Acoustics of Speech and Hearing

Lecture 1-2

Sound Pressure Level

Overview

- How is sound pressure and loudness related?
- How can we measure the size (quantity) of a sound?
- The Sound Pressure Level scale
  - Logarithmic scales in general
  - Decibel scales in general

Terms to describe sound

Subjective	Objective
Loudness	Intensity
Pitch	Repetition frequency (week 3)
Timbre	Spectral envelope +… (week 4)

The study of this relationship is called **Psychoacoustics**

Loudness

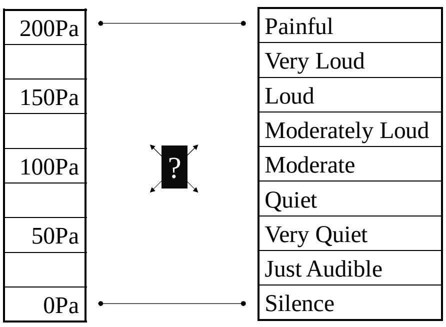
- Some pressure variations so small can't hear them:
  - below the Threshold of Hearing
  - smaller than ± 0.00002Pa (20μPa)
- Some pressure variations so large cause pain:
  - above the Threshold of Pain
  - larger than ± 200Pa
- Loudness has a wide range!
  - 10,000,000 to 1

20μPa

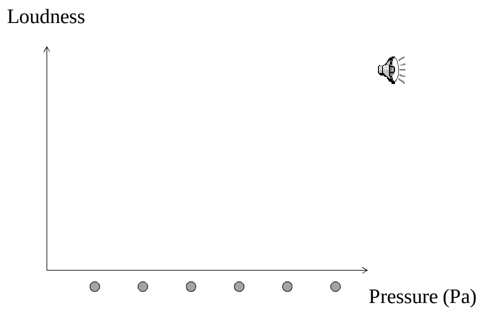
200Pa

10million

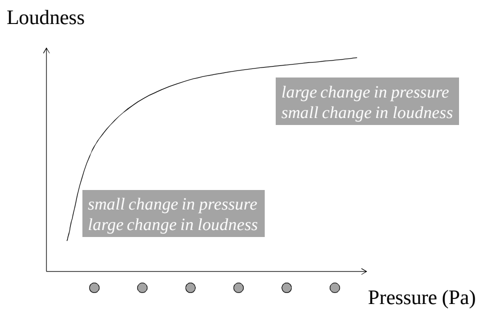
Matching Pressure to Loudness



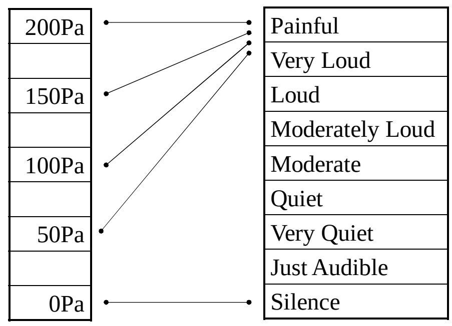
Loudness vs. Pressure



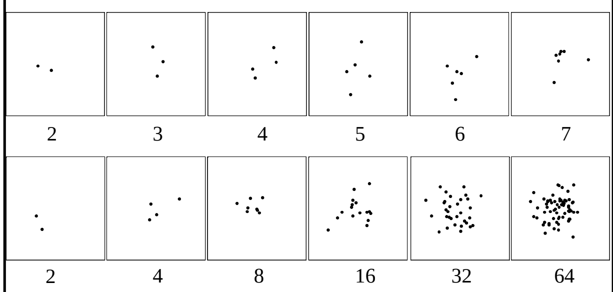
Loudness vs. Pressure



Matching Pressure to Loudness



Linear vs. Exponential Series



Linear vs. Exponential Series

- In a linear series, each step is a constant size

  `0 2 4 6 8`

  `(add 2)`

- In an exponential series, each step is a constant multiplying factor

  `1 2 4 8 16`

  `(multiply by 2)`

Logarithms

- Logarithms are a way of saying
  - "Ten to the power of *what* is this number?"
- For example: $\log_{10}(100)$
  - Ten to the power of *what* is 100?
  - Ten to the power of **two** is 100
  - Therefore $\log_{10}(100)$ is 2.
- Logarithms convert numbers into powers of 10

The logarithm of x is some number y where 10^y is equal to x

Logarithms Connect

- Logarithms convert an exponential series into a linear series:

```
     x= 1    10   100  1000 10000
log(x)= 0     1     2     3     4
```

- So if the property we want to measure changes exponentially, the logarithm of that value will change linearly.
- Loudness is like this.

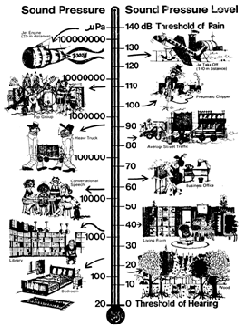
Measuring Objective "Loudness"

- Need a scale related to pressure but which is closer to our perception of sound
- Two key ideas:
  1. Let zero on the scale represent threshold of hearing
  2. Let each step on the scale be approximately equal steps of perceived loudness change

Sound Pressure Level Scale

Sound Pressure Level

- Is a **logarithmic** scale: that is each step along the scale represents a multiplication of the underlying pressure by a constant factor
- Is based on **ratios** of a pressure value to a reference pressure value
- Is a variation of the **decibel** scale



Logarithmic Ratio Scale

- On a **ratio scale**, the values being measured are first expressed as proportions of some underlying reference value:

$$\text{scaled value} = \left(\frac{\text{measured value}}{\text{reference value}}\right)$$

- On a **logarithmic ratio scale**, the log of the ratio is used:

$$\text{scaled value} = \log\left(\frac{\text{measured value}}{\text{reference value}}\right)$$

decibel Scale

- A **decibel scale** is a logarithmic ratio scale scaled up by ×20 to make the unit steps smaller and more usable:

$$\text{scaled value}(dB) = 20.\log_{10}\left(\frac{\text{measured value}}{\text{reference value}}\right)$$

- $\log_{10}$(ratio) turns ratio into power of 10
- 20 decibels represents a change of ×10
- 1 decibel represents a change of ×1.12

Sound Pressure Level

$$\text{Intensity}(dBSPL) = 20\log_{10}\left(\frac{\text{Pressure}(Pa)}{20\mu Pa}\right)$$

- The standard reference pressure of 20µPa is approximately equal to human threshold for sound under optimum conditions
- A change of 1dB is approximately equal to the smallest noticeable change in loudness

dBSPL Examples

$$20\log_{10}\left(\frac{\text{Pressure}(Pa)}{20\mu Pa}\right)$$

- Threshold of Hearing (20µPa)

  $20 \times \log_{10}(20\mu Pa/20\mu Pa)$
  $= 20 \times \log_{10}(1) = 20 \times 0$
  $= 0$ dBSPL

- Threshold of Pain (200Pa)

  $20 \times \log_{10}(200Pa/20\mu Pa)$
  $= 20 \times \log_{10}(10000000) = 20 \times 7$
  $= 140$ dBSPL

dBSPL Examples 2

$20\log_{10}\left(\frac{\text{Pressure}(Pa)}{20\mu Pa}\right)$

- Moderately loud sound (1Pa)

  $20 \times \log_{10}(1\text{Pa}/20\mu\text{Pa})$

  $= 20 \times \log_{10}(50000) = 20 \times 4.7$

  $= 94$ dBSPL

- Doubling in pressure (1Pa → 2Pa)

  $20 \times \log_{10}(2\text{Pa}/20\mu\text{Pa})$

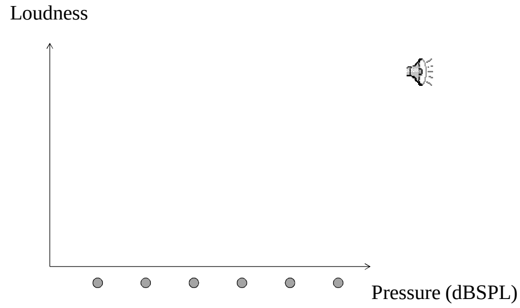
  $= 20 \times \log_{10}(100000) = 20 \times 5$

  $= 100$ dBSPL

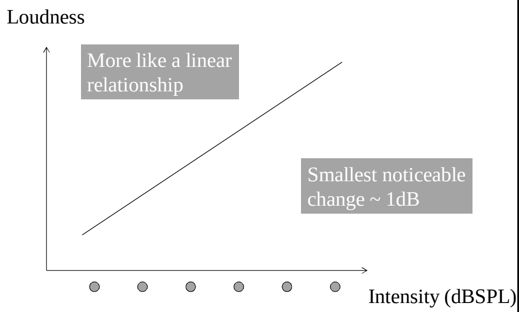
  $= 94 + 6$ dBSPL

A doubling in pressure always gives an increase of +6dB

Loudness vs. dBSPL



Loudness vs. dBSPL



Matching dBSPL to Loudness

200 Pa	140dB	Painful
20 Pa	120dB	Very Loud
2 Pa	100dB	Loud
0.2 Pa	80dB	Moderately Loud
0.02 Pa	60dB	Moderate
0.002 Pa	40dB	Quiet
0.0002 Pa	20dB	Very Quiet
0.00002 Pa	0dB	Just Audible
<0.00002 Pa	<0dB	Silence

Amplitude and Intensity

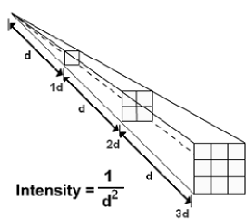
- Strictly, dBSPL scale is a measure of relative **intensity**
  (intensity = amount of energy delivered per unit area per unit time)
- However intensity turns out to be simply related to amplitude, and so we use **amplitude** in the dBSPL formula

intensity *amplitude*

$$\text{Sound Pressure Level } (dBSPL) = 20\log_{10}\left(\frac{\text{Pressure}(Pa)}{20\mu Pa}\right)$$

Intensity and Distance

- Sounds get quieter (less loud) the further you get from their source
- Easy to see that in a free field, the power per unit area falls with square of the distance
- Or in decibel terms, falls by 6dB every doubling of distance



Summary

- Objective and subjective scale of sound quantity
- Sound Pressure Level scale (dBSPL)
  - logarithmic ratio scale
  - with a reference at the threshold of hearing
  - which is convenient, standard, and closer to our perceptions of loudness

Lab Experiment

- Build your own sound level meter
- Calibrate its readings against some standard sounds
- Use your meter to measure how the intensity of a sound falls with distance
- Get a feel for how the dBSPL scale works.