Intensity

What is Stress?

- Examples of stress in English:

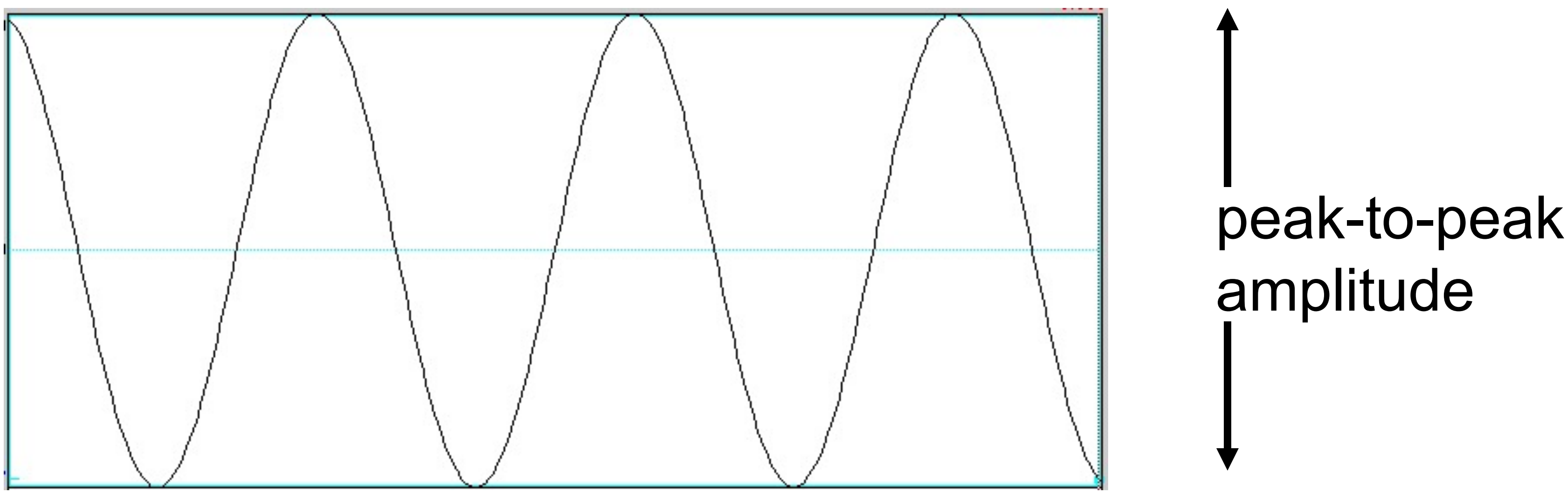
  [pɹəˈsidz] (V) vs. [ˈpʰɹo͡ʊsidz] (N)

  [kənˈtʰɹæst] (V) vs. [ˈkʰɑntɹæst] (N)

- Phonetically, stress is hard to define
  - I.e., it is hard to **measure**.
- It seems to depend on an interaction of three quantifiable variables:
  - Pitch
  - Duration
  - Loudness
  - Quality

Loudness

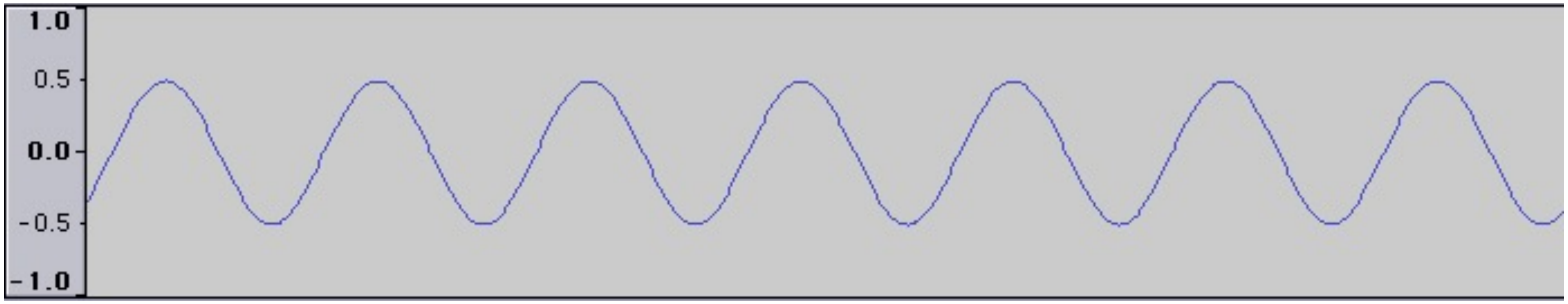
- How do we measure how loud a sound is?
- Recall: one parameter of a sinewave is its **amplitude**.

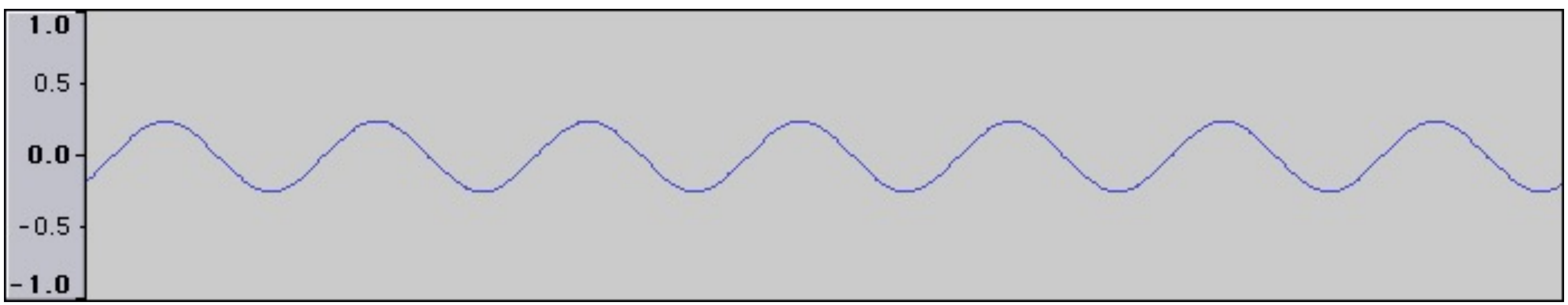


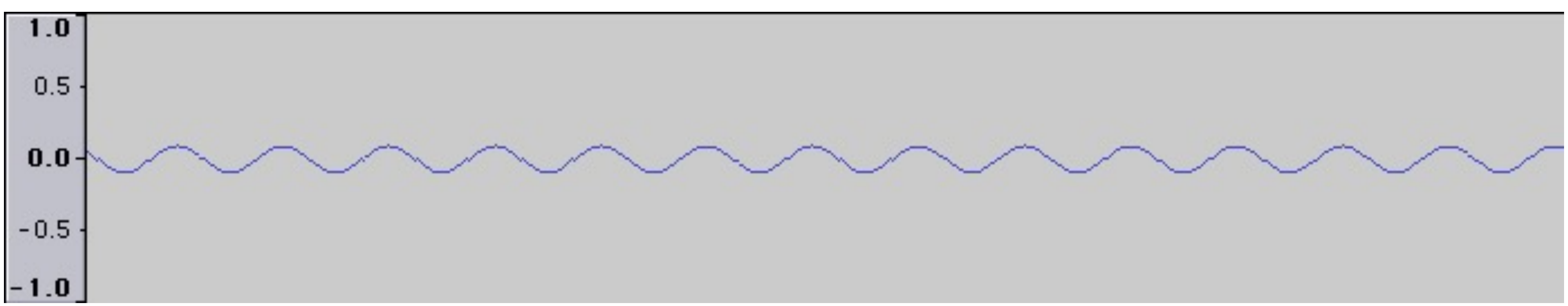
- Peak amplitude (for sound) is the highest sound pressure reached during a particular wave cycle.

Amplitude/Loudness Examples

- The higher the peak amplitude of a sinusoidal sound, the louder the sound seems to be.







RMS amplitude

- Peak-to-peak amplitude is sufficient for characterizing the loudness of sinewaves, but speech sounds are more complex.
- Another method of measuring loudness:

  root-mean-square (RMS) amplitude
- To calculate RMS amplitude:

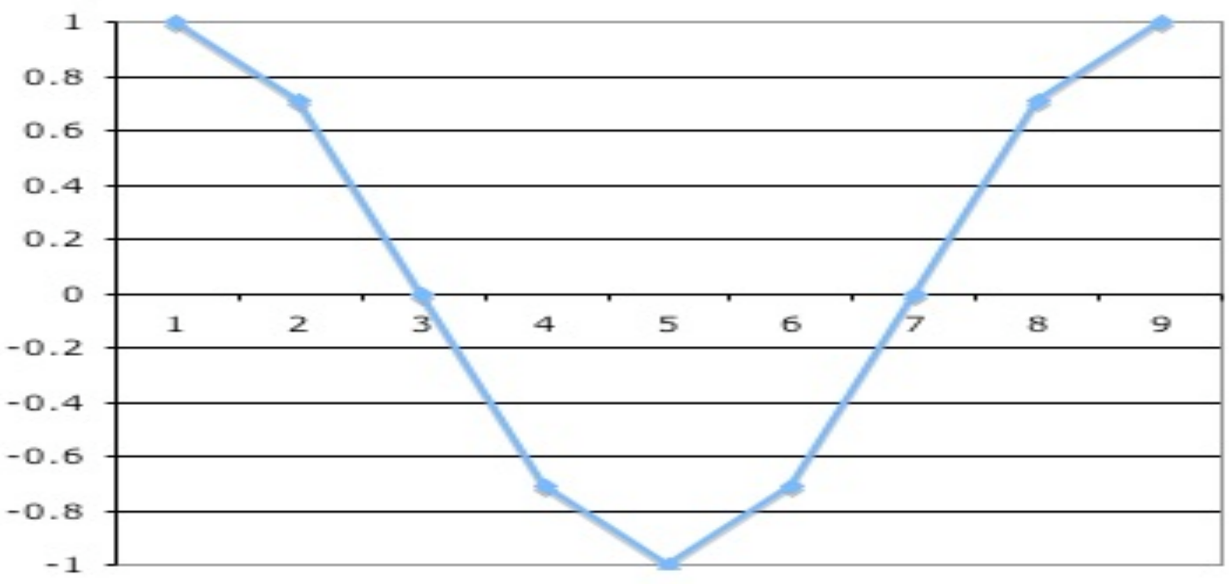
  1. **Square** the pressure value of the waveform at each point (sample) in the sound file
  2. **Average** all the squared values
  3. Take the **square root** of the average

RMS example

- A small sampling of a "sinewave" has the following pressure values:

pressure	1	0.707	0	-0.707	-1	-0.707	0	0.707	1
sample	1	2	3	4	5	6	7	8	9

- It looks like this (in Excel):



RMS calculations

pressure	1	0.707	0	-0.707	-1	-0.707	0	0.707	1
sample	1	2	3	4	5	6	7	8	9

- To calculate RMS amplitude for this sound, first square the values of each sample (only up to sample #8!):

square	1	0.5	0	0.5	1	0.5	0	0.5	
sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	

- Then average all the squared values

(1 + .5 + 0 + .5 + 1 + .5 + 0 + .5) / 8 = 4/8 = .5

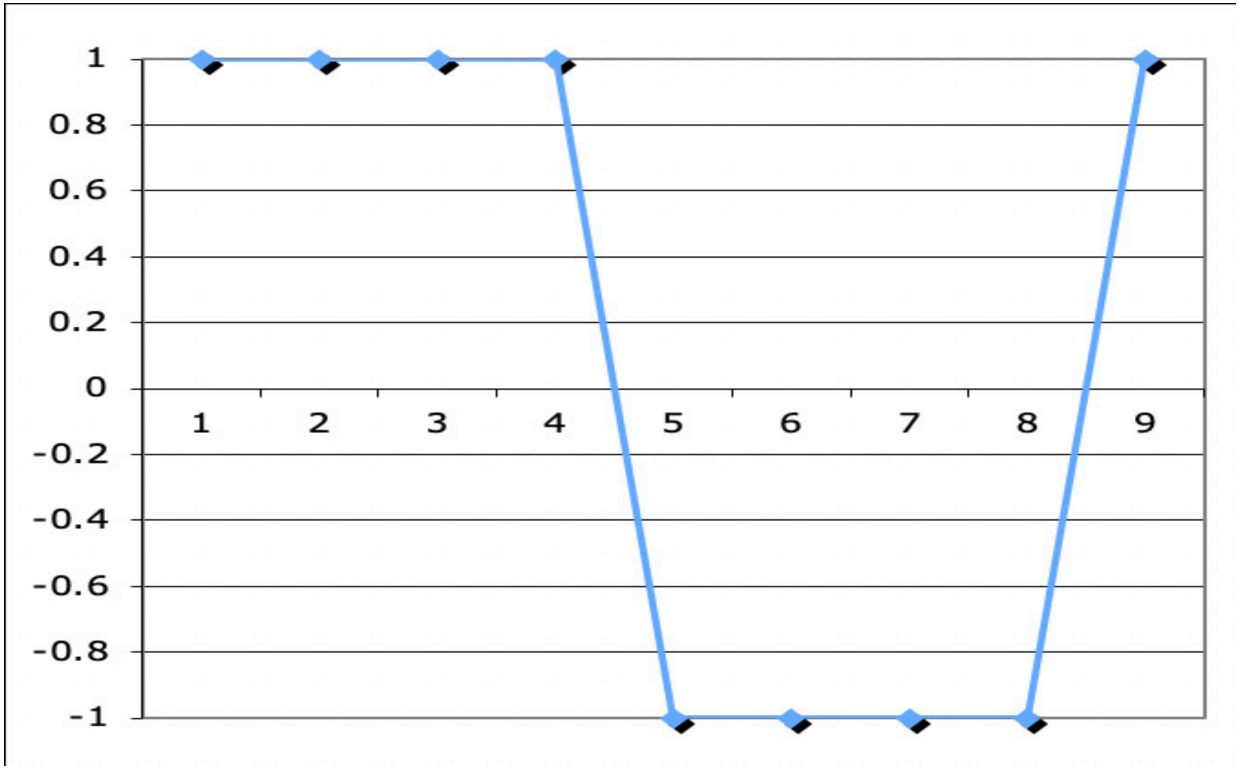
- Then take the square root of the average
    - RMS amplitude = .707

Another example

- What about the RMS amplitude of this sound wave?

pressure	1	1	1	1	-1	-1	-1	-1	1
sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

- It looks like this (in Excel):



RMS calculations

- This one will be a little easier!
- To calculate RMS amplitude for this sound, first square the values of each sample (only up to sample #8!):

square	1	1	1	1	1	1	1	1
sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

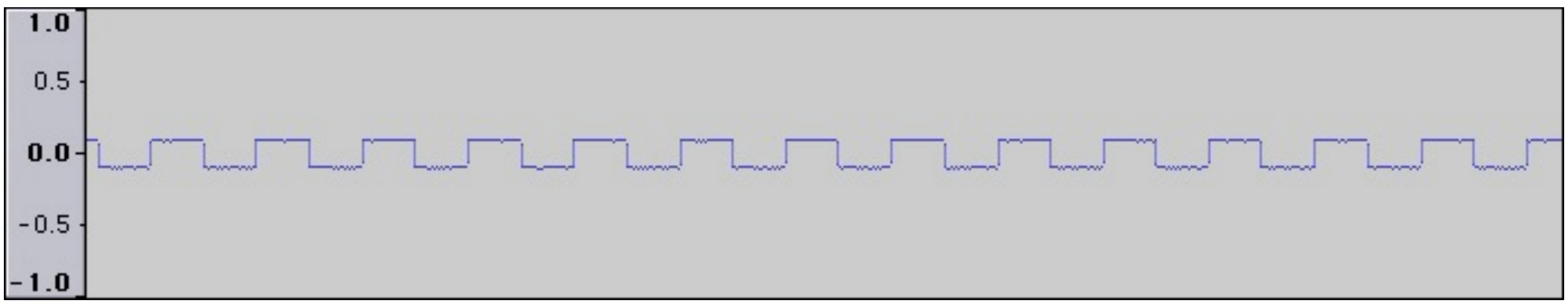
- Then average all the squared values

(1 + 1 + 1 + 1 + 1 + 1 + 1 + 1) / 8 = 8/8 = 1

- Then take the square root of the average
    - RMS amplitude = 1

More Complex Waveforms

- The following waveforms all have the same peak-to-peak amplitude:



Intensity

- Two related concepts are acoustic **power** and **intensity**.
- **Power** is just the square of amplitude.
    - $P = A^2$
- The **intensity** of a sound is its power relative to the power of some reference sound.
- Intensity is usually measured in decibels (dB).
    - Decibels is a measure of intensity with reference to the quietest sound human ears can hear.

Some Numbers

- The intensity of a sound x can be measured in **bels**, where a **bel** is defined as:

  $= \log_{10} (x^2 / r^2)$

  - r^2 is the power of the reference sound
  - x^2 is the power of sound x.

- A **decibel** is a tenth of a bel.

  $\Rightarrow$ Intensity (in decibels) = $10 * log_{10}\left(\frac{x^2}{r^2}\right)$

- Let's make sure we understand what this math means by answering this question:
  - How does the acoustic power of a 60 dB sound compare to the acoustic power of a 30 dB sound?

Simplify, Simplify

- Let's say that Sound **x** has an intensity of 60 dB.
  - $\Rightarrow$ 60 dB = $10 * log_{10}\left(\frac{x^2}{r^2}\right)$
- We can divide both sides of this equation by 10 to get:
  - 6 = $log_{10}\left(\frac{x^2}{r^2}\right)$
- Now let's say that Sound **y** has an intensity of 30 dB.
  - $\Rightarrow$ 30 dB = $10 * log_{10}\left(\frac{y^2}{r^2}\right)$
  - $\Rightarrow$ 3 = $log_{10}\left(\frac{y^2}{r^2}\right)$

What’s a logarithm, anyway?

- We want to compare x^2 and y^2. They're both stuck in that log() factor, though. How do we get them out?
- Fun fact:
  - if you're calculating the $\log_{10}()$ value of some number, you're effectively calculating **how many times you have to multiply 10 by itself** to get that number.
- So: $\log_{10}(10) = 1$
- Likewise, $\log_{10}(100) = 2$ (= 10*10)
- $\log_{10}(1000) = 3$ (= 10*10*10), etc.
- Maybe you can see that the $\log_{10}()$ function is just counting the number of zeroes in the numbers we're analyzing here.
  - With that in mind: $\log_{10}(1) = 0$

Unboxing

- The relationship between a logarithm and its value gives us a tool for unpacking the numbers inside the parentheses in these equations.
- If:
  - $\log_{10}(1000) = 3$
- That's because:
  - $10^3 = 1000$
- Likewise, if: $\log_{10}(100) = 2$
  - That's because: $10^2 = 100$
- The general pattern: if $\log_{10}(b) = a$
  - Then: $10^a = b$

Back to Simpler Times

- Okay. With that algebraic trick in our toolkit, we can go back to an equation like this:
    - $log_{10}\left(\frac{x^2}{r^2}\right)$ = 6
- And unpack it as:
    - $10^6 = \frac{x^2}{r^2}$
- If we multiply both sides of that equation by r^2, then we get:
    - $x^2 = 10^6 * r^2$

One More Time!

- We can try the same thing with the similar equation we derived for Sound y:
  - $log_{10}\left(\frac{y^2}{r^2}\right) = 3$
- We can unpack that as:
  - $10^3 = \frac{y^2}{r^2}$
- If we multiply both sides of that equation by r^2, then we get:
  - $y^2 = 10^3 * r^2$

A Level Playing Field

- We now have these two equations for our two sounds:
  - $x^2 = 10^6 * r^2$
  - $y^2 = 10^3 * r^2$
- How do the powers of the two sounds match up with one another?
- x^2 is $10^6/10^3$ times greater than y^2
  - = 1000 times more powerful
- In other words, a 30 dB increase in intensity translates to a 1000-fold increase in acoustic power.
  - (Not a 30-fold increase in power!)
- IMPORTANT: intensity (in decibels) increases linearly when power increases exponentially.

Some Numbers

- The logarithmic relationship at the core of the calculation of intensity enables the decibel scale to capture the very wide range of intensities that human ears are sensitive to.
- Some typical decibel values:

30 dB Quiet library, soft whispers

40 dB Living room, refrigerator

50 dB Light traffic, quiet office

60 dB Normal conversation

70 dB Vacuum cleaner, hair dryer

80 dB City traffic, garbage disposal

Numbers, continued

• At 90 dB, sustained exposure to the sound starts to cause hearing damage:

90 dB Subway, motorcycle, lawn mower

100 dB Chain saw, pneumatic drill

120 dB Rock concert in front of speakers, thunderclap

• Above 130 dB, sounds cause pain and immediate hearing damage:

130 dB Pain threshold

140 dB Gunshot blast, jet plane

180 dB Rocket launching

Intensity Interactions

- Perceived loudness depends on frequency, as well as amplitude.
- Mid-range frequencies sound louder than low or extremely high frequencies.
- 100 Hz
- 250 Hz
- 440 Hz
- 1000 Hz
- 4000 Hz
- 10000 Hz

An Interesting Fact

- Some vowels are louder than others
- dB of different vowels relative to [ɑ] (Fonagy, 1966):

[ɑ] :	0.0
[e] :	-3.6
[o] :	-7.2
[i] :	-9.7
[u] :	-12.3

- Why?