HUMAN FACTORS ENGINEERING: DESIGN OF MEDICAL DEVICES

Lecture 2

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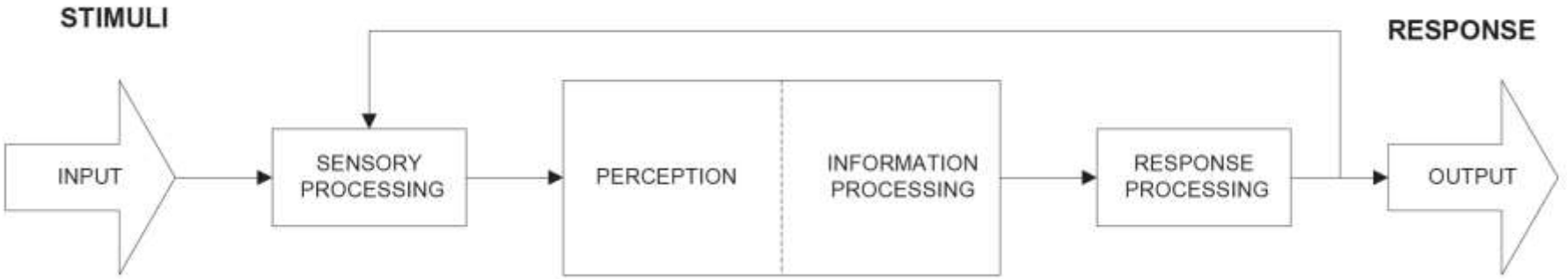
Basic human skills and abilities

- Flow of how humans sense, perceive, process, and respond to the world around them



- Vision and visual perception
- Audition and speech
- Sensation
- Information (cognitive) processing & Memory
- Human response capabilities
- Human vs. machine trade-offs

Vision

- Visual threshold
  - Minimum light level in which an object can be visually identified
  - Rod vision: most sensitive to shades of B&W
  - Cone vision: sensitive to color and operate best under higher light levels
- Visual acuity (static vs. dynamic)
  - minimum distinguishable (detection of detail in an arbitrary test target)
  - minimum perceptible (detection of a spot, e.g., on MRI image)
  - minimum separable (detection of a gap between parts of a target)
  - stereoscopic acuity (detection of depth for a 3D target)
  - Vernier acuity (detection of lateral displacement of one line from another).

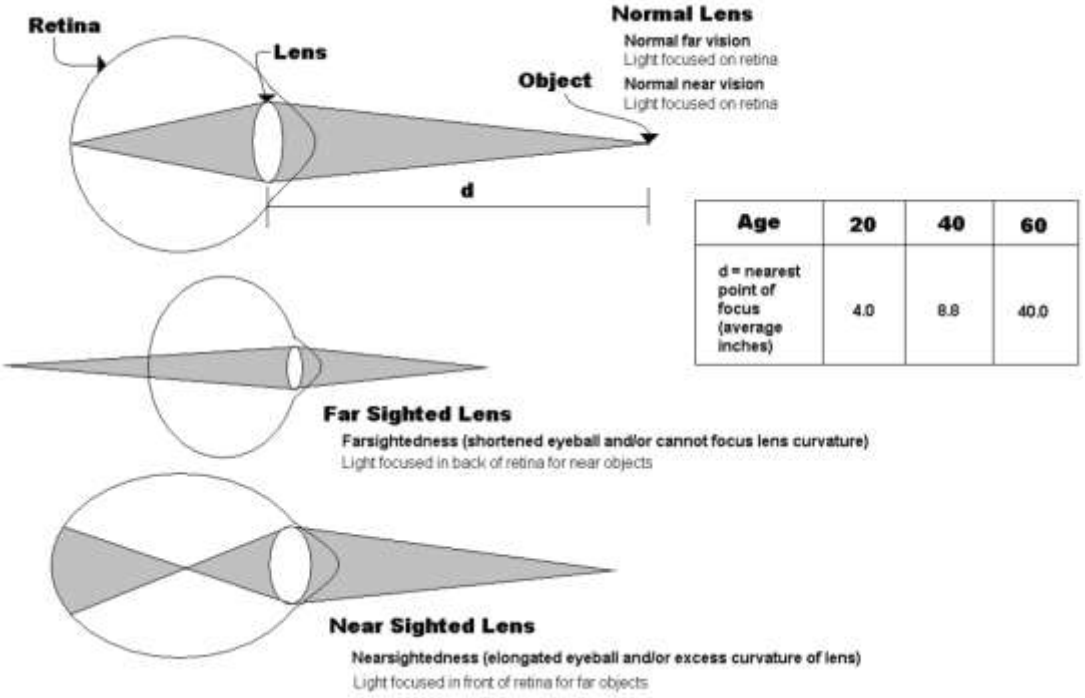
Vision

Table 6.1—Factors that affect visual acuity

Factor	Positive example	Negative example
Amount and kind of illumination	Bright operating room light	Glare from outside light on intravenous (IV) pump screen
Viewing time	Momentary occlusion message on IV pump screen	Long time period for viewing pulse oximeter readings
Object contrast with background	Yellow numbers showing pulse rate on a dark-background patient monitor	Yellow trace lines of respiratory rate on a white-background patient monitor
Object size (visual angle)	Large font indicating On/Off for a ventilator power switch	Small print on a catheter package label indicating French size
Object color	Flashing visual alarm signal on an enteral pump indicating it is empty	Lettering in pale pastel colors indicating length of a nasogastric tube
Direction of viewing (position of the image on the retina)	Patient monitor screen placed at a 45° angle above a patient's bed	Patient-controlled analgesia (PCA) pump placed on the bottom of an IV pole
Movement of the object or viewer	Stationary IV pump screen	Heart monitor vibrating because of the motion in an ambulance
Accommodation or focusing abilities of the viewer's visual system	Large-screen monitor (more than 17 inches) for an ultrasound machine	Fatigued user of a patient monitor
Optical alignment of both eyes or convergence abilities	Ability of a surgeon to accurately judge the depth of cutting with a scalpel	Surgeon attempting to judge distance from a laparoscopic pincer by looking at a video monitor
Dark adaptation	Ambulance driver reading red gauges while driving at night	Clinician trying to find a central line in a darkened patient room after entering from a brightly lit hallway

Vision

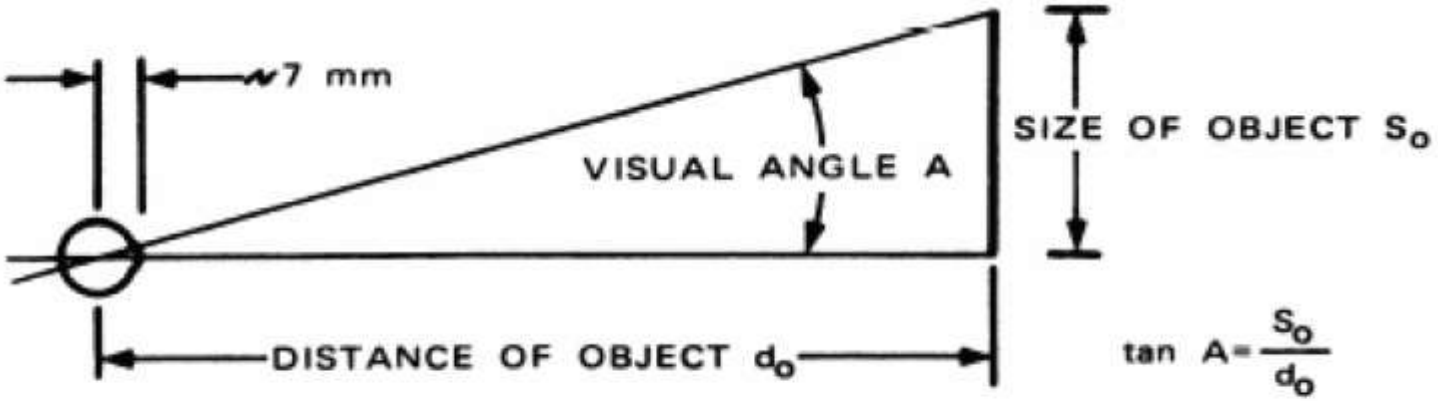
- Focusing abilities
  - Deficiencies: myopia, hyperopia or presbyopia, and astigmatism
  - Necessitate increased text and image size and higher contrast on labels, displays, and written documentation



Age	20	40	60
d = nearest point of focus (average inches)	4.0	8.8	40.0

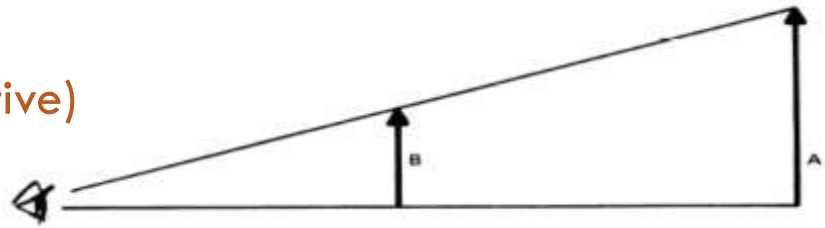
Vision

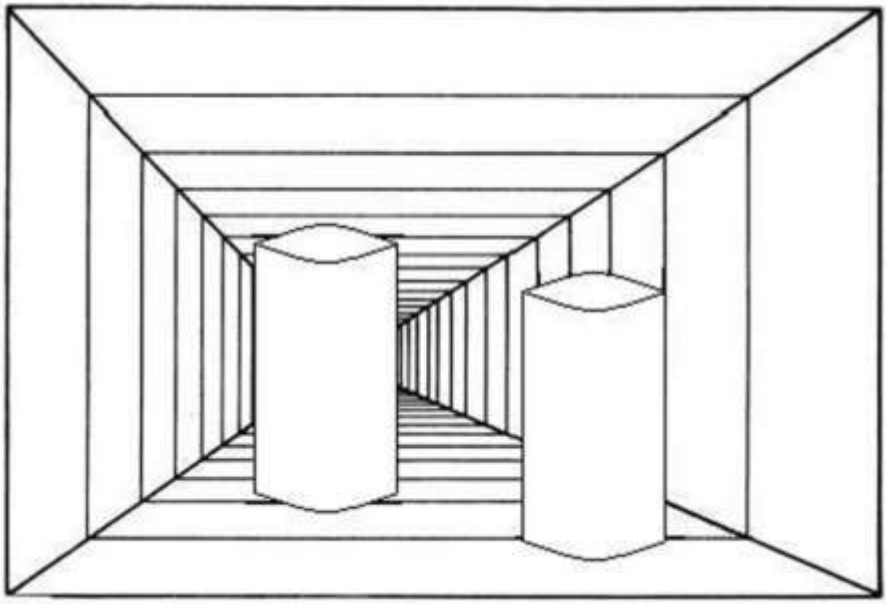
- Visual angle
  - Visual angle subtended on the retina
  - Preferred angle for reading English text is 20 to 22 minutes of arc
  - Marginally acceptable angles range from 16 to 18 minutes of arc, with 12 minutes considered the threshold of readability

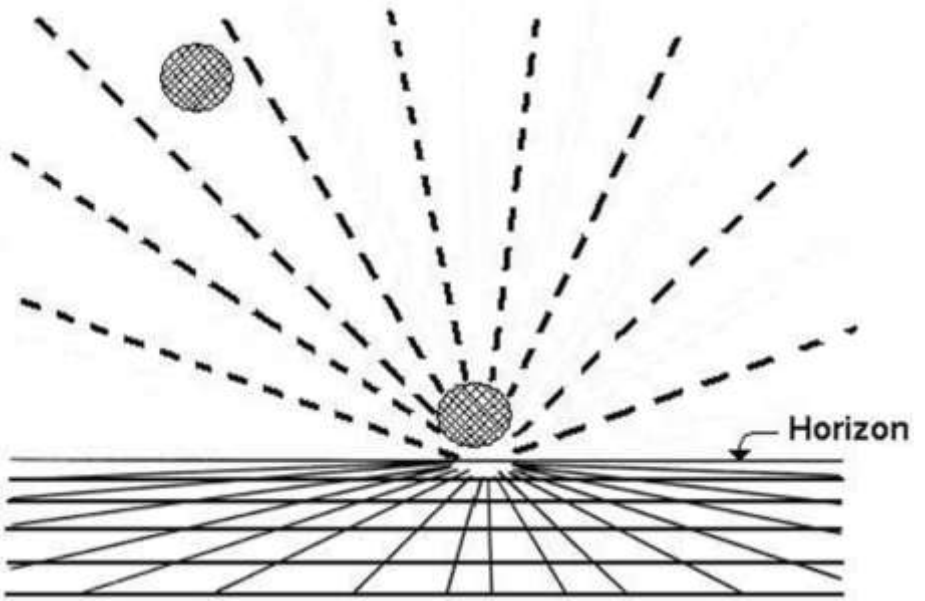


Vision

- Visual perception
  - Distance and perceived size (perspective)
  - True object size
  - Object size and distance misperceptions







Vision

- Minimum type size

Character height (inches) = Distance (minutes of arc)/(57.3 x 60)

Font size (points) = Character height (inches)/0.013837

Table 6.2—Recommended character height and corresponding font sizes for various reading distances[1]

Character height (inches)[2]	Reading distance (inches)	Visual angle (minutes of arc)		Font size (points)[3]
0.112	16	24		8
0.168	24	24		12
0.251	36	24	Upper size limit	18
0.838	120	24		60.5
1.257	180	24		91
0.102	16	22		7.5
0.154	24	22		11
0.230	36	22	Preferred (upper bound)	16.5
0.768	120	22		55.5

Vision

- Common visual illusions
  - Parallax error: apparent change in the position of an object, such as a meter reading, because of changes in the observer's line of sight

Viewing from the left

Viewing from the right

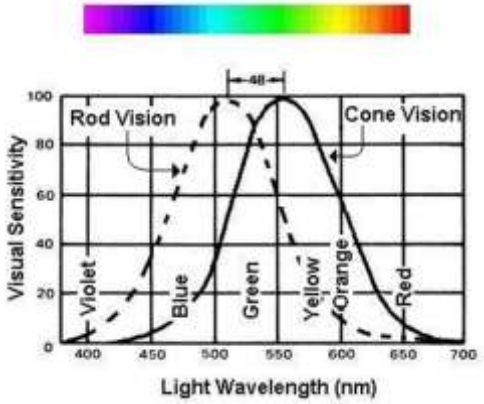
- Perception of motion
  - Apparent motion in TV, movies
  - Phi phenomenon: successive flashes of individual lights arranged in a row

Vision

- Flickering lights
  - Long (> 20 min) perception of flicker causes visual fatigue and annoyance.
  - Frequency at which a flashing light is perceived as having a continuous intensity level is called the critical fusion frequency (CFF)
  - CFF increases with increasing average light intensity and with decreasing proportion of the light–dark cycle occupied by the flash (duty cycle)
  - CFF varies from 2 Hz up to 50 or 60 Hz for high-intensity light sources
- Photosensitive epilepsy
  - Light flashing at a certain speed or a computer monitor's flicker can trigger seizures
  - Flicker frequencies between 4 and 60 Hz can trigger seizures (peak sensitivity is 20 Hz)
- Display flicker
  - LCDs have no flicker and are preferable to CRTs for seizure patient rooms

Vision

- Color Vision
  - Approximately 8% of males and 2% of females have some degree of deficient color vision
  - Relative visibility of colors for rod and cone vision



- Color coding
  - For people with normal color vision, up to eight saturated surface colors (excluding B&W) can be used for color coding with practically error-free discrimination
  - Fewer colors are less of a memory demand
  - Higher error rates occur for color coding with more than eight colors
  - In any color-coding scheme, colors should subtend a visual angle of at least 15 min
  - Color should be a redundant information source and never the only means of coding

Vision

- Recommendations for printed colors

Table 6.4—Recommended printed color codes using the Munsell Color System

8-color code		7-color code		6-color code		5-color code		4-color code	
n[1]	p[1]	n	p	n	p	n	p	n	p
1R	999	5R	1008	1R	999	1R	999	1R	999
9R	892	3YR	890	3YR	890	7YR	884	1Y	946
1Y	946	5Y	1128	9Y	1131	7GY	960	9G	1099
7GY	960	1G	1103	5G	1101	1B	1093	1P	1135
9G	1099	7BG	1095	5B	1087	5P	1007		
5B	1087	7PB	1133	9P	1005				
1P	1135	3RP	1003						
3RP	1003								

Color description	Wavelength (nanometers)	RGB Values		
		R	G	B
Red	642	255	12	0
Burnt Orange	610	255	137	0
Orange	596	255	192	0
Yellow	582	255	247	0
Yellow-Green	556	168	255	0
Green	515	18	255	0
Light Green	504	0	255	76
Cyan	494	0	255	204
Pale Blue	476	0	184	255
Medium Blue	430	28	0	255

- Recommendations for colored lights

Color discrimination	Colors recommended
Easiest	Red and green lights are easiest to recognize by color normal individuals.
Easiest	The best set of three colors is red, green, and white
Easier	White light is the next easiest to recognize.
Difficult	Yellow (or orange) is the last recognized.
More difficult	Blue and green lights are very difficult to differentiate far away (e.g., more than 10 feet away).
Most difficult	Yellow, white, and orange lights are the most difficult to differentiate far away (e.g., more than 10 feet away).

Vision

- Recommendations for color combinations (legibility and visibility)
  - Black on white (most legible)
  - Black on yellow (most attention gained)
  - Green on white
  - Red on white
  - White on blue

  Combinations of pure red and green or red and blue are not satisfactory.
- Visibility of colors under typical lighting conditions
  - Yellow (most luminous and visible)
  - Orange and red-orange (maximum attention value)
  - Blue (likely to be out of focus and indistinct)

  Red on blue or blue on red should be avoided because each focuses differently on the retina and creates an induced 3D effect called chromosteriopsis

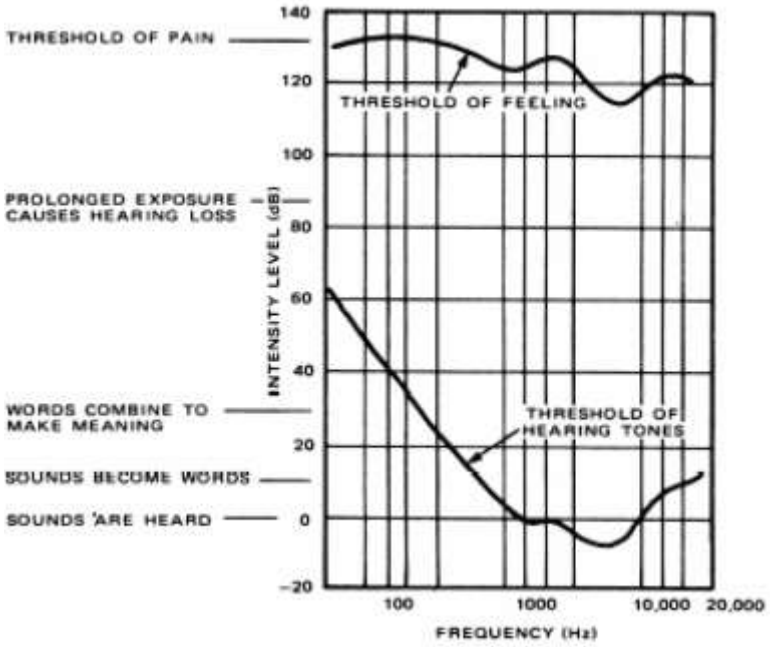
Vision

- Visibility under low lighting conditions
  - Red and orange are poorly visible under low-light conditions and should be avoided
  - Blue, green, and yellow are good color choices because they are equally visible under both low and higher light conditions
  - Under low-light conditions, blues and cyan colors are more visible

  Under lower-light conditions, there is a shift in color sensitivity toward the blue end of the color spectrum

Audition

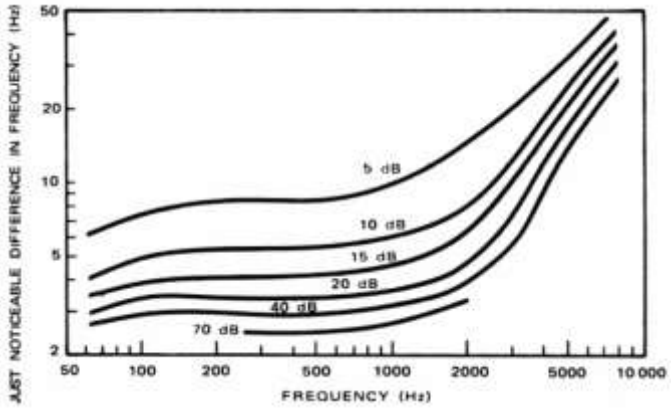
- Loudness measurements
  - Phones (loudness level): Phones are a measure of tone intensity computed as Sound Pressure Level (SPL) in dB of a standard 1000 Hz tone
  - Sones (loudness): Sones are a measure of relative sound intensity whereby 1 sone is the loudness of a 1000 Hz tone at 40 dB SPL

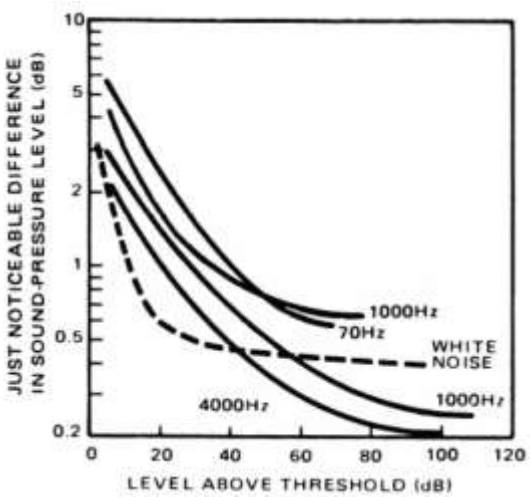


	SPL (dB)	Loudness (sones)
Patient room at night (EPA recommended)	35	< 0.5
Residential inside, quiet	42	1
Patient room during day (EPA recommended)	45	1.3
Household ventilating fan	56	7
Automobile 50 feet away	68	14
Typical patient room (peaks)	70	24
Anesthesia equipment (peaks)	76	54
Intensive care unit (peak sound levels)	80	74
IV pump auditory-alarm signal	85	99
Hospital beeper	89	127
Operating room (peaks)	90	164
MRI	95	222
Punch press 3 feet away	103	350
Nail-making machine 6 feet away	111	800
Pneumatic riveter	128	3000

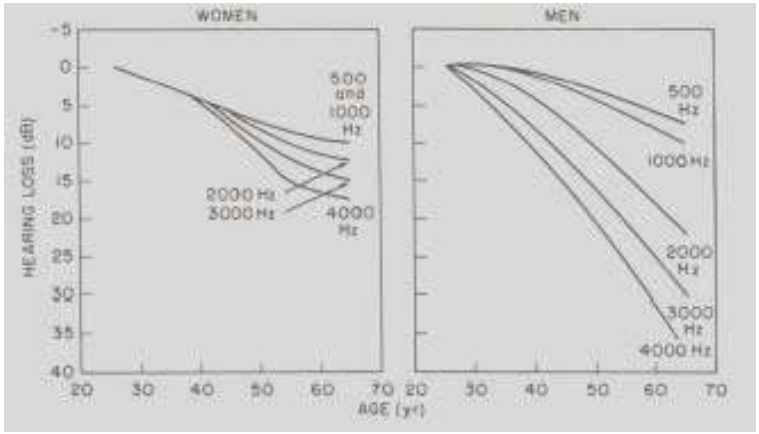
Audition

- Hearing thresholds





- Effects of aging on hearing sensitivity



Speech

- Loudness levels of speech

Table 6.8—Sound-pressure levels of speech 1 meter from a speaker

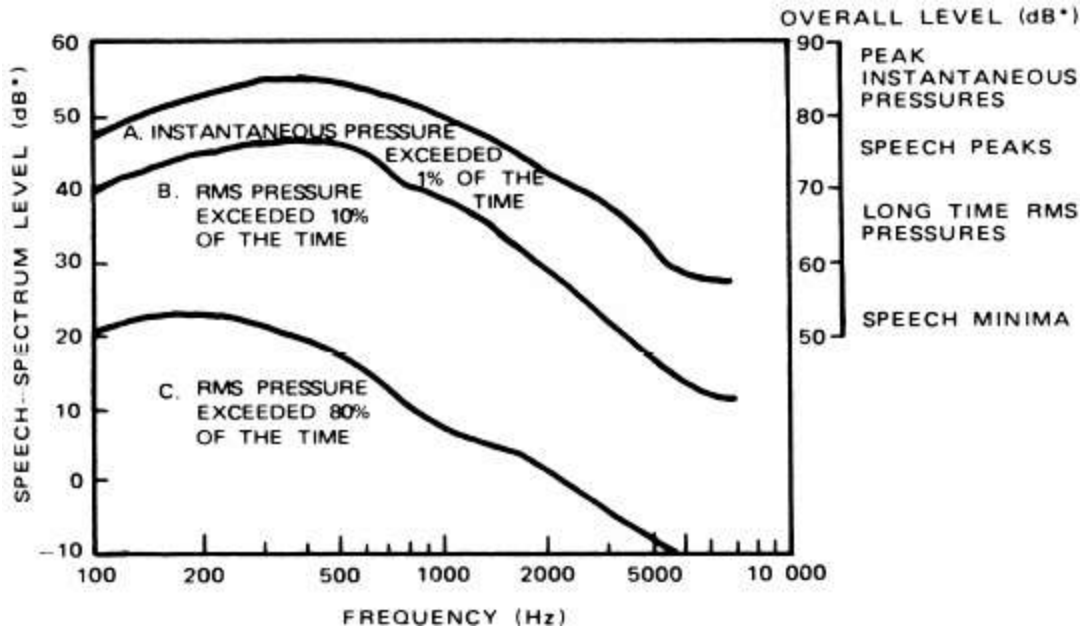
Measure of sound pressure	Whisper (dB)	Normal level (dB)			
		Minimum	Average	Maximum	Shout
Peak instantaneous pressure	70	79	89	99	110
Speech peaks	58	67	79	87	98
Long-time root mean square (RMS) Pressures	46	55	65	75	86
Speech minimum	30	39	49	59	70

Table 6.9—Distributions of speaking volume for persons using the telephone

Percentage of speakers	Volume level range (dB)[1]	Percentage of speakers	Volume level range (dB)[1]
7	Below 54	17	66 to 69
9	54 to 57	9	69 to 72
14	57 to 60	4	72 to 75
18	60 to 63	~0	Above 75
22	63 to 66		

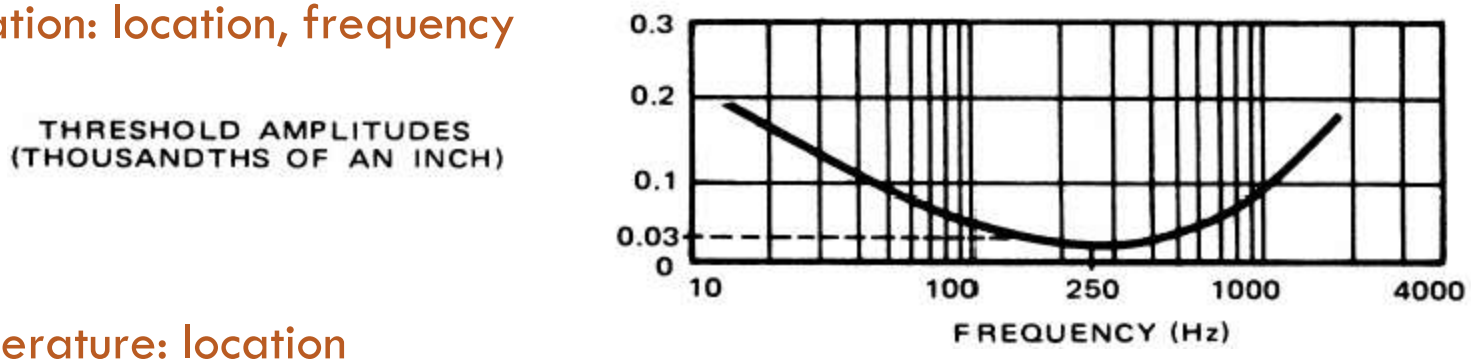
Speech

- Frequency characteristics of speech
  - Speech is a complex time-varying quantity that makes measuring speech complex. It is usually divided into several frequency bands and a number of time segments
  - Average frequency is 128 Hz (males) and 256 Hz (females)
  - Energy is mostly below 1000 Hz with very little above 5 KHz



Other Sensory Modalities

- Generally poorer information input systems than visual or auditory systems
- Skin (somesthetic) senses
  - Touch: static, dynamic adaptation
  - Vibration: location, frequency



  - Temperature: location
  - Pain: hazardous condition
  - Other skin sensations: combinations or variations of primary skin senses

Other Sensory Modalities

- Muscle sense
  - Sensory feedback mechanisms for motor muscle control and body posture
  - *Proprioception: unconscious* perception of spatial orientation arising from stimuli within the body itself includes knowledge of where a joint is positioned
  - *Kinesthesis is the sensation that informs the brain about joint motion and acceleration*
- Sense of balance (vestibular system)
  - Sensory data needed to maintain balance or orientation and to detect motion of the body (e.g., acceleration)
- Chemical senses (taste & smell)
  - unsuitable for reliable information transmission: quickly adapt to incoming stimuli so that awareness of these stimuli ceases

Human Information Processing

- Stimulus discrimination
  - Channel capacity is similar among the sensory modalities (absolute)
  - Max number of levels for a single dimension of a sensory channel is approximately 7, which represents 2.8 bits of information
  - Humans make better relative judgments than absolute judgments
- Attention
  - Humans attend to only one source of sensory data at any instant
  - Single-channel processors: time-sharing for multi-tasking
  - Unattended input channels not totally blocked: incompletely processed
  - Ability of humans to shift priorities between tasks on the basis of the perceived importance

Human Information Processing

- Vigilance (sustained attention)

Table 6.10—Task conditions that affect vigilance performance

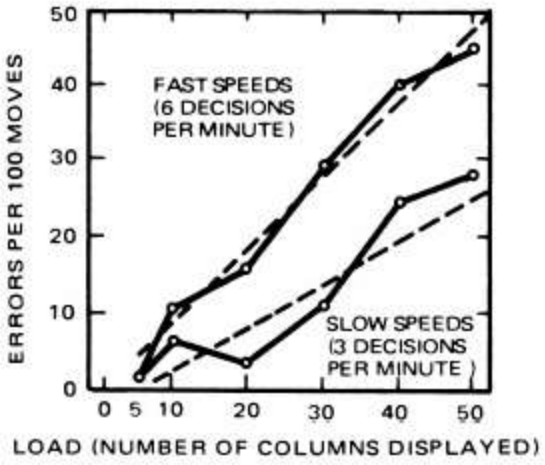
Improved probability of detection	
• Simultaneous presentation of signals to dual channels. • Observers monitoring a display in pairs; members of pairs permitted to speak with one another; 10 minutes' rest each 30 minutes of work; random schedule inspection by supervisor. • Introduction of artificial signals during vigilance period to which a response is required. • Introduction of knowledge of results of artificial signals.	
Decreased probability of correct detection	
• Introduction of artificial signals for which a response is not required. • Higher or lower task load on the user. • Introduction of a secondary display monitoring task. • Users report only signals of which they are sure.	
Change in probability of detection with time	
• A short pretest followed by infrequently appearing signals during vigilance.	• High initial probability of detection, decreasing rapidly.
• A few pretest signals before vigilance period.	• Reduces decrement in probability of detection with time.
• Prolonged continuous vigilance.	• Decreases probability of correct signal detection.

Human Information Processing

- Speed of information processing
  - Reaction time (RT): time for a person to react to an input stimulus and initiate a response (decreases with training, increases with age, fatigue, and the use of drugs)

Stimulus type	Reaction time (milliseconds)
Visual	150 to 225
Auditory	120 to 185
Tactual (haptic)	115 to 190
Pain	400 to 1000
Cold	150
Warm	180
Movement (body rotation)	520

  - Speed vs. accuracy tradeoff



Human Memory

- 3 Types: sensory, short-term and long-term
  - Sensory not important for device design
- Working (short-term) memory (STM)
  - Can be characterized by fast access and retrieval time, limited capacity, and rapid loss of content, unless actively attended to
- Long-term memory (LTM)
  - Capacity ranging from 10^9 to 10^{15} or more bits of information
  - Declarative LTM (facts) retrieval is slower than STM
  - Procedural LTM (how to do things) is best learned by actively practicing a skill and appears to be very slow to decay

Human Memory

Characteristic	Working memory (short-term)	Long-term memory	
		Declarative	Procedural
Primary function	Center of all thought and learning Subset of declarative Temporary storage in flux	Stores meaning of inputs Storage of facts	Permanent storage of how-to knowledge
Capacity	Highly limited (7 ± 2 chunks)	Unlimited	Unlimited
Contents	Primarily acoustical codes Secondarily visual and spatial codes	Semantic codes (primary) Spatial codes Acoustic codes Motor codes (physical movement skills) Temporal codes	Same as declarative
Information units	Same as declarative	Concepts Schemata, frames, scripts	Production rules from very specific to general (if–then rules)
Organization	Same as declarative	Hierarchical with multiple levels of complexity	Flat
Learn/forget processes	Decays with time (73 seconds for one item, 7 seconds for three items) Increased decay time with rehearsal Interference from similar stimuli Displacement (3 to 7 slots)	Learning by being told (passive advice-taking) Encoding Very slow decay Limited by retrieval paths and associations	Learning by doing (active practice) Problem solving Analogies Generalizations (Inductive and deductive) Discrimination Strengthening and reinforcement

Human Memory

- Estimation and decision-making abilities limitations
  - Overestimation of true probability of low-probability events and underestimation of true probability of high probability events
  - Overestimation of true probability of events viewed as favorable and underestimation of true probability of events viewed as unfavorable
  - "Gambler's fallacy"
  - Frequent lack of logic in human decision-making
  - Avoidance of false alarms at all costs when it comes to safety-related events (answering Y/N questions related to a dangerous disease screening results in more "y" for simple therapy and less "y" for painful therapy)

Human Memory

Table 6.13—Human estimation of physical quantities

Physical quantity	Human estimation tendency	Comments
Horizontal distance	Underestimate	30% of population has some depth perception deficiencies (Richards, 1973).
Vertical height	Overestimate when looking up Underestimate when looking down	Pilots at night tend to overestimate the most (Weintrab and Virsu, 1972).
Speed of another object	Overestimate if object is accelerating	(Hatayama and Tada, 1972)
Constancy of speed	Speed perceived as fluctuating	(Runeson, 1974)
Geometric angle	Underestimate acute angles Overestimate obtuse angles	(Weintrab and Virsu, 1972)
Ambient temperature	Overestimate when hot Underestimate when cold	Depends on adaptation level, humidity, and air movement (Geldard, 1972).
Weight of object	Overestimate if bulky Underestimate if compact	(Geldard, 1972)
Number of items (without counting)	Consistently underestimate	(Bevan et al., 1963)
Volume, area, object temperature, acceleration, and compass bearing	Unreliable estimates with no general tendency	(Geldard, 1972)

Human Response Capabilities

- Speed of movement
  - Fitts' Law: Movement time increases proportionally with distance to a target and decreases with larger target sizes
- Principles of motion economy
  - Repetitive manual tasks should be avoided (machines are better)
  - Horizontal hand movements are faster than vertical
  - Hands should be relieved of work that can be performed by feet
  - Movements that take advantage of gravity are less fatiguing
  - Limb movements terminated by a mechanical stop are more efficient than those terminated solely by visual cues

Human vs. Machine Capabilities

Human
Limitations
Force: Limited strength.
Endurance: Fatigues easily.
Speed: Significant time needed for decision-making and movement.
Accuracy: Unreliable, makes constant and variable errors.
Computing: Slow and error-prone.
Decision-making: Best strategy not always adapted; emotions interfere.
Information processing: Basically a single-channel processor that is easily overloaded; performance greatly dependent on motivation.
Limited short-term working memory; long-term memory, although large, has unreliable and slow access.
Advantages
Visual acuity and range very good.
Visual information processing system extremely logical and flexible.
Range of detection extremely wide with good sensitivity for audition and vision.
Perception: Ability to make order out of complex situations; detection possible under high noise.
Can reason inductively; can follow up intuition.
Very flexible; can easily change rules of operation with changes in situation.
Attention is easily shifted; only essential information can be selected for processing.
When highly motivated, can perform under adverse conditions with parts out of order (injuries).

Human vs. Machine Capabilities

Machine
Limitations
Decision-making limited.
Inductive reasoning not possible.
Must be monitored.
All activities must be planned and pre-programmed thoroughly.
Must get careful maintenance.
Might not operate at all, if some parts are broken.
Advantages
Great forces possible.
Does not fatigue easily.
High speed.
Great accuracy attainable.
Large short-term working memory.
For narrow applications, superior long-term memory.
Complex problems can be handled deductively.
Excellent for repetitive work; unaffected by emotions and motivational needs.
Can perform simultaneous operations easily.

Covered Material

- Chapter 6