JOHNS HOPKINS BLOOMBERG SCHOOL of PUBLIC HEALTH

Noise

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Section A

Introduction and Definitions

Noise and Sound

- *Noise*—Excessive or unwanted sound which potentially results in annoyance and/or hearing loss (can be from occupational and/or non-occupational sources)
- *Sound*—A pressure variation (wave) that travels through air and is detected by the human ear

Continued

Noise and Sound

- Physical manifestation of noise is a pressure wave
  - Caused by vibrating surfaces
- We can't measure acoustic energy very well, but we can measure sound pressure well
  - Sound pressure is a surrogate for acoustic energy

Noise

- Focus is on preventing hearing loss associated with noise exposure
  - There are other physiologic effects of noise
- Noise-induced hearing loss has been observed for centuries
- Prior to the Industrial Revolution, few people were exposed to high noise levels

Noise-Induced Hearing Loss (NIHL)

- Noise-exposed workers are employed in wide range of industries
  - Agriculture, mining, construction, manufacturing, transportation, military

Continued

Noise-Induced Hearing Loss (NIHL)

- NIOSH estimates that > 4 million production workers are exposed to hazardous noise
  - This represents approximately 17% of all production workers

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Section B

Physics of Sound

Physics of Sound

- Theory
  - The vibration of a source causes pressure changes in air which result in pressure waves
  - Perceived sound is comprised of numerous pressure waves of varying characteristics

Continued

Physics of Sound

- Pressure wave characteristics
  - *Amplitude*—The amount of sound pressure measured in decibels (dB)
  - *Frequency*—The rate of vibration per unit time measured in cycles per second, more commonly known as *hertz (Hz)*; range of normal perception for young person is 20–20,000 Hz

Octave Bands

- Quantifies effective frequencies without looking at each frequency one at a time
- Standardized notation used to characterize the frequency dependence of noise

Continued

Octave Bands

- Characterized by center frequency
- Covering range of human hearing
  - (20–20,000 Hz)

Continued

Octave Bands

- $f_c = (f_1 f_2)^{1/2}$
  - Where: f_c is center frequency and f_1 and f_2 are lower and upper band edges respectively

Hz

31.5, 62, 125, 250, 500, 1K, 2K, 4K, 8K, 16K

Sound Pressure

- Pressure is fundamental to acoustics
- Definition
  - Pressure = force per unit of area
- Units
  - *Newtons per square meter (N/m_2)*—Called a *Pascal* (modern unit)
  - *Dynes per square centimeter (D/cm^2)*—Not commonly used

Sound Pressure

- Human hearing covers a wide range of sound pressures
  - Threshold of hearing: 0.00002 Pa
  - Loud noise: 200 Pa

Continued

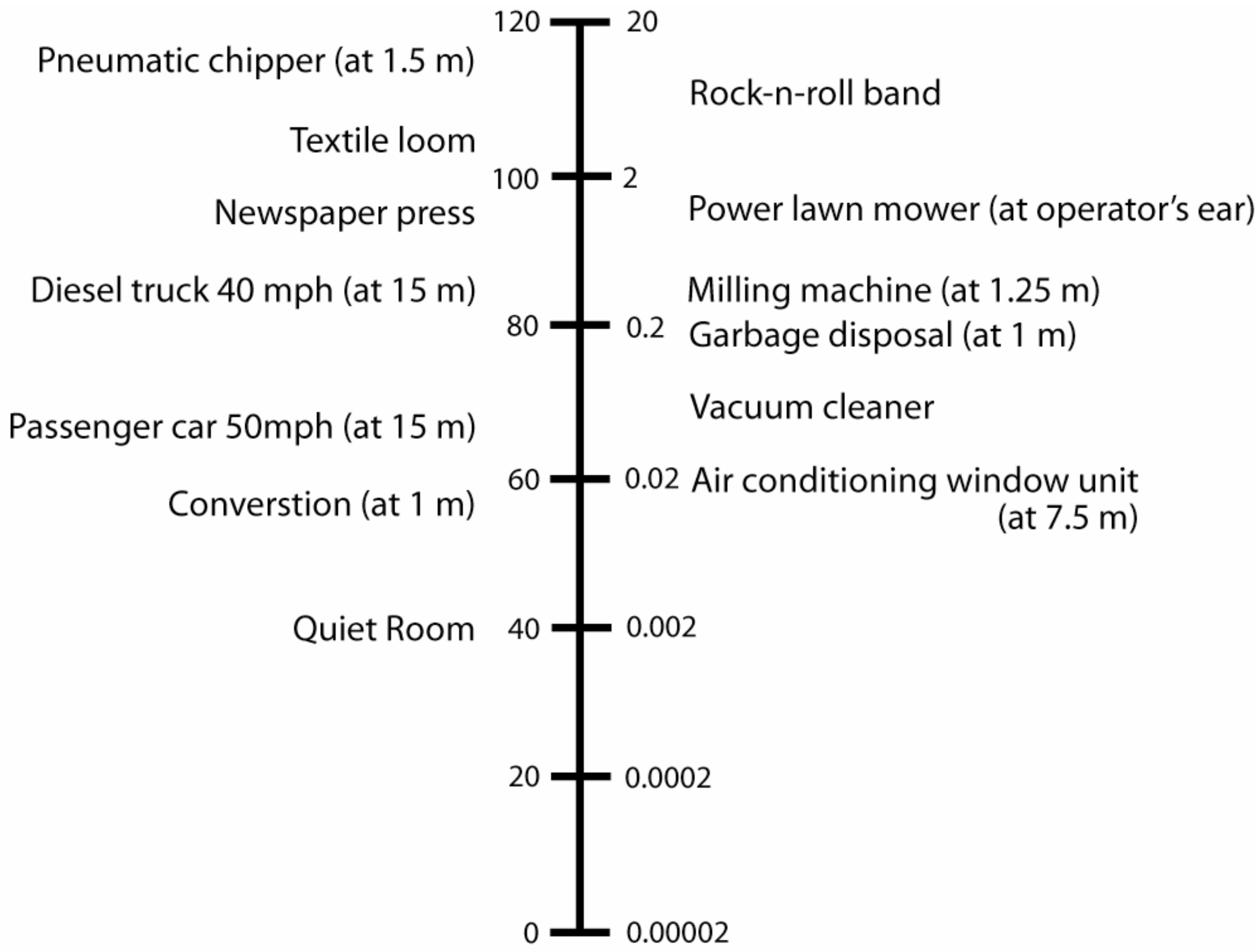
Sound Pressure

- *Decibel (dB) scale* is a log-based scale developed to quantify sound
  - Compresses range to 0–140 dB
  - Scale starts at zero when sound pressure equals the threshold of human hearing

Section C

Decibel Notation

Sound Pressure Level (SPL) and Sound Pressure (Pa)



Sound Pressure

- Decibel scale

$$\text{decibel} = 10\text{Log}\left(\frac{\text{acoustic energy}}{\text{reference energy}}\right)$$

  - Reference energy is the threshold of human hearing
  - 10 * Bel = decibel (dB)
  - Sound pressure level (SPL)

Decibel Scale

- Acoustic energy cannot be readily measured
- Acoustic energy is proportional to the square of the sound pressure
- Therefore

$$dB = 10 \log \left(\frac{p^2}{p_o^2} \right)$$

Continued

Decibel Scale

- Which is the same as

$$dB = 10\log\left(\frac{p}{p_o}\right)^2 = 20\log\left(\frac{p}{p_o}\right)$$

  - Where p is the sound pressure, and p_o is the reference which is equal to the threshold of human hearing (i.e., 0.00002 Pa or 20 uPa)

Sound Pressure Exercises

- If sound pressure is 0.02 Pa, what is the sound pressure level?

$$20 \times \mathrm{Log}\left(\frac{0.02Pa}{0.00002Pa}\right) = 60dB$$

Continued

Sound Pressure Exercises

- If sound pressure is 0.06 Pa, what is the sound pressure level?

$$20 \times \text{Log}\left(\frac{0.06Pa}{0.00002Pa}\right) = 69.5dB$$

Adding Sound Pressure Levels

- Since SPLs are based on a log scale, they cannot be added directly
  - I.e., 80 dB + 80 dB $\neq$ 160 dB

$$SPL_T = 10 \times \text{Log}\left(\sum_{i=1}^{n} 10^{\left(\frac{SPL_i}{10}\right)}\right)$$

  - Where: SPL_T is the total sound pressure level, and SPL_i is the ith sound pressure level to be summed

Continued

Adding Sound Pressure Levels

- Given two machines producing 80 dB each, what is the total SPL?

$$SPL_T = 10 \times Log\left(\sum_{i=1}^{n} 10^{\left(\frac{SPL_i}{10}\right)}\right)$$

$$= 10 \times Log\left(10^{(80/10)} + 10^{(80/10)}\right)$$

$$= 10 \times Log\left(2 \times 10^{8}\right)$$

$$= 83\,dB$$

Continued

Adding Sound Pressure Levels

- Important rule of thumb …
- Adding two sound pressure levels of equal value will always result in a 3 dB increase!
  - 80 dB + 80 dB = 83 dB
  - 100 dB + 100 dB = 103 dB
  - 40 dB + 40 dB = 43 dB

Continued

Adding Sound Pressure Levels

- Given four machines producing 100 dB, 91dB, 90 dB, and 89 dB respectively, what is the total sound pressure level?

$$SPL_T = 10 \times \text{Log}\left(\sum_{i=1}^{n} 10^{\left(\frac{SPL_i}{10}\right)}\right)$$

$$= 10 \times \text{Log}\left(10^{(100/10)} + 10^{(91/10)} + 10^{(90/10)} + 10^{(89/10)}\right)$$

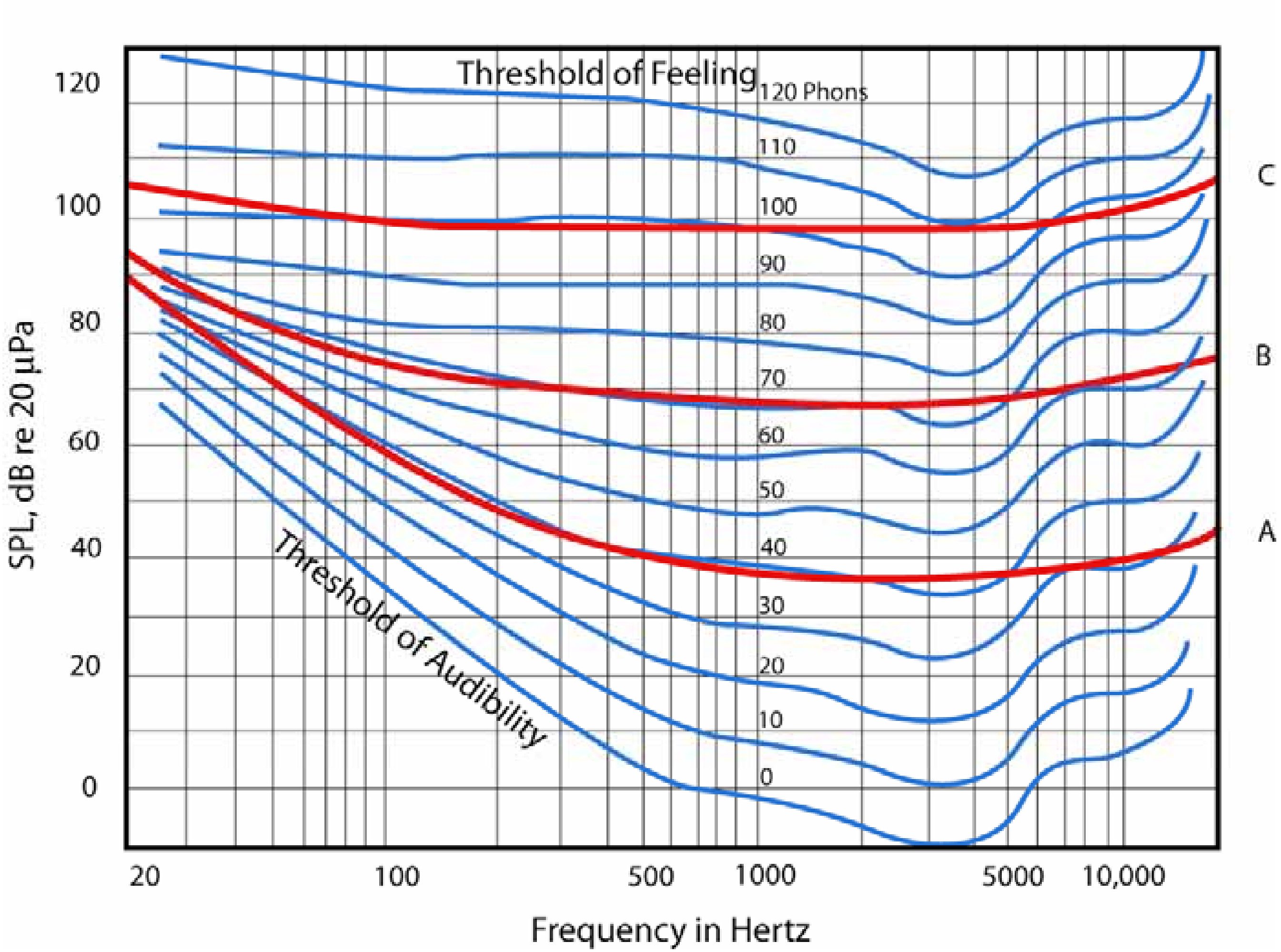
$$= 10 \times \text{Log}\left(10^{10} + 10^{9.1} + 10^{9} + 10^{8.9}\right)$$

$$= 101.2\,dB$$

Section D

Sound Weighting Factors

Fletcher-Munson Curves



Adapted by CTLT

Sound Weighting

- Weighting comes from Fletcher-Munson Curves
  - "A" – 40 Phon equal loudness contour
  - "B" – 70 Phon equal loudness contour
  - "C" – 100 Phon equal loudness contour

Continued

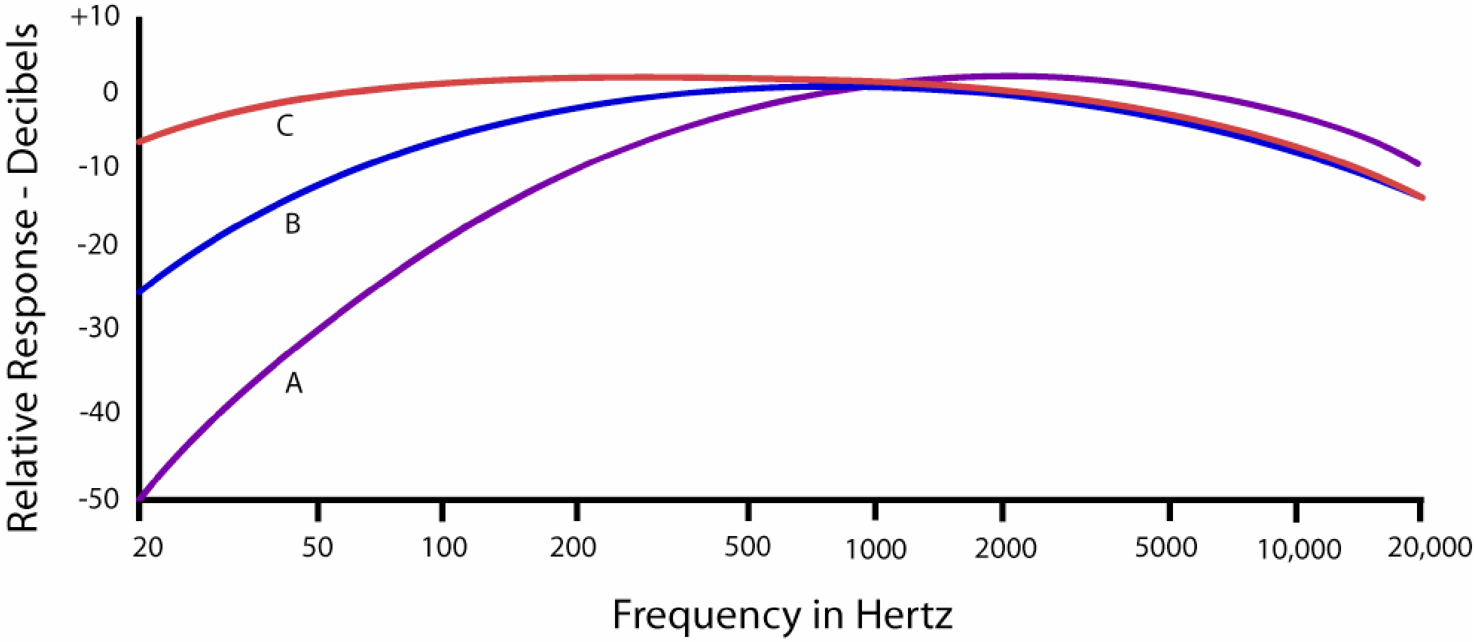
Sound Weighting

- dBA used for risk purposes
  - De-emphasizes low and very high frequencies which pose less of a risk to hearing
- dBC used for hearing protector selection

Continued

Sound Weighting

- Sound weighting filters are incorporated into noise-measuring equipment



SLM Weighting Curves - ANSI S1.4-1983

Section E

Standards and Guidelines

Noise Standards and Guidelines

Three parts to any standard or guideline:

1. **Criteria level**
   - Eight-hour average SPL above which risk for hearing loss exists (usually either 85 or 90 dBA)

Continued

Noise Standards and Guidelines

Three parts to any standard or guideline:

2. **Threshold level**
   - SPL below which no damage occurs
3. **Exchange rate**
   - Based on a damage model assumption
   - Trade-off between exposure level and exposure time

OSHA Noise PEL

- Same as originally adopted in 1971
  - Criteria level (PEL): 90 dBA
  - Threshold level: 90 dBA
    - Practical implication—Can be exposed to 89 dBA forever
  - Exchange rate: 5 dB
    - 95 dBA for 4 hours is as bad as 90 dBA for 8 hours

OSHA PEL (1971–Present)

Exposure Time, Hrs	PEL, dBA
No time limit	<90
8	90
4	95
2	100
1	105
0.5	110

Hearing Conservation Amendment to PEL

- Hearing Conservation Amendment (HCA) 1981–1983
- Recognition that PEL was not protective
  - Action level = 50% of PEL = hearing conservation program require
  - Criteria level = 90 dBA
  - Threshold level = 80 dBA
  - Exchange rate = 5 dBA

OSHA Noise HCA (1983–Present)

Exposure Time, Hrs	PEL, dBA
32	80
16	85
8	90
4	95
2	100
1	105
0.5	110

Calculating % Noise Dose

$$\%\,\text{Dose} = \left(\frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots + \frac{C_n}{T_n} \right) \times 100$$

- C = the actual time exposed at each dB level
- T = the time allowed to be exposed at each dB level

% Noise Dose

Exercise 1A

- Given four hours of 90 dBA exposure, two hours of 95 dBA exposure, and two hours of 85 dBA exposure, what is the % dose using the PEL? (Is this person overexposed compared to PEL?)

$$\left(\frac{4}{8}+\frac{2}{4}+\frac{2}{\infty}\right)\times 100 = 100\% \text{ of PEL}$$

- Answer: Borderline, since dose = 100%

% Noise Dose

Exercise 1B

- Given four hours of 90 dBA exposure, two hours of 95 dBA exposure, and two hours of 85 dBA exposure, what is the % dose using the HCA? (Does this person need to be in a hearing conservation program?)

$$\left(\frac{4}{8} + \frac{2}{4} + \frac{2}{16} \right) \times 100 \;\; = 112.5\%$$

- Answer: Yes, since dose is >50%

% Noise Dose

Exercise 2A

- Given four hrs of 80 dBA exposure, two hours of 90 dBA exposure, and two hours of 85 dBA exposure, what is the % dose using the PEL? (Is this person overexposed compared to PEL?)

$$\left(\frac{4}{\infty}+\frac{2}{8}+\frac{2}{\infty}\right)\times 100 = 25\% \text{ of PEL}$$

- Answer: No, since dose <100%

% Noise Dose

Exercise 2B

- Given four hours of 80 dBA exposure, two hours of 90 dBA exposure, and two hours of 85 dBA exposure, what is the % dose using the HCA? (Does this person need to be in a hearing conservation program?)

$$\left(\frac{4}{32}+\frac{2}{8}+\frac{2}{16}\right)\times 100 = 50\% \text{ of PEL}$$

- Answer: Borderline, since dose = 50%

Noise Exposure

- In evaluating worker exposure to noise, the industrial hygienist should answer two main questions:
  1. Is the OSHA PEL met or exceeded?
  2. Does the worker need to be in the hearing conservation program?
- Modern dosimeters calculate dose both ways

TLV and REL for Noise

- The ACGIH TLV and NIOSH REL recommended for noise is as follows:
  - Criteria level = 85 dBA,
  - Threshold level = 80 dBA
  - Exchange rate = 3 dBA
- These guidelines are much more protective

ACGIH and NIOSH Guidelines

Exposure Time, Hrs	TLV/REL, dBA
25	80
11	82
8	85
5	88
2	91
0.5	110

Challenges

- Reducing noise exposure in industry is difficult since guarding and sound-proofing materials make machines harder to clean or are hard to clean themselves, noise reduction is expensive, etc.
- Hearing protection is not very effective because it is often not used properly and is uncomfortable