type of Activity	Reference Area
G	200-300-500	Performance of visual tasks of low contrast and very small size over a prolonged period, e.g., fine assembly; very difficult inspection; fine bench and machine work; extra fine assembly.	
H	500-750-1000	Performance of very prolonged and exacting visual tasks, e.g., the most difficult inspection; extra fine bench and machine work; extra fine assembly.	Illuminance on task via a combination of general and supplementary local lighting.
I	1000-1500-2000	Performance of very special visual tasks of extremely low contrast and small size, e.g., surgical procedures.	

Example

- A classroom has a reflectivity of 60%, based on the color combinations of the immediate environment. What would be the recommended illumination?

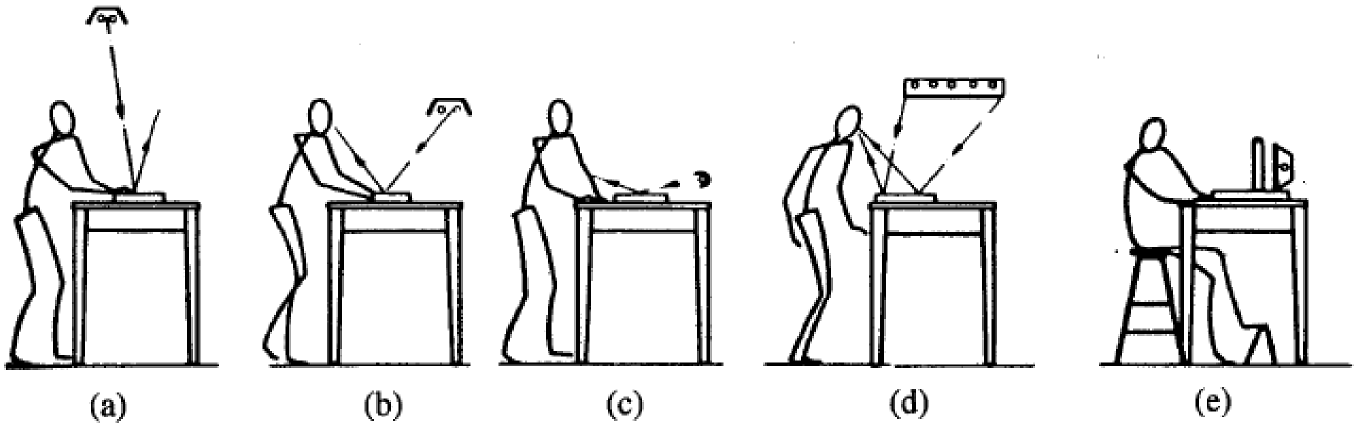
Distribution of light

- a) Direct lighting for both general and task
- b) Indirect lighting that is reflected (ambience)
- c) Mixed direct and indirect – task and reflected
- Consider two sources – general and task



Control light sources – avoid glare

- a) Place light overhead or behind
- b) Position light away from line of sight
- c) Grazing light for inspection
- d) Use several lamps of lower intensity
- e) Transillumination for inspection



Other factors to reduce glare

- Use light shields, baffles, blinds, hoods, diffusing lenses
- Use non-glossy matte work surfaces
- Avoid flashing reflections from moving parts
- Place lights further from line of sight (Tradeoff with increased intensity)
- Have windows higher up

Daylighting

- Cost-effective way of lighting
- Natural light
- Need to consider placement
  - Glare
  - Contrast
  - Reflective surfaces
- Additional lighting

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

Solved Problems

1. A 60–watt, 400 cd point source bulb hangs 4 ft from above a brown desk (reflectance=50%). Ali reading black letters (reflectance=10%) on a yellow sheet of paper (reflectance=80%). His eyes are 16 inches from the paper.

a. What is the illumination on the paper?

b. What is the brightness of the type as seen by Ali?

c. What is the contrast of the letters on the paper?

d. What is the minimum strokewidth that Ali could read assuming he has 20/20 vision?

1. a. fc = 400 cd / 4*4 ft = 25 fc

1. b. B = RE = 0.10 (25) = 2.5 ft–L

1. c. C = (Rb – Rd) / Rb or Rd, depending on which form of the contrast function you use. So, C = .875 (0–1 scale), or C = 7 (0–infinity scale).

1. d. 1 arc min = 3438(x)/16; x = .0046 inch

2. A worker's job is to detect a 0.01 inch space between two wires on an electronic component. One day the worker forgets his glasses (he has 20/50 uncorrected vision). What is the farthest distance away the worker can be and still see the space between the wires?

Step 1:

20/50 Snellen acuity is equivalent to 2.5 arc minutes

Step 2:

Solve for distance using –

V.A.(arc min) = (3438 x Space)/Distance

Distance = (3438 x Space)/Visual Angle

= (3438 x 0.01")/ 2.5 = 13.752 inches

= 1.146 feet

3. A snowmobile driver was killed by a 3/8-inch thick wire that was strung across a dirt road at a height of about 4 feet. On the dark night, the only illumination was provided by the 1800 Candela headlight of the snowmobile, which was 40 feet from the wire when the wire was observable. Measurements showed that the wire had a reflectance of 30%. The luminance of the background was 0.03 ft-Lamberts. The driver has a Snellen acuity of 20/40. Assuming both the observer and the lamp are 40 feet from the wire when initially observed; determine the minimum required wire thickness so that it is observable:

a. Based only upon visual angle criteria.

b. Based upon lighting visibility considerations.

c. Determine whether the driver was at fault in this legal case, based upon your data.

a. Based only on visual angle, we know that a Snellen 20/40 can just identify an object with subtended angle 2 arc minutes. Solving for the object height, 2 = 3438(H)/[40(12)] = 0.28 inches.

b. Based upon lighting visibility considerations:
At the wire the illuminance (E)=1800 Cd/(40*40)=1.12 ft.-Candles
The wire luminance (Bg) = RE = .3(1.12) = 0.3375 ft.-Lambert
The background luminance (Bd) = 0.03 ft.-Lambert
The Blackwell Contrast = (.3375-.03)/.03 = 10.25
From Blackwell's Curves, we have VAreq'd = 4 arc minutes
4 = 3438(H)/480, so H = 0.56 inch = required wire thickness

c. In ideal (daytime) conditions, the driver should have been able to see a target of 0.28 inches, which is smaller than the .375 inch actual target. However, in the dark lighting conditions here, only a target diameter of 0.56 inch was observable, which is greater than the actual wire thickness. So, based upon this analysis, the wire should not be observable, and the owner of the property is at fault

Alphanumeric Displays

Most important characteristics:

- **Visibility**:
  - quality of the character that makes it separately visible from its surroundings (i.e. **detectability**)
- **Legibility**:
  - attribute that makes a character identifiable from others (i.e. **discriminability**)
  - depends on stroke width, form of characters, contrast, and illumination
- **Readability**
  - ability to recognize information content of material when represented by alphanumeric characters, words, sentences (i.e. **meaningfulness**)
  - depends more on spacing between lines and letters, etc. than on specific features of characters

Alphanumeric Displays: Typography

- Typography≡ various features of alphanumeric displays
- Circumstances when it is important to use preferred forms of typography:
  - Viewing **conditions** are **unfavorable** (e.g. low illumination, limited viewing time)
  - **Information** is **important**/critical (e.g. emergency labels, important instructions)
  - **Viewing** occurs at a **distance**
  - Displays for **low vision** people
- Note, above forms must still satisfy all conditions mentioned in last slide
- When faced with ≥ 1 of these conditions, typography features must be considered:

A-N Displays: Typography Features

A. Hardcopy

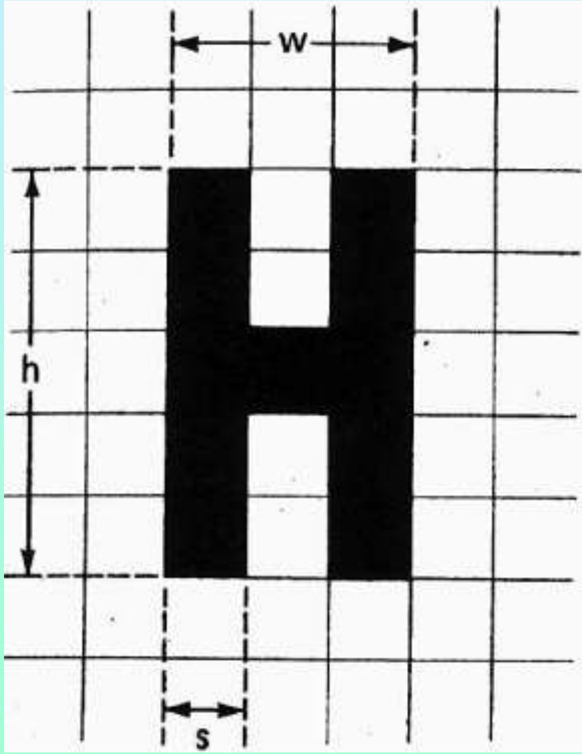
1. Stroke Width
2. Width-height Ratio
3. Styles of Type
4. Size of Characters
   a) at Reading Distance
   b) at a Distance
5. Layout of Characters

B. VDT Screens

6. Illuminated Alphanumeric Characters
7. Character Distance and Size

A-N Displays: 1. Stroke Width

- Stroke-Width-to-height-ratio ≡ ratio of the thickness of the stroke (s) to the height (h) of the letter/number (**stroke ratio** for short)
- Example (right):
  - Stroke width-to-height:1:5 = 0.2
  - Note, Width-to-height: 3:5 = 0.6
- Stoke Width is affected by:
  - Background
    - black on white or
    - white on black
  - Illumination



A-N Displays: 1. Stroke Width (Cont.)

- **Irradiation:**
  - causes **white** features **on** a **black** background to appear to ‘**spread**’ into adjacent dark areas
  - But reverse (**black on white**) isn’t true (no spread)
  - Thus, black-on-white letters should be thicker i.e. lower ratios than white-on-black letters
  - With good illumination, stroke width ratios:
    - Black on white: 1:6 to 1:8
    - White on black: 1:8 to 1:10
  - With reduced illumination:
    - Thick letters become more readable (both types above)
    - Letters should be: boldface with low stroke ratios (e.g. 1:5)
  - For highly luminous letters, ratios: 1:12 to 1:20.
  - For black letters on a very highly luminous background, very thick strokes are needed

A-N Displays: 1. Stroke Width (Cont.)

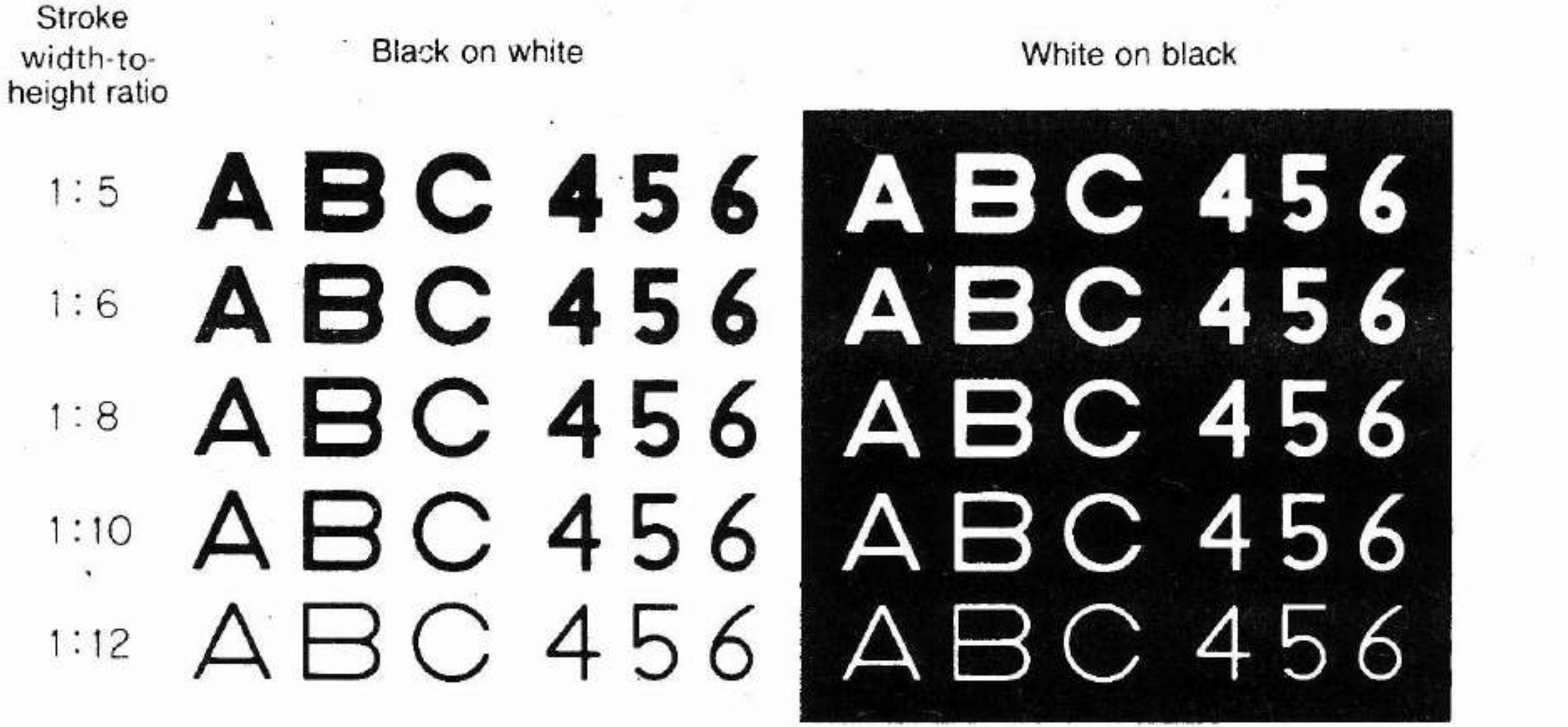
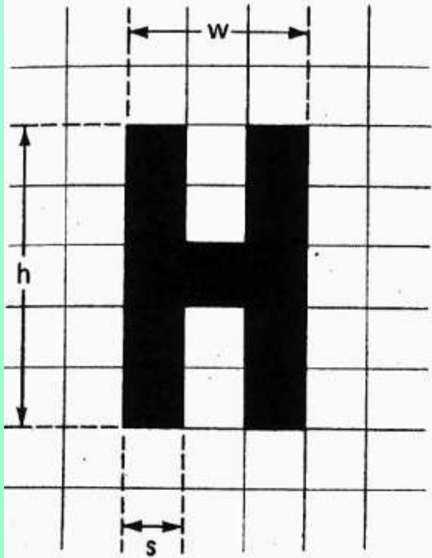


FIGURE 4-7
Illustrations of stroke width-to-height ratios of letters and numerals. With reasonably good illumination, the following ratios are satisfactory for printed material: black on white, 1:6 to 1:8; and white on black, 1:8 to 1:10.

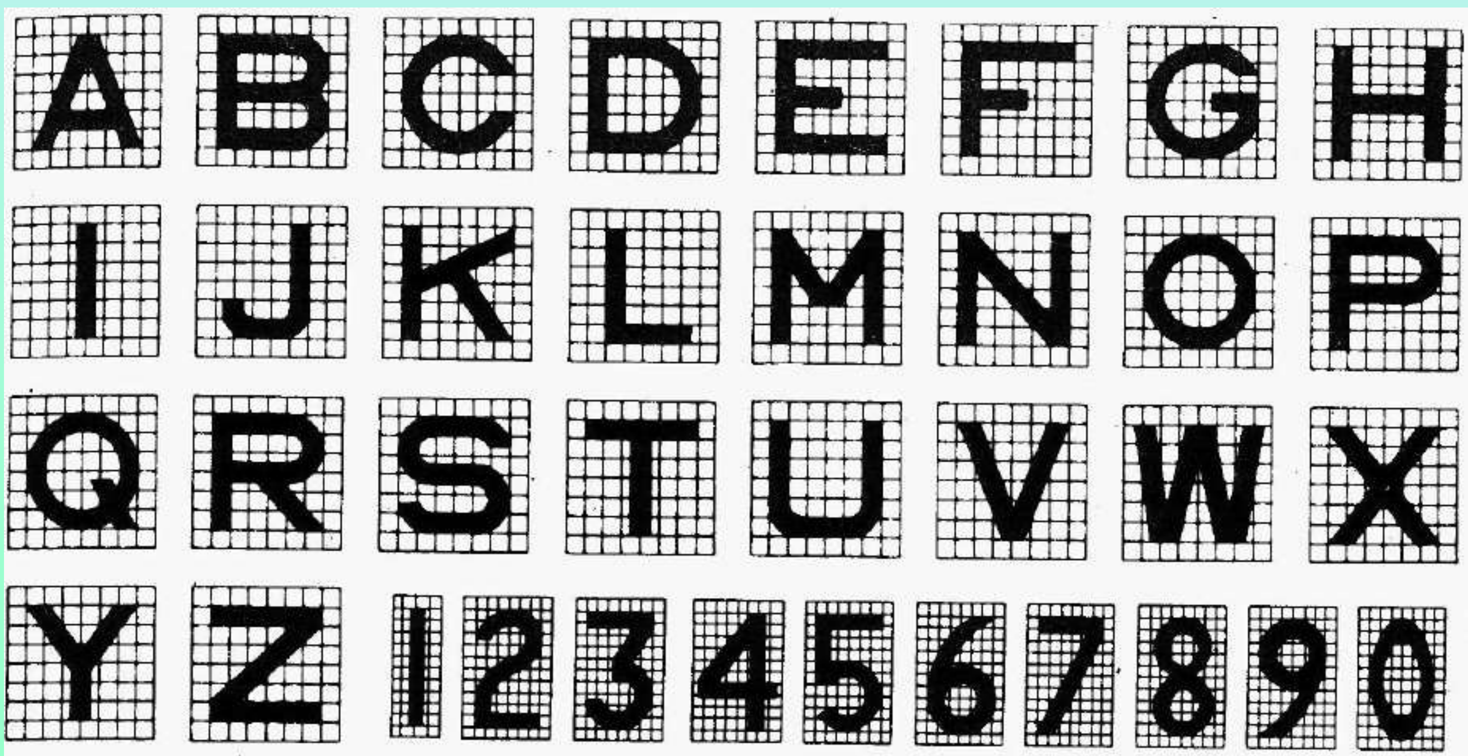
A-N Displays: 2. Width-height ratio

- Width-to-height (AKA width-height ratio):
  - Relationship between width and height of alphanumeric character
  - Expressed as ratio (e.g. 3:5 = 0.6; *back 3 slides*)
  - e.g. **B**: width-height ratio = 3:5
    - 3 vertical strokes (or layers)
    - 5 horizontal strokes
  - Most letters can be expressed with ratio 3:5
  - *Heglin*:
    - Disagrees with fixed ratios for letters:
    - For **O**: perfect circle
    - For **A** and **V**: equilateral triangles



A-N Displays: 2. Width-height Cont.

- Cont. width-height ratio
  - 3:5 satisfactory for most purposes
  - wider letters: appropriate certain circumstances:
    - e.g. engraved legends
    - such cases 1:1 ratios are more appropriate
    - Below: letters: 1:1 (except?); numbers: 3:5 (except?)



A-N Displays: 3. Styles of Type

- Styles (AKA typefaces, fonts of type)
  - > 30,000 exist!
  - 4 major classes (each including many types)

I. **Roman**: most common class;
letters have serifs (little flourishes, embellishments)

II. **Sans serif** (AKA Gothic): uniform stroke width;
used for headings, labels, etc.

III. *Script: simulate modern handwriting. (eg wedding cards)*

IV. **Block Letter**: resembles German manuscript handwriting
used in the fifteenth century (above)

- Roman: most used styles for conventional text
- *Italics: emphasis, titles, names, special words, etc*
- **Boldface: headings, labels, special emphasis, legibility in poor reading conditions**
- Last slide: style used for military (non-standard)

A-N Displays: 4. Character Size

- **Points**:
  - used to measure size of type in printing business
  - 1 point (pt) = 1/72 in. (0.35 mm)
  - this is the height of the *slug* on which the type is set, e.g.
    - tail of the letter "q" (called *descender*)
    - top of letter "h" (called *ascender*)
    - space between lines of text
    - Capital letters
  - Better approximation to letter size:
    - **1 pt = 1/100 in.** (0.25 mm)
  - e.g. letter size, with slug size, heights of cap. letters (in.):
    - This line is set in 4-pt type (slug = 0.055; letters = 0.04).
    - This line is set in 6-pt type (slug = 0.084; letters = 0.06).
    - This line is set in 8-pt type (slug = 0.111; letters = 0.08).
    - This line is set in 9-pt type (slug = 0.125; letters = 0.09).
    - This line is set in 10-pt type (slug = 0.139; letters = 0.10).
    - This line is set in 11-pt type (slug = 0.153; letters = 0.11).
    - This line is set in 12-pt type (slug = 0.167; letters = 0.12).

A-N Displays: 4. Size (Cont.)

a) **For Close-Up Reading**:

- Normal reading distance (e.g. book)
  - 12-16 in.
  - 14 in. (35.5 cm): nominal reading distance
- Type size in most printed material
  - from 7 to 14 pt
  - most common about 9 to 11 pt
  - i.e. letters = 0.09 – 0.11 in. (2.3-2.8 mm; VA = 22-27 min??)
- Character heights should be increased:
  - poor illumination (see table)

TABLE 4-2
ONE SET OF RECOMMENDED HEIGHTS OF ALPHANUMERIC CHARACTERS FOR CRITICAL AND NONCRITICAL USES UNDER LOW AND HIGH ILLUMINATION AT 28 IN VIEWING DISTANCE

	Height of numerals and letters*	
	Low luminance (down to 0.03 fL)	High luminance (1.0 fL and above)
Critical use, position variable	0.20-0.30 in (5.1-7.6 mm)	0.12-0.20 in (3.0-5.1 mm)
Critical use, position fixed	0.15-0.30 in (3.8-7.5 mm)	0.10-0.20 in (2.5-5.1 mm)
Noncritical use	0.05-0.20 (1.27-5.1 mm)	0.05-0.20 (1.27-5.1 mm)

* For other viewing distances (D), in inches, multiply tabled values by D/28.
Source: Adapted from Heglin (1973) and Woodson (1963).

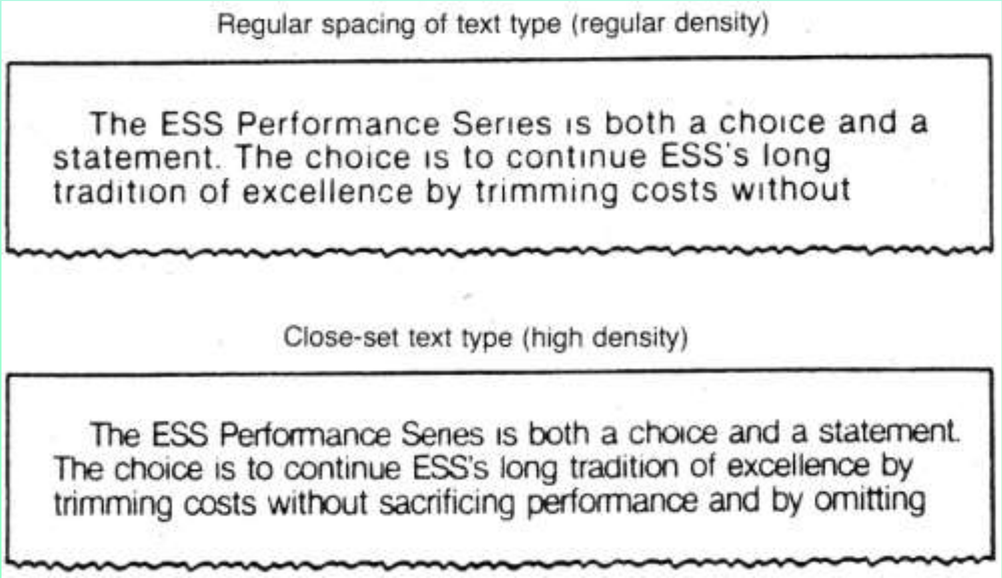
A-N Displays: 4. Size (Cont.)

b) For Distance Reading:

- Readability and legibility of alphanumeric characters are equal at various distances, provided that:
  - As viewing distance ↑ ⇒
  - Characters size ↑ (and vice versa) ⇒
  - VA (visual angle) subtended at the eye stays the same
- Formula: letter height as function of distance and Snellen visual acuity:
  - $W_s = 1.45 * 10^{-5} * S * d$
  - $H_L = W_s / R$
    - W_s, d, H_L must be in same units (mm, in.)
    - W_s: stroke width
    - S: denom. of Snellen visual acuity (e.g. acuity = 20/40 ⇒ S = 40)
    - d: reading distance
    - H_L: letter height
    - R: stroke width-to-height ratio of font (e.g. R = 0.20 for ratio: 1:5)
- For low illumination, low contrast ⇒ use large letters
- Design signs for people with at best: Snellen acuity:20/40

A–N Displays: **5. Layout of Characters**

- Previous discussion: design of characters
- Layout of characters can influence reading:
  - **Interletter Spacing**:
    - i.e. how “tight” are letters packed (i.e. density)
    - *High*–density letters: read **faster** than *low* density
    - Reason: more characters viewable in quality visual field (i.e. fovea) at each fixation (see figure below)
  - **Interline Spacing**:
    - More spacing ⇒ ↑ text clarity
    - Less spacing ⇒ eye strain, headache

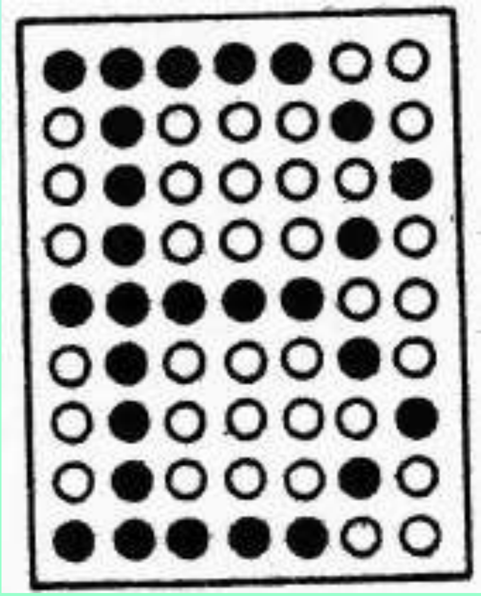


A-N Displays: 6. Illuminated AN Characters

- Characters also presented on
  - VDT (visual display terminal), AKA:
  - VDU (visual display unit, i.e. computer screen)
- Characters on VDT
  - readable: 20-30% slower than on hardcopy
  - reason:
    - Dot-matrix VDT: composed of pixels "**pic**ture **el**ement**s**"
    - Horiz. line of pixels form "raster scan" or scan lines
    - Pixels are lit (turned "on" and "off" to form images)
    - e.g. 640 * 480 VDT screen: 480 lines by 640 pixels
    - Higher "resolution" ⇒ more pixels per image ⇒ less difference between reading from VDT vs. hardcopy
    - Lower resolution (or old VDT): poor accommodation

A-N Displays: 6. Illuminated Characters (Cont.)

- Dot-Matrix displays:
  - Characters made up of a matrix of pixels
  - Individual character: matrix 5 * 7 to 15 * 24
  - See e.g. below: 7 * 9 dot matrix letter 'B'
  - Note, ALL letters/numbers can be created on this formation of dots
  - 7 * 9: minimum size for reading continuous text
  - Small matrices (e.g. 5 * 7):
    - individual matrix pixels: visible
    - ⇒ reading is affected
  - Large matrices:
    - Individual pixels: not distinct
    - ⇒ performance improves



A-N Displays: 7. Distance & Size (VDT)

- Distance
  - VDT Viewed normally farther than hardcopy text
  - Eye-to-screen distances:
    - 24-36 in. (61-93 cm)
    - Mean: 30 in. (76 cm)
  - ANSI standard: viewing monitor: upright position
    - 18-20 in.
    - Take 20 in. (50 cm): nominal VDT reading distance
- Size
  - At 20 in. reading distance
    - Recommended subtended VA = 11-12 min. of arc
    - ⇒ character height = 0.06-0.07 in. (1.5-1.8 mm) (?)
    - This is smaller than for hardcopy (0.09-0.11 in.)

A-N Displays: 7. Distance & Size (cont.)

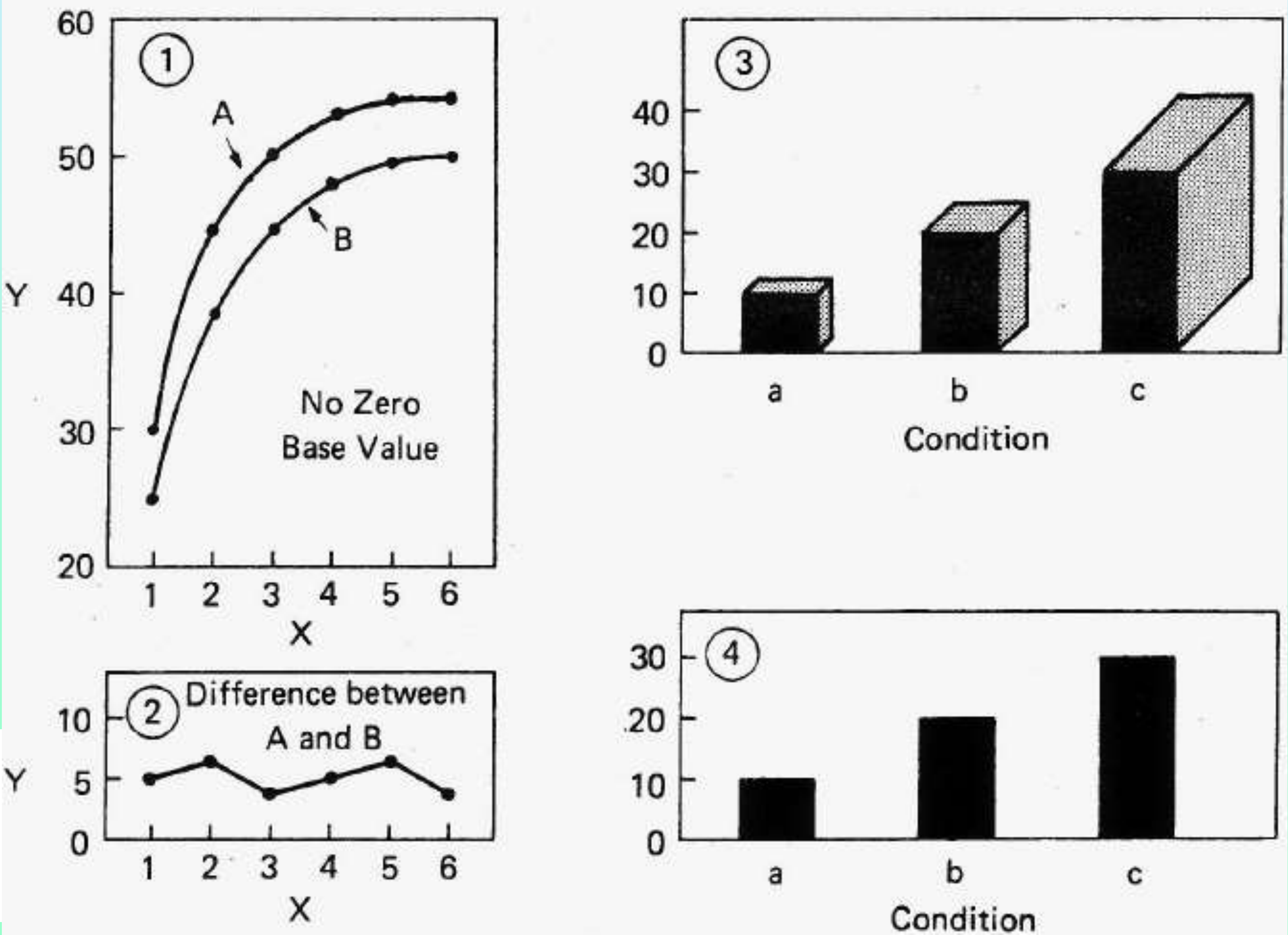
- Size (Cont.)
  - ANSI: size for high legibility reading (@ 20 in.)
    - Minimum: 16 min. ⇒ Height = 0.09 in. (2.3 mm)
    - Preferred: 20-22 min. ⇒
      0.116-0.128 in. (2.9 – 3.3 mm)
      Note, these are closer to hardcopy reading heights
    - Maximum: 24 min. ⇒ 0.14 in. (3.6 mm)
      - This is threshold height for *comfortable* reading
      - When character size ↑ ⇒ more foveal fixation required

GRAPHIC REPRESENTATIONS

- Graphic Representations of Text
  - Pictorial information: important for speed
  - Text information: important for accuracy
  - Instructional material: should combine:
    - Pictures + Text ⇒ speed + accuracy + retention
- Graphic Representations of Data
  - Data graphs:
    - e.g. Pie charts, bar charts, line graphs
    - 2-D graphs, 3-D graphs
  - graph should be
    - consistent with numerical data
    - Properly, clearly labelled (all variables, units, etc.)
  - Some representations: distort data perception
    - e.g. May change differences between 2 variables
    - e.g. May give impression of false increases (next)

GRAPHIC REPRESENTATIONS (cont.)

Examples of possible distortions in perceptions of data presented in graphics. Part 1 can suggest that the difference between *A* and *B* increases; however, part 2 shows that this is not the case. Part 3 can suggest disproportionate increases from condition *a* to *b* to *c*; part 4 corrects for such an impression.



SYMBOLS

- Visual symbols should be very clear
  - e.g. men vs. women restroom sign
- Comparison of Symbolic & Verbal Signs
  - Verbal sign may require “recoding” (i.e. interpretation)
    - E.g. sign saying “beware of camels”
  - Symbols mostly do not require “recoding”
    - E.g. Road sign showing camels crossing
    - ⇒ no recoding (i.e. immediate meaning)
  - Note, some symbols require learning & recoding
  - *Ells* and *Dewar* (1979):
    - Conducted study on traffic signs and symbols
    - Mean reaction time for correct response was less for symbols

SYMBOLS (cont.)

- Objectives of Symbolic Coding Systems
  - Symbolic coding system consists of:
    - *symbols*: that best represent their ***referents***
    - *referents:* concept that symbol represents
  - Objective: strong association: symbol–referent
  - Association depends on:
    - any established association, “recognizability”
    - ease of learning such an association
  - Guidelines for using coding systems (discussed earlier)
    - Detectability
    - Discriminability
    - Compatibility
    - Meaningfulness
    - Standardization

SYMBOLS (cont.)

- Symbols:
  - Either are used confidently
  - Tested experimentally for suitability
- Criteria for Selecting Coding symbols
  - **Recognition**: Subjects presented with symbols and asked:
    - to write down
    - or say what each represents
  - **Matching**:
    - symbols are presented to subjects along with a list of all referents represented
    - Subjects match each symbol with its referent
    - $\Rightarrow$ *confusion matrix* : indicating number of times each symbol is confused with every other one
    - Also reaction time may be measured

SYMBOLS (cont.)

- Criteria for Selecting Coding symbols (cont)
  - **Preferences and Opinions**: subjects are asked to express their preferences or opinions about design of symbols
- Examples of Code Symbol Studies
  - Mandatory-Action Symbols
    - E.g.: “recognition” testing of symbols + training

Symbols of mandatory-action messages used in a study of recognition and recall of such symbols. The percentages below the symbols are the percentages of correct recognition, as follows: O = original test; R = recall 1 week later. (*Source: Adapted from Cairney and Siess, 1982, Fig. 1.*)

	1: Must use ear protection	2: Must use eye protection	3: Must use foot protection	4: Must use hand protection	5: Must use head protection	6: Must use breathing protection
O →	10%	20%	30%	50%	37%	13%
R →	73	96	100	97	97	97

SYMBOLS (cont.)

- Examples of Code Symbol Studies (cont.)
  - **Comparison of Exit Symbols for Visibility**:
    - Example of symbol recognition/matching
    - Note, Some “no-exit” symbols: perceived as “exit”!

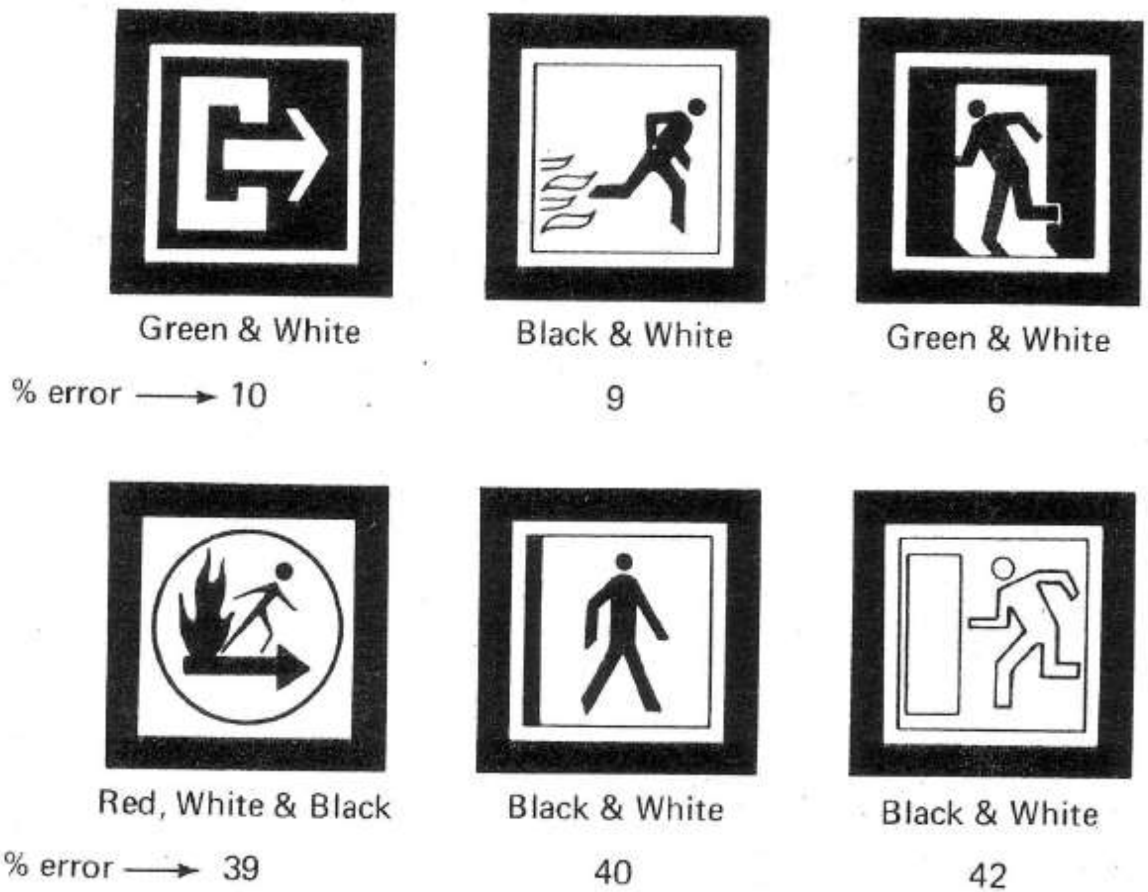


FIGURE 4-17
Examples of a few of the 18 exit signs used in a simulated emergency experiment, with percentages of errors in identifying them as exit signs. (*Source: Adapted from Collins and Lerner, 1983.*)

SYMBOLS (cont.)

- Examples of Code Symbol Studies (cont.)
  - Generalizations about features of signs
    - **Filled figures** superior to outline figures
    - **Square or rectangular backgrounds**: better identified than circular figures
    - **Simplified figures** (i.e. reduced number of symbol elements) are better than complex figures

SYMBOLS (cont.)

- Perceptual Principles of Symbolic Design
  - **Figure to Ground**: e.g. Direction must be clear
  - **Figure Boundaries**:
    - solid boundary better than outline boundary
  - **Closure**: figure should be closed (ie continuous)
  - **Simplicity**: include only necessary features
  - **Unity**:
    - Include text and other detail close to symbol

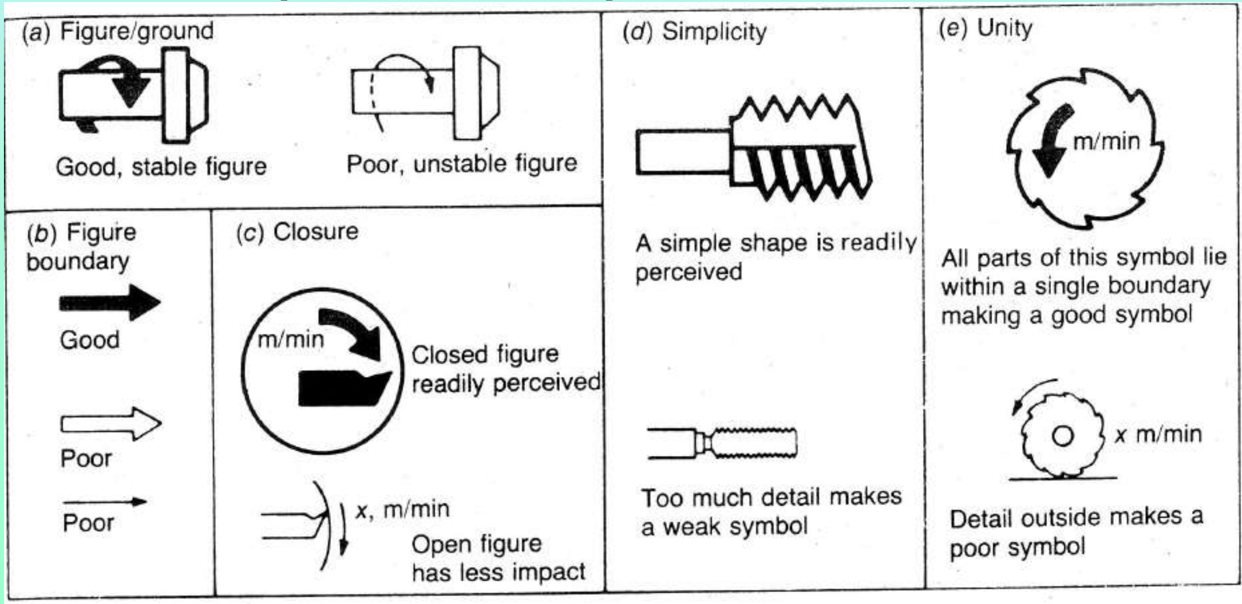


FIGURE 4-18
Examples of certain perceptual principles relevant to the design of visual code symbols. These particular examples relate to symbols used with machines. (*Source: Adapted from Easterby, 1970.*)

SYMBOLS (cont.)

- Standardization of Symbolic Displays
  - Symbols should be standardized if:
    - Used for **same referent**
    - Used by the **same people**
    - E.g. international road signs (below)

(*a*) Danger signs (*b*) Instruction signs (*c*) Information signs

FIGURE 4-19
Examples of a few international road signs. These are standardized across many countries, especially in Europe. Most of these signs are directly symbolic of their referents.

CODES

- Coding elements:
  - *Referents*: items to be coded
  - *Code*: sign/symbol used to indicate referent
  - *coding dimensions*: visual stimuli used (e.g. colors, shapes, sizes, numbers, letters)
  - codes could have
    - single dimension
    - or more than one dimension (*multidimensional*)

CODES (cont.)

- Single Coding Dimensions
  - Experiments done to see best dimension
  - Experiment: *Smith and Thomas*: varied
    - Shapes, geometric form, symbols, colors (below)
    - Mean time to count target class was measured
    - Color showed greatest superiority

Aircraft shapes	C-54	C-47	F-100	F-102	B-52
Geometric forms	Triangle	Diamond	Semicircle	Circle	Star
Military symbols	Radar	Gun	Aircraft	Missile	Ship
Colors (Munsell notation)	Green (2 5 G 5/8)	Blue (5 BG 4/5)	White (5 Y 8/4)	Red (5 R 4/9)	Yellow (10 YR 6/10)

CODES (cont.)

- Single Coding Dimensions (cont.)
  - Different coding dimensions differ in relevance for various tasks and situation
  - Table (right): guide to selecting appropriate visual code

TABLE 4-5
SUMMARY OF CERTAIN VISUAL CODING METHODS

(Numbers refer to number of levels which can be discriminated on an absolute basis under optimum conditions.)

Alphanumeric	Single numerals, 10; single letters, 26; combinations, unlimited. Good; especially useful for identification; uses little space if there is good contrast. Certain items easily confused with each other.
Color (of surfaces)	Hues, 9; hue, saturation, and brightness combinations, 24 or more. Preferable limit, 9. Particularly good for searching and counting tasks. Affected by some lights; problem with color-defective individuals.*†
Color (of lights)	10. Preferable limit, 3. Limited space required. Good for qualitative reading.‡
Geometric shapes	15 or more. Preferable limit, 5. Generally useful coding system, particularly in symbolic representation; good for CRTs. Shapes used together need to be discriminable; some sets of shapes more difficult to discriminate than others.‡
Angle of inclination	24. Preferable limit, 12. Generally satisfactory for special purposes such as indicating direction, angle, or position on round instruments like clocks, CRTs, etc.§
Size of forms (such as squares)	5 or 6. Preferable limit, 3. Takes considerable space. Use only when specifically appropriate.
Visual number	6. Preferable limit, 4. Use only when specifically appropriate, such as to represent numbers of items. Takes considerable space; may be confused with other symbols.
Brightness of lights	3–4. Preferable limit, 2. Use only when specifically appropriate. Weaker signals may be masked.‡
Flash rate of lights	Preferable limit, 2. Limited applicability if receiver needs to differentiate flash rates. Flashing lights, however, have possible use in combination with controlled time intervals (as with lighthouse signals and naval communications) or to attract attention to specific areas.

CODES (cont.)

- Color coding
  - Color is a very useful visual code
  - Q: What is # of distinct colors that normal color vision person can differentiate (absolute basis)?
  - Jones (1962) found that the normal observer could identify 9 surface colors
  - With training, people are able to identify around 24 colors
  - But when dealing with untrained people, it is wise to use a smaller number of colors
  - Color coding is very useful in "searching"/ "spotting" (as compared to other dimensions)
    - e.g. searching maps, items in a file, identifying color-coded wires
  - Note, color not universal "identification" code

CODES (cont.)

- Multidimensional codes
  - Recommended: no more than 2 dimensions be used together for rapidinterpretation
  - Certain combinations do not ‘go well’ together (see figure)
  - ⇒ not always more effective than single-dimension codes

Potential combinations of coding systems for use in multidimension coding. (*Source: Adapted from Heglin, 1973, Tables VI-6, VI-22.*)

	Color	Numeral and letter	Shape	Size	Brightness	Location	Flash rate	Line length	Angular orientation
Color		X	X	X	X	X	X	X	X
Numeral and letter	X			X		X	X		
Shape	X			X	X		X		
Size	X	X	X		X		X		
Brightness	X		X	X					
Location	X	X						X	X
Flash rate	X	X	X	X					X
Line length	X					X			X
Angular orientation	X					X	X	X	