King Saud University

College of Engineering

IE – 341: “Human Factors Engineering”

Fall – 2016 (1^{st} Sem. 1437-8H)

Human Capabilities

Part – B. Hearing (Chapter 6)

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Lesson Overview

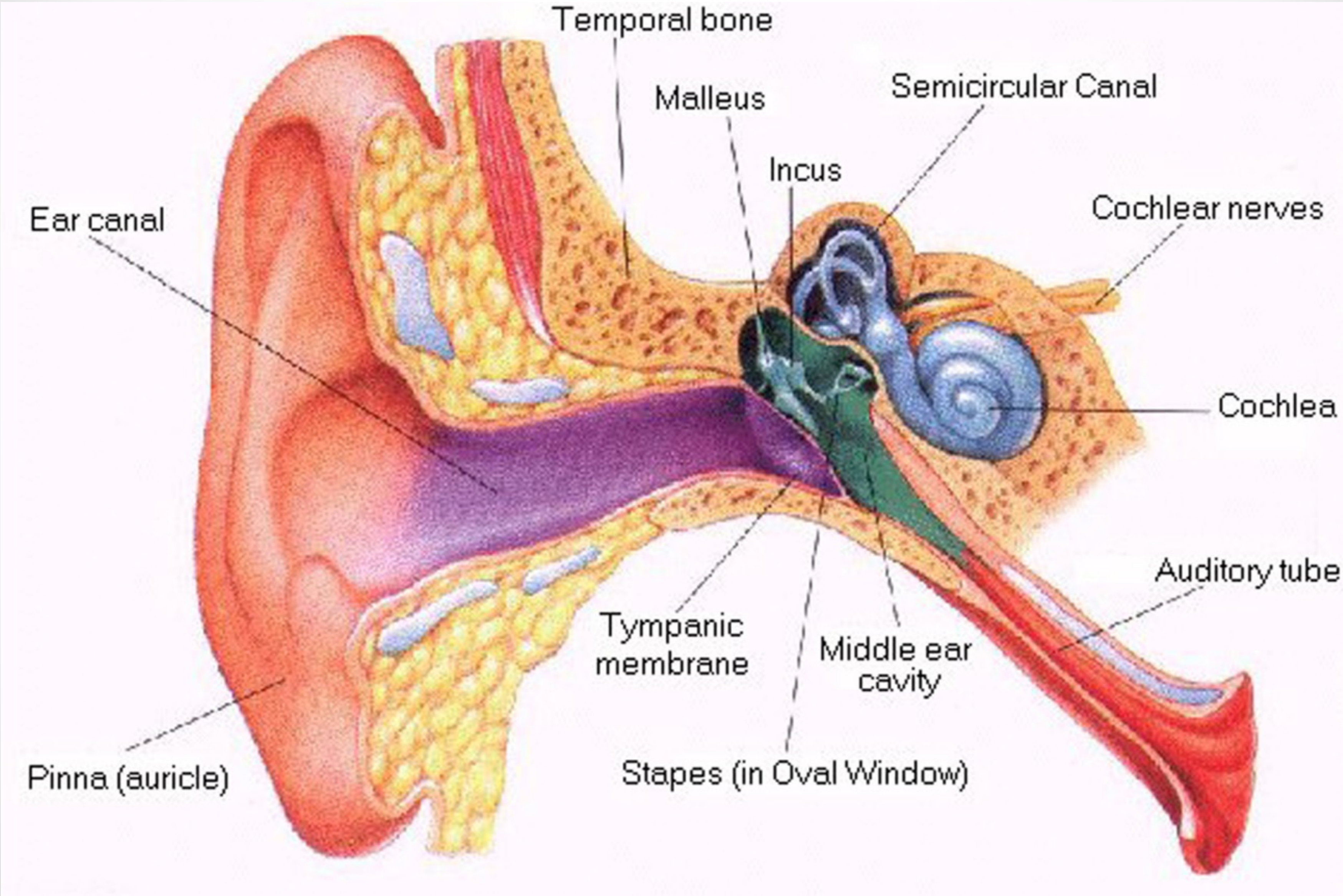
- Hearing
  - o Ear Anatomy
  - o Nature and Measurement of Sounds
    - Frequency of Sound Waves
    - Intensity of Sound
    - Complex Sounds
  - o Masking
- Auditory Displays
  - o Detection of Signals
  - o Relative Discrimination of Auditory Signals
  - o Absolute Identification of Auditory Signals
  - o Sound Localization
- Noise

Hearing

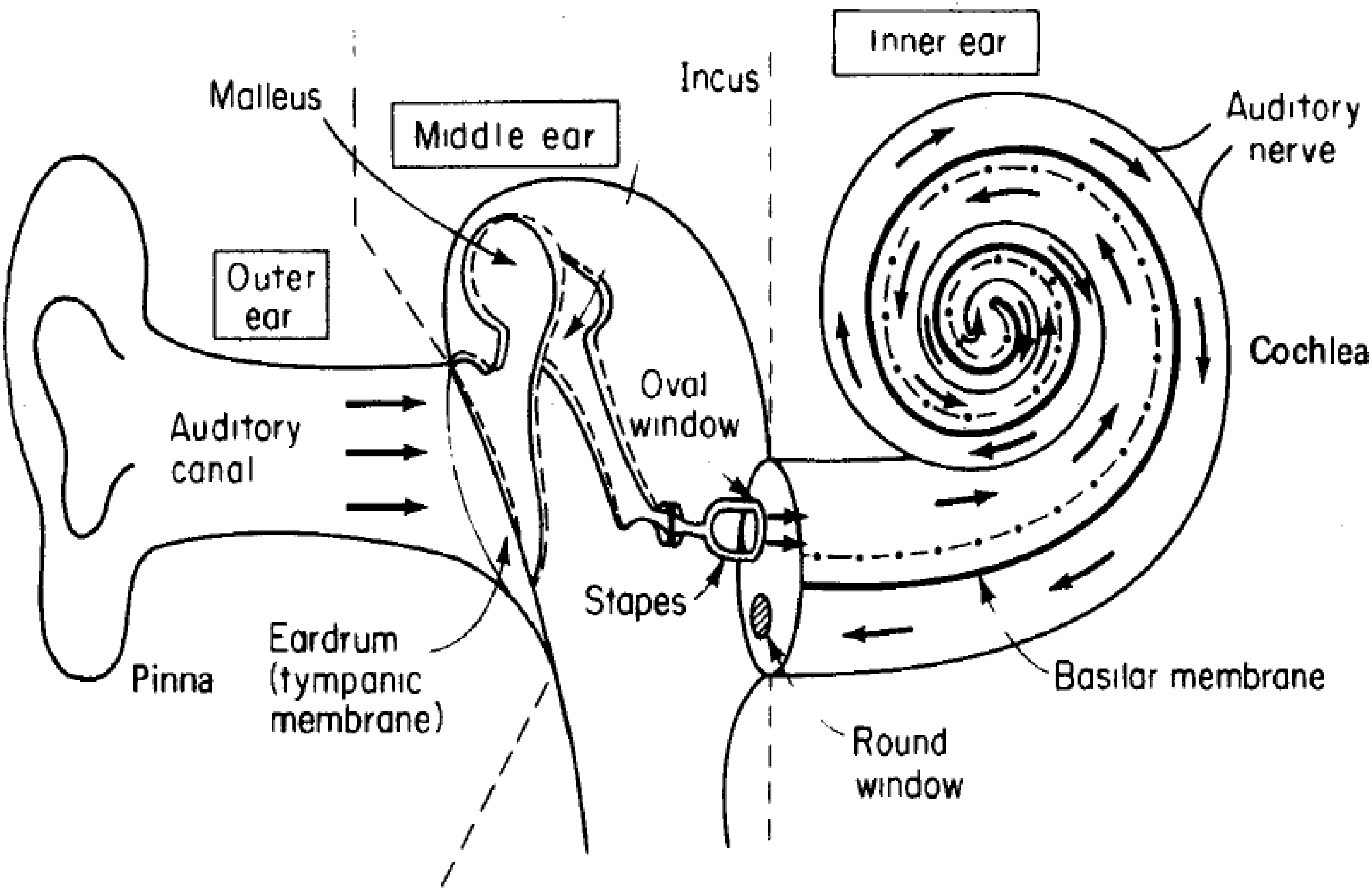
Ear Anatomy

- Complex process
  - Pneumatic (i.e. filled with air) pressure waves
  - Hydraulic waves
  - Mechanical vibrations
  - Electrical impulses
- More information about hearing:
  - https://youtu.be/0NJ_EAQjR3c (excellent short video)

Cont. Ear Anatomy



Cont. Ear Anatomy



Cont. Ear Anatomy: Outer Ear

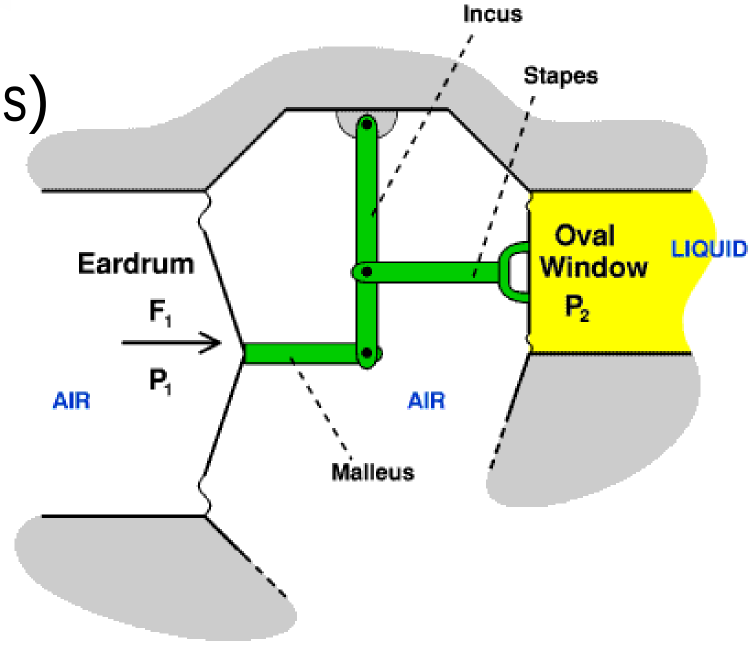
- Collects sound energy
- External part: pinna or conchae
- Auditory canal (meatus)
  - Bayonet shape
  - 1″ long
  - Resonant property
    - Sensitivity to frequencies: 2 – 5 kHz
    - Enhances SPL by as much as 12 dB (see slide 17)

- Eardrum (tympanic membrane)

Cont. Ear Anatomy: Middle Ear

- Chain of **3** small bones (ossicles)
  - Malleus
  - Incus
  - Stapes

- Transmit vibrations
  - eardrum to oval window
  - Stapes acts like a piston on oval window



Function of the Ossicles (Middle Ear)

Eardrum surface area
+
Lever action of ossicles

Pressure of stapes against oval window is amplified 22 times

Sound pressure to fluid of inner ear

Cont. Ear Anatomy: Cont. Middle Ear

- Two muscles
  - Tensor tympani muscle (to malleus)
  - Stapedius muscle (to stapes)

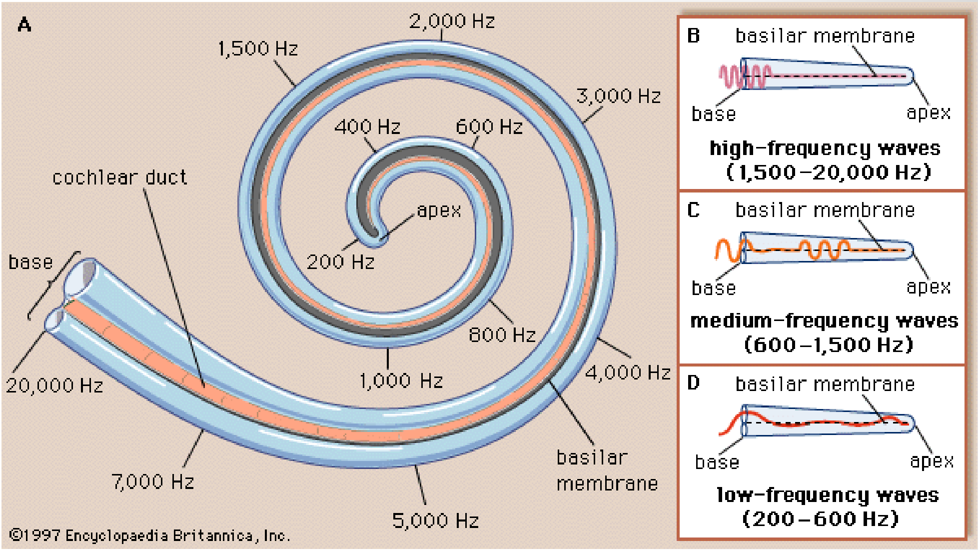
Acoustic (aural) Reflex of Muscles:

- Tighten in response to loud noise
  - Q: can you compare this with pupil action?
- Protection against intense sounds
  - Reduces sound transmission
  - Occurs when sound is 80 db above threshold level
  - Up to 20 db attenuation (i.e. reduction of severity)
- More responsive to
  - **Broadband sounds** (i.e. wide range of frequencies) than to pure tones
  - **Lower frequencies** than to higher frequencies
- Muscles remain flexed (i.e. contracted)
  - up to 15 min in intense steady-state noise

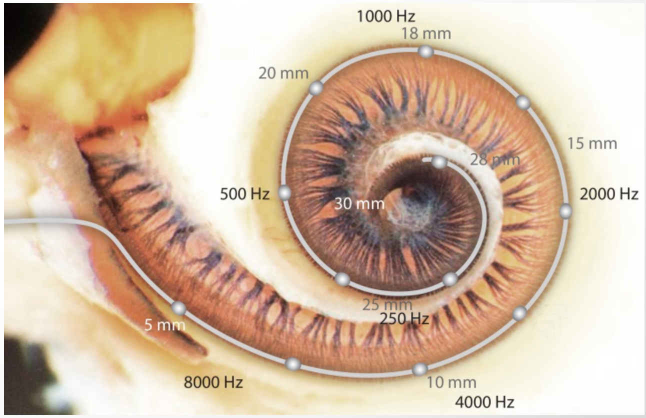
Cont. Ear Anatomy: Cont. Middle Ear

- Intense impulse noise:
  - Muscle contraction delay (Latency: 35 – 150 ms)
  - Not much protection against initial impulse
  - Protection against subsequent impulses; interval less than one second
- Another movie: transmission of sound in the ear:
  - https://youtu.be/fllAxGsV1q0

Cont. Ear Anatomy: Inner Ear – *cochlea*



- Spiral (Snail)
- 30 mm long (uncoiled)
- Filled with fluid
- Stapes ➔ Piston
  ➔ fluid back & forth in response to pressure
- Fluid movement ➔ basilar membrane
  ➔ vibration to *organ of Corti*
- Organ of Corti
  - Hair cells & nerve endings
  - Sensitive to changes in pressure
  - Transmits sound to brain via auditory nerve



Cont. Ear Anatomy:

Conversion of Sound Waves to Sensations

- Place (resonance) theories
  - Fibers of basilar membrane like piano strings
  - Different fibers are sensitive differently to different frequencies
- Temporal theories
  - Pitch is related to time pattern of neural impulses emitted by the fibers
- Current understanding:
  - Place theory: high tones
  - Temporal theory: low tones
  - Combination of both (i.e. complementary): middle tones

Nature and Measurement of Sounds

- Direct vs. Indirect hearing:
  - Direct hearing: e.g. baby's natural cry
  - Indirect hearing: e.g. doorbell ⇒ someone at door
  - Indirect stimulus can be more effective than direct
    - e.g. fire alarm (100% detectable) vs. heat/smoke (75%)

- Nature and Measurement of Sounds
  - **Sound** is created by vibrations from a source and is transmitted through a medium (such as atmosphere) to the ear
    watch video: https://youtu.be/nGKffdaI4Pg
  - Two primary attributes of sound:
    - **Frequency**
    - **Intensity** (or **amplitude**)

Cont. Nature and Measurement of Sounds

- Frequency of Sound Waves :
  - o When sound is generated,
    - vibration ⇒ air molecules to move back and forth
    - this alternation ⇒ ↑ and ↓ in air pressure
  - o Vibration forms sinusoidal (sine) waves
    - height of wave above and below the midline represents the amount of above-normal and below-normal air pressure respectively
    - The waveform above the midline is the image of the waveform below the midline in a sine wave.
    - The waveform repeats itself again and again in a sine wave
    - **frequency** of sound:
      - o "number of cycles per second"
      - o expressed in: hertz (Hz) ; 1 Hz ≡ 1 cycle / 1 second

Cont. Nature and Measurement of Sounds

- Cont. Frequency of Sound Waves :
  - Sinusoidal wave created by a simple sound-generating source

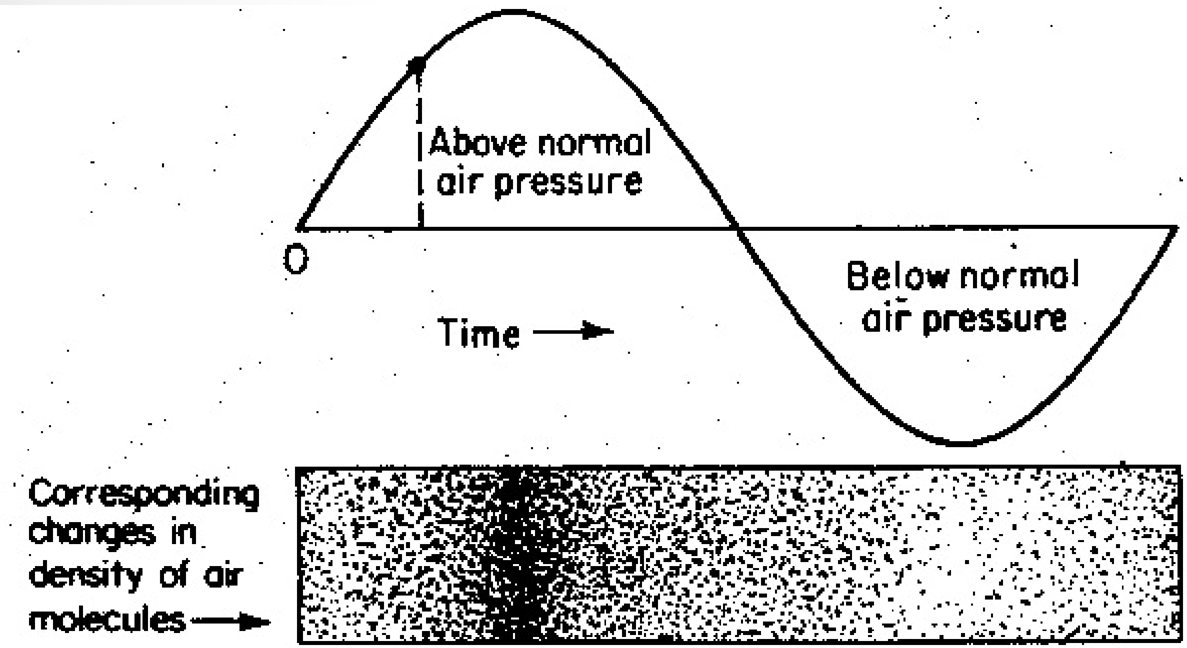


FIGURE 6-1
Sinusoidal wave created by a simple sound-generating source. The magnitude of the alternating changes in air pressure can be represented by a sine wave, shown in the upper part of the figure. The lower part of the figure depicts the changes in the density of the air molecules caused by the vibrating source and corresponding to the sine wave changes in pressure.

Cont. Nature and Measurement of Sounds

- Cont. Frequency of Sound Waves :
  - o The human ear is sensitive to frequencies
    - 20 to 20,000 Hz
    - highest sensitivity: between 1,000 to 3,000 Hz
  - o Ear is not equally sensitive to all frequencies
  - o People differ in their relative sensitivities to various frequencies
  - o See what frequencies you can/can't hear at the following Web Site: The Mosquito Ringtone (http://www.freemosquitoringtone.org/)
- Pitch
  - o Highness or lowness of a tone
  - o High frequencies ➔ high pitched tones
  - o Low frequencies ➔ low pitched tones

Cont. Nature and Measurement of Sounds

- Intensity of Sound (amplitude/loudness):
  - Sensation of loudness
  - Defined in terms of power per unit area (W/m^2)
  - The Bel (B) [after *Alexander Graham Bell*]
    - is the basic unit for measuring sound
    - measured: logarithm to the base 10 of two sound intensities
  - The most convenient measure is:
    - decibel (dB)
    - $1\ dB = 0.1\ B$
  - Problem: most measuring instruments don't directly measure sound power of source

Cont. Nature and Measurement of Sounds

- Cont. Intensity of Sound (amplitude/loudness):
  - Sound power: directly proportional to square of the sound pressure
    - Sound Pressure Level (SPL):

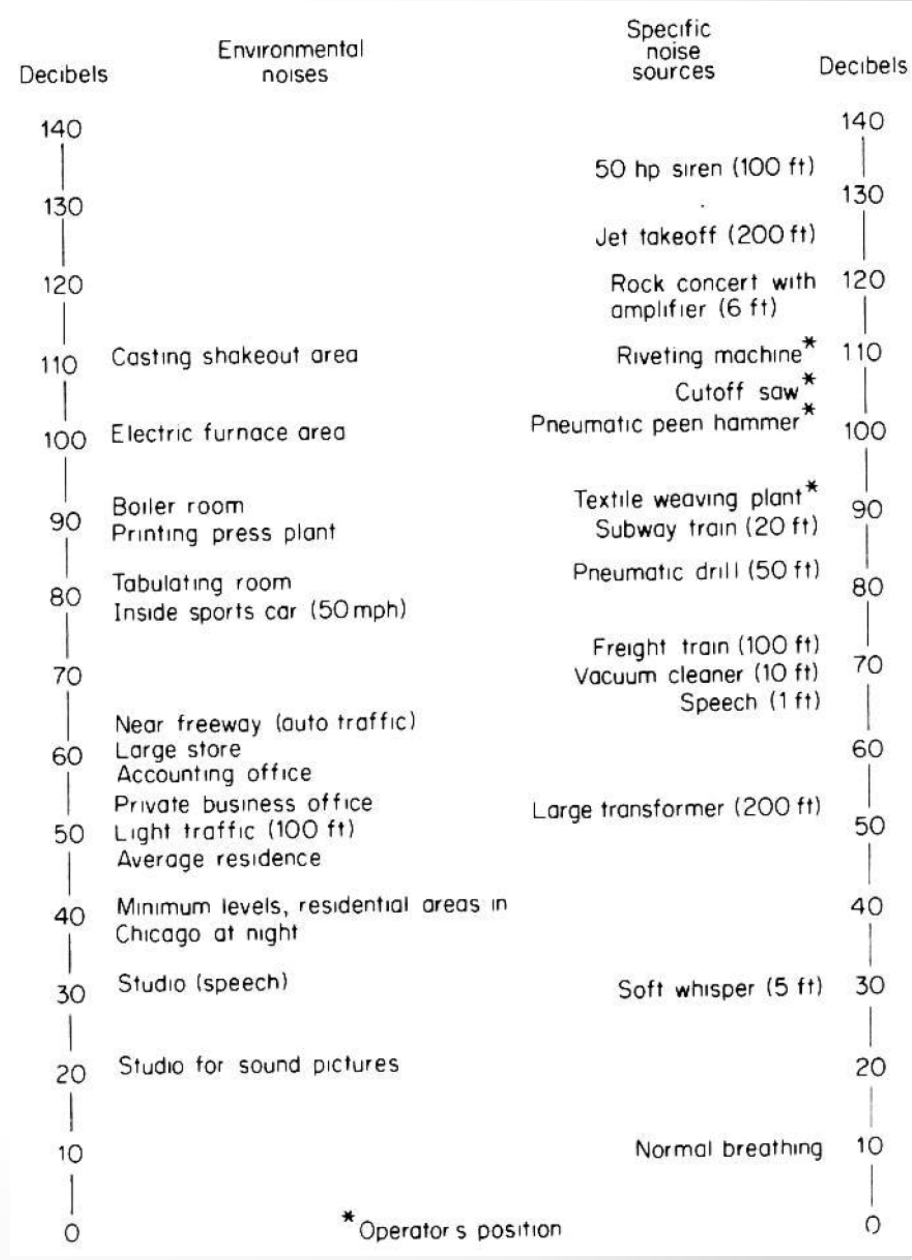
$$SPL\ (dB) = 10\ \log\frac{P_1^{\,2}}{P_0^{\,2}}$$

$$SPL\ (dB) = 20\ \log\frac{P_1}{P_0}$$

    - P_1 = sound pressure of the sound to be measured
    - P_0 = reference sound pressure (represents 0 dB – can't be zero; why?)
  - Most common reference value of P_0 is 20 $\mu N/m^2$ (20 micro Pascal)
    - Roughly equivalent to lowest intensity for 1000 Hz pure tone that healthy adult can just *barely hear* under ideal conditions (e.g. mosquito)
  - Sound pressure is measured by: sound-level meters (A, B, C *weightings*)

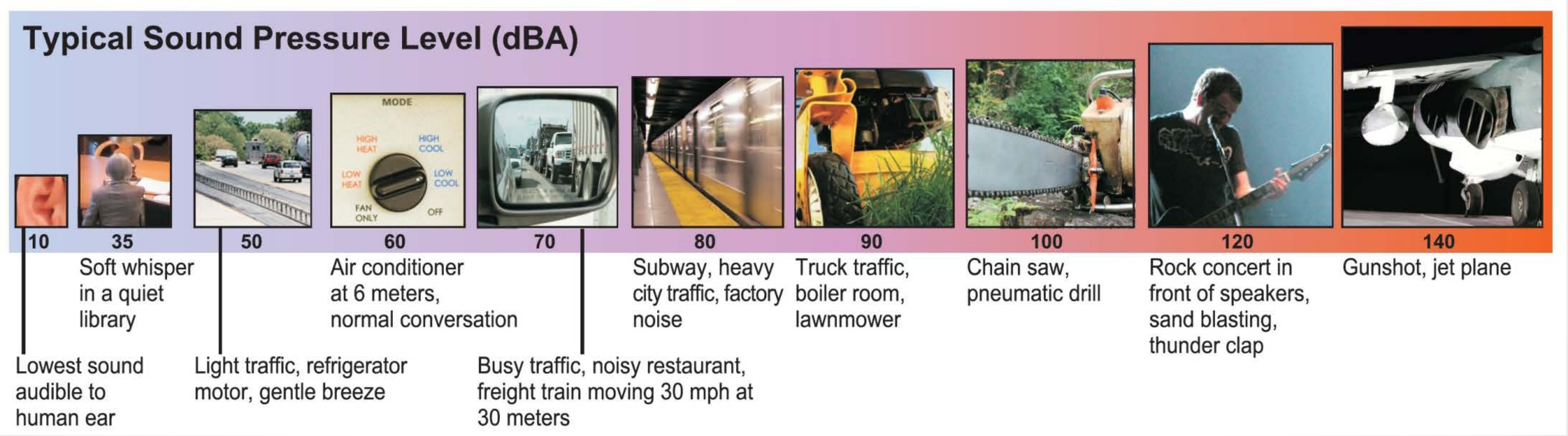
Cont. Nature and Measurement of Sounds

- Cont.
  Intensity of Sound
  - Figure 6-2:
    Decibel levels for
    various sounds (0-150 dB)
  - Note ↑ 10 dB ⇒
    ↑ 10 fold sound power ⇒
    ↑ 100-fold sound pressure (why?)
  - Signal-to-Noise Ratio
    (SNR): difference bet.
    meaningful signal,
    & background noise
    - e.g. 90 dB signal,
      70 dB noise ⇒
      SNR = +20 dB



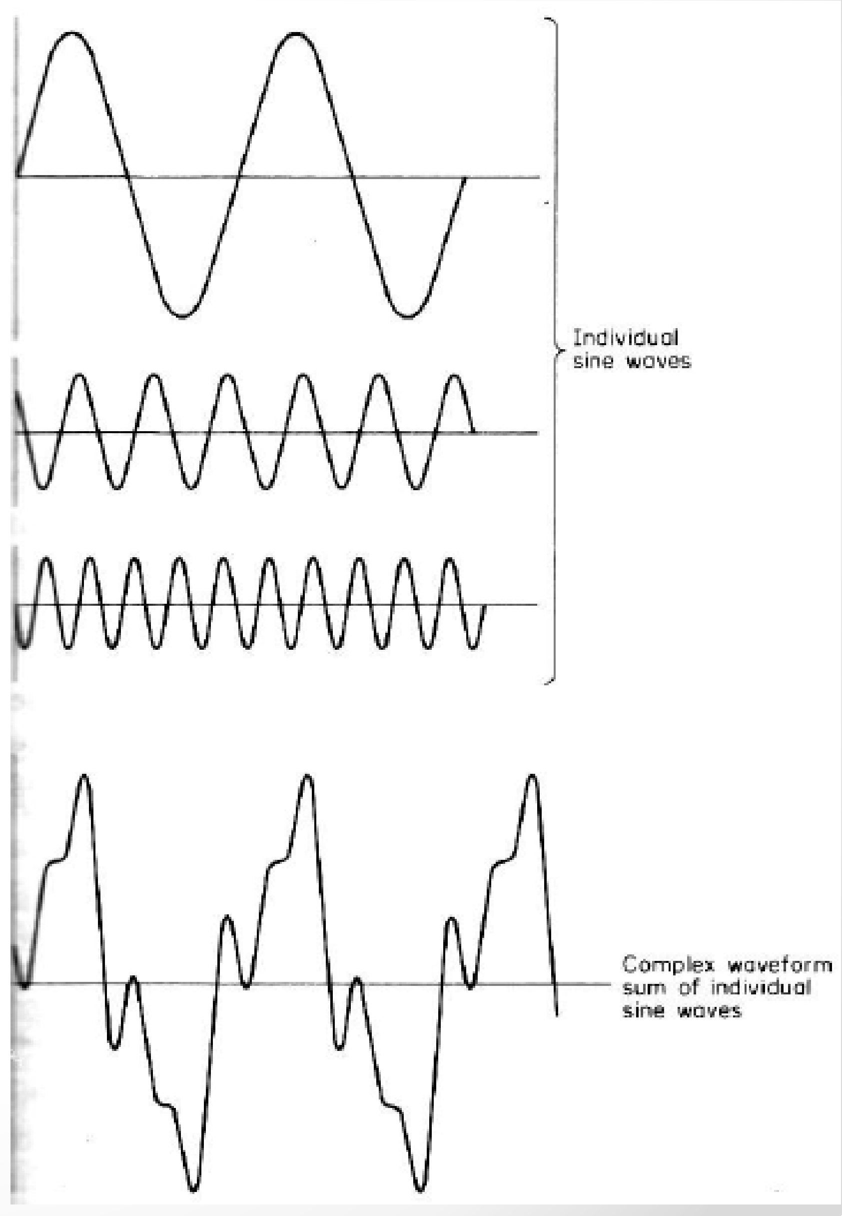
Cont. Nature and Measurement of Sounds:

Ranges of Typical Sound Levels for Common Sounds



Cont. Nature and Measurement of Sounds

- Complex Sounds:
  - Very few sounds are pure
  - Most complex sounds are non-harmonic
  - Figure 6-3: waveform depiction of a complex sound formed by 3 individual sine waves (method 1)
  - Q: what is different in individual waves: frequency or amplitude?



Cont. Nature and Measurement of Sounds

- Cont. Complex Sounds:

  Method 2 of depiction: Sound Spectrum

  - Divide sound into frequency *bands,*
  - Measure intensity of sound in each band
  - Achieved using "frequency-band analyzer"
  - Narrower bandwidth ➔
    - greater detail of the spectrum
    - lower sound level within each bandwidth

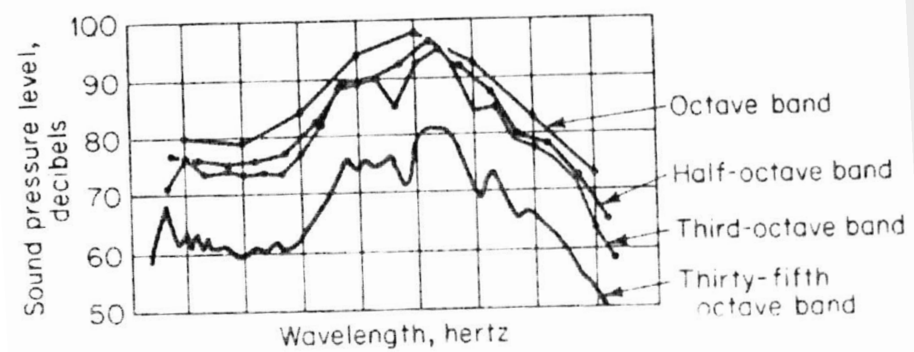


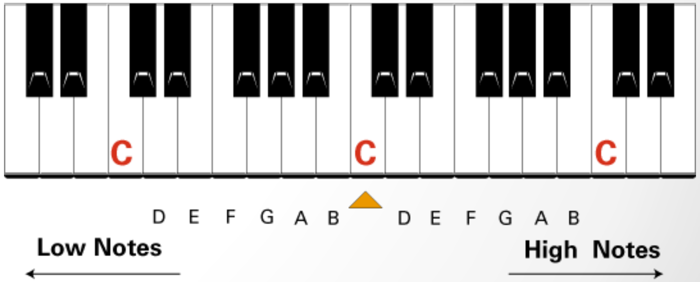
FIGURE 6-4
Spectral analyses of noise from a rope-closing machine. Analyzers used varying bandwidths. The narrower the bandwidth, the greater the detail and the lower the sound-pressure level within any single bandwidth. (*Source: Adapted from* Industrial noise manual, *1966, p. 25.*)

Cont. Nature and Measurement of Sounds

- Cont. Complex Sounds:

  Methods of dividing the sound spectrum:

  - Method 1: Octaves
    - 1 octave has double the frequency of the one below it
    - E.g. "Middle C" has a frequency of 256 Hz
    - one octave above "middle C" has a frequency of 512 Hz
    - i.e. octave is Interval between one pitch and another with half or double its frequency



  - Method 2: Bands (ANSI)
    - divide audible range into 10 bands
    - center frequencies @:

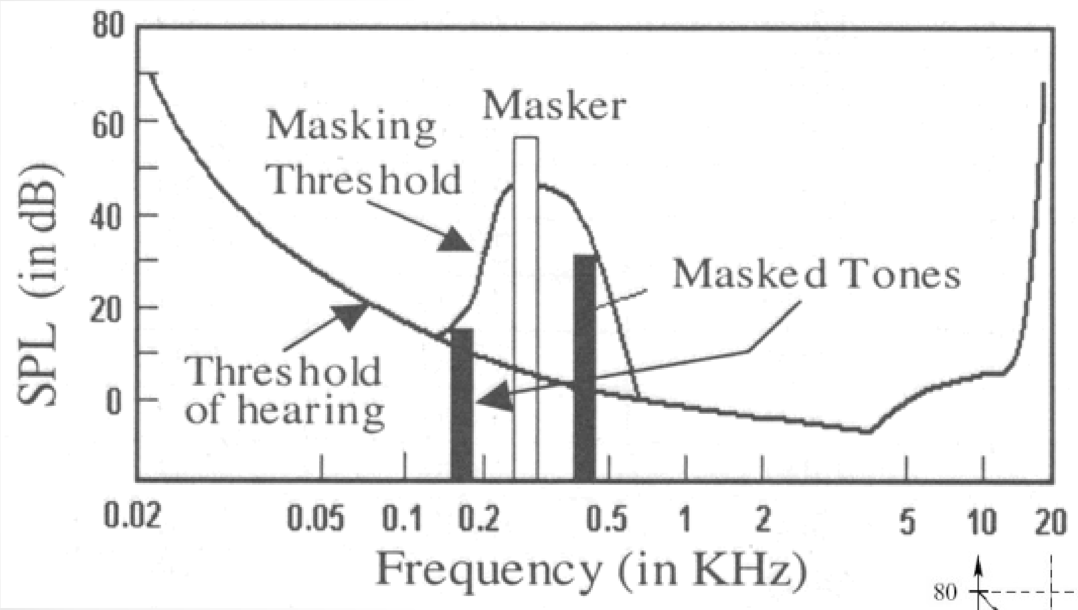
      31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, 16000 Hz

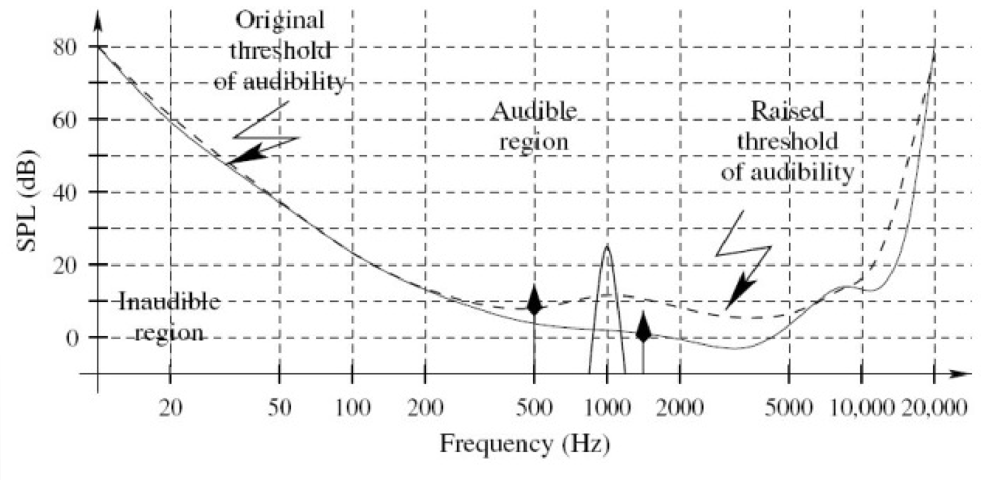
Masking

- Masking (defined):
  - o Condition when one component of the sound environment reduces the sensitivity of the ear to another component
  - o It is amount that the “**threshold of audibility**”* of a sound (the masked sound) is raised by the presence of another (masking) sound
  - o Experimentally:
    - 1: get absolute threshold (i.e. minimum audible level) of sound to be masked (by itself)
    - 2: repeat this in the presence of masking sound (see next slide)
  - o Masking must be considered when considering noise in auditory displays
  - o **Q**: Can you a give an example of “masked” and “masking” sounds from our everyday lives?
  - o **Q**: difference between masked and complex sounds?

Cont. Masking

- Masking examples:
  - Can you analyze the examples below?
  - What effect does masker (i.e. masking sound) have on masked sound(s)?





Auditory Displays

Auditory Displays

- Chapter 3: auditory vs. visual modality (e.g. auditory preferred: message is short, simple, urgent, etc.)
- 4 types of human functions/tasks involved in the reception of auditory signals:

1. **Detection** (i.e. whether a signal is present)
2. **Relative discrimination** (differentiating bet. ≥2 signals presented together)
3. **Absolute identification** (only 1 signal is present)
4. **Localization** (knowing the direction that the signal is coming from)

Cont. Auditory Displays

1. Detection of signals
   - Signals can occur in “peaceful” surroundings or noisy surroundings
   - The signal plus noise (SN) should be distinct from the noise (N) itself
   - Otherwise, signal cannot always be detected in the presence of noise
     - i.e. signal (masked sound) + noise (masking sound) ⇒ **threshold of detectability** is elevated (see slides on masking)
     - ⇒ signal must be > threshold to detect signal
   - Using filters ⇒ noise removed

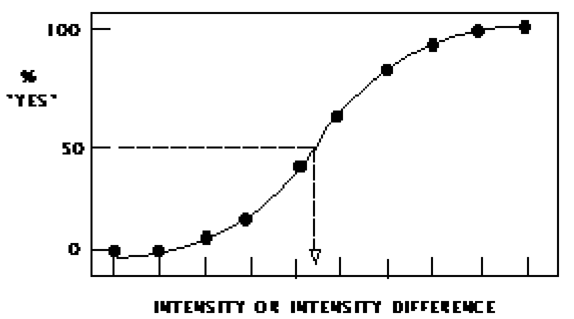
     ⇒ ↑ detectability, SNR

     ⇒ more audible sound*

Cont. Auditory Displays

2. Relative Discrimination of Auditory Signals

- Relative discrimination of signals on basis of
  - intensity
  - frequency



- A common measure of discriminability:

  just-noticeable difference (JND):
  - JND: “the smallest difference or change along a stimulus dimension (frequency, intensity) that can just be detected 50% of the time by people.”
  - The smaller the JND, the easier it is for people to detect differences on the dimension being changed.
    - Small JND ⇒ subjects could detect small changes
    - Large JND ⇒ large change necessary before noticing change

Cont. Auditory Displays

3. Absolute Identification

- This is used when it is necessary to make an absolute identification of an individual stimulus (by itself)
- e.g. identify
  - someone's pitch/frequency
  - specific animal/bird
  - certain car siren/honk tone
  - Sound durations
- Number of levels along a continuum (range or scale) that can identified usually is quiet small (see Table 6-1)

TABLE 6-1
LEVELS OF AUDITORY DIMENSIONS IDENTIFIABLE ON AN ABSOLUTE BASIS

Dimension	Level(s)
Intensity (pure tones)	4–5
Frequency	4–7
Duration	2–3
Intensity and frequency	9

Source: Deatherage, 1972; Van Cott and Warrick, 1972.

- It is better to use more dimensions with fewer steps or levels of each dimension, than to use fewer dimensions and more levels of each (see last row of table, can you explain?)

Cont. Auditory Displays

4. Localization

   - ***Stereophony:*** **“**the ability to localize (guess/predict) the direction from which the sound is emanating (coming from)”
   - Primary factors/cues used to determine direction
     - intensity of sound
     - phase (lag) of sound
     - e.g. if sound reaches directly one side of head first, sound reaches the nearer ear approx. 0.8 ms before other ear ⇒ localizing sounds below 1500 Hz
     - For frequencies > 3000 Hz, intensity is used to localize sound (e.g. try to gradually increase volume in one speaker and decrease volume in opposite speaker)
     - Sounds between 1500-3000 Hz: hard to localize*

Cont. Auditory Displays

- Special purpose auditory displays:
  - Warning and alarm signals
    - Each signal having preferred frequency, intensity
    - Each causing certain “attention-getting” and “noise-penetration” ability
  - Aids for the blind
    - Mobility aids (go-no-go safety signals at certain distance)
    - Environmental sensors (information about surrounding, e.g. surface characteristics, directional information, distance)

Noise

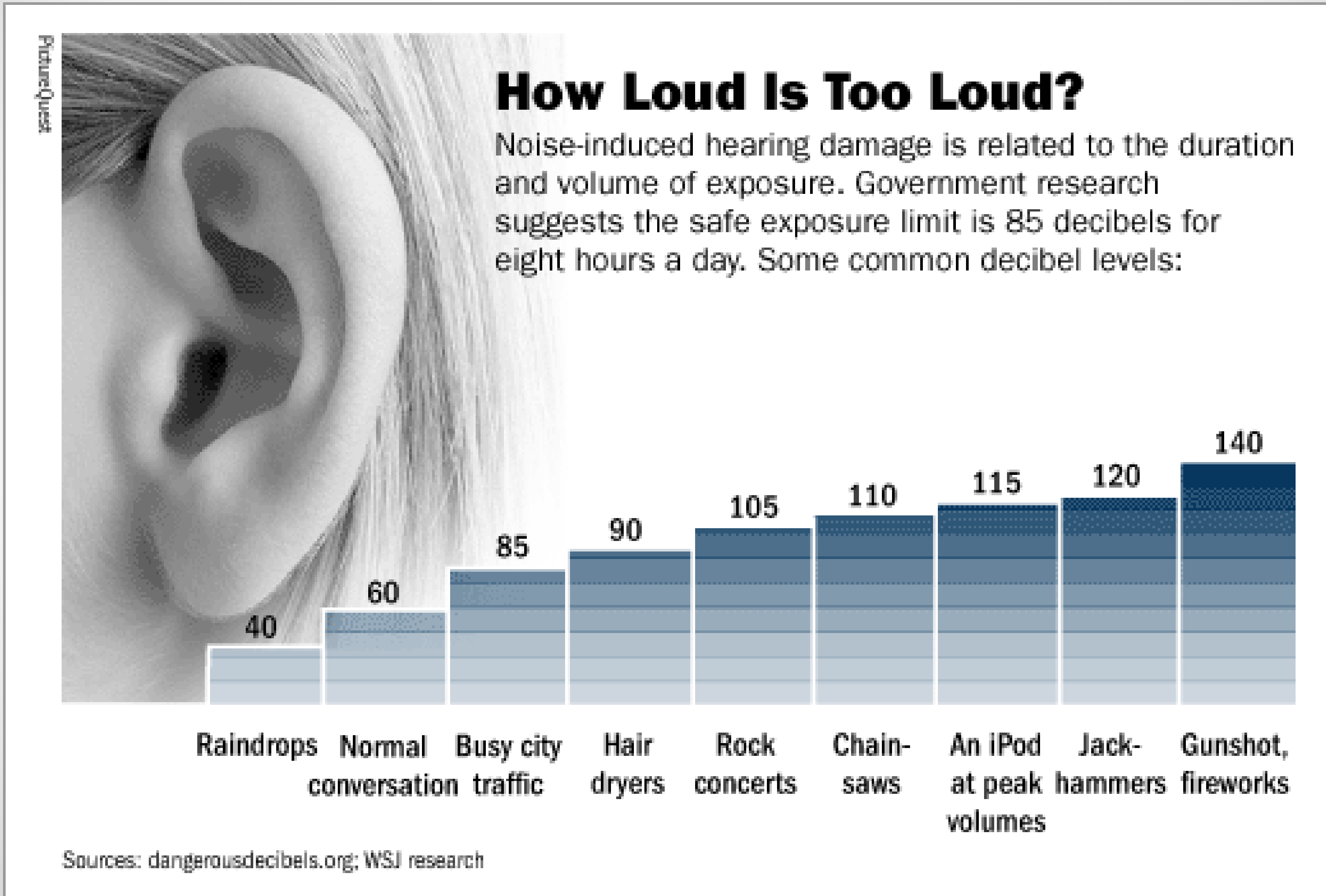
Noise

- Noise
  - "Unwanted sound"
  - Information theory: "auditory stimulus of stimuli bearing no informational relationship to the presence or completion of the immediate task"
  - Causes: startle response, annoyance
  - Interferes with speech, sounds (i.e. masking)
  - Decreases "complex" task performance
    - But actually may increase "simple" task performance!*
- Effects of noise
  - Hearing loss (e.g. occupational hearing loss)
  - Temporary loss, permanent loss
  - Physiological effects
  - Psychological effects

Cont. Noise

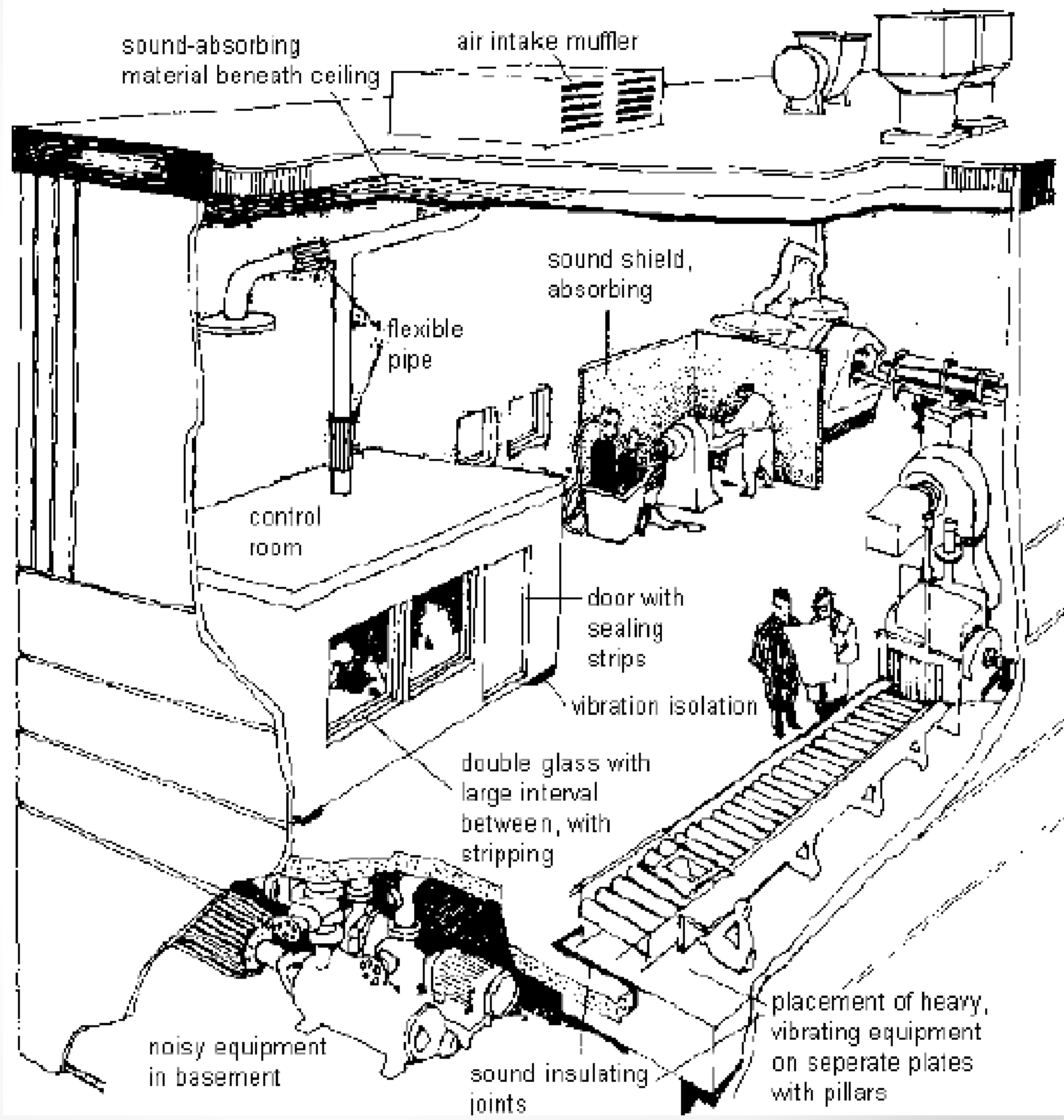
- Hearing loss
  - o Long term exposure → hearing loss
    - ↑ with ↑ in frequency and ↑ in duration
    - First signs appear in range: 4-6 kHz
    - Risk of damage ↑ in frequency range: 2400-4800 Hz
    - Effect: damage to hair cells (i.e. nerve damage)
  - o Conductive hearing loss
    - Damage to eardrum and middle ear
    - Measured with "audiometer": bone vs. air conduction tests
  - o Age-related hearing loss
    - 30% of people > 65 have significant hearing loss
    - Natural damage occurs to hair cells (higher freq.: 4-6 kHz)
    - Aging brain cannot filter background noise (can cause "tinnitus")
  - o Watch video on noise and hearing loss: https://youtu.be/ZeYRxlP4YEQ

Cont. Noise



PictureQuest
How Loud Is Too Loud?
Noise-induced hearing damage is related to the duration and volume of exposure. Government research suggests the safe exposure limit is 85 decibels for eight hours a day. Some common decibel levels:
40
Raindrops
60
Normal conversation
85
Busy city traffic
90
Hair dryers
105
Rock concerts
110
Chain-saws
115
An iPod at peak volumes
120
Jack-hammers
140
Gunshot, fireworks
Sources: dangerousdecibels.org; WSJ research

Cont. Noise: Occupational Noise Control: industrial prevention methods



References

- **Human Capabilities - Hearing**
  - ***Human Factors in Engineering and Design***. Mark S. Sanders, Ernest J. McCormick. 7th Ed. McGraw: New York, 1993. ISBN: 0-07-112826-3.
  - **Slides by: *Dr. Khaled Al-Saleh*; online at:** http://faculty.ksu.edu.sa/alsaleh/default.aspx
  - **Slides by: *Dr. Tamer Khalaf***
  - **Slides by: *Prof. Mohammed Z. Ramadan***
  - **See what frequencies you can/can't hear at the following Web Site:**

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