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How Different Variations of Cones Affect Volume from a Cell Phone

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Abstract

Sound amplifiers such as megaphones can greatly affect the volume of a speaker based on its shape, material and length to produce better and louder sound quality. In this study, different lengths of paper cones and different types of paper folded into cones are the main factors of interest, with the objective to investigate whether these factors could increase the volume of the phone speaker. A complete randomized design using 2 factors with factor 1 being different length of paper cones and factor 2 being type of paper was carried out. Length of paper has 3 levels - 21.5cm, 16.5cm & 11.5cm, and paper type has 2 levels - printer paper and cardstock paper. The main response was the volume from the speaker while having the different material and length cones attached to the end of the phone speaker, and it was measured in decibel. The results show that length of the cones significantly produced a greater volume of a phone speaker compared to the type of paper. No interaction was found between the two factors.

1. Introduction

In this experiment we were looking to see if different lengths of paper cones of different paper types would make a phone speaker louder. We became interested in this experiment after watching a video of a woman folding a paper cone that attached to the speaker side of the phone. We want to see if using a different material and having different length cones would increase the decibels, or keep the sound the same.

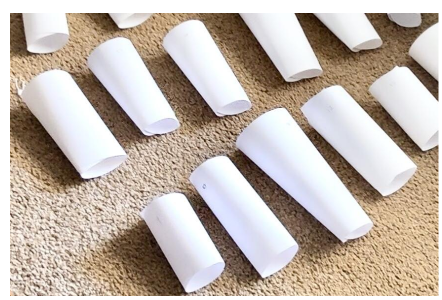
First we looked into how megaphones work. This relates to our experiment because a megaphone is a cone that people yell into to amplify their voices. We also found some experiments that were related to ours. The experimenters used cups and cones to help amplify a sound but were not interested in reading the output.

Instead of just using a single cup or cone to amplify the sound we used cardstock and printer paper at three different lengths to have 6 different treatments that we needed to test. We wanted to see which paper type and length combination had the loudest decibel output. Our expectation was that the longest cardstock cone was going to be the loudest.

2. Materials and Methods

The experiment was conducted on April 30th, 2022 from about 1pm to 3pm in an apartment where noise could be kept at minimum. The main equipment used was cardstock, printer paper, 3 mobile phones, tape, scissors, a ruler, and a pencil, which could all be easily bought at a local stationary store.

Each type of paper was initially cut into 3 different lengths (21.5cm, 16.5cm & 11.5cm). Each length for each paper type was replicated 4 times and folded into a cone shape around the same phone. Due to the availability of paper size, the paper lengths were slightly modified during the actual experiment from (25cm, 20cm , 15cm) to (21.5cm, 16.5cm & 11.5cm) where the difference between each length remained 5cm.



A completely random design was used in this study, so to simulate a random run order of treatments, we used JMP before starting our data collection. Each paper cone was selected based on this randomized run order provided by the JMP output and slid onto the speaker end of the phone. The recording device was facing the cone directly at a fixed distance. A note “C” was played on the phone for about 10 seconds and the volume, measured in decibels, was recorded using the *DecibelX application* on the other phone.

2.1 Treatment Structure

We used a 3x2 factorial treatment structure with paper length and type of paper as factors of interest. The levels for the paper length were 21.5cm, 16.5cm & 11.5cm. We used these specific lengths because the lengths provided enough of a length change to hear a difference by ear (without recording) but not go too short so that there would be no significant change. It also created the least amount of paper scraps. The reason why we chose printer paper and cardstock as our levels for the type of paper was that we thought that using cardstock might lead to higher values, since the vibrations are better reflected from the cone wall with "hard material". This means that we had 6 different treatment combinations which we applied to each experimental unit.

2.2 Response Variable(s)

The response variable we were interested in was the speakers' volume, which was measured with the iPhone App (called DecibelX). To avoid possible differences between the measurements, we defined a certain place where the phone was located. The goal of our experiment was to achieve high decibel values (which represented our units of measurement) in order to show an effect of the interaction of both factors or each factor by themselves on the measured speakers' volume.

2.3 Experimental Unit

We acquired our experimental units - which were the two papers - in two different stores. For the "printer paper" we bought the "ASPEN® 30" multi-use recycled copy paper from BOISE® which has a thickness of 4.2 mil which is .10668 mm. The cardstock we used was Recollections™ cardstock which we got from Michaels Arts and Crafts store.

Since there are hundreds of different types of paper available in stores, our main inclusion criteria was that the paper was inexpensive. We chose our paper based on what was the least expensive.

2.4 Design Structure

We decided to use a Complete Randomized Design (CRD) as our design structure since we could not find a possible source of variation to block on. As a result, we considered randomly assigning our treatments to each experimental unit and the number of replications we should use. Four replicates per treatment was deemed enough, allowing sufficient information without wasting a lot of paper.

For the random assignment of the treatments to our experimental units, we took 12 pieces of printer paper and 12 pieces of cardstock out of their packaging and shuffled them separately within their respective types. We then cut and taped them up to fit the phone. Later, we organized the cones in the randomized JMP order and labelled them to avoid any error grabbing the correct cones.

2.5 Dealing with other sources of variation

As in almost every other experiment there were many different sources of variation we were not interested in, consequently we had to use direct control and randomization of run order in an attempt to minimize those sources of variation. Following is a list of sources of variation where we used direct control.

How the paper is folded: In our Design Protocol form we said that we would use a template but we found that the template did not fit any of our phones and there was no way to adjust the template. We ended up folding the paper around the same phone in as similar of a way as possible.

Volume measurement device: If we had changed the device and its location during the experiment it would have been a possible source of variation, so we decided to use the same phone for all the 24 measurements and kept it in the same place, without touching it.

Distance to the measurement device: Since the distance between the measurement device and the phone plays a huge impact on the response variable, we wanted to make sure that we did not accidentally change the distance, so we marked a place on the table where we put the phone with a cone attached.

Place where the cone is put next to the mobile phone: We put a piece of tape on the phone that made it so the cone couldn't slide any further up the phone. This was done to keep the distance of the cone on the phone the same to avoid any variation that could have occurred from unknowingly shortening the cone length.

2.6 Statistical model and data analysis

An effects model was used to analyze the experiment:

$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$ where i = 1, 2, 3; j = 1, 2 and k = 1, 2, 3, 4. y_{ijk} represents the k^{th} measurement of the i^{th} level of paper length and j^{th} paper type. μ represents the global mean response. α_i = effect of the i^{th} paper length on the measured speaker volume. β_j = the effect of the j^{th} paper type on the measured speaker volume. $(\alpha\beta)_{ij}$ = the effect of the i^{th} level of paper length crossed with the j^{th} level of paper type on the measured speaker volume ε_{ijk} = random error on the k^{th} response of the i^{th} level of paper length and j^{th} level of paper type. This model is assuming that ε_{ij} ~ iid Normal$(0,\sigma^2)$. To study the effects of the two factors and their interaction, we ran the analysis on JMP Pro Version 16.0 which gave a summary statistics, ANOVA and Post-hoc comparison test.

3. Analysis and Results

From our experiment we found that the two factors of paper type and paper length do affect the decibel output of a phone speaker, but there is no interaction between the two factors.

3.1 Descriptive statistics

Figure A below shows that there exists main effects of paper type and length of paper. Observe that as the length of paper increases from 11.5cm to 16.5cm, there is a significant improvement in speaker volume for both types of paper. However, the volume remains relatively similar (around 79.7 dB) for both paper types when the paper length is 21.5cm. Figure B and C are to help visualize the difference in means and the variation within the factor levels.

Figure A: Interaction Plot

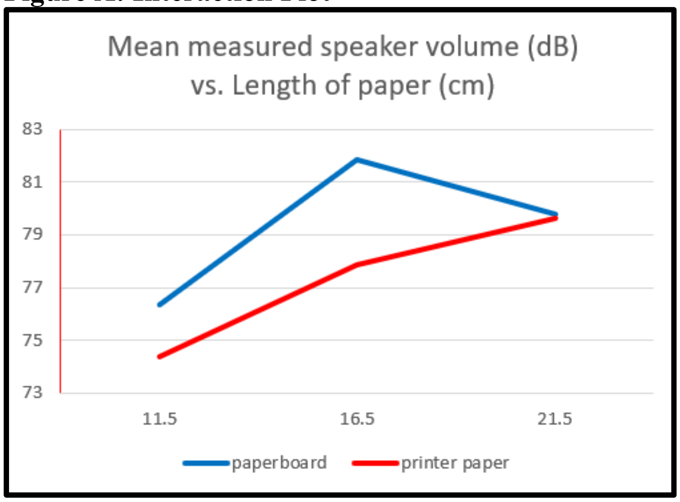


Figure B: Boxplot 1

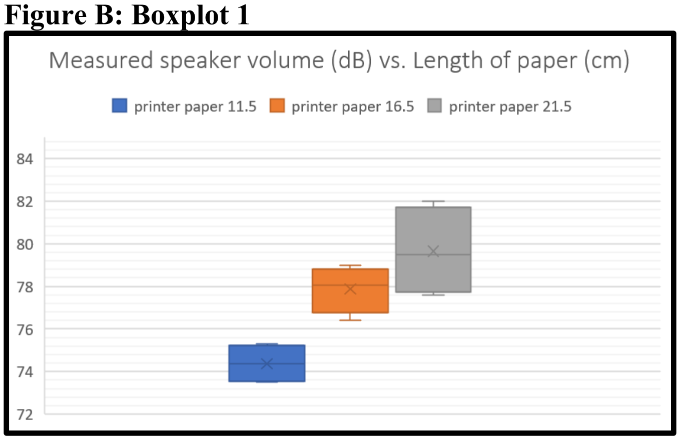
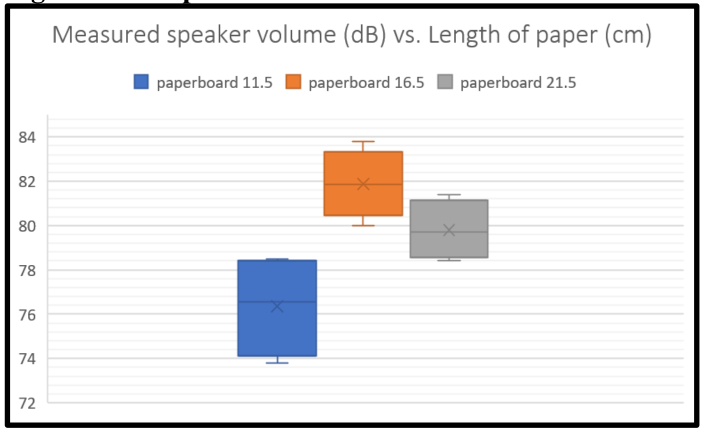


Figure C: Boxplot 2



3.2 Inferential findings

Table 3.0: ANOVA table

Source	DF	Sum of Squares	Mean Squares	F–Ratio	p-value
Model	5	144.95	28.991	10.88	<0.0001
Error	18	47.92	2.6624		
C. Total	23	192.87			

Table 3.1: Effect Tests

Source	DF	Sum of Squares	F–Ratio	p-value
Paper	1	25.01	9.34	0.0067
Length	2	105.11	19.74	<0.0001
Paper*Length	2	14.85	2.78	0.0883

ANOVA assumptions (for Table 3.0)

Independence of random errors: Random assignment of papers to treatments and randomization of run order were used – so independence assumption was not violated.

Normality of random errors: The Shapiro-Wilk test (p-value = 0.4341) indicates no evidence of violation of the normality of random errors.

Equal variance of random errors: The residuals versus predicted plot does not exhibit any sort of "fanning" pattern indicating no evidence of violation of the equal variances assumption.

Significance of effects: A small p-value (< 0.0001) for the global F-test shows that at least one factor of our model has an effect on the volume of the phone's speaker (Table 3.0). The effect tests explain that paper length has the most significant effect on the volumes of the speaker due to its small p-value (< 0.0001) compared to the paper type with a p-value of just 0.0067 (Table 3.1). Based on a large p-value of 0.0883,we do not have enough evidence that there is an interaction between paper type and paper length.

Table 3.2: Mean (± SE) measured volume (dB) for paper type

Type of paper	Mean	SE
cardstock	79.3417	0.4710238
printer paper	77.3	0.4710238

Table 3.3: Letters report for type of paper
α = 0.017 | t = 2.62976

Level			Mean
cardstock	A		79.3417
printer paper		B	77.3

Note: Levels that share a letter have means that are not statistically significantly different.

Table 3.4: Mean (± SE) measured volume (dB) for paper length

Paper length (cm)	Mean	SE
11.5	75.3625	0.57688
16.5	79.875	0.57688
21.5	79.725	0.57688

Table 3.5: Letters report for paper length
α = 0.017 | t = 2.62976

Level			Mean
16.5	A		79.875
21.5	A		79.725
11.5		B	75.3625

Note: Levels that share a letter have means that are not statistically significantly different.

Table 3.6: LSMeans Difference Tukey for paper length

Level - Level	Difference	p-value
16.5 - 11.5	4.51	< 0.0001
21.5 - 11.5	4.36	0.0001
16.5 - 21.5	0.15	0.9816

Table 3.7: LSMeans Difference Tukey for paper length

Level - Level	Difference	p-value
Paperboard - Paper Printer	2.04	0.0067

4. Conclusion

After completing our experiment and analyzing the data we found strong evidence that paper length contributed the most to the decibel output of the phone speaker. We also have strong evidence that paper length also affects the decibel output. The printer paper and cardstock cones with length 16.5cm and 20.5cm have a larger decibel output than the 11.5cm cones. We found that the treatment combination of the cardstock cone with length 16.5cm was the loudest of all of the treatments and the least effective was the printer paper with length 11.5cm. We found that as the length of the cone increases, the type of paper becomes irrelevant in the decibel output of the speaker.

5. Next steps

If we were to rerun this study there would be a few ways we could improve it. First, the phone that played the tone tended to get louder after about nine seconds of continuous playing, so to account for this we could maybe use a different device such as a tuner that a musician uses and find a different way to make the cones. Second, we realized that the cones would have some variation because we couldn't find a template to fit our phones. Next time we could find a way to fold and tape the cones more uniformly so that there is less variation between the cones. Lastly, we would change the environment. There was a decent amount of noise that could have created some error in our decibel readings. We weren't able to get a practice room in the music department on such short notice but I believe that would help dampen any outside noise.

After completing the experiment, there was one factor that would be interesting to control to see how much variation it would explain. This study could be improved by looking to see if different angles of propping up the phone would be louder from further away. Such as propping the phone up at 90º, 45º, and 0º.

References

- Dan Ketchum (2019), "Science Activities on Sound for the Second-Grade Level" *www.sciencing.com* https://sciencing.com/science-activities-sound-secondgrade-level-6400841.html
  last access: 05/20/22

- AcousticalEngineer, "Megaphones: Heard above the noise" https://acousticalengineer.com/megaphones-heard-above-the-noise/ - last access: 05/20/22

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Appendix

Randomization scheme:

	Pattern	Type of paper	Length of paper	Measured speaker volume (dB)
1	13	printer paper	25cm	•
2	13	printer paper	25cm	•
3	21	paperboard	10cm	•
4	22	paperboard	20cm	•
5	21	paperboard	10cm	•
6	22	paperboard	20cm	•
7	22	paperboard	20cm	•
8	23	paperboard	25cm	•
9	11	printer paper	10cm	•
10	12	printer paper	20cm	•
11	13	printer paper	25cm	•
12	12	printer paper	20cm	•
13	11	printer paper	10cm	•
14	23	paperboard	25cm	•
15	21	paperboard	10cm	•
16	22	paperboard	20cm	•
17	12	printer paper	20cm	•
18	12	printer paper	20cm	•
19	23	paperboard	25cm	•
20	23	paperboard	25cm	•
21	13	printer paper	25cm	•
22	11	printer paper	10cm	•
23	21	paperboard	10cm	•
24	11	printer paper	10cm	•

ANOVA Table:

Analysis of Variance

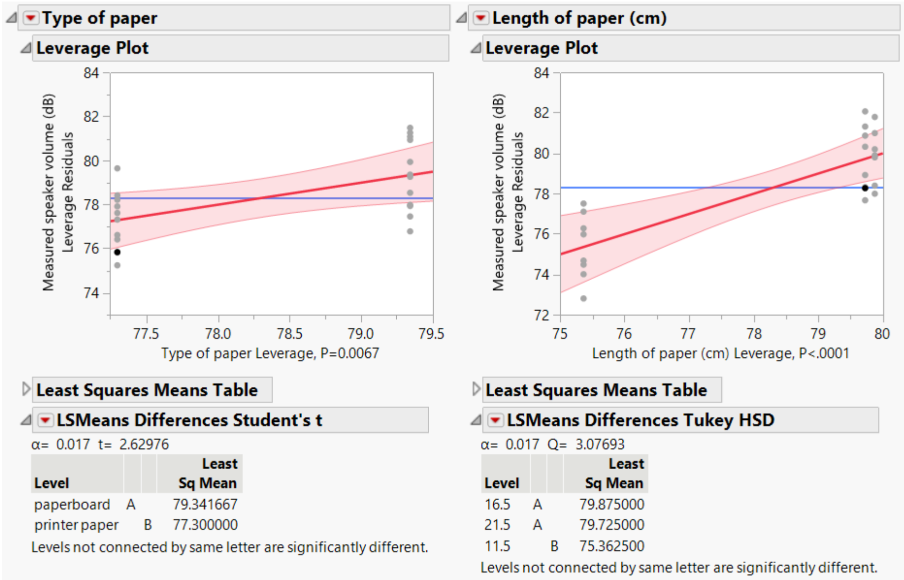
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	144.95708	28.9914	10.8894
Error	18	47.92250	2.6624	**Prob > F**
C. Total	23	192.87958		<.0001*

Effects tests:

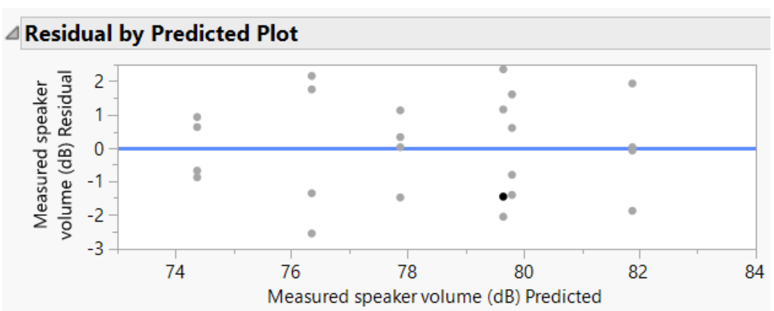
Effect Tests

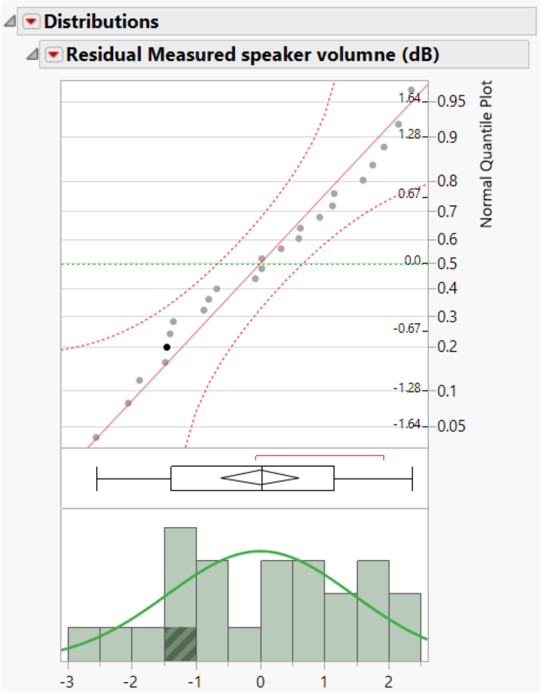
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Type of paper	1	1	25.01042	9.3941	0.0067*
Length of paper (cm)	2	2	105.11083	19.7402	<.0001*
Type of paper*Length of paper (cm)	2	2	14.83583	2.7862	0.0883

Tukey comparison outputs:



ANOVA assumptions:





Fitted Normal Distribution

Parameter		Estimate	Std Error	Lower 95%	Upper 95%
Location	μ	-5.92e-15	0.2946458	-0.577495	0.5774951
Dispersion	σ	1.4434635	0.1791004	1.1318566	1.5637329

Measures	
-2*LogLikelihood	84.727231
AICc	89.29866
BIC	91.083339

Goodness-of-Fit Test

	W	Prob<W
Shapiro-Wilk	0.9597824	0.4341

	A2	Simulated p-Value
Anderson-Darling	0.3156165	0.5416

Boxplots & other graphs from the text: