# Summer Youth Program 2016
# Human Hearing

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Dr. Andrew Barnard
Miles Penhale

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# Agenda

- Human Hearing
  - Source – Path – Receiver
  - Sound waves
  - Ear
    - Anatomy and Function
  - Hearing loss (DEMO)
    - Causes, Prevention, Treatment
    - Hearing loss in the Military
  - Perception of sound
    - Everyone perceives sound differently – Its Subjective!
    - Equal Loudness (DEMO)
    - Frequency Filtering (DEMO)
    - Perceived Relative Sound Level (DEMO)
  - Masking (DEMO)

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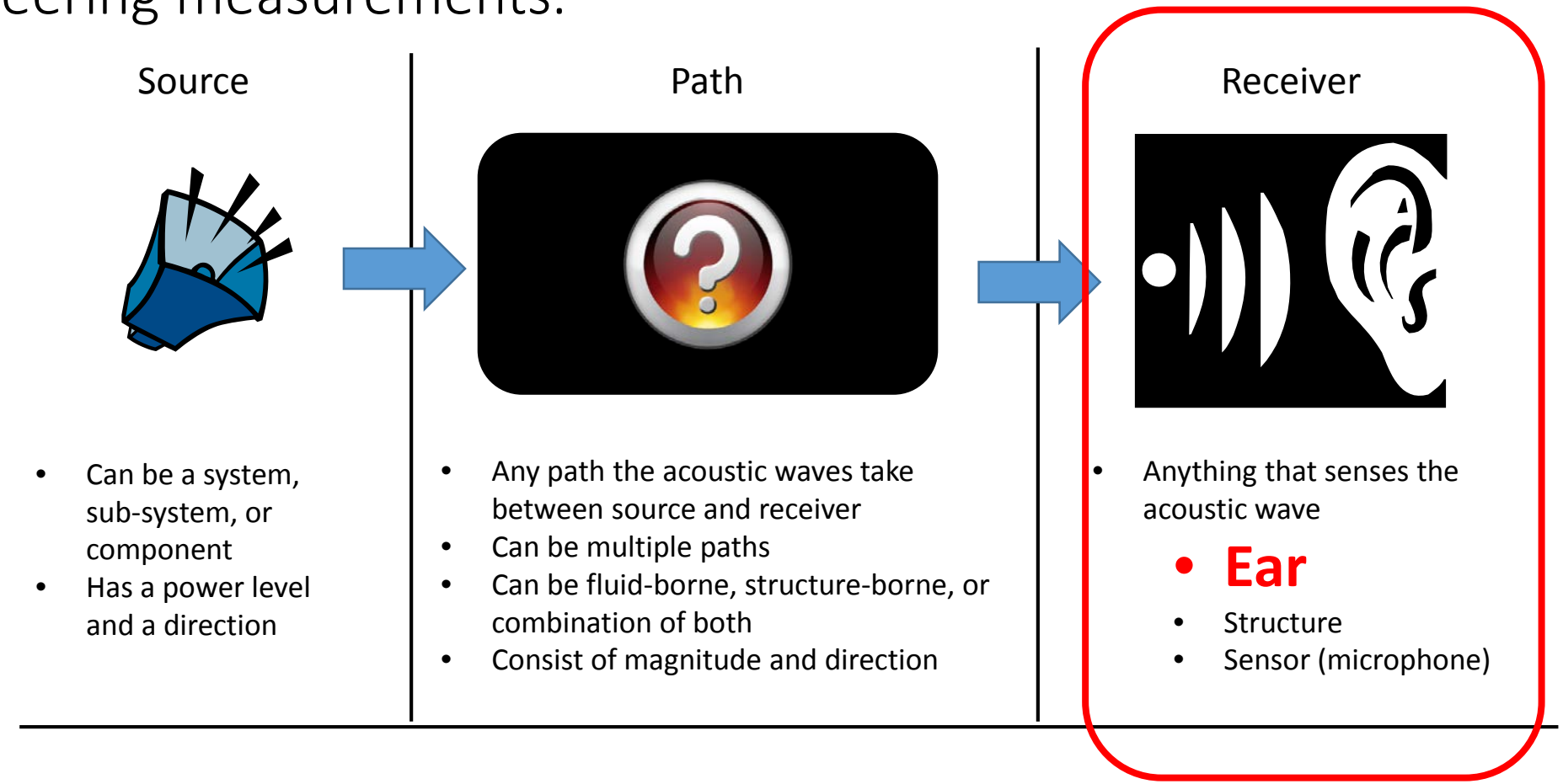
# The source-path-receiver paradigm is very important for noise control engineering measurements.

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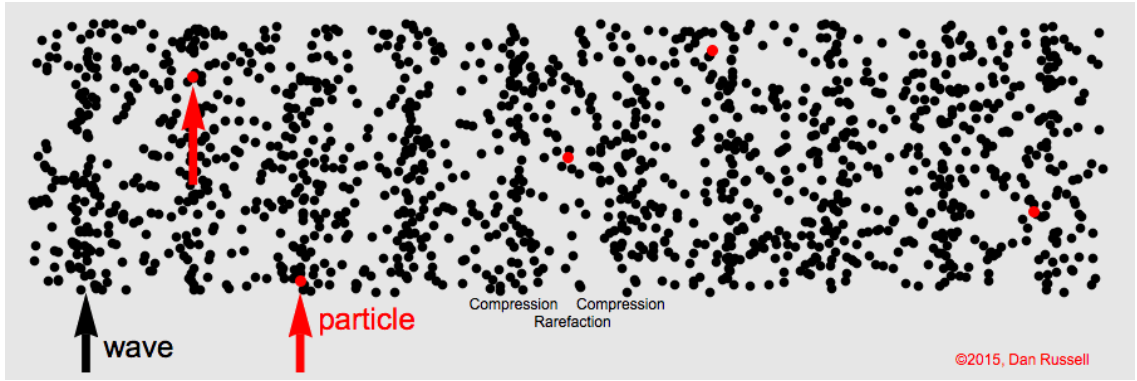
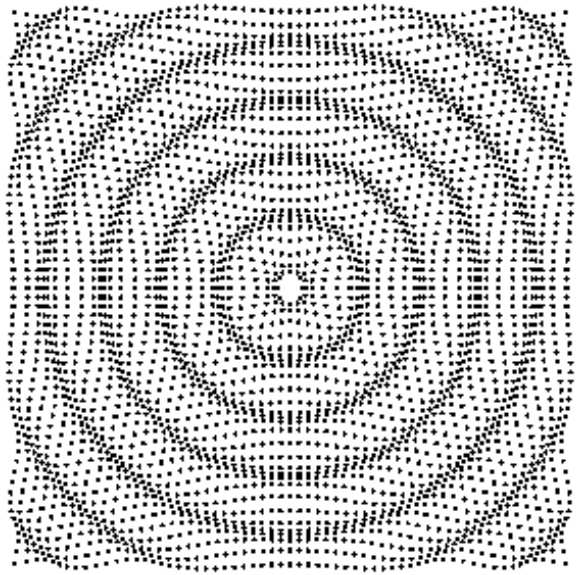
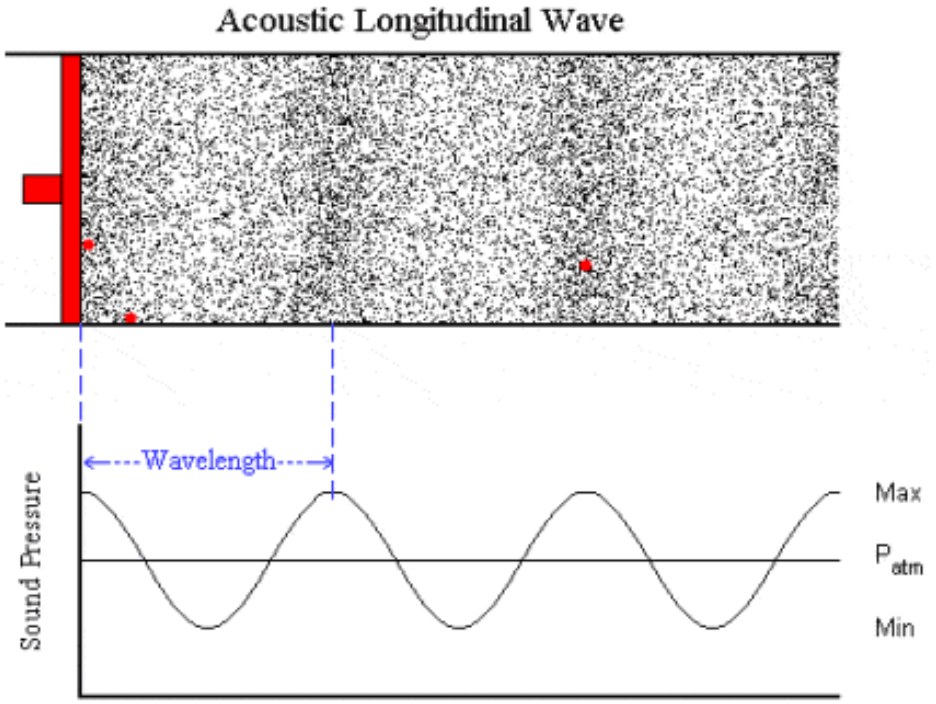
# Sound is a pressure wave in air



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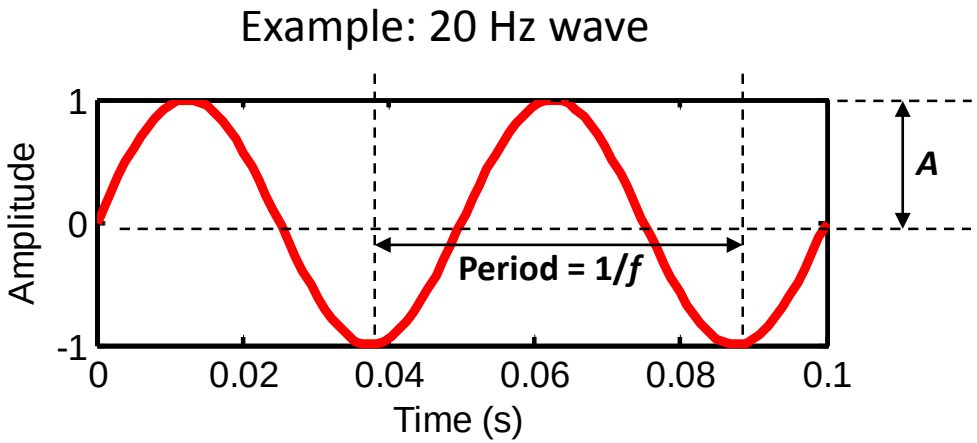
# Equation of pressure wave

- $y(t) = A * \sin(\omega t + \varphi)$

- $A$: amplitude of the pressure wave (Pa)
- $\omega$: angular frequency (rad/s) $= 2\pi f$ (Hz)
- $\varphi$: phase shift (rad). Represents how much time delay the waveform has with respect to time $t = 0\ sec$.

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# Frequency, Sound Speed, & Wavelength

- $f = \frac{c}{\lambda}$
- Speed of Sound depends on Temperature of Air
  - $c = \sqrt{\gamma RT} = 20.05\sqrt{T}$
    - T in Kelvin: $K = {}^{\circ}C + 273$
  - At 20˚C, c=343m/s or 1126 ft/s

## Units are Important!

- Frequency units are $Hz$ $\left(\frac{cycles}{s}\right)$
- Speed units are $\left(\frac{m}{s}\right)$
- Wavelength units are $(m)$

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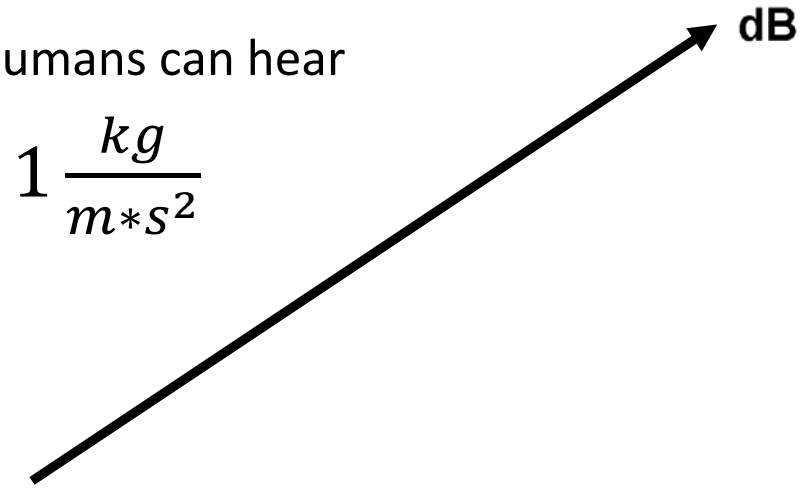
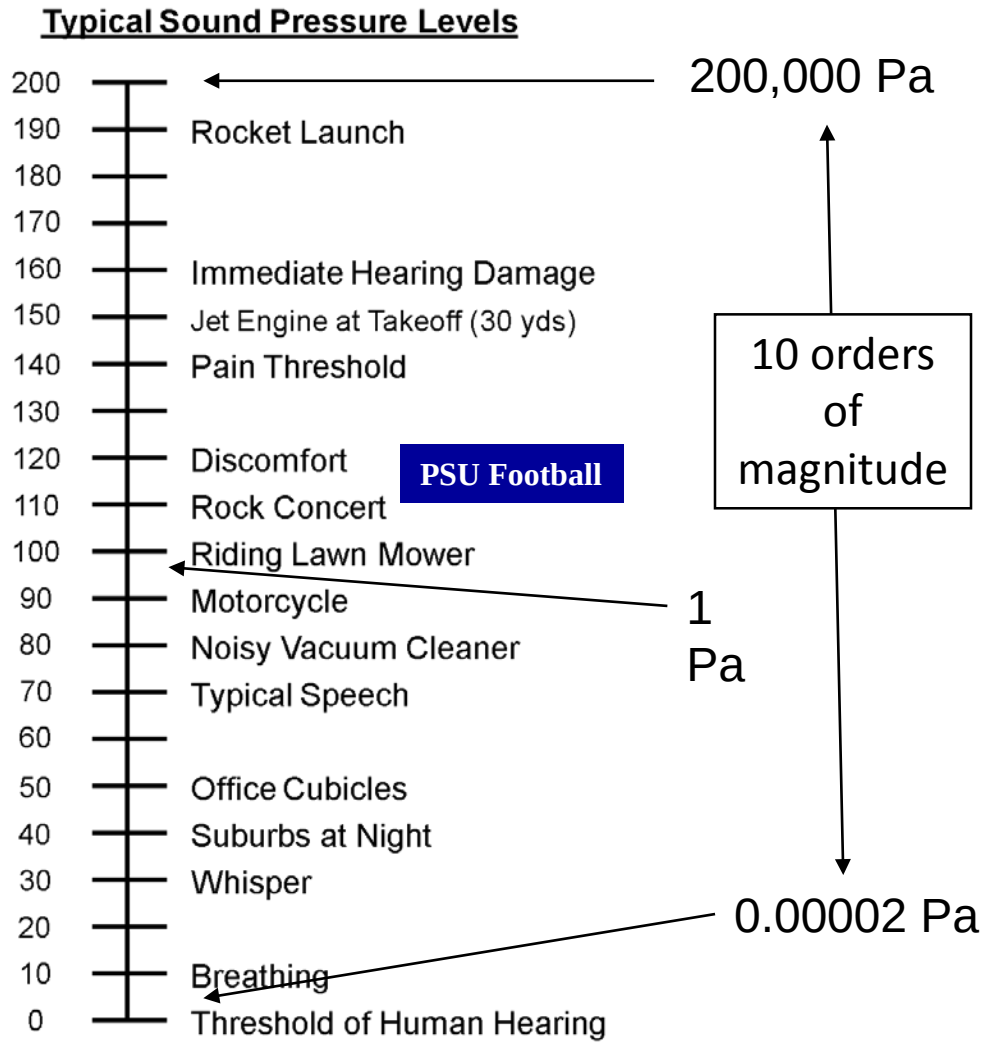
# Sound Pressure Level

- $L_p = 20 * \log_{10}\left(\frac{p_{meas}}{p_{ref}}\right)$ dB
- $p_{ref} = 20\ \mu Pa$
  - Quietest sound humans can hear
- $1\ Pa = 1\frac{N}{m^2} = 1\frac{kg}{m*s^2}$




Sound pressure amplitude is usually measured as a level in decibels to compress its large range of values

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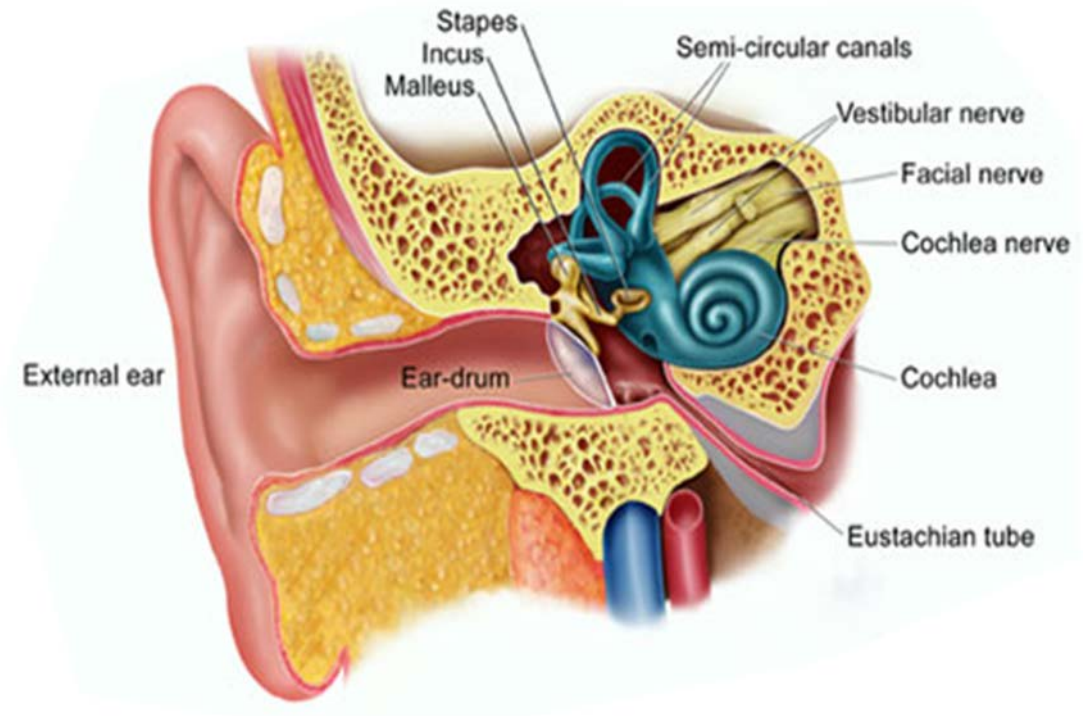
# Human Ear Anatomy and Function

1. Sound wave in air
2. Tympanic Membrane– vibrates when sound wave interacts with it
3. Malleus, Incus, Stapes – Small bones connect ear drum and cochlea
4. Cochlea – fluid filled and lined with tiny hairs called cilia
5. Cilia – move and vibrate creating an electrical nerve impulse
6. Electrical impulse travels to the brain to be interpreted

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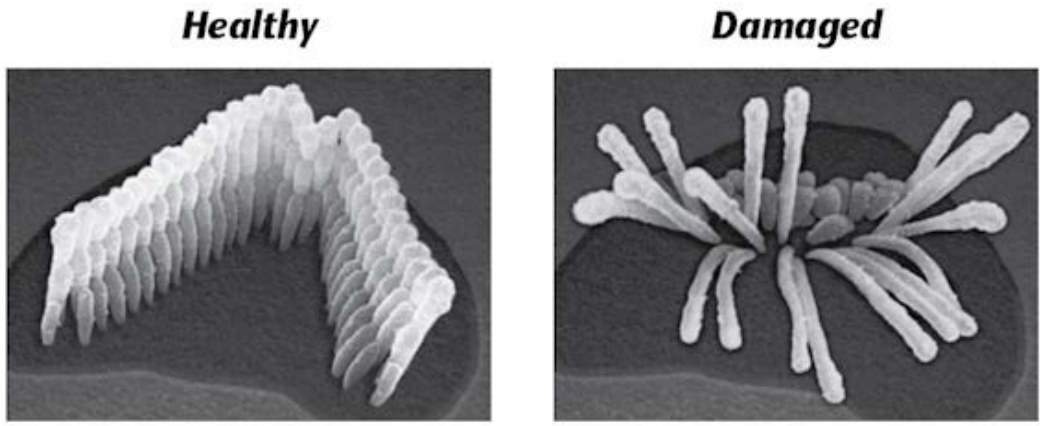
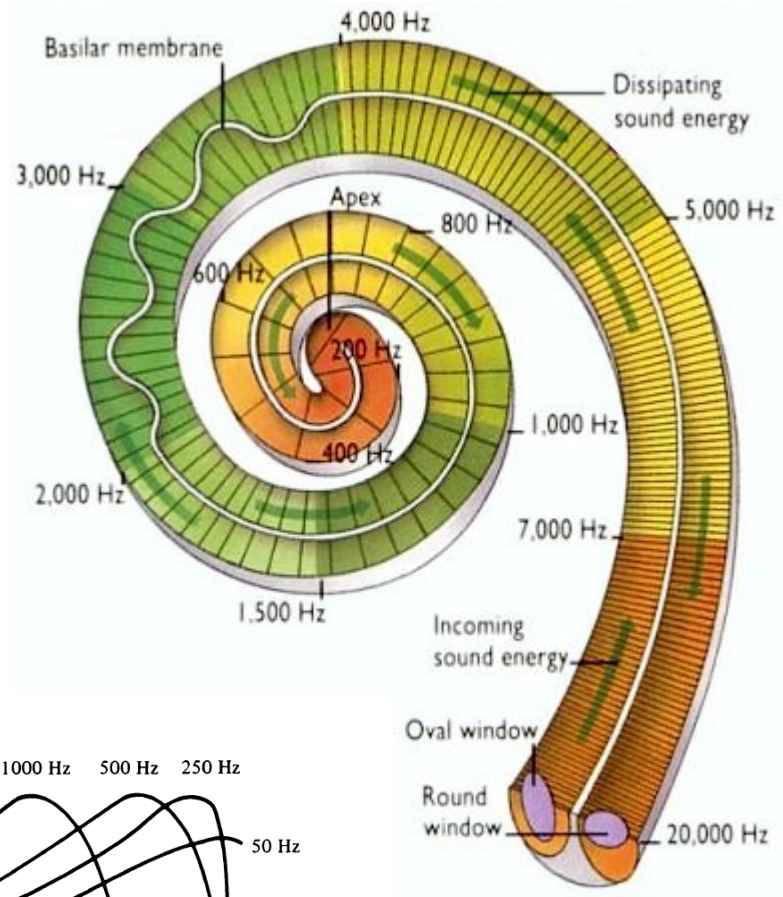
# Basilar Membrane

- Inside of the Cochlea, about 23,000 tiny hair cells on the Basilar membrane act as voltage transducers for the auditory nerve endings
- Hearing loss can happen if cilia get permanently bent over

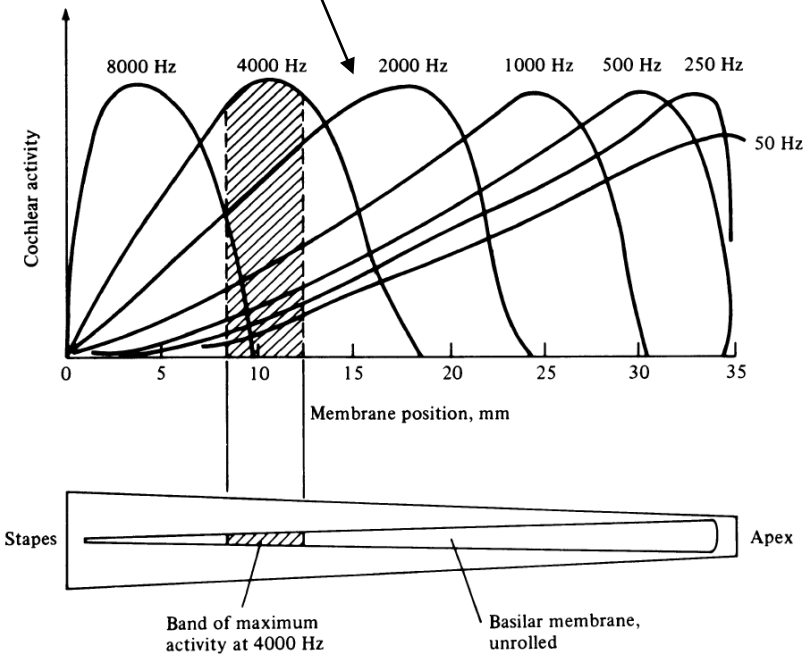



Source: 'Dangerous Decibels Program' OHSU — www.dangerousdecibels.org

Repeated exposures to loud noise can damage hair cells to the point that they won't recover.




These are called Critical Bands

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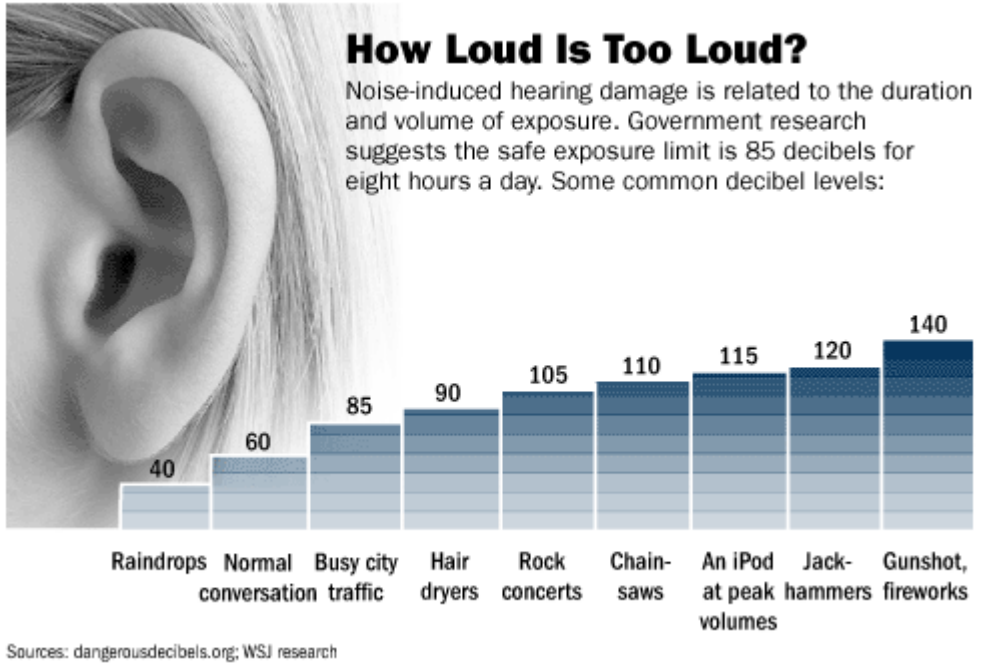
# Causes of hearing loss

- Listening to extremely loud noises
- Listening to moderately loud noises for extended periods of time
- “Natural” loss of hearing with Age (*presbycusis*)

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# Several organizations work to protect workers from noise induced hearing damage



**CHABA**: National Research Council, Committee on Hearing, Bioacoustics, and Biomechanics

**MIL Std. 1474D**: All US military personnel and personnel occupied areas


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# Reference chart for hearing loss prevention

| Allowable Exposure Time | OSHA (dB) | NIOSH & MIL (dB) |
|---|---|---|
| 8 hrs | 90 | 85 |
| 4 hrs | 95 | 88 |
| 2 hrs | 100 | 91 |
| 1 hr | 105 | 94 |
| 30 min | 110 | 97 |
| 15 min | 115 | 100 |
| 7.5 min | | 103 |
| 195 sec | | 106 |
| 97 sec | | 109 |
| 49 sec | | 112 |
| 24 sec | | 115 |
| Never Exceed | 115 | 115 |

Note: These are levels at the ear, not in the surrounding environment. Hearing protectors can, and should, be used to extend exposure time in high level environments.

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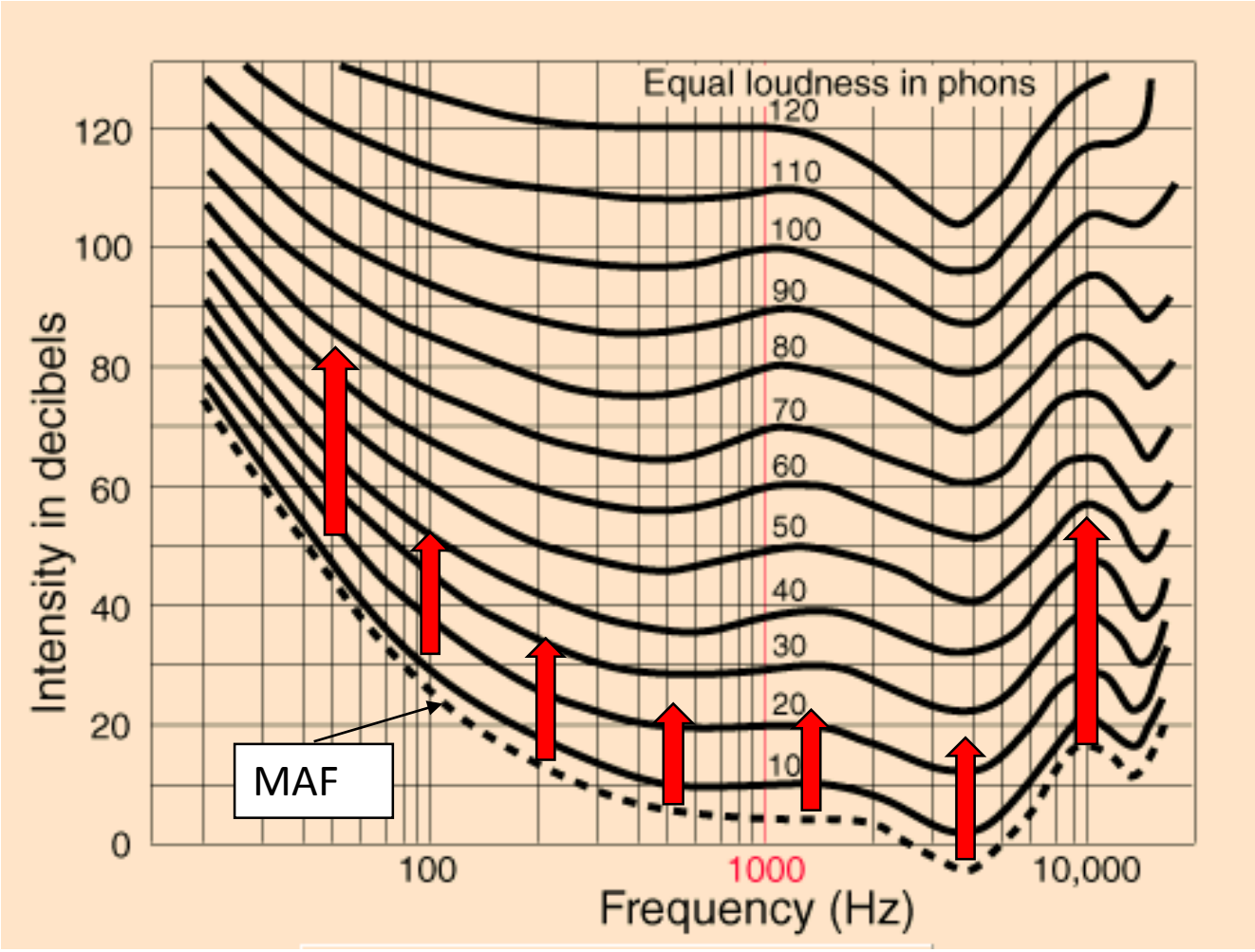
Hearing damage is present when the Minimum Audible Field (MAF) function increases due to aging or noise induced hearing loss

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# Definition of hearing handicap in the speech range

**Table 2.2 Guideline for the relations between the average hearing threshold level for 500, 1000, and 2000 Hz and degree of handicap as defined by the Committee on Hearing of the American Academy of Ophthalmology and Otolaryngology**

| Class | Degree of handicap | Average hearing threshold level for 500, 1000, and 2000 Hz in the better ear | | Ability to understand speech |
|---|---|---|---|---|
| | | More than dB | Not more than dB | |
| A | Not significant | | 25 | No significant difficulty with faint speech |
| B | Slight handicap | 25 | 40 | Difficulty only with faint speech |
| C | Mild handicap | 40 | 55 | Frequent difficulty with normal speech |
| D | Marked handicap | 55 | 70 | Frequent difficulty with loud speech |
| E | Severe handicap | 70 | 90 | Can understand only shouted or amplified speech |
| F | Extreme handicap | 90 | | Usually cannot understand amplified speech |

*Source:* Davis, *Trans. Am. Acad. Ophthalmol. Otolaryngol.*, 1965. With permission.

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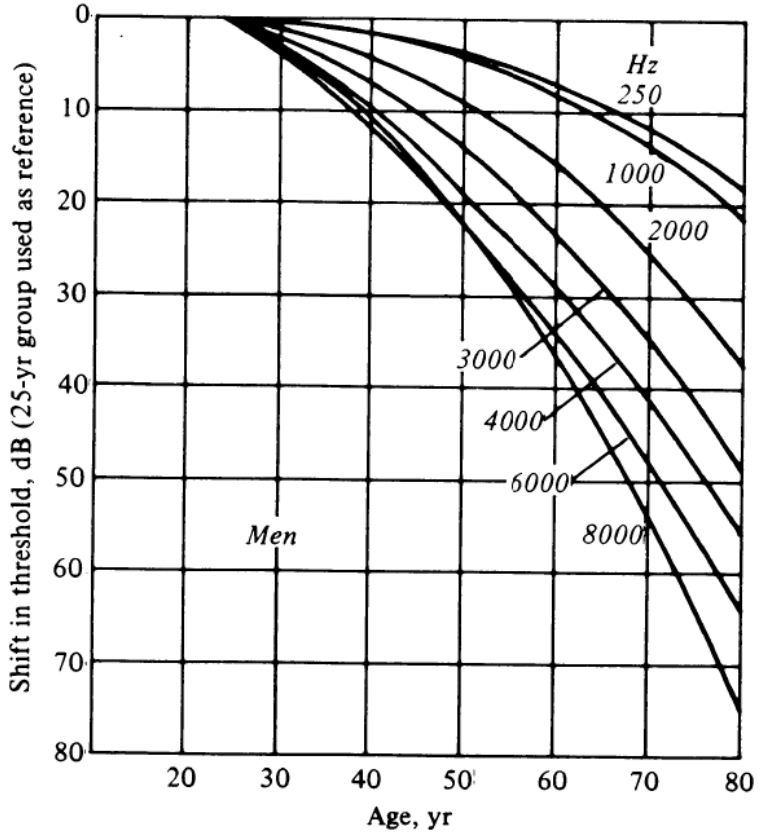
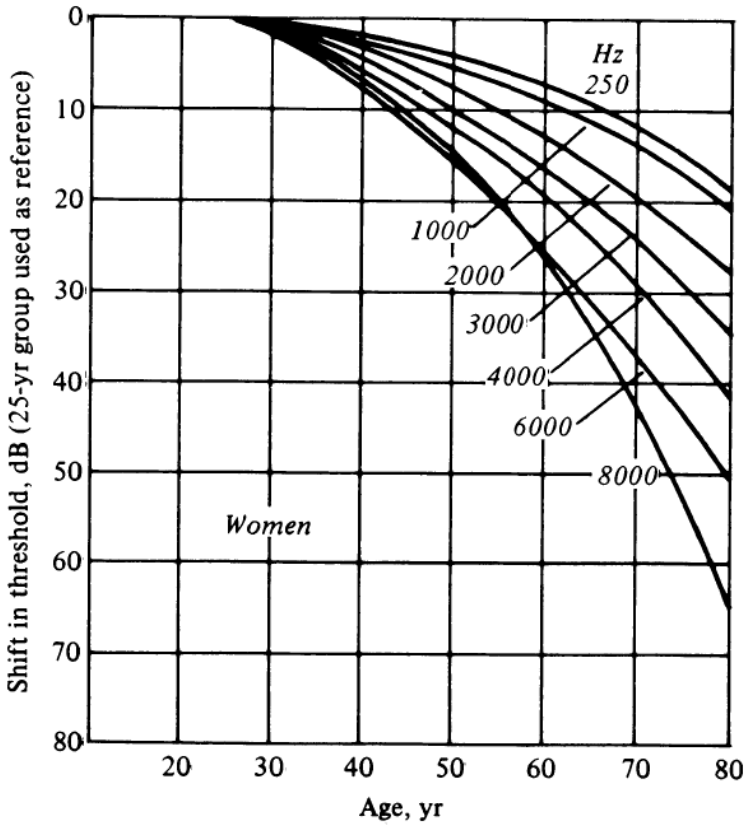
# Threshold shifts over time “Filter” the sound that you should be hearing

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# Noise induced hearing loss is defined statistically

- Assumptions
  - Average hearing MAF at 20 yrs old (probably a bad assumption these days)
  - Sustained exposure over a 40 year working life
  - Statistical risk percentage

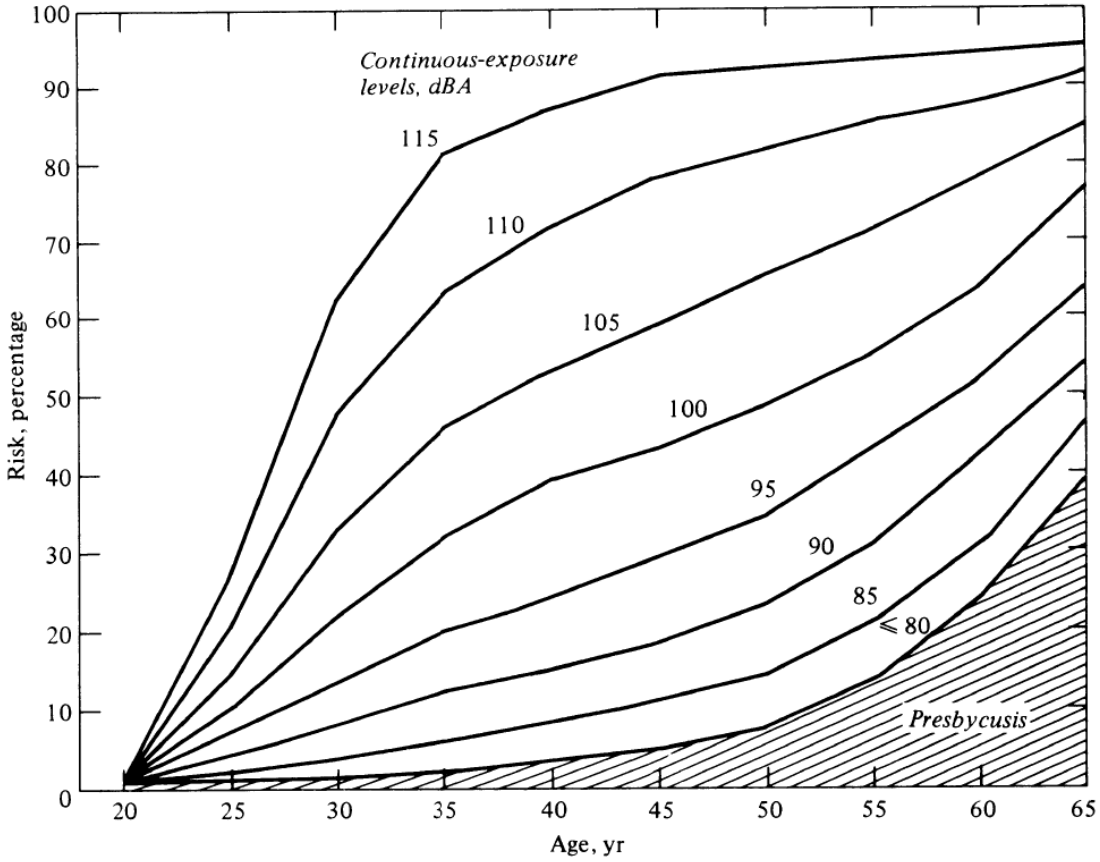


**Figure 2.6** Percentage risk associated with hearing handicap under sustained occupational noise exposure.

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# Hearing Loss in the Military

- Extremely important problem!
  - Largest military expenditure for veteran disability care
  - Over $1.1 Billion annually

## FY13 Veterans Affairs Annual Report

Most prevalent disabilities of all compensation recipients

| Disability | Body system | Male | % | Female | % | Total | %Total |
|---|---|---|---|---|---|---|---|
| Tinnitus | Auditory | 1,056,443 | 7.4% | 47,149 | 2.8% | 1,121,709 | 7.0% |
| Hearing loss | Auditory | 823,134 | 5.8% | 13,466 | 0.8% | 854,855 | 5.3% |
| Post-traumatic stress disorder | Mental | 600,193 | 4.2% | 38,076 | 2.3% | 648,992 | 4.0% |
| Lumbosacral or cervical strain[20] | Musculoskeletal | 519,957 | 3.7% | 92,082 | 5.4% | 616,937 | 3.8% |
| Scars, general | Skin | 503,411 | 3.5% | 59,455 | 3.5% | 574,191 | 3.6% |
| Limitation of flexion, knee | Musculoskeletal | 390,144 | 2.7% | 60,650 | 3.6% | 453,704 | 2.8% |
| Diabetes mellitus | Endocrine | 383,916 | 2.7% | 4,665 | 0.3% | 398,480 | 2.5% |
| Paralysis of the sciatic nerve | Neurological | 322,212 | 2.3% | 18,517 | 1.1% | 346,572 | 2.2% |
| Limitation of motion of the ankle | Musculoskeletal | 303,079 | 2.1% | 38,359 | 2.3% | 343,834 | 2.1% |
| Degenerative Arthritis of the Spine | Musculoskeletal | 293,540 | 2.1% | 39,597 | 2.3% | 335,692 | 2.1% |
| **Total most prevalent disabilities** | | **5,196,029** | **37%** | **412,016** | **24%** | **5,694,966** | **35%** |
| **Total number of disabilities** | | **14,179,086** | **100%** | **1,691,759** | **100%** | **16,105,400** | **100%** |

All GWOT compensation recipients and estimated annual payments

| Gender | Number of Veterans | Estimated total amount paid annually | Estimated average individual amount paid annually |
|---|---|---|---|
| Male | 614,348 | $ 7,889,012,940 | $ 12,841 |
| Female | 97,186 | $ 1,216,434,216 | $ 12,517 |
| **Total[14]** | **714,380** | **$ 9,134,739,468** | **$ 12,787** |

http://backhome.news21.com/article/hearing/
http://usnews.nbcnews.com/_news/2012/11/13/14728839-hearing-loss-the-most-prevalent-injury-among-returning-veterans

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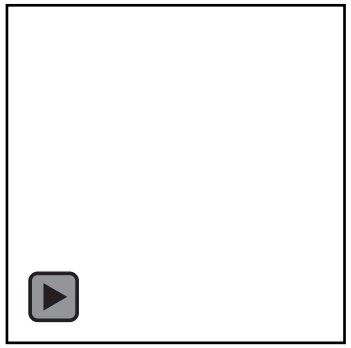
# Demonstration of hearing loss



HEARING LOSS

http://www.hse.gov.uk/noise/demonstration.htm

http://www.starkey.com/hearing-loss-simulator
http://howihear.herokuapp.com/
http://shelaza.com/links/what-do-hearing-loss-hearing-aids-and-cochlear-implants-sound-like/

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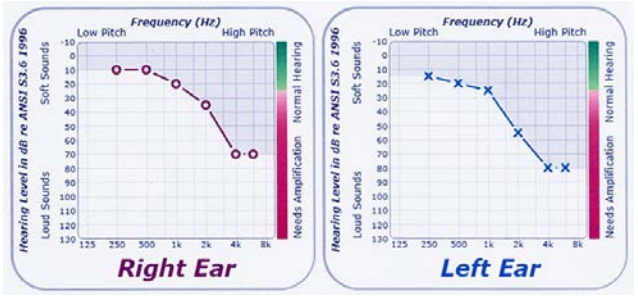
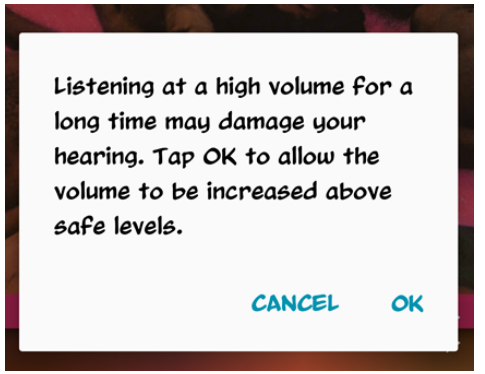
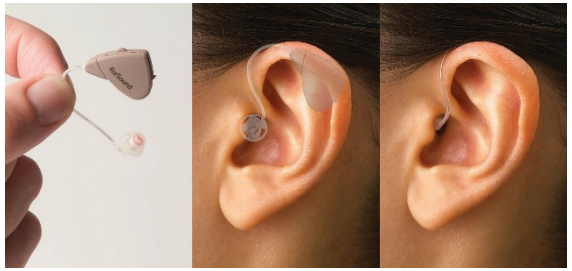
# Treatments for hearing loss

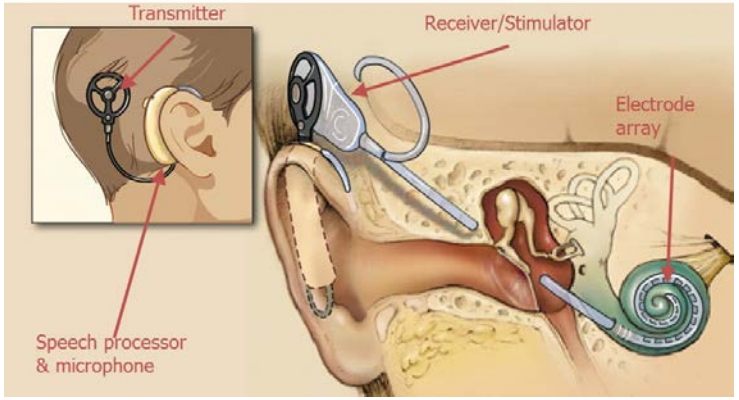
- Prevention
  - Use hearing protection in loud environments: Ear plugs/muffs
  - Turn music down when listening
  - Routine hearing testing to track your
- Hearing Aids



- Cochlear Implants

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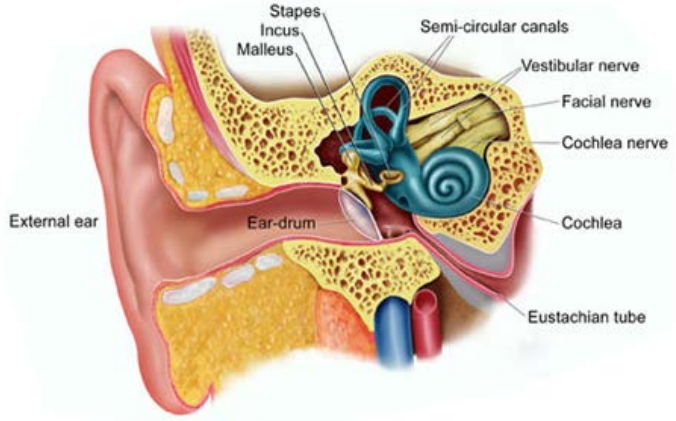
# Sound Quality is the “opinion” of people about sound.

Objective

- Linear
- Calibrated


Subjective

- non linear
- non-calibrated




As engineers we try to create **objective** measures of sound to describe **subjective** responses of people.

This is really hard because every person is different → Statistics are you friend!



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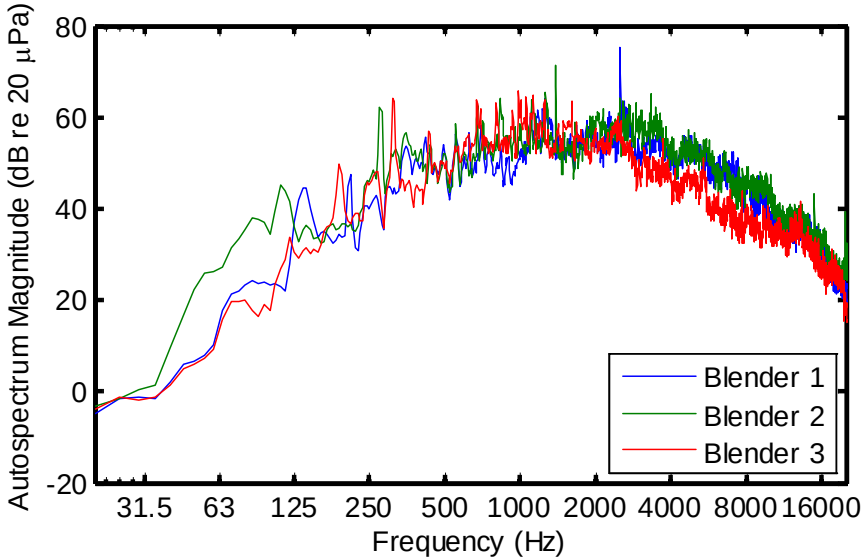
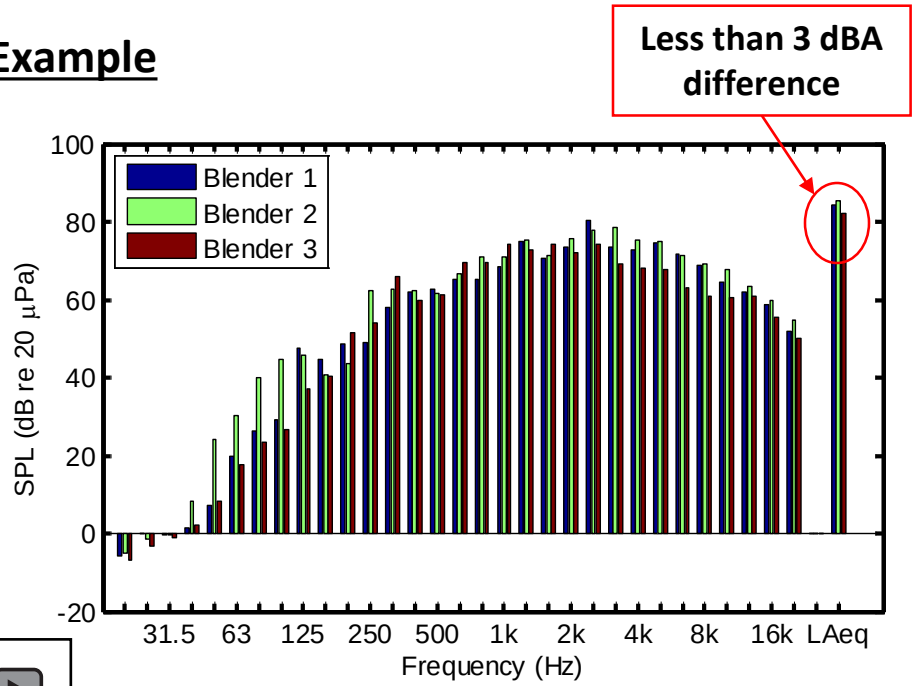
# Conventional sound metrics, like SPL, have difficulties because human hearing can discriminate between different sounds of the same level.

Car Door Closures:

**Blender Example**



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# Sound Quality has a subjective nature

**Sound Quality** depends on :

- environment
- Social Norms and Subjective Attitudes
- Race, Age and Sex
- Expectations and Experience
- Cultural background

**If our ear anatomy was exactly the same, we would still perceive sounds Differently due to our brains interpretation.**

The challenge in Sound Quality is to develop objective measures ( metrics) for this subjective phenomenon

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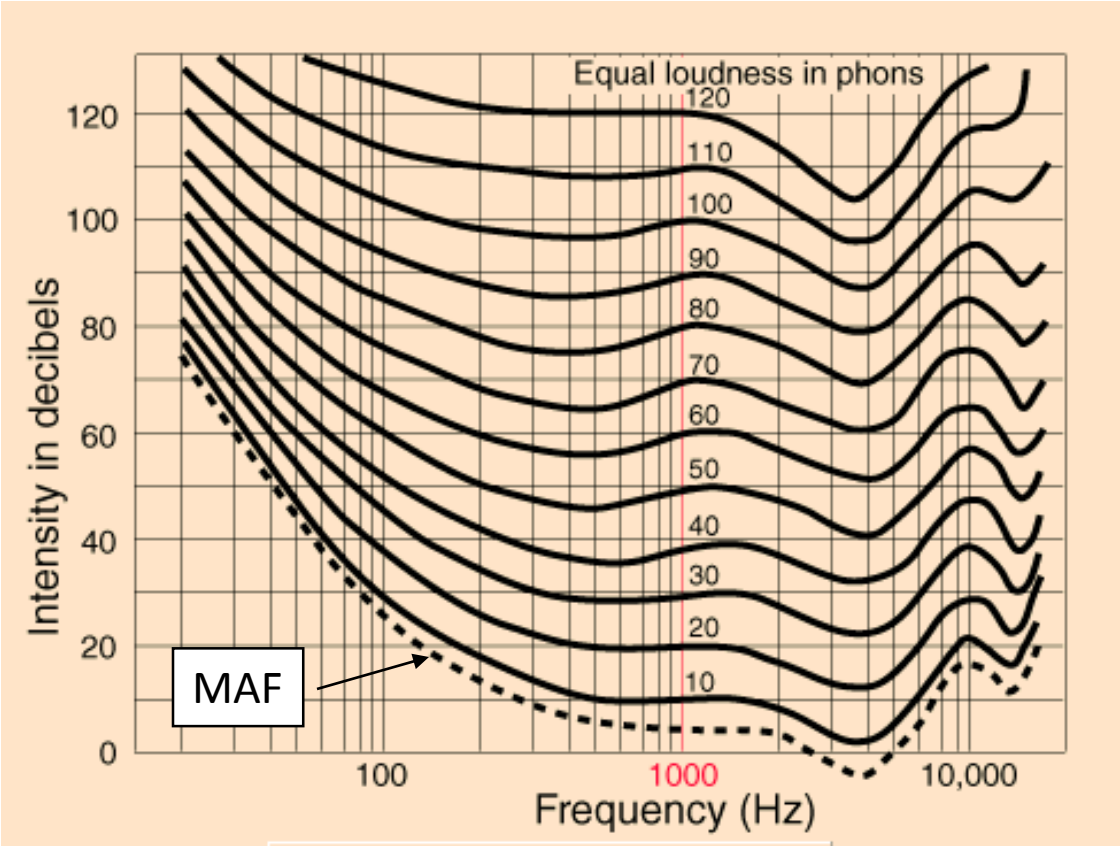
# The Fletcher-Munson curves show equal perceived loudness levels of **pure tones** from large jury studies in the 1930s.




[Fletcher & Munson – 1933]

Because our ear is non-linear, it responds differently to varied frequencies and levels.

A loudness unit of 40 Phons was defined as the loudness of 40 dB SPL at 1000 Hz

MAF = Minimum Audible Frequency Curve



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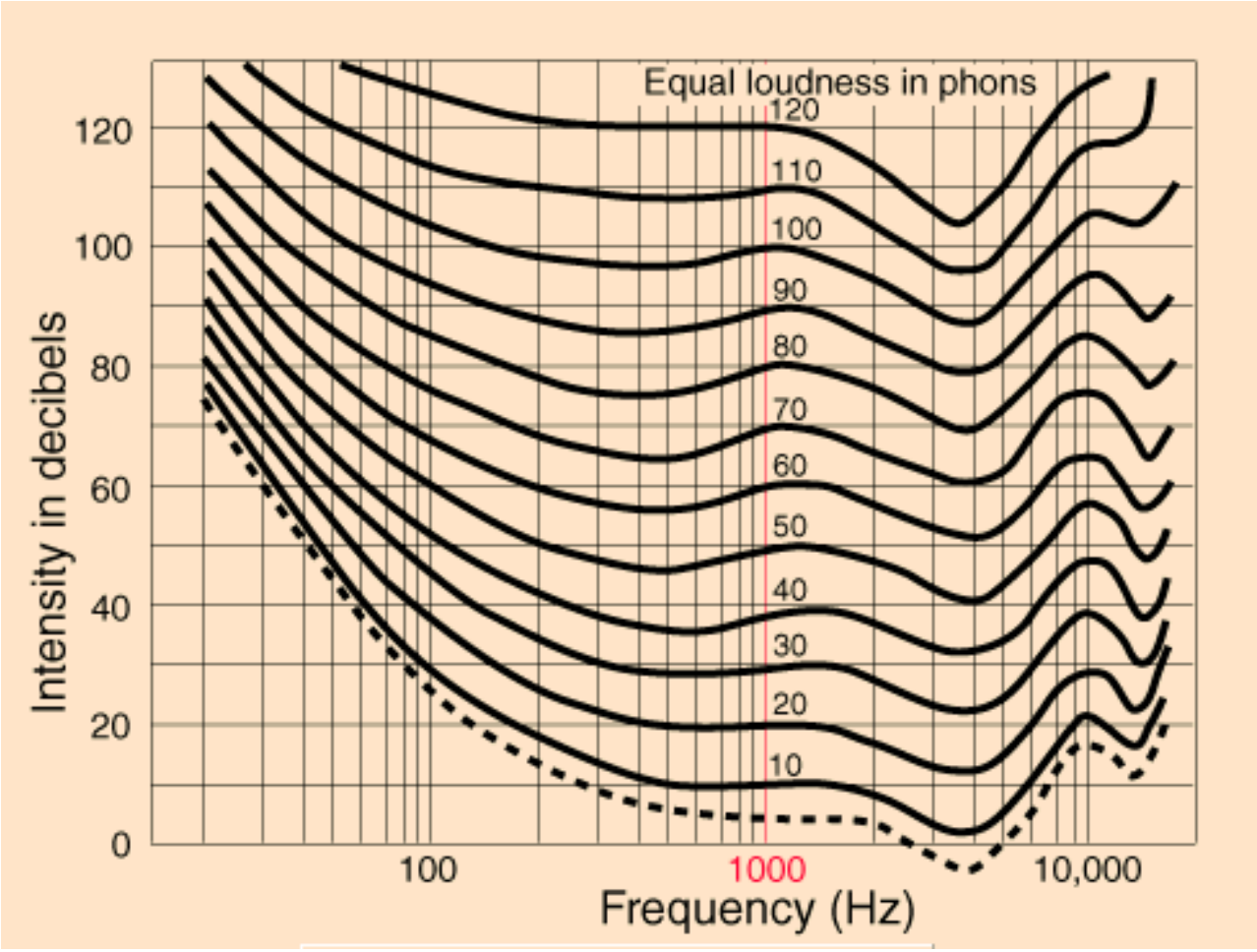
# Now lets try an experiment to see if we can replicate the Fletcher-Munson curves!




Cal Signal (1000 Hz)

63 Hz

125 Hz

250 Hz

500 Hz

2000 Hz

4000 Hz

8000 Hz

EQUAL LOUDNESS



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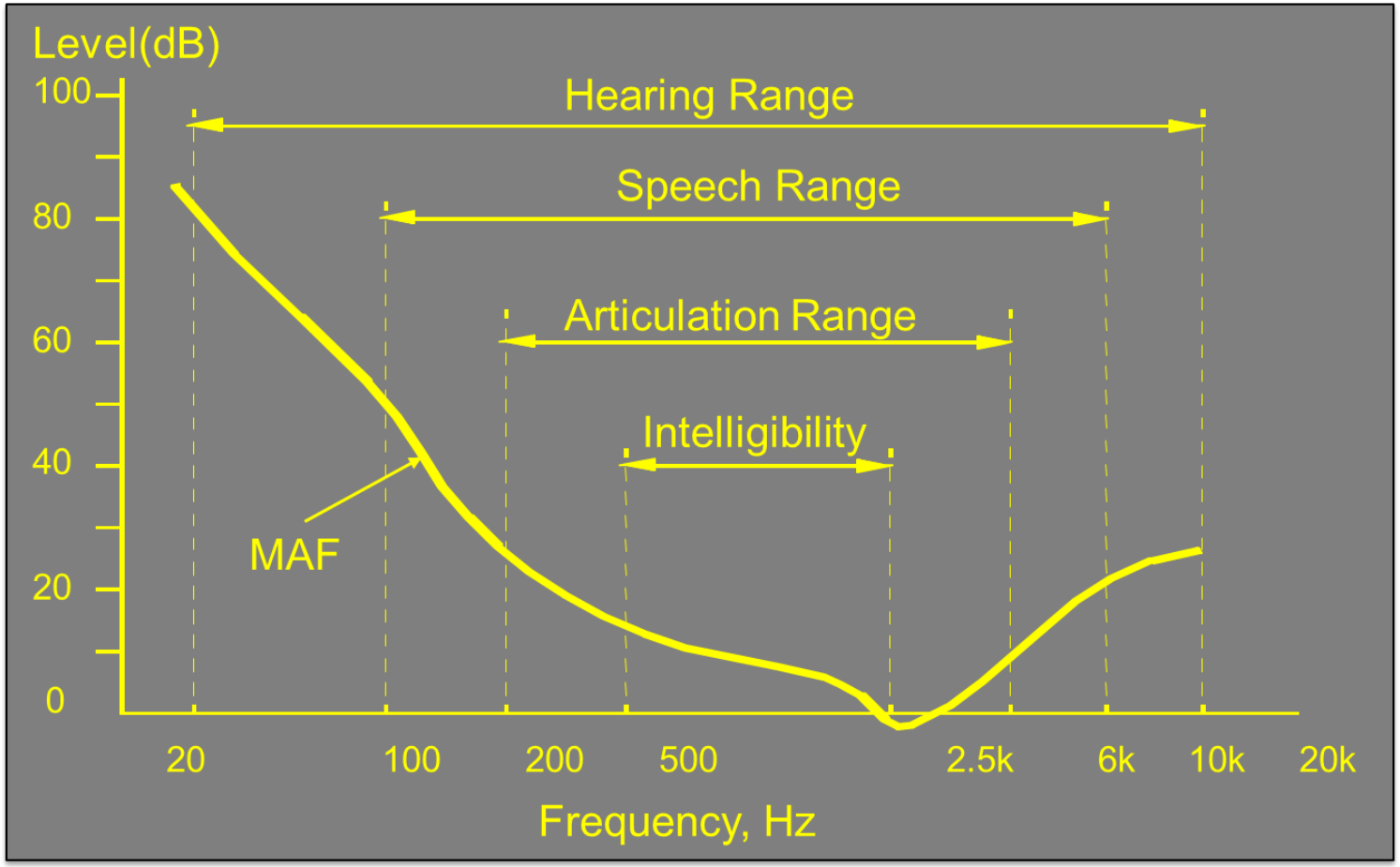
# The MAF curve is minimized (maximum sensitivity) in the most important frequency ranges for communication.




OTO BANDS

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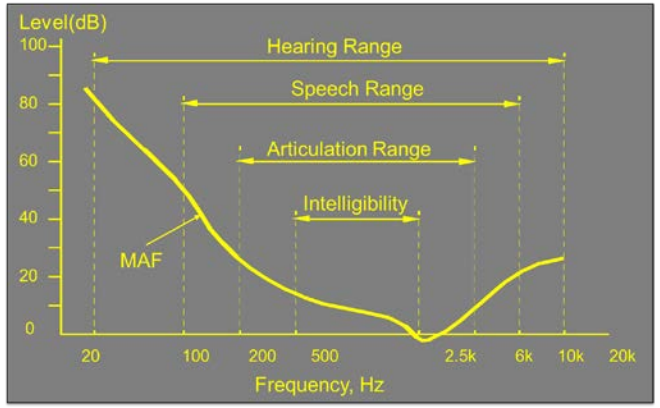
# Detection vs. Communication

- Low frequencies travel farther than high frequencies
  - Important to attenuate low frequency content to reduce detection distance for military applications
- Humans have difficulty hearing low frequencies
  - We communicate with frequencies between 200-2500 Hz therefore our ear are most adapt at perceiving these.




Human hearing is most sensitive at 1000 Hz

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# Now let’s try to determine relative perceived sound levels

| Description | Relative Level |
|---|---|
| Hardly Noticeable | <2 dB |
| Noticeable, but not significant | 3 dB |
| Significant change | 5 dB |
| Twice as loud | 10 dB |

PERCEIVED SOUND LEVEL



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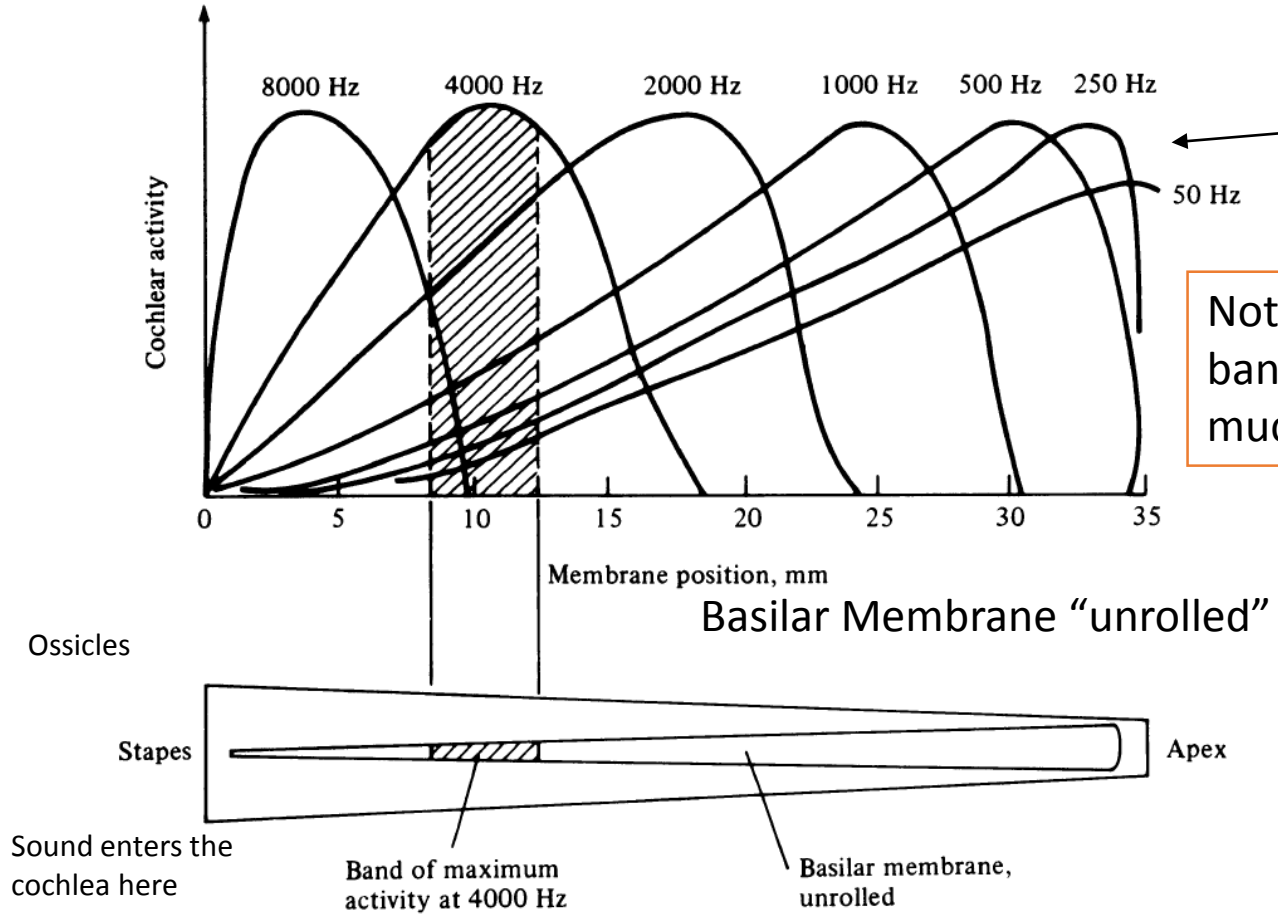
# The frequency of the incoming sound excites a region of hair cells on the Basilar Membrane




These are called Critical Bands

Note the bandwidth of the critical bands increases with frequency, much like octave bands

Basilar Membrane "unrolled"

Figure 2.3 from Lord, Gatley, Evensen, *Noise Control for Engineers*

# Masking Demo

MASKING

- Low frequencies can be used to “mask” other sounds
  - 500 Hz
  - 1000 Hz
  - 4000 Hz
  - White noise 200-700 Hz

- Bonus! Beat frequency between 1000 Hz and 1001 Hz

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