King Saud University

College of Engineering

IE – 341: "Human Factors Engineering"

Spring – 2024 (2nd Sem. 1445H)

Human Capabilities

Part – A. Vision (Chapter 4)

Part 2 (a): Alphanumeric Displays

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Lesson Overview: Vision

Part 1:

- 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 (this part):

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

Alphanumeric Displays

Alphanumeric Displays

Most important characteristics:

- **Visibility**:
  - quality of the character that makes it separately visible from its surroundings (i.e. **detectability**)

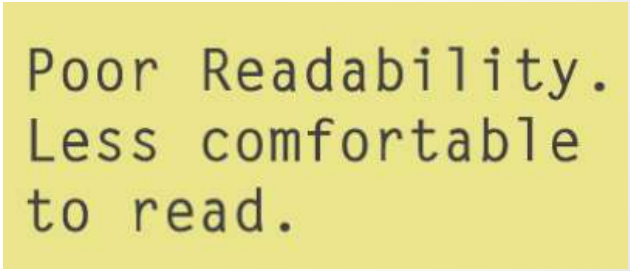
- **Brinton charts 14 degrees of visibility [Brinton, 1939]**
- **most legible: black type on a yellow background**
- **least legible (most offensive): blue type on red**

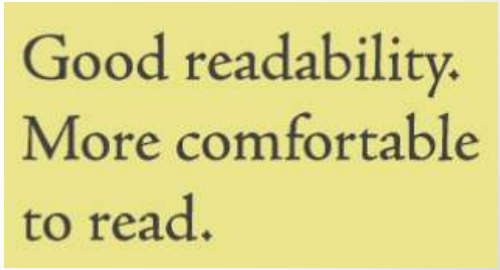
Alphanumeric Displays

Most important characteristics:

- **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, margins, etc. than on specific features of characters
  - watch this video about legibility and readability: https://youtu.be/74sZJ4b0_Lc

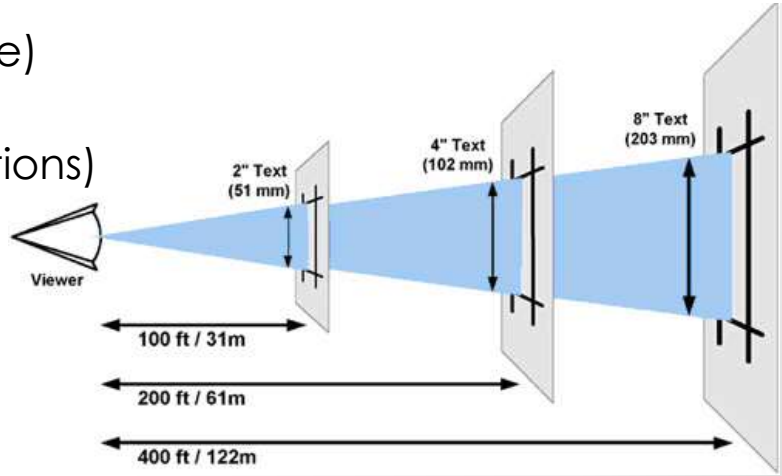




Alphanumeric Displays: Typography

- **Typography**:
  - various features of alphanumeric displays
  - "art of arranging letters and text to make written language legible, readable, and appealing"

- Circumstances when it is important to use preferred (i.e. optimum) forms of typography:
  - viewing **conditions** are **unfavorable** (e.g. poor 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 points must also still satisfy all conditions mentioned in last 2 slides
  - when faced with ≥ 1 of these conditions, the following typography features must be considered (next slide):

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
  - Def^{n}: ratio of the thickness of the stroke (*s*) to the height (*h*) of the letter/number (we will call it "stroke ratio" for short)

- Example (right):
  - stroke width-to-height ratio: 1:5 = 0.2
  - note, width-to-height ratio: 3:5 = 0.6

- Stroke width is affected by:
  - background:
    - black on white or
    - white on black
  - illumination

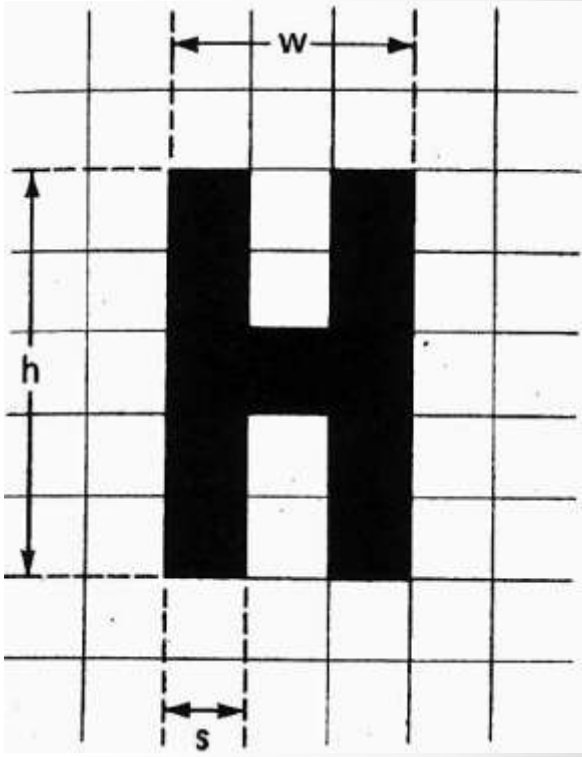
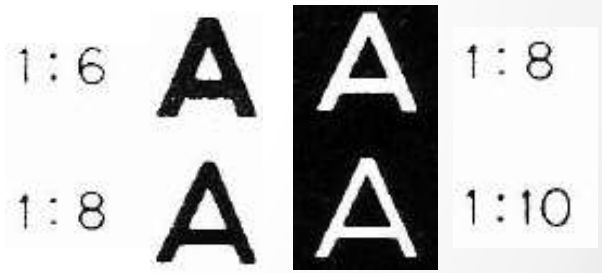


FIGURE 4-6
Dimensions used to compute stroke width-to-height and width-to-height ratios. Ratios can also be expressed as a proportion, e.g., 1:10 = 0.10. The letter shown has a stroke width-to-height ratio of 1:5 (0.20) and a width-to-height ratio of 3:5 (0.60).

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

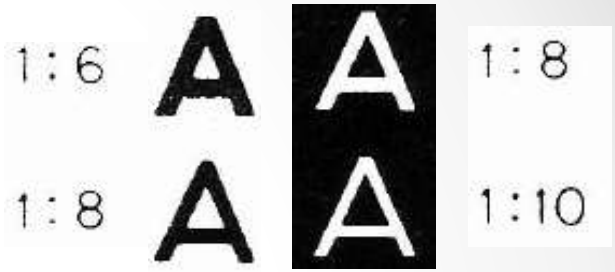
- Irradiation:
  - causes **white** features **on** a **black** background to appear to '**spread**' into adjacent dark areas (see below)
  - but reverse (**black on white**) isn't true (i.e. no spread)

  - thus, black-on-white letters should be thicker, i.e. lower ratios than white-on-black letters



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

- Some generalizations (good contrast) [Heglin,1973]:
  - with good illumination, use stroke 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

  - Summary: next slide

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

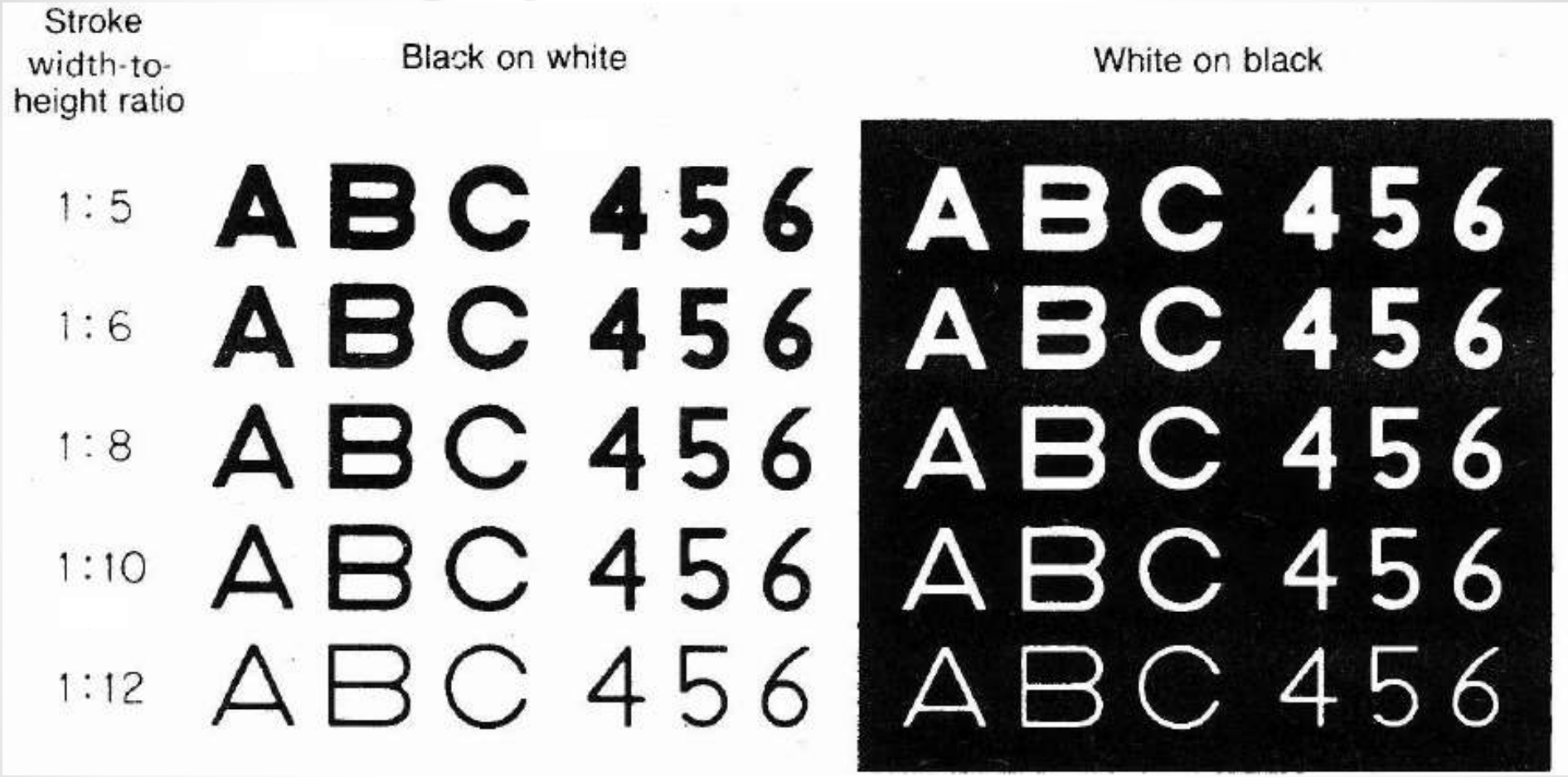
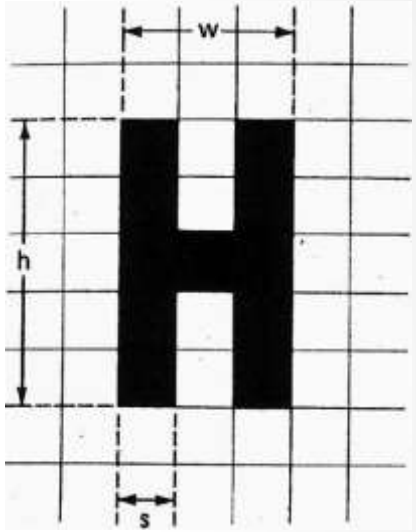


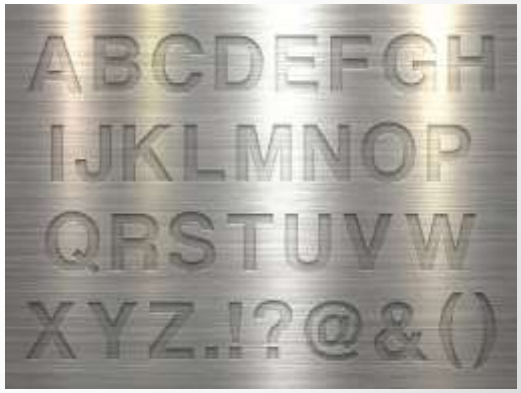
FIGURE 4-7
Illustrations of stroke width-to-height ratios of letters and numerals. With reasonably good illumination, the following ratios are satisfactory for printed material: black on white, 1:6 to 1:8; and white on black, 1:8 to 1:10.

A-N Displays: 2. Width-height ratio

- Width-to-height (aka width-height) ratio:
  - relationship between width (*w*) and height (*h*) of alphanumeric character
  - expressed as ratio (e.g. 3:5 = 0.6)
  - e.g. **B**: width-height ratio = 3:5
    - 3 vertical strokes (or layers/elements)
    - 5 horizontal strokes



  - most letters can be expressed with ratio 3:5
  - *Heglin* [1973]:
    - disagrees with fixed ratio for all letters
    - instead, adjust width to basic geometric forms
    - e.g. for O: perfect circle ("Century Gothic" font), i.e. stroke ratio = 1:1
    - e.g. for A and V: equilateral triangles
    - wider letters: appropriate certain circumstances e.g. engraved legends
    - such cases: 1:1 ratios are more appropriate (next slide)



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

- Cont. width-height ratio:

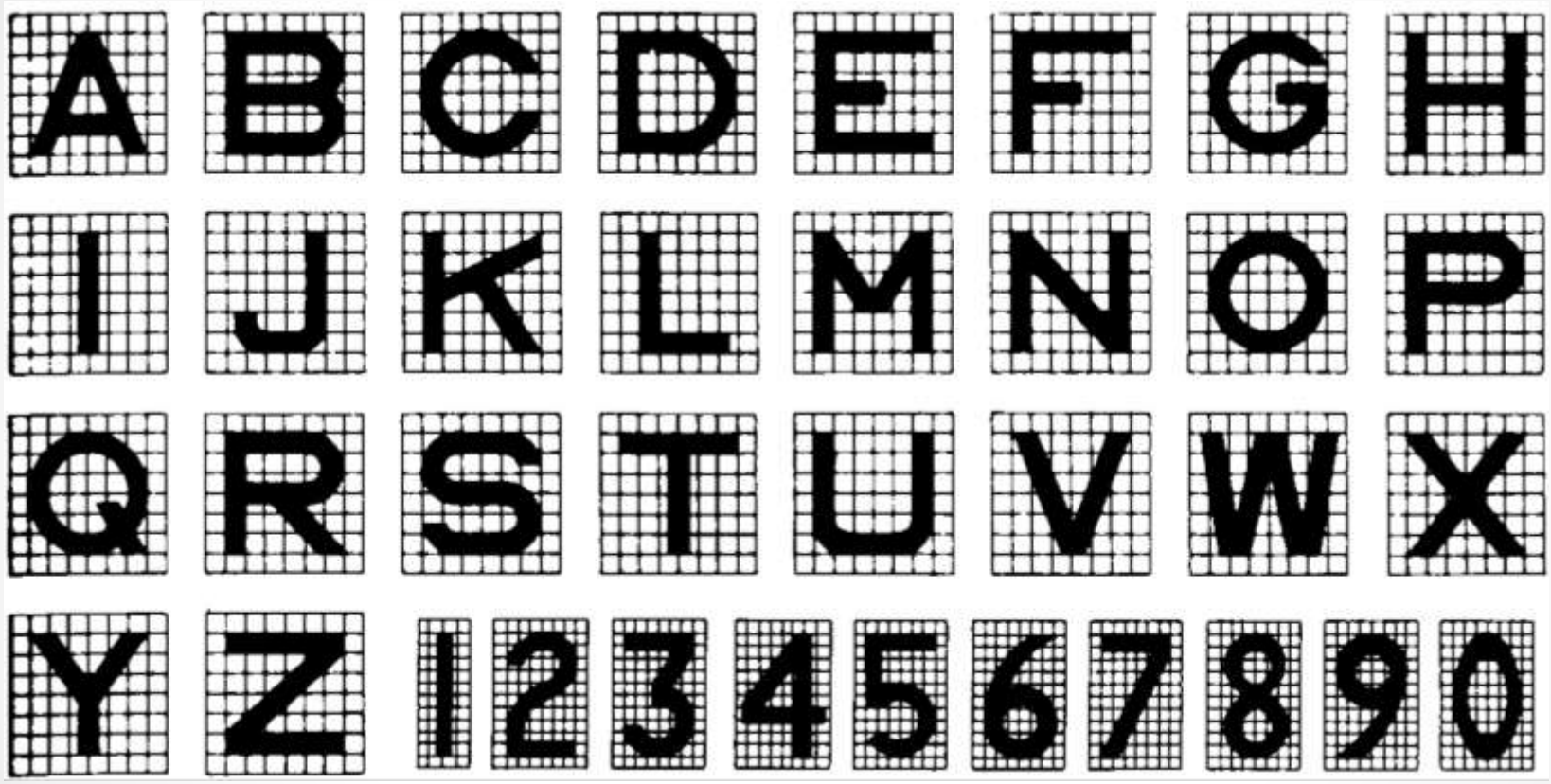
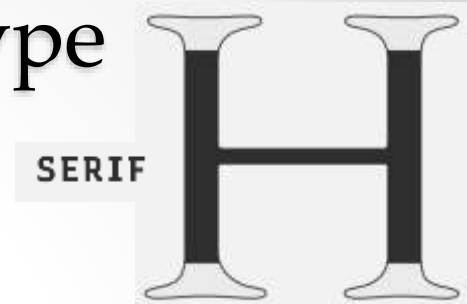


FIGURE 4-8
Letter and numeral font of United States Military Specification no. MIL-M-18012B (July 20, 1964); also referred to as NAMEL (Navy Aeronautical Medical Equipment Laboratory) or AMEL. The letters as shown have a width-height ratio of 1:1 (except for I, J, L, and W). The numerals have a width-height ratio of 3:5 (except 1 and 4).

A-N Displays: 3. Styles of Type

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

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



II. **Sans serif** (aka Gothic):
uniform stroke width; e.g. Calibri, Arial);

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

IV. ***Block Letter:*** resembles German manuscript handwriting used in the 15th century

- watch following video on origins of typeface:
- http://youtu.be/GUCcObwlsOs

A-N Displays: 3. Styles of Type (Cont.)

- Roman:
  - most used styles for conventional text (e.g. Times New Roman since 1931)


Monday, Octobe

A NEW FACE

issioned Morison Morison imes for phically s super- y Victor depart- an older design, conomy or news- wspaper

The **Times of London** debuted the new typeface, & after one year the design was released for commercial sale. The *Linotype* version, called simply "Times," was optimized for line-casting technology, though the differences in the basic design are subtle. The typeface was *very* successful for the Times of London, which used a *higher grade of newsprint than most newspapers*. The better, whiter paper enhanced the new typeface's high degree of **contrast** and sharp serifs, and created a sparkling, modern look. In 1972, Walter Tracy designed TIMES EUROPA for The Times of

a

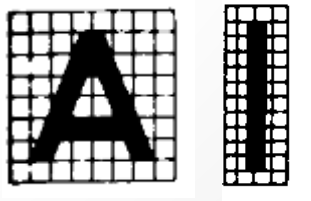
***bold**, lower-case "a"*

a

- *Italics:*
  - *emphasis, titles, names, special words, etc*
- **Boldface:**
  - **headings, labels, special emphasis**
  - **to aid legibility in poor reading conditions**

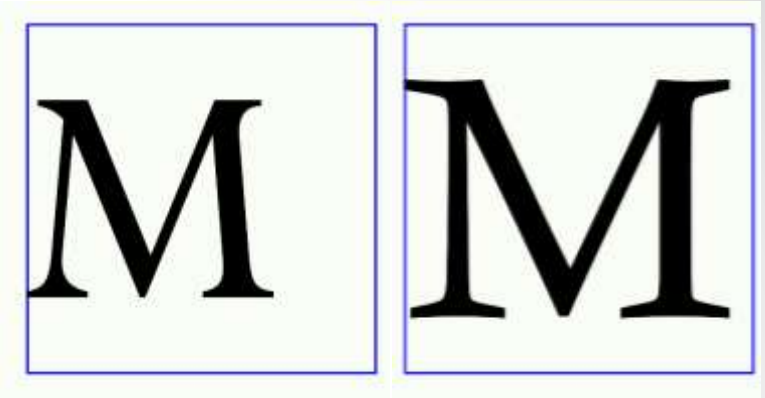
Normal
Bold
Italic
Bold italic

- Type style shown:
  - consists of uppercase letters, numbers
  - used words and abbreviations in labels
  - it is a non-standard font



A-N Displays: 4. Character Size

- Size
  - important to measure size of typeface in printing business
  - measured in points
  - 1 point (pt.) = 1/72 in. = 0.0139 in. (0.35 mm)
  - note, point size refers to the height/size of the font (not the height of the letter)
  - it is also called “slug”, or "em" size
  - em size: defined as the width of the capital ‘M’



Width of a capital ‘M’ is less than an ‘em’ wide

- each box is one em square
- M on the left is in Perpetua (relatively narrow characters)
- M the one on the right is in Calisto (relatively wide characters)

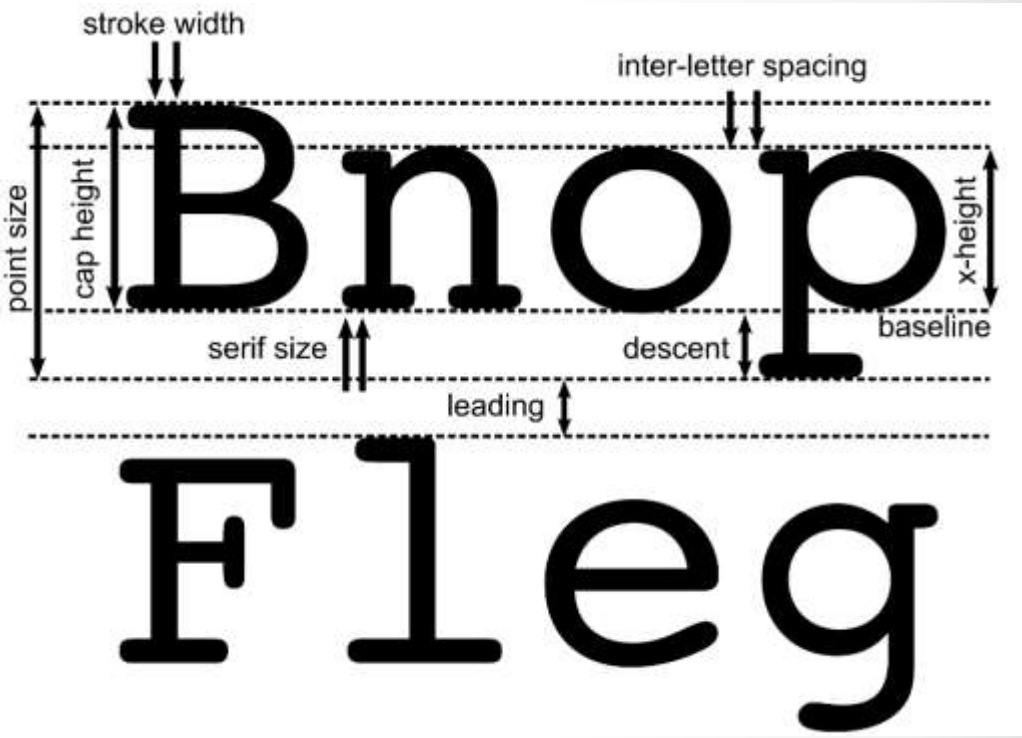
Source: The point of point sizes Philip Rothman (2022)

Academico **Century Schoolbook** **Helvetica** **Palatino** **Times New Roman** **Minion Pro** **Cailbri**

(all have the same point size)

A-N Displays: 4. Character Size

- Size (cont.)
  - height of the "*slug*" on which the type is set includes:
    - tail of the letter, e.g. "q" (called *descender*)
    - top of letter, e.g. "h" (called *ascender*)
    - space between lines of text
    - capital letters
  - so pt. size is not a good approximation of letter size
  - authors (Sanders/McCormick) suggest to unify pt. size by using height of capital letters as alternative approximation to letter size:
    - **1 pt = 1/100 in.** = 0.01 in. (0.25 mm)



A-N Displays: 4. Character Size

- Size (cont.)
  - 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).

This line is set in 14-pt type (slug = 0.194; letters = 0.14).

This line is set in 16-pt type (slug = 0.222; letters = 0.16).

This line is set in 18-pt type (slug = 0.25; letters = 0.18).

This line is set in 22-pt type (slug = 0.306; letters = 0.22).

This line is set in 30-pt type (slug = 0.417; letters = 0.30).

This line is set in 40-pt type (slug = 0.555; letters = 0.40).

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

a) For Close-Up Reading:

- normal reading distance (e.g. book)
  - 12 – 16 in. (30.5 - 40.6 cm)
  - **14 in.** (35.5 cm): **nominal reading distance**

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

- type size in most printed material
  - from 7 to 14 pt.
  - most common (e.g. newspapers): 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
  - critical use
  - characters can change (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)

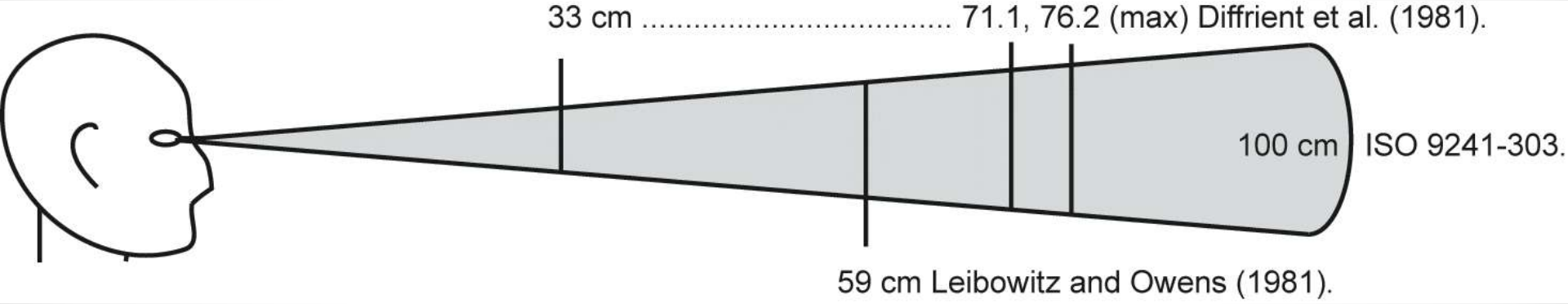
* For other viewing distances (D), in inches, multiply tabled values by D/28.
Source: Adapted from Heglin (1973) and Woodson (1963).

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

b) For Distance Reading:

- readability and legibility of alphanumeric characters are equal at various distances, provided that:
  - as viewing distance increases ⇒
  - characters size increases (and vice versa), and
  - VA subtended at the eye stays the same

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



Recommended reading distances (different studies):

- For reading displays: *Diffrient* et al. [1981] suggest: 33 – 71.1 cm (with absolute max. of 76.2 cm)
- *Van Cott and Kincade* [1972] also suggest 71 cm (as this is a reachable arm length)
- Leibowitz and Owens [1975]: a good reading distance is about 59 cm as the resting state of the eyes

Source: Normark, Gärling (2015)

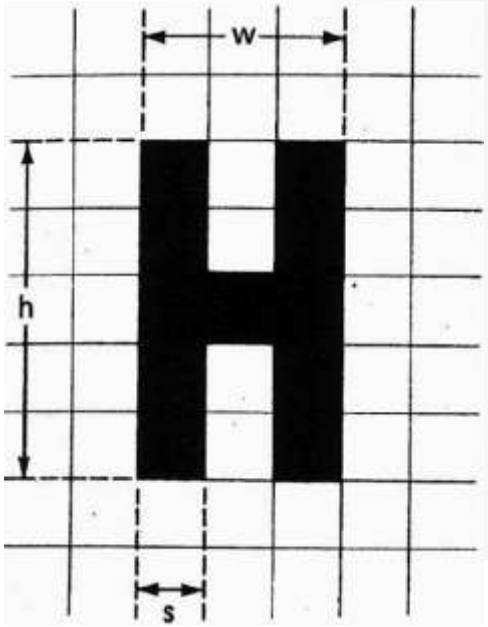
A-N Displays: 4. Character Size (Cont.)

b) For Distance Reading (cont.):

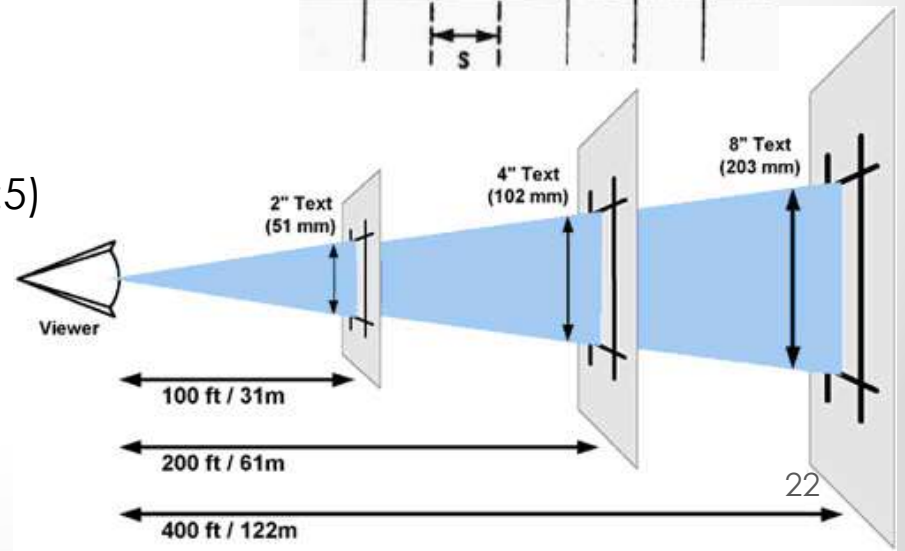
- formula [*Howett, 1983*]: for finding stroke width/height of letters as function of distance and Snellen visual acuity:

$$W_s = 1.45 * 10^{-5} * S * d$$

$$H_L = W_s / R$$



- 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)



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

b) For Distance Reading (cont.):

- for low illumination, low contrast ⇒ use large letters
- design signs for people with Snellen acuity at best: 20/40 (see below)
- table below shows how to use this formula
  - to find recommended letter height, H_L
  - for various stroke width-to-height ratios, *R*
  - at various distances, *d* (in., ft.)
  - using a Snellen acuity score, *S* of 20/40

$$W_s = 1.45 * 10^{-5} * S * d$$
$$H_L = W_s / R$$

TABLE 4-3
RECOMMENDED LETTER HEIGHTS (IN INCHES) FOR VARIOUS STROKE WIDTH-TO-HEIGHT RATIOS AT VARIOUS DISTANCES*

Stroke width-to-height ratio	Distance				
	28 in	10 ft	20 ft	100 ft	1000 ft
1:6 A	0.097	0.418	0.835	4.175	41.75
1:8 A	0.130	0.557	1.114	5.570	55.70
1:10 A	0.162	0.696	1.392	6.960	69.60

* Letter heights computed using formulas presented in the text and assuming a Snellen acuity score of 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)
    - study by *Moriarty* [1984] : *high*-density (close-set) letters were read *faster* than *regular-spaced* letters (see figure below)
    - reason: more characters viewable in quality visual field (i.e. fovea) at each fixation

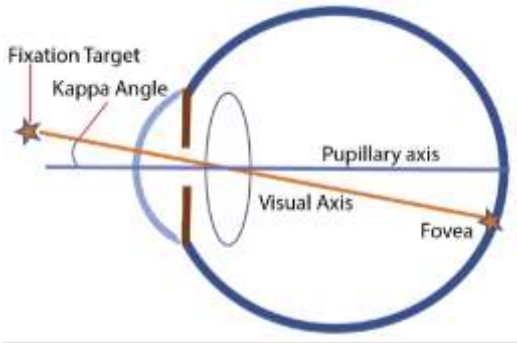
FIGURE 4-9
Portions of an advertising brochure used in a study of reading speed of regularly spaced types and of close-set (high-density) type. The close-set type was read more rapidly.

Regular spacing of text type (regular density)

The ESS Performance Series is both a choice and a statement. The choice is to continue ESS's long tradition of excellence by trimming costs without

Close-set text type (high density)

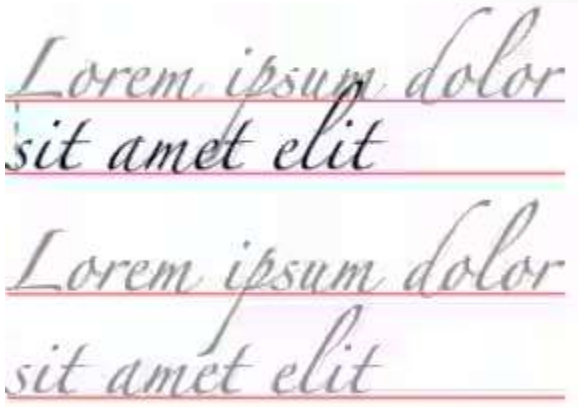
The ESS Performance Series is both a choice and a statement. The choice is to continue ESS's long tradition of excellence by trimming costs without sacrificing performance and by omitting



A-N Displays: 5. Layout of Characters

- Layout of characters influences reading (cont.):
  - Interline Spacing:
    - more spacing ⇒ increased text clarity
    - less spacing ⇒ eye strain, headache
    - see examples below

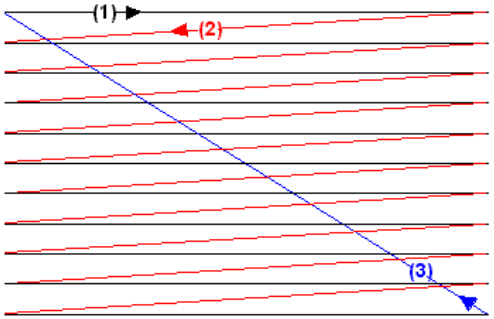
The interline spaces are too small between some of the lines. Why so? This is the continuation of the text.



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 (several studies)
  - reason:
    - dot-matrix VDT: composed of 1000's of pixels "**pic**ture **el**ement**s**" (1960's)
    - horizontal line of pixels form "raster scan" or scan lines
    - pixels are lit (i.e. turned "on" and "off") to form images
    - e.g. 640 * 480 VDT screen: 480 lines by 640 pixels
    - higher "resolution" (e.g. 1920 *1080) ⇒ more pixels per image ⇒ less difference between reading from VDT vs. hardcopy
    - lower resolution (or old VDT): poor accommodation



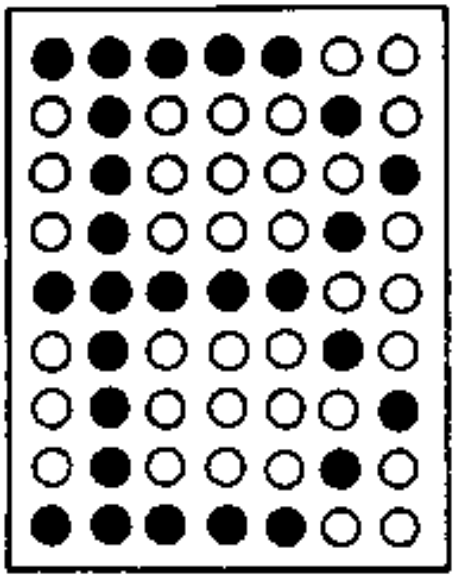
A-N Displays: 6. Illuminated AN Characters

- Dot-Matrix displays:
  - characters made up of a matrix of pixels
  - individual character: matrix 5 * 7 (i.e. 5 columns * 7 rows) 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

  - smaller matrices (e.g. 5 * 7):
    - individual matrix pixels are visible
    - ⇒ reading is affected

  - larger matrices:
    - individual pixels: not distinct
    - ⇒ performance improves

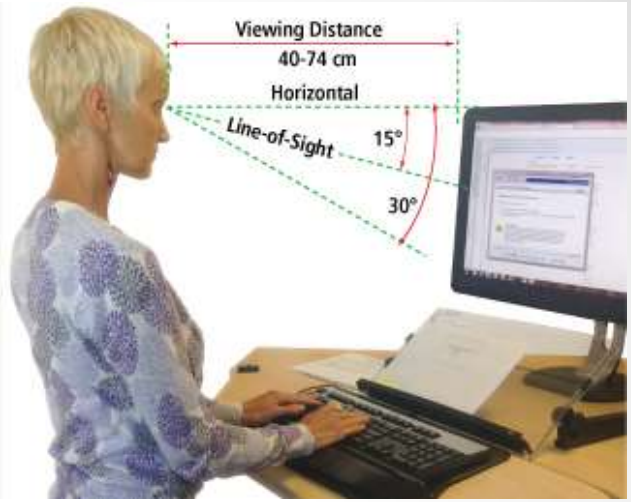


7 X 9 dot matrix

FIGURE 4-10
Example of a dot-matrix letter. All letters and numerals can be formed from combinations of the dots.

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

- Distance
  - VDT viewed normally farther than hardcopy text
  - eye-to-screen distances (studies in 1980's):
    - 24 – 36 in. (61 to 93 cm)
    - mean: 30 in. (76 cm)
  - ANSI standard (1988):
    viewing monitor in an upright position,
    - screen should be placed
      at about distance:
      18 – 20 in. (45 to 50 cm)
    - and since people don't usually sit in an
      upright posture,
      we will take **nominal VDT reading distance**:
      20 in. (50 cm):
    - compare this with
      nominal reading distance for hardcopy



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

- Size
  - at 20 in. nominal reading distance (several studies):
    - recommended minimum subtended VA = 11 – 12 min. of arc
    - ⇒ character height = 0.06 – 0.07 in. (1.5 to 1.8 mm)
    - this is smaller than for hardcopy (0.09 – 0.11 in.)

  - ANSI (1988): size for high legibility reading for capital letter (@ 20 in.) :
    - minimum VA: 16 min. ⇒ height = 0.09 in. (2.3 mm)
    - preferred VA: **20 – 22 min.** ⇒ **0.116 – 0.128 in.** (2.9 – 3.3 mm)
      note, these are closer to hardcopy reading heights
    - maximum VA: 24 min. ⇒ 0.14 in. (3.6 mm)
      - this is threshold height for *comfortable* reading
      - reason: when character size increases
        ⇒ more foveal fixation is required
        ⇒ more fixations are required to read a sentence

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

References

- **Human Capabilities - Vision**
  - ***Human Factors in Engineering and Design***. Mark S. Sanders, Ernest J. McCormick. 7th Ed. McGraw: New York, 1993. ISBN: 0-07-112826-3.