The Effects of Drop Height on Sound Pressure

Megan Schuettke, Tualatin High School

Return

Table of Contents

Background

With sound being produced all around us, it's only natural to wish to better understand it. In basics, how we perceive sounds is derived from sound waves themselves, which are a type of energy in the form of longitudinal waves. Sound energy is produced when an exerted force causes objects to vibrate, creating sound waves (Sound Energy). For example, when a drum is hit, there is a noticeable vibration occurring with its head, and it's how they are able to create such intense sounds in the human ear. In fact, the structure of the human ear is not so far off from a drum itself, if one of the most commonly known parts of the ear being called an eardrum didn't signify this already. The eardrum functions in a way where the outside sound waves that are funneled into the ear cause the eardrum to vibrate in a similar fashion. These vibrations carry on the sound through the middle and inner ear to be further processed before being converted into electrical energy and sent from the nerves of the ear to the brain, allowing humans to perceive sound (How the Ear Works). For some like myself, however, this sound processing can be more risky due to sensitivities to certain frequencies, which is why it's so important to be aware of the relationship between how much sound pressure can be produced from the energy an object receives and dispels. Understanding these concepts has a better chance of preventing ear damage for those with my sensitivity.

What is a Decibel? .:. Top

With all of that said, sound pressure, or the intensity of the sound, is measured through decibels. Their creation was a means to fit the normally large range of power and intensity produced from sound pressure into one that would model how humans perceive sound. This can be reasoned when understanding its logarithmic nature with a base of 10, meaning if one hears 10 dB, there's 10 W of power. However, if one hears 20 dB, there's 100 W. 30 dB gives 1000 W, and so on (What's a Decibel?). Relying on the raw wattage or intensity alone can create very large and very small numbers that become more tedious to keep track of, so this system of measurement aims to rectify that (McAllister).

The Purpose & Variables .:. Top

This investigation aims to find the relationship between decibels produced on impact and the drop height of a ping-pong ball if any exists. In addition, comparing that to the relationship between intensity produced and drop height by converting the decibels measured into watts per meter squared is another understanding I wish to investigate. The dependent variable is the decibels measured per impact, while the independent variable is the different heights the ping-pong ball is dropped. Controlled variables include, but are not limited to, the position in reference to the impact site and the weighting settings of the decibel reader, the impact location of the ping-pong ball and the impact site's material, the mass of the ping-pong ball, and the tape measure used. The weighting of the decibel reader refers to the frequencies the reader is inclined to pick up. In this instance, the decibel reader's weighting was set to C as it is better for measuring peaks of sounds, which is more beneficial for the purpose of this investigation (Frequency Weightings). Position of the decibel reader must be kept constant as to not introduce a factor of decay of intensity as sound moves through the air, and the position of the impact site should be kept constant to reduce variation in surface quality affecting the sound produced. Mass of the ping-pong ball also must be kept constant to not create variation in momentum and therefore variation in energy gathered and released, which is done by using the same ball throughout the experiment. The same tape measure is used to mitigate variation of increments of measurement between different measuring tools.

Hypothesis .:. Top

I hypothesize that as the drop height of the ball increases, the energy released through sound upon impact will also increase, which would be represented graphically in decibels to increase in a logarithmic manner as described previously. I predict that this is the case considering more distance for the ping-pong ball to fall through allows it to accelerate to a higher velocity, translating to more energy to disperse through sound. With that, I speculate converting the decibels back into intensity would graphically show a linear relationship between intensity and drop height since I would be inverting the logarithmic function.

Method

.:. Top

For this experiment, I will be doing 20 different variations of my independent variable, starting at 5.0 cm and going up by 5.0 cm until 100.0 cm is reached. Each variation will have five trials when gathering data points. I chose to do five trials since gathering data points is fairly straightforward, meaning I could afford to get more data without sacrificing a great deal of my time. Before properly settling on the variations of the independent variable, I tested out a few different ranges, which were in steps of 9.0 cm instead of 5.0 cm and went to 180.0 cm. Doing that led me to realize that the data, while trending upward, flattened out fairly quickly. With that knowledge, testing a smaller range felt more convenient and acceptable. Since 180.0 cm is quite taller than 100.0 cm, it became a bit more strenuous for someone of my stature to try and drop the ball from those higher heights in the smaller environment I had to conduct my experiment to reduce echo. The data flattening like it did was also the reason I only did 20 variations of my independent variable and not anything more as it would have likely become somewhat repetitive.

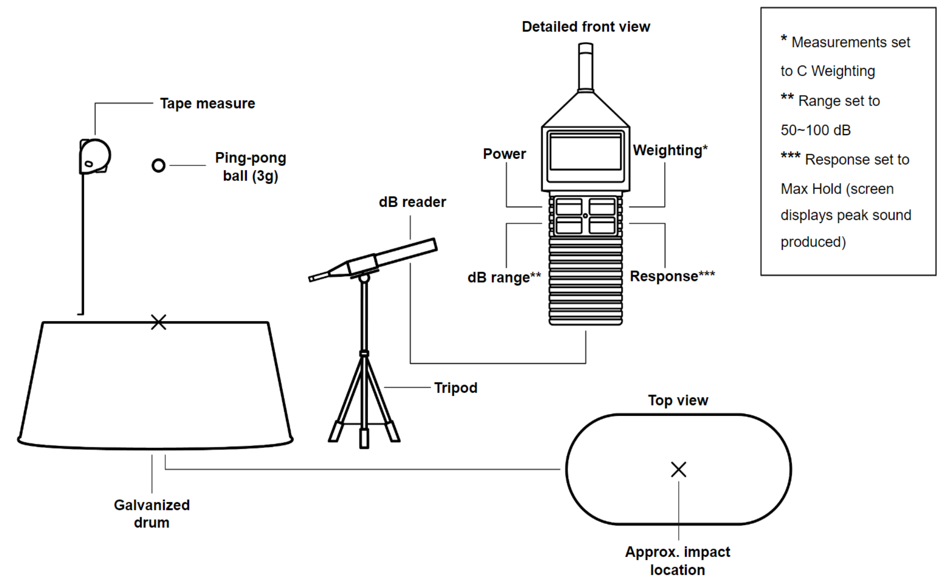
Materials & Set Up .:. Top

As seen in Figure 1. below, I used the following materials:

1) Tape measure with a locking mechanism
2) A 3-gram ping-pong ball
3) A galvanized drum
4) An Extech Instruments decibel reader
5) A tripod for the decibel reader

I first set up my galvanized drum as my impact site, marking an “x” to indicate where I would aim the ping-pong ball to fall. This is so that variations in vibration due to physical differences within the top of the drum between different areas can be avoided, allowing the only factor influencing the vibrations to be the energy dispersed from the impact of the ping-pong ball from different heights. Additionally, I opted for this galvanized drum to produce a more prominent sound that the decibel reader could easily pick up. Then, I set up the decibel reader on the tripod and positioned it so that it pointed to the “x” on the drum at an angle. I made sure that the decibel reader’s settings were set to measure in C weighting and that it was set to “Max Hold” so that I could write down the amplitudes of sound. Once I was set up, I began to measure my data by unraveling the measuring tape until the mark for the desired height overlaid the edge of its opening. I lock it in place and carefully set the metal tab slightly above the surface of the drum so as to not disturb its vibration when impact occurs. Holding the tape measure in place, I line the ping-pong ball **above** the mark of the height measured and align it with the “x” on the drum. When everything is lined up and ready, I drop the ball onto the “x” and measure the amplitude of the decibels produced displayed on the reader. I did this for each of the 20 heights for five trials, as long as I used the same ball throughout the data-collecting process and was able to keep the galvanized drum and decibel reader in the same position throughout data collection.

Figure 1. Diagram of Set Up and Decibel Reader



Possible Safety & Ethical Concerns .:. Top

In terms of safety concerns, which relate to the nature of my motivation for investigating the relationship between drop height and sound produced, the only possible concern that could arise is potential hearing damage. However, this is a controlled environment, and the decibels I'm testing, while on the higher end of the decibel scale, are still considerably safe since neither I nor anybody else would be experiencing prolonged exposure to them but rather a quick burst of sound. Prolonged exposure of 8 hours (or less according to the increase in decibels) to decibels of 85 and up is considered dangerous to the human ear, so that is not a concern in this investigation (Loud Noise Dangers).

When considering any potential ethical concerns, the only concern one may have is when conducting the experiment where others might hear and be annoyed by the repetitive sounds. Generally, the experiment should be conducted in well-soundproofed rooms anyway as to reduce echo and external noises from interfering with the decibel reader. Overall, quite harmless to others, but easily annoying for some.

Data Results & Analysis

.:. Top

Data File .:. Graphs

After gathering all of my data, I imported it into Google Sheets and calculated each data point's averages and uncertainties to obtain this table of my raw data:

Figure 2. Raw Data with Averages and Uncertainties

Drop Height	Decibels Produced						
+/- 0.05	dB					dB	dB
x / cm	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Uncty
5.0	78.5	79.2	79.3	78.7	78.6	78.9	0.4
10.0	81.8	81.8	81.4	81.6	81.5	81.6	0.2
15.0	83.3	83.2	83.3	83.0	83.4	83.2	0.2
20.0	84.3	84.5	84.4	84.6	84.6	84.5	0.1
25.0	85.5	85.3	85.8	85.3	85.3	85.4	0.3
30.0	86.1	86.1	85.9	86.1	86.0	86.0	0.1
35.0	86.6	86.9	87.0	86.7	86.8	86.8	0.2
40.0	87.4	87.5	87.4	87.2	87.2	87.3	0.1
45.0	87.5	87.6	87.5	87.4	87.7	87.5	0.1
50.0	87.9	87.7	87.7	87.7	87.9	87.8	0.1
55.0	87.9	87.9	87.9	87.8	88.1	87.9	0.1
60.0	88.4	88.2	88.3	88.6	88.2	88.3	0.2
65.0	88.6	88.5	88.6	88.7	88.6	88.6	0.1
70.0	88.8	88.6	88.7	88.7	89.1	88.8	0.3
75.0	88.9	89.2	89.4	89.0	89.1	89.1	0.3
80.0	89.3	89.5	89.3	89.6	89.2	89.4	0.2
85.0	89.3	89.8	89.5	89.6	89.7	89.6	0.3
90.0	89.6	89.7	90.0	89.7	89.6	89.7	0.2
95.0	89.9	90.0	89.9	89.9	90.0	89.9	0.0
100.0	90.1	90.6	90.9	90.2	90.4	90.4	0.4

Since the smallest increment of measurement of the tape measure I used was a millimeter, half of that was used as the uncertainty for each drop height. Additionally, the decibel reader only reads to the tenth of a decibel, so the averages and uncertainties reflect that as well.

I calculated the averages of each data point by adding each trial and dividing by 5. For example, calculating the decibel average for the data gathered at the 5.0 cm drop height went as follows:

$$\frac{78.5+79.2+79.3+78.7+78.6}{5} = 78.86,$$

which was rounded to 78.9 dB(C) since, as previously mentioned, the decibel reader only read to the tenth's place.

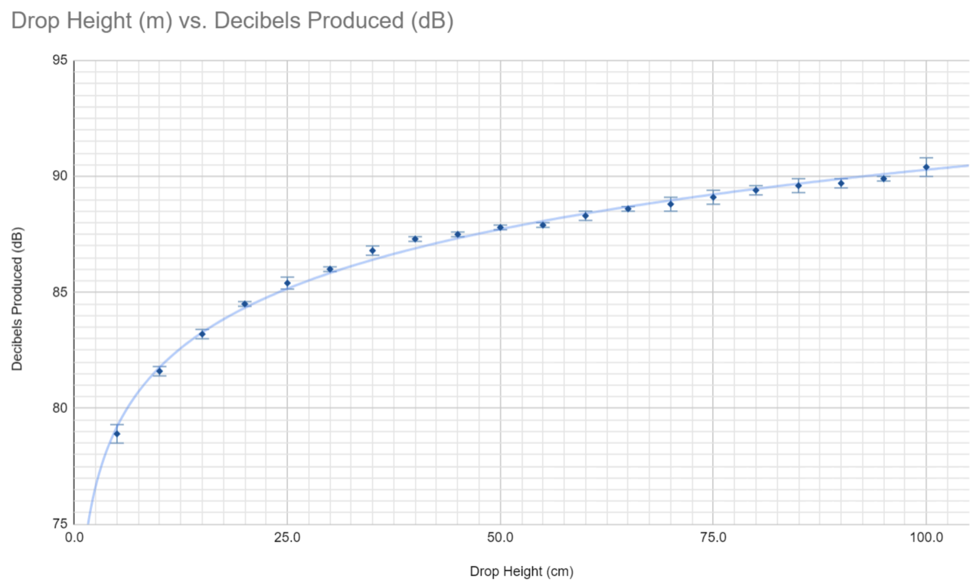
Uncertainty was calculated by subtracting the minimum value of the trials from the maximum and dividing by 2. An example of this when calculating uncertainty for the 5.0 cm drop height appeared as such:

$$\frac{79.3-78.5}{2} = .4,$$

which in this instance, I didn't need to round to tenth's place.

Using the average and uncertainties of the data points I got from each height, I was able to create a graph of my raw data:

Figure 3. Averaged Data Graphed with Uncertainties



***Equation of regression line is 73.3+3.7ln(x)**

From this graph, it can be seen that as the drop height increases, so do the decibels produced, yet even as the drop height increases in a linear fashion, the increase in decibels becomes smaller and smaller the higher the ball is dropped. The logarithmic nature in which decibels are measured and produced can be clearly seen, confirming the information I gathered during my preliminary research. The logarithmic regression line represented in the graph also allows us to go beyond the range tested and predict the c-weighted decibels the ping-pong ball would produce from drop heights beyond 100.0 cm, further displaying how the logarithmic scale of decibels reacts to higher drop heights. For example, if I took the equation of the regression line,

$$73.3 + 3.7ln(x) = dB(C)$$

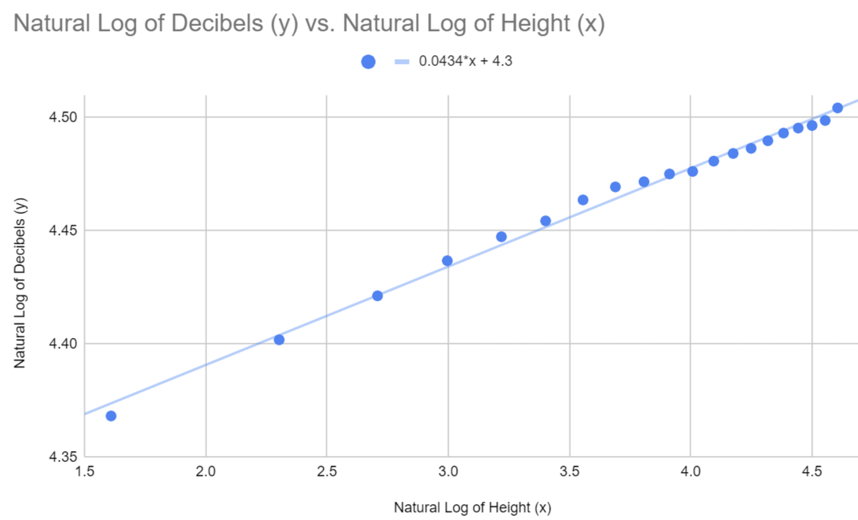
(the variable x being drop height), and plugged in 150.0 cm, I could predict that roughly 91.8 dB(C) could be produced at that height according to

$$73.3 + 3.7ln(150) = 91.83935059...$$

Linearization .:. Top

To analyze further the relationship between drop height and sound produced, I created a Log vs. Log graph by taking the natural log of both the drop height and average decibels produced from the values of Figure 2.

Figure 4. Log vs. Log Graph



I did this since I could see that my data could be represented through a power function. Using the values from the Log vs. Log graph, I could find the values of A and n within the power equation $y = Ax^n$ to further linearize my data. Taking the coefficient of x, .0434, in the Log vs. Log graph, I could use it for the power n. To get A, I used the y-intercept as the power of e:

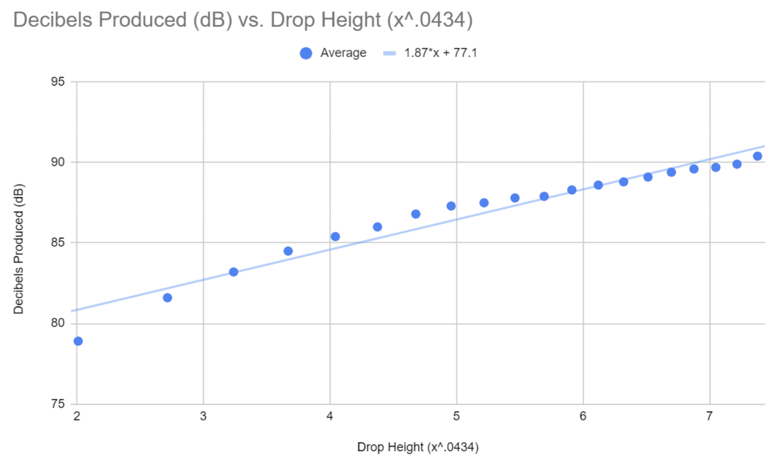
$$e^{4.3} = 73.6997937...$$

Using the value .0434 as the power for x, I get this function to plug the drop heights in:

$$y = x^{.0434}$$

With the newly calculated values of x put against the decibel averages, I can further linearize my data to appear as such:

Figure 5. Decibels Produced Graphed with x^.0434



As can be seen from this graph, a linear relationship can be seen, meaning that the proposed power relationship of Figure 3. is a valid one. This also further strengthens the idea of decibels being a logarithmic function.

Converting to Intensity .:. Top

In order to better compare the relationship between energy dispersed through sound and drop height, I thought it would be logical to convert the decibels back to intensity in watts per meter squared. Watts per meter squared being joules per second per meter squared, converting back allows us to see how many joules are released upon impact per second and per square meter. This further helps relate how the intensity of noise can be processed within the ear as well as determine what kinds of intensity it can handle, which is once again relevant to my motivations to study their relationship. Using the base formula of

$$dB = 10log_{10}(\frac{p_1}{p_0}),$$

I can solve for the power ratio as a means to calculate the sound's intensities. By first dividing by 10,

$$\frac{dB}{10} = log_{10}(\frac{p_1}{p_0}),$$

and taking the inverse of $\log_{10}$, I get the equation I can use to convert decibels back to power:

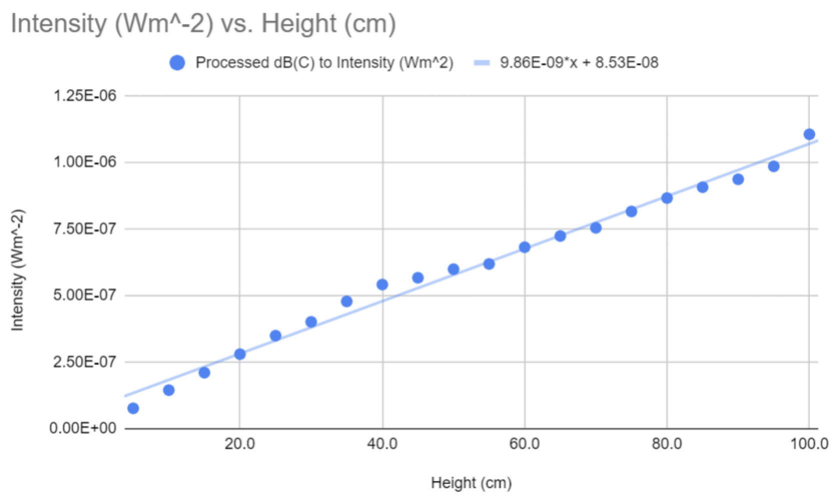
$$\frac{p_1}{p_0} = 10^{\frac{dB}{10}}.$$

Then, to convert the power ratio into intensity, I just need to multiply by 10^{-12} (Sound Intensity and Sound Level), giving me the equation for intensity as follows:

$$I = 10^{-12}(10^{\frac{dB}{10}}).$$

With this equation, I plug all of my averaged decibels in to get the intensity they all represent. Then, I graph the newly calculated intensities against drop height and create this graph:

Figure 6. Decibels Converted to Intensity (Wm^-2)



The most notable difference between the decibels and intensity represented in Figure 3. and Figure 6. is how the data linearized when converting back to intensity. This further demonstrates the logarithmic behavior of decibels since intensity was calculated by inverting the logarithm, which gave a linearized intensity graph. Additionally, by viewing the range in Figure 6. it can be seen how a range of about 78 dB(C) to 90 dB(C) converts to the much larger relative range of about 7.69E-8 Wm^-2 to 1.11E-6 Wm^-2. This further ties back to the justification of the creation of the decibel to better measure sound to minimize mistakes in dealing with very large and small numbers, which is very interesting to see in action.

Admittedly, error is certainly present within this graph considering that one, the y-intercept implies that at a drop height of 0 cm, 8.53E-8 Wm^-2 are produced, and two, the raw converted data portrays almost two separate slopes. This can be easily attributed to human error, but it can also be attributed to calibration errors of the decibel reader. In general, implying that 8.53E-8 Wm^-2 can be produced from essentially no impact, especially when the lowest raw converted data point is lower than that value, is entirely illogical and should be taken into account when analyzing this data.

Conclusion .:. Data File .:. Top

It is fairly evident from the data gathered that as the drop height of an object increases, so do the decibels produced. However, as introductory information confirmed, decibels increase in a logarithmic scale whereas converting it back into intensity in watts per meter squared using $I = 10^{-12}(10^{\frac{dB}{10}})$ would show how intensity and drop height have a more linear relationship. This implies that as the ball, and in turn any object, falls through the air, it linearly increases in intensity. I can deduce this from the idea that when dropping the ball from 5.0 cm, the wattage per meter squared calculates to very roughly 7.69E-8 Wm^-2 released upon impact. If I compare this to the 1.45E-7 Wm^-2 released at 10.0 cm, I can see that as drop height doubles, the wattage per meters squared released essentially does too, also accounting for significant error. At 15.0 cm, the wattage per meter squared increases roughly by 6.60E-8 Wm^-2, increasing to 2.11E-7 Wm^-2, which is close to the initial intensity when once again considering significant error. A pattern can be seen of an increase of roughly 7.00E-8 Wm^-2 to 1.40E-7 Wm^-2 and finally 2.10 Wm^-2. While I am appearing to make large leaps with what I consider close in terms of comparing intensities, it still makes sense to acknowledge the pattern considering the relative range is so large and error propagation allows it.

All of that being said, everything I mentioned previously also goes to support the initial hypothesis I created. Decibels produced indeed increase in a logarithmic fashion when drop height increases, and converting it back to intensity does in fact present a linear relationship with drop height too.

Errors & Improvements .:. Top

As briefly described throughout my analysis of the data, there were considerable errors that occurred that affected how my data was taken. This was both due to human error and technological flaws.

One notable error that was present was the slight inconsistency in drop height. Since I was eyeing where to hold the ball in comparison to the measuring tape and having to focus to make sure that it lined up with the “x” on the impact site, shifts in my hand’s position occurred. This led to the ball being dropped slighting above or below the intended drop height, likely having skewed the data. With that, there was not only a slight inconsistency in the drop height but also the impact site since the drift of my hand could have displaced where the ball would land. In order to minimize this human error, I would likely have to use a more independently stable measuring device where I wouldn't have to take up a hand and focus to keep it steady, which would at least allow more focus and precision to go to the ball's position before dropping it. Admittedly, this won't get rid of the human error, but it would hopefully minimize it. An interesting, though possibly odd, idea to help align the ball with the impact site would be to set up a laser that is pin-pointed on it. Then, one could line the laser up with a mark on the ball, which could allow for an easier time in lining everything up.

Another potential source of error has to do with the wear of the ping-pong ball across multiple trials. When considering the energy released when the ball makes an impact with the drum, some of that energy also travels through the ball itself, which slowly but surely alters its physical structure, creating a more ovoid shape and a difference in internal air pressure. The slight variation in structure could also change how much more or less energy travels through itself upon impact, which, according to the law of conservation of energy, would also alter the energy released in sound pressure. Admittedly, this is a much pickier error with little solutions besides essentially replacing each ball with a new one after each data point, but that solution would probably introduce much more error than before due to the greater chance of variation between the different masses. Overall, for the solution to work, special care would need to be taken to make sure that each new ball has the same mass and internal pressure.

Lastly, one of the greatest sources of error had to do with the decibel reader itself. Unfortunately, and not unlike some other decibel readers, the calibration is extremely fine tuned and unable to be effectively done outside of a professional and controlled environment, hence the existence of specialized calibration facilities. Not only was the decibel reader unable to be calibrated before use, it was also unable to hold a peak value. Even when it was set to "Max Hold", it tended to have random downward and sometimes upward variation in its tenth's place after an impact sound was processed. It changed so frequently within gathering a data point that I often had to cut my losses and just put down the first value I read off of it. The variation in shape in Figures 3., 5., and 6. could easily be attributed to this inconsistency, such as why Figure 6. seemingly had two slopes as opposed two one. To hopefully minimize this, I would likely either need to send it to a calibration facility to get precisely calibrated or try to find newer and less potentially worn down technology to help me measure the decibels produced. Whether this new technology be a newer model of a decibel reader or an app that could be used on a phone, either option has a higher chance of negating the issues I had with the decibel reader I used.

Further Research

.:. Top

If I were to continue my research on sound pressure, I would be interested to understand more about the decay rate of sound energy as it travels through the air. It would be useful to know the relationship between the distance of the listener to the original position of the sound, especially if I wanted to continue with my motivation to better understand how to mitigate ear damage. Overall, it was very fascinating to see how my data was able to confirm the math behind the decibel. It's always so interesting to see how experimental data influences others' research, how it's recreatable, and how one can expand upon it with their own research.

Related Links

.:. Top

- https://en.wikipedia.org/wiki/Decibel: Mentions the origin of the unit of decibels, which include how it's expressed in a ratio. It also talks about how the unit was first coined.
- https://www.noisemeters.com/help/faq/frequency-weighting/: Talks about the different definitions of decibel weighting and what they are relevant for.
- https://spinningnumbers.org/a/decibel.html#back-story: Discusses the mathematics of the energy to decibel conversion.
- https://courses.lumenlearning.com/atd-austincc-physics1/chapter/17-3-sound-intensity-and-sound-level/: This one also helped me with the mathematics to convert the decibels into intensity to better contextualize the energy produced.
- https://www.asha.org/public/hearing/loud-noise-dangers/: This one helped contextualize the impact of the decibel on the human ear. It's a good reference for safety as it relates certain decibel readings to real life noises.

Bibliography

.:. Top

"Frequency Weightings - A-Weighted, C-Weighted or Z-Weighted." NoiseMeters, https://www.noisemeters.com/help/faq/frequency-weighting/. Accessed 4 January 2024.

"How the Ear Works." Johns Hopkins Medicine, https://www.hopkinsmedicine.org/health/conditions-and-diseases/how-the-ear-works. Accessed 4 January 2024.

"Loud Noise Dangers." ASHA, American Speech-Language-Hearing Association, https://www.asha.org/public/hearing/loud-noise-dangers/. Accessed 20 January 2024.

McAllister, Willy. "Decibel." Spinning Numbers, https://spinningnumbers.org/a/decibel.html#back-story. Accessed 4 January 2024.

"Sound Energy: Everything You Need to Know About This Electrifying Source." Just Energy, https://justenergy.com/blog/sound-energy-everything-you-need-to-know/. Accessed 4 January 2024.

"Sound Intensity and Sound Level." Lumen Learning, https://courses.lumenlearning.com/atd-austincc-physics1/chapter/17-3-sound-intensity-and-sound-level/. Accessed 24 January 2024.

"What's a Decibel?" BTS Data Inventory, https://data.bts.gov/stories/s/What-s-a-Decibel-/568r-4fsv/. Accessed 4 January 2024.