Spring 2020

Spectrographic Analysis of the Lombard Effect

Julia Saxon
jcs183@zips.uakron.edu

Recommended Citation

Saxon, Julia, "Spectrographic Analysis of the Lombard Effect" (2020). *Williams Honors College, Honors Research Projects*. 1030.
https://ideaexchange.uakron.edu/honors_research_projects/1030

Spectrographic Analysis of the Lombard Effect
Honor’s Project

Julia Saxon
Sponsor: Dr. James Steiger, Ph.D.
The University of Akron

Pseudohypoacusis

Pseudohypoacusis can be described as an observed hearing impairment without organic cause or pathological rationale for such a degree of loss (Martin and Clark, 2015). Synonyms for this condition include pseudohypacusis, functional hearing loss, and nonorganic hearing loss (Martin and Clark). Some clinicians may prefer one term over another due to their views of false or embellished hearing loss, but all the aforementioned terms are recognized as valid. The incidence of functional hearing loss has been measured in populations of veterans, children, and those involved in worker’s compensation cases. Among Veterans Administration patients, the incidence was observed to be somewhere between 11-45%, while in children it is currently reported to be between 2% and 7% (Lin and Staeker, 2006). However, this is believed to be a conservative estimate (Lin and Staeker). For those seeking work-related hearing loss compensation, the incidence is estimated to be nearly 25% (Lin and Staeker). Motivations to fabricate or embellish a hearing loss can include lawsuits with monetary compensation and cases involving workers compensation due to injury of the auditory system. In the case of children, the development of a nonorganic hearing loss may be to gain parental attention, acceptance from their peers, and to make excuses for a poor academic record (Martin and Clark).

Non Audiologic Indicators

Observations of those with nonorganic hearing loss can include a wide variety of behaviors. These can include exaggerated, and at times performative, displays of lip-reading, hearing postures, and an observable lack of peripheral vision when entering the clinic (Martin and Clark, 2015). Despite these obvious signs of impairment, the patient might not be wearing hearing aids or make use of hearing assistive technology. The patient may communicate more effectively with the receptionist before they feel the need to embellish with the audiologist. It can also be observed that patients with nonorganic hearing loss can be late for appointments and are observed to be impatient and irritable (Stach, 2010).

Behavioral Audiologic Indicators

Those with nonorganic hearing loss will often perform unreliably during the standard battery of tests. This might be observed as inconsistency in thresholds on a pure tone test or a marked difference between pure tone thresholds and speech recognition thresholds (Martin and Clark, 2015). As stated by Martin and Clark, p. 384) “The test-retest reliability of most patients with organic hearing loss is usually quite good, with threshold differences rarely exceeding 5 dB.” In cases of patients exhibiting a nonorganic hearing loss, this threshold of difference is typically much greater.

Physiologic Audiologic Indicators

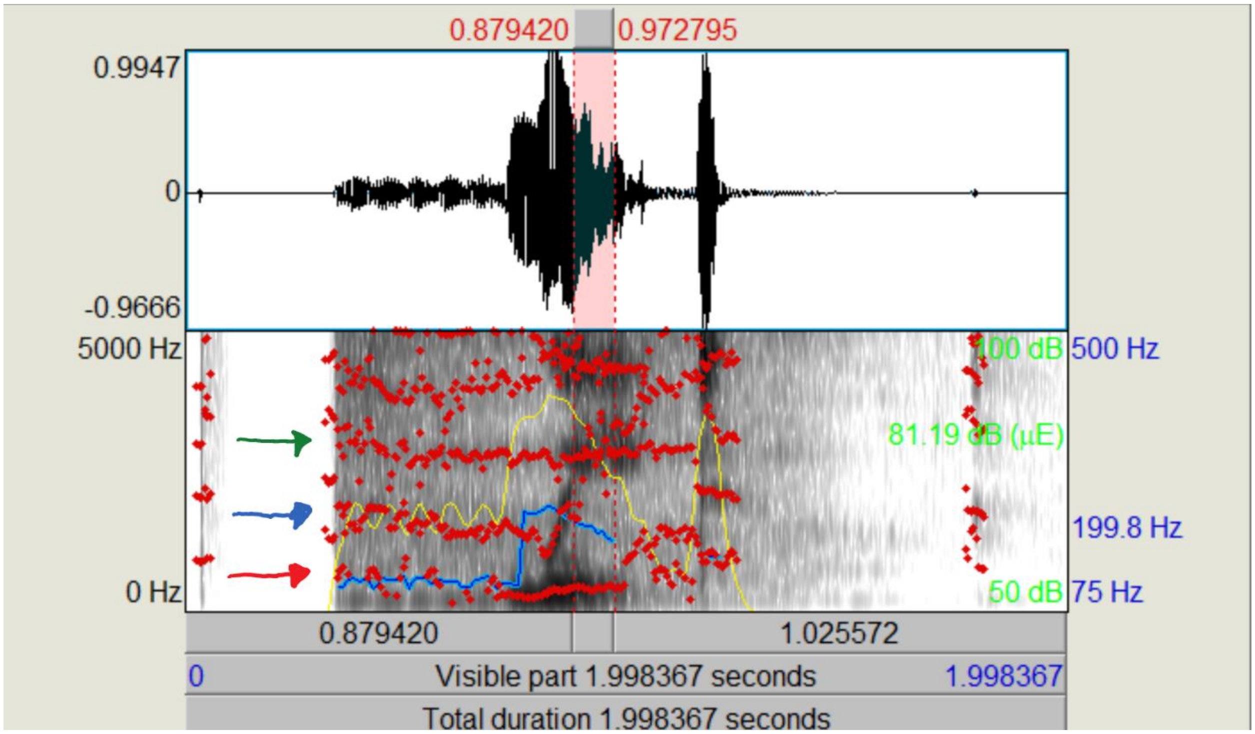
There are objective audiologic tests that cannot be falsified or embellished due to the involuntary nature of the response. Two such tests are otoacoustic emissions (OAE) and the auditory brainstem response (ABR). OAEs are the result of activity within the sensory organ of hearing, the cochlea. Specifically, the cochlea contains cells, called outer hair cells, which react to sound wave vibration delivered by the audiologist. Normal outer hair cells react to sound waves by contracting and expanding, thus effectively amplifying soundwave vibration. In turn, this contracting and expanding generates sound waves not present in the original stimuli delivered by the audiologist. These new sound waves, called OAEs, are emitted back into the ear canal where they may be measured (Martin and Clark, 2015). Thus, if OAEs are present, cochlear outer hair cell damage is ruled out. ABR is a test of neural function, specifically of the VIII cranial nerve and brainstem, in response to sensory cell functioning. Audiologists strategically place electrodes on patients' skulls and deliver sounds to patients' ears. If the auditory system is functioning, they will cause VIII nerve and brainstem neuronal activity. Thus, if ABR are normal, auditory damage is ruled out (Martin and Clark).

Lombard effect and the Lombard test

The Lombard effect is a response to background noise that manifests as an increase in vocal intensity, or volume. According to Silman and Silverman (1991, p. 142), "[a study] supported Lombard's hypothesis that an increase in vocal intensity in noise resulted from the speaker's attempt to monitor his or her own voice." This effect can be applied to patients with a nonorganic hearing loss, because if the patient truly cannot perceive noise because of hearing loss, then they will not raise the intensity of their voice to compensate. If a nonorganic patient reflexively raises his or her voice, the noise must have been heard despite the patient's efforts to hide that fact (Martin and Clark, 2015). This test has fallen out of favor with practicing audiologists, perhaps due to the uncertain amount of sound required to produce the effect, and the lack of objective measures to show the effect (Martin and Clark).

The current author can find no evidence in the literature of spectrographic analysis used to measure the Lombard effect for the purpose of assessing pseudohypoacusis. Spectrographs parse out the frequency and intensity of components of speech allowing the investigator to evaluate and document them on a spectrogram. For example, vowel's fundamental frequency (fo) can be measured along with vowel formant frequencies, intensity (both maximum and minimum), and duration. The spectrograph also allows for measurement of noise and its frequency, intensity, and duration associated with consonants. There are many other features of phonemes that can be measured by a spectrograph.

Below is a sample spectrograph of the word wait, or /weɪt/. The key will demonstrate the overall intensity of the diphthong as well as locations of the diphthong's /eɪ/ F1 and F2 frequencies.



- Formants appear as red lines on spectrograms. The first vowel formant (F1) is the red line that is closest to the bottom of the spectrogram. It is marked by a red arrow to the left of the graphic. F1 frequency varies over the course of the utterance.
- The second vowel formant (F2) is marked by a blue arrow to the left of the graphic. F2 frequency varies over the course of the utterance.

  - The third vowel formant (F3) is marked by a green arrow to the left of the graphic. F3 frequency varies over the course of the utterance.
  - The utterance's intensity contour varies over time as shown by the yellow line. Intensity frequency varies over the course of the utterance.
  - The utterance's fo contour varies over time as shown by the blue line. The fo frequency varies over the course of the utterance.

The purpose of this project was to determine the feasibility using spectrogram analysis of a quick-Lombard test of functional hearing by first establishing outcomes on normally hearing subjects. It was hypothesized that spectrographic analysis might mitigate one of the arguments against using the Lombard test for nonorganic hearing loss, specifically, spectrograms can be used as hard copy documentation. Further, by establishing a "quick" protocol we might mitigate test time as another argument against the Lombard test. The spectrograms were measured using a free online spectrograph analysis tool called Praat (Boersma and Weenink, 2005). Specifically, the author asked subjects to utter the vowels /i/ and /u/ and she then measured, in quiet and in noise, vowel fo, F2 frequency, F3 frequency, intensity as dB Max (maximum), and intensity as dB Min (minimum). The dB maximum intensity measures reflected the traditional Lombard effect. Frequency measures were also studied because it was hypothesized that the anatomical movements required for the Lombard intensity effect might also effect changes in frequency. This was shown in an unpublished dissertation (Rosen, 1997).

Methods

- All testing was completed in a sound room meeting American National Standards Institute standards (ANSI 1991). Speech noise was routed from a GSI 61 Audiometer calibrated to ANSI standards for audiometers (2004).

- Participants were a convenience sample of six students in the SLPA undergraduate program at the University of Akron. All the participating subjects were women between the ages of 20 and 22. Participants were tested individually; they were seated in the patient side of the sound suite so they could not see the audiometer. TDH39 earphones were placed over the participants' ears. Participants were instructed, when signaled, to say the vowels /i/ and /u/ at a rate and duration of approximately one second per vowel and with a brief pause in between. The participants were told to continue no matter what they heard through the earphones. They spoke the vowel pairs into a laptop computer microphone (ASUS X200M Notebook) and were recorded for later analysis using Praat.
    - Quiet 1 condition: The first three vowel pairs were uttered in quiet (Quiet 1 Condition).
    - Noise condition (70 dBHL Noise Condition): The tester delivered 70 dBHL speech noise routed from the audiometer to the earphones and three more vowel pairs were recorded in Praat.
    - Quiet 2 condition: three more vowel pairs were uttered in quiet (Quiet 2 Condition).
- The author and a licensed audiologist served as judges; they reviewed the recordings for analysis. The second vowel of each pair was targeted for analysis. The two judges agreed on the entire length of each vowel for analysis, and using Praat analysis, identified the following for each vowel:

Recorded Measures

- /i/ dB Min (minimum)
- /i/ dB Max (maximum intensity)
- /u/ dB Min (minimum)
- /u/ dB Max (maximum intensity)
- /i/ mean fo
- /u/ mean fo
- /i/ F2 mean frequency
- /i/ F3 mean frequency
- /u/ F2 mean frequency
- /u/ F3 mean frequency

Results

Descriptive data (medians, means, and standard deviations) are in Appendix A for all conditions and for each vowel. Analysis of the data was made using nonparametric tests because of our small sample size (Siegel, 1988). Of interest to this researcher was whether the noise condition resulted in measurable changes that could be attributable to the Lombard effect. I examined this using the chi square goodness of fit test for each measure for each vowel, specifically comparing: (1) the number of subjects for which the noise trial was highest for the given measure, (2) the number of subjects for which the noise trial was lowest for the given measure, and (3) the number of subjects for which the noise trial was neither highest nor lowest for the given measure (Appendix A). The only significant chi square finding ($p < .05$) was the number of subjects for which the noise trial /u/ Max dB condition was highest, a finding consistent with the Lombard effect.

Similarly, the results from Friedman's repeated measures test for ranked data (Appendix B) shows /u/ Max dB was significantly higher ($p < .05$) in the presence of noise. A follow-up sign test indicated that the Quiet 1 vs Noise conditions differed significantly ($p < .05$), whereas Quiet 1 vs Quiet 2 conditions and Quiet 2 vs Noise conditions were not significantly different ($p < .05$).

As proof of concept that spectrograms can be used in Lombard analysis, spectrogram data for the vowel /u/ are shown in Appendix C.

Discussion

I studied the feasibility of a quick-Lombard test by measuring outcomes on normally hearing subjects, and by making objective measures using a free online spectrograph analysis tool called Praat (Boersma and Weenink, 2005). I studied subjects' utterances of vowels in isolation, namely /i/ and /u/. Each was said in Quiet 1 condition, Noise condition, and Quiet 2 condition. It was expected that the Lombard effect, as reported in the literature, would result in increased vocal intensity in the Noise condition compared to the Quiet conditions. We also looked for frequency differences in fo, F2, and F3 among the three conditions that might be related to Lombard effect. Only the /u/ Max dB condition showed the Lombard effect; Max dB was more intense in the Noise condition than it was in the initial quiet condition. While this finding is of interest, it stands alone, suggesting that our quick-Lombard test is not useful for identifying functional hearing loss. However, we have demonstrated the potential for using Praat software for objective analysis of the Lombard effect.

Future Research

Though the quick-Lombard test described in this paper and tested in this study appears to be ineffective, a more traditional methodology should be studied, specifically by having patients read an unfamiliar passage such as a story or text, possibly over a longer time period. The expectation is that the well-known Lombard effect could occur as expected and manifest as the anticipated increase in spoken intensity in noise, and possibly changes in fo, F2, or F3 frequencies.

The data in this study suggested that the /u/ Max dB shows more promise than any other condition for /u/ or /i/. Future researchers should consider measurments isolating /u/ Max dB in the analysis of spectrograms of unfamiliar passage readings. Also, in this study, the researcher used 70 dBHL noise. Future researchers should experiment with other noise levels to determine what is optimal. Finally, researchers should study listeners being asked to feign hearing loss.

Appendix A

	Number of subjects for which the noise trial was highest	Number of subjects for which the noise trial was lowest	Number of subjects for which the noise trial was neither highest nor lowest
/i/ Min dB	2	0	4
/i/ Max dB	2	0	4
/i/ Fo	2	1	3
/i/ F2	2	4	0
/i/ F3	0	2	4

	Number of subjects for which the noise trial was the highest	Noise trial was lowest	Noise trial was neither highest nor lowest
/u/ Min dB	2	2	2
/u/ Max dB*	5	0	1
/u/ Fo	2	0	4
/u/ F2	2	1	3
/u/ F3	1	3	2

*Chi square goodness of fit significant $p < .05$

Appendix B

/i/ min dB
Friedman's test for repeated measures not significant p < .05

Quiet 1	Noise	Quiet 2
66.29	62.72	55.08
52.51	59.92	64.03
14.40	45.04	42.88
42.88	48.16	65.88
72.99	60.22	58.90
38.53	63.38	39.06
Median: 47.695	Median: 60.07	Median: 56.99
Mean: 47.93	Mean: 56.57	Mean: 54.3
SD: 21.09	SD: 7.9	SD: 11.07

/i/ max dB
Friedman's test for repeated measures not significant p < .05

Quiet 1	Noise	Quiet 2
85.16	89.69	83.44
81.88	81.41	79.65
77.09	45.04	42.88
84.82	83.60	82.55
79.71	80.52	77.23
82.64	84.04	84.69
Median: 82.26	Median: 82.505	Median: 81.1
Mean: 81.88	Mean: 77.38	Mean: 75.07
SD: 3.09	SD: 16.17	SD: 16

/i/ fo
Friedman's test for repeated measures not significant p < .05

Quiet 1	Noise	Quiet 2
206.53	245.00	212.74
187.50	195.96	180.63
206.43	207.00	208.70
216.43	208.14	208.85
240.55	250.80	258.37

265.05	267.15	290.45
Median: 211.48	Median: 226.57	Median: 210.795
Mean: 220.42	Mean: 229.01	Mean: 226.62
SD: 27.88	SD: 28.97	SD: 40.07

/i/ F2
Friedman's test for repeated measures not significant p < .05

Quiet 1	Noise	Quiet 2
2618.59	2534.74	2563.33
2694.47	2535.91	2813.69
2788.79	2696.70	2754.04
2546.39	2589.65	2499.93
2738.78	2472.59	2651.40
2850.18	2857.76	2501.32
Median: 2716.625	Median: 2562.78	Median: 2607.365
Mean: 2706.2	Mean: 2614.5	Mean: 2630.62
SD: 111.32	SD: 140.87	SD: 132.29

/i/ F3
Friedman's test for repeated measures not significant p < .05

Quiet 1	Noise	Quiet 2
3012.32	2868.73	2835.64
3222.31	3022.57	3308.95
3284.31	3126.91	3179.59
2865.68	2872.38	3037.06
3849.94	2940.00	2923.34
3257.78	3144.10	2864.10
Median: 3240.045	Median: 2981.285	Median: 2980.2
Mean: 3248.72	Mean: 2995.78	Mean: 3024.78
SD: 336.49	SD: 121.98	SD: 188.02

/u/ Min dB
Friedman's test for repeated measures not significant p < .05

Quiet 1	Noise	Quiet 2
81.27	39.56	59.33
57.15	65.49	41.24
53.01	53.21	72.27
34.97	48.28	33.12
51.00	51.33	56.09
44.71	29.53	56.10
Median: 52.005	Median: 49.805	Median: 56.095
Mean: 53.68	Mean: 47.9	Mean: 53.02

SD: 15.57	SD: 12.3	SD: 13.89

/u/ Max dB*

*Friedman's test for repeated measures significant p < .05
*Sign test Quiet 1 vs noise significant p < .05
Sign test Quiet 1 vs Quiet 2 not significant p < .05
Sign test Noise vs Quiet 2 not significant p < .05

Quiet 1	Noise	Quiet 2
85.17	87.06	85.76
84.15	85.43	80.59
82.23	85.54	77.87
78.22	79.04	75.07
81.15	81.65	80.77
76.86	78.69	80.77
Median: 81.69	Median: 83.54	Median: 80.68
Mean: 81.3	Mean: 82.9	Mean: 80.14
SD: 3.26	SD: 3.6	SD: 3.56

/u/ fo
Friedman's test for repeated measures not significant p < .05

Quiet 1	Noise	Quiet 2
246.76	247.80	232.33
218.49	216.35	207.19
194.28	198.09	180.40
249.11	238.78	227.05
271.12	259.18	245.27
208.03	211.88	245.27
Median: 232.625	Median: 227.565	Median: 229.69
Mean: 231.3	Mean: 228.68	Mean: 222.92
SD: 29.04	SD: 23.53	SD: 25.14

/u/ F2
Friedman's test for repeated measures not significant p < .05

Quiet 1	Noise	Quiet 2
1263.17	1315.92	1240.63
1396.19	1299.50	1265.24
1354.89	1336.10	1284.32

1311.52	1307.65	1237.67
1331.38	1243.52	1405.63
1256.40	1533.87	1425.25
Median: 1321.45	Median: 1311.785	Median: 1274.78
Mean: 1318.92	Mean: 1339.43	Mean: 1309.79
SD: 53.84	SD: 100.17	SD: 83.83

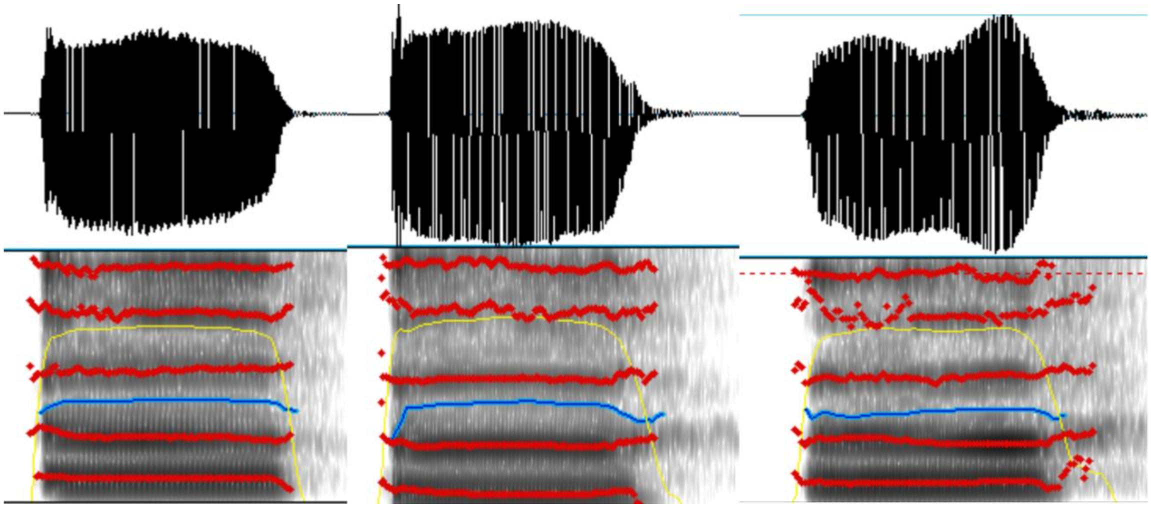
/u/ F3
Friedman’s test for repeated measures not significant $p < .05$

Quiet 1	Noise	Quiet 2
2596.78	2546.78	2554.09
2754.39	2782.10	3015.90
2839.07	2710.86	3124.77
3760.08	3900.07	2897.75
3148.18	3130.69	2990.57
3896.88	2893.20	3000.72
Median: 2993.625	Median: 2837.65	Median: 2995.645
Mean: 3165.9	Mean: 2993.95	Mean: 2930.63
SD: 545.48	SD: 484.74	SD: 198.16

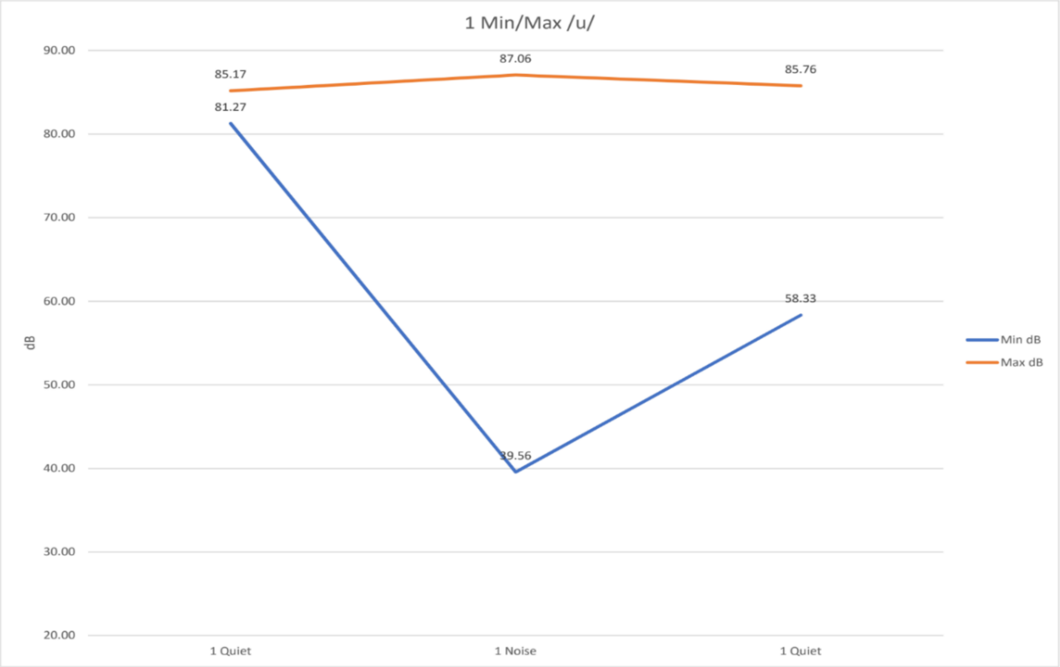
Appendix C-

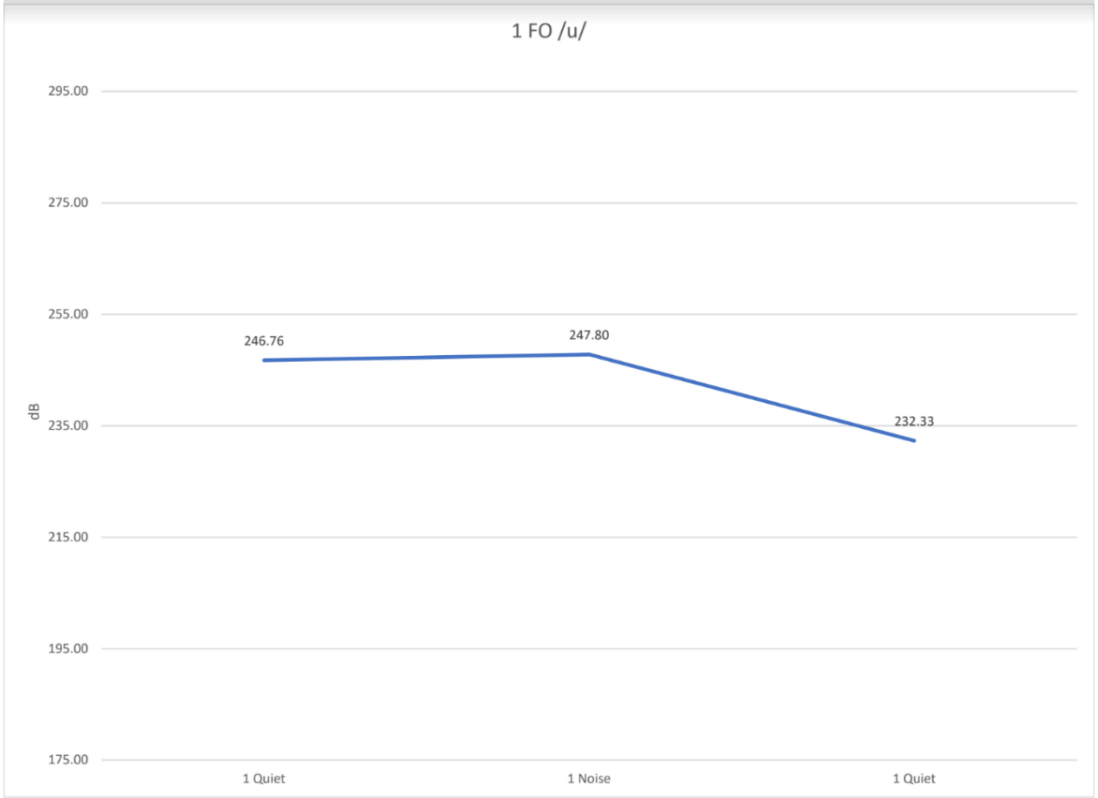
Shown below are three wave envelopes (top) and more importantly spectrograms (bottom) of the vowel /u/. Leftmost is the Quiet 1 condition, the middle is the Noise condition, and rightmost is the Quiet 2 condition. In each of those three, the red horizontal lines are the mean formant frequencies over time. The inferior most line is F1 and the superior most is F5. The yellow line is the intensity contour and the blue line is the fo contour.

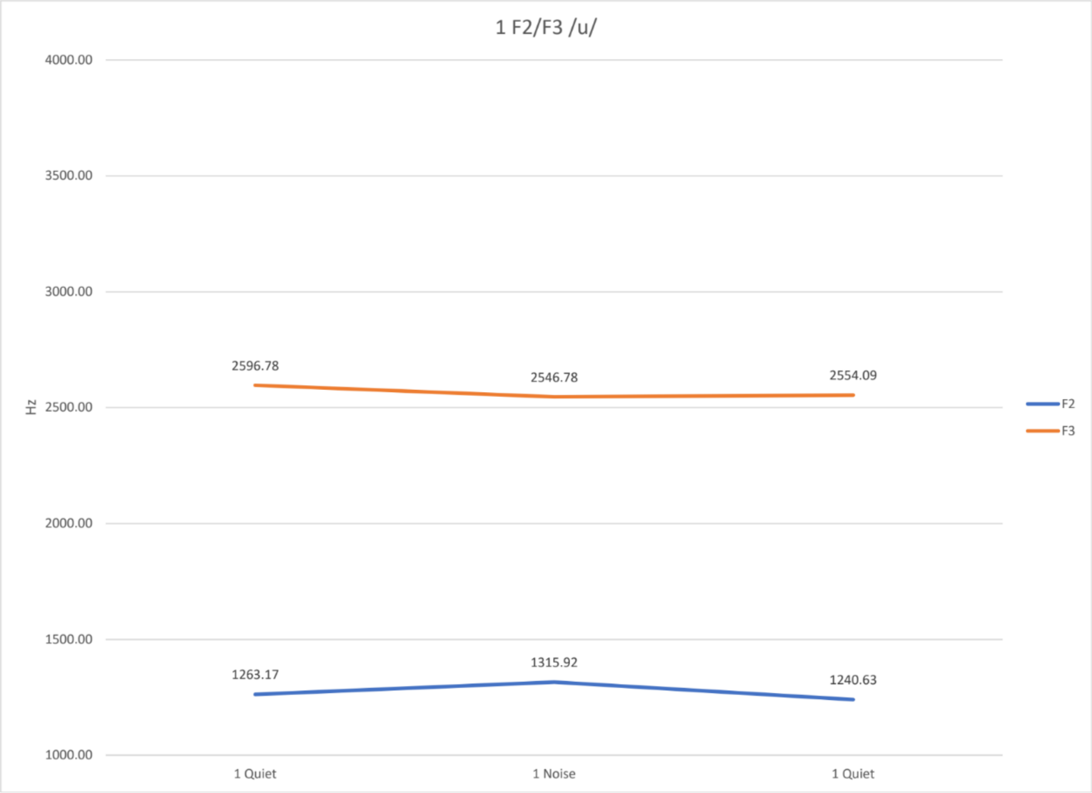
Subject 1:



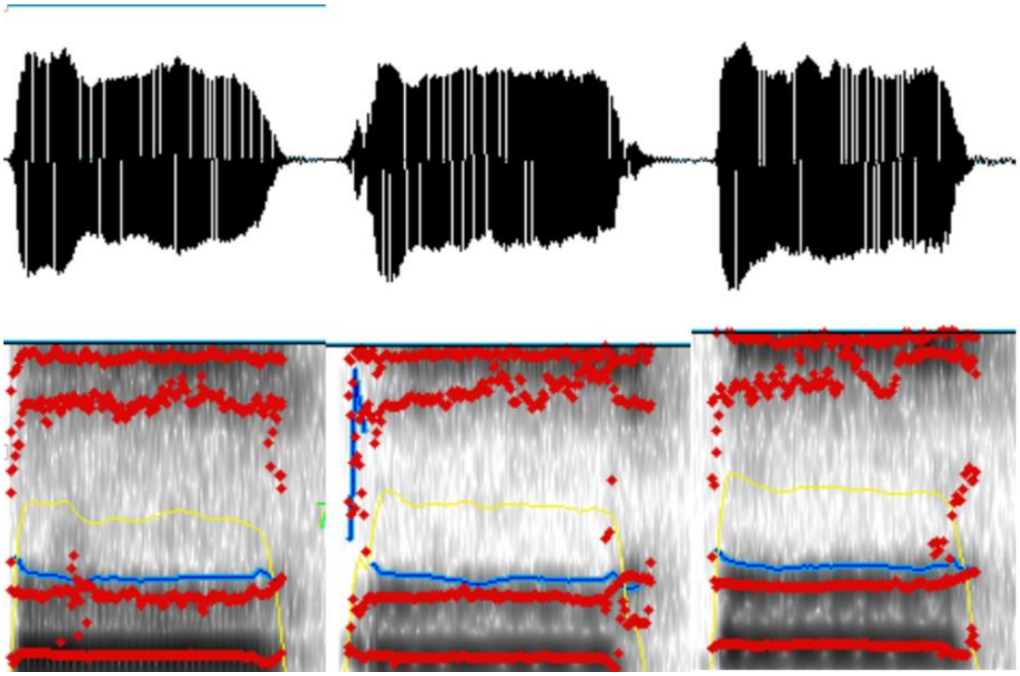
For comparison, shown below is the above data represented as a line graph.


1 Min/Max /u/
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
dB
85.17
87.06
85.76
81.27
58.33
39.56
1 Quiet
1 Noise
1 Quiet
Min dB
Max dB

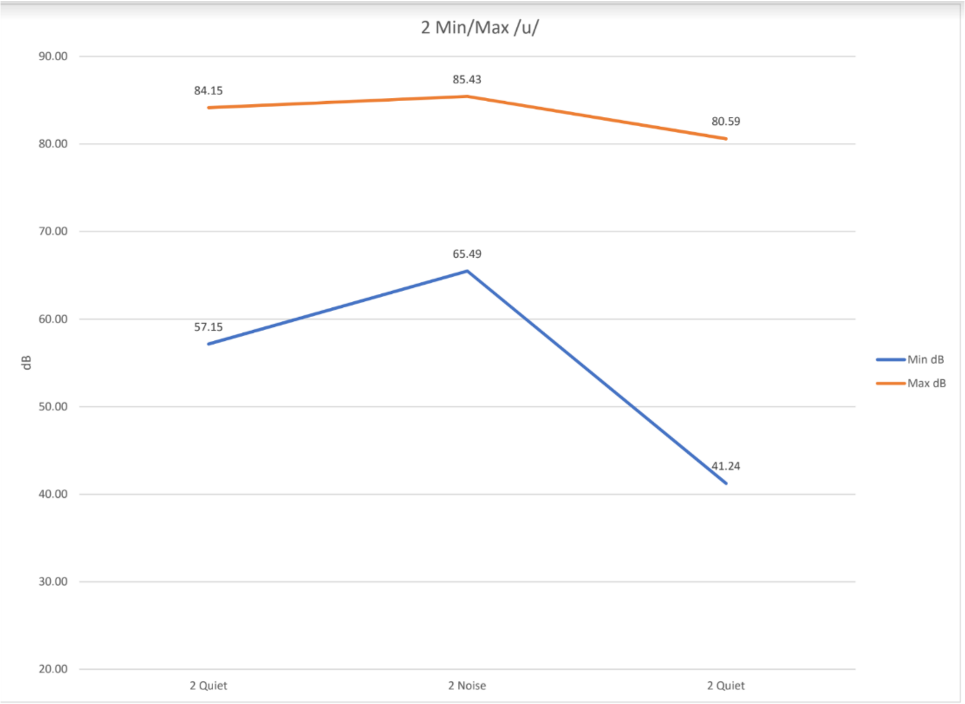

1 FO /u/
295.00
275.00
255.00
235.00
215.00
195.00
175.00
dB
246.76
247.80
232.33
1 Quiet
1 Noise
1 Quiet

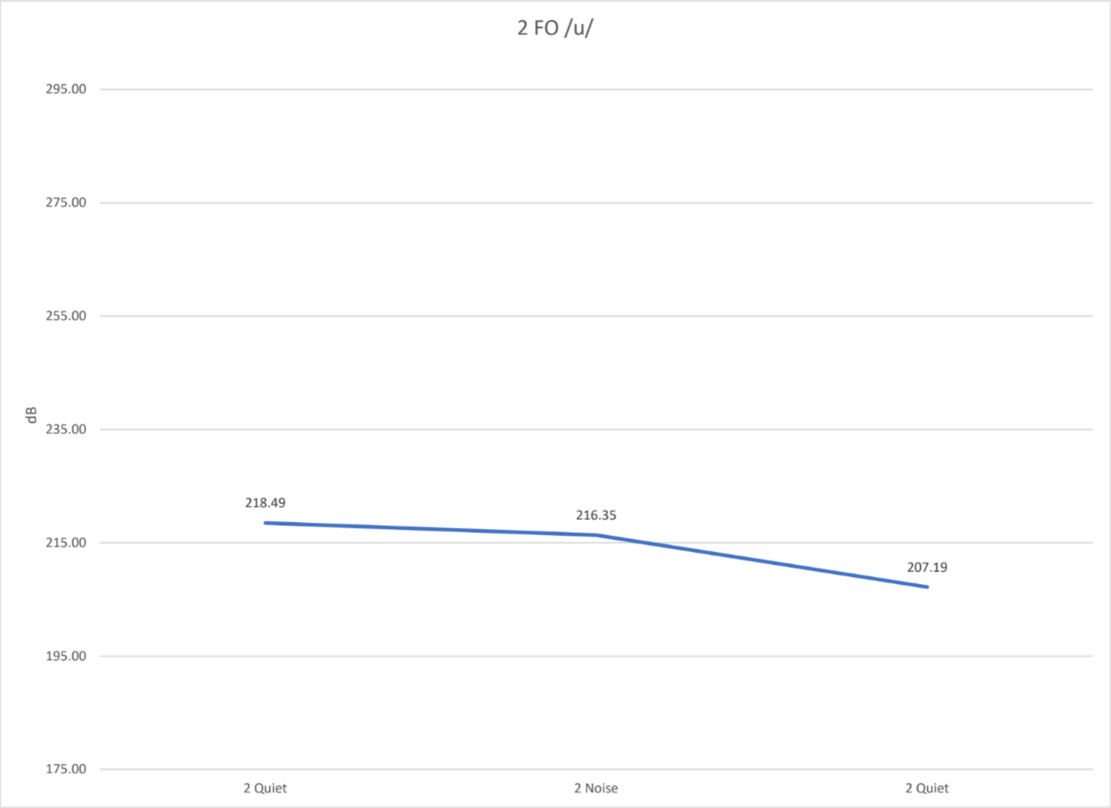

1 F2/F3 /u/
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
Hz
2596.78
2546.78
2554.09
1263.17
1315.92
1240.63
1 Quiet
1 Noise
1 Quiet
F2
F3

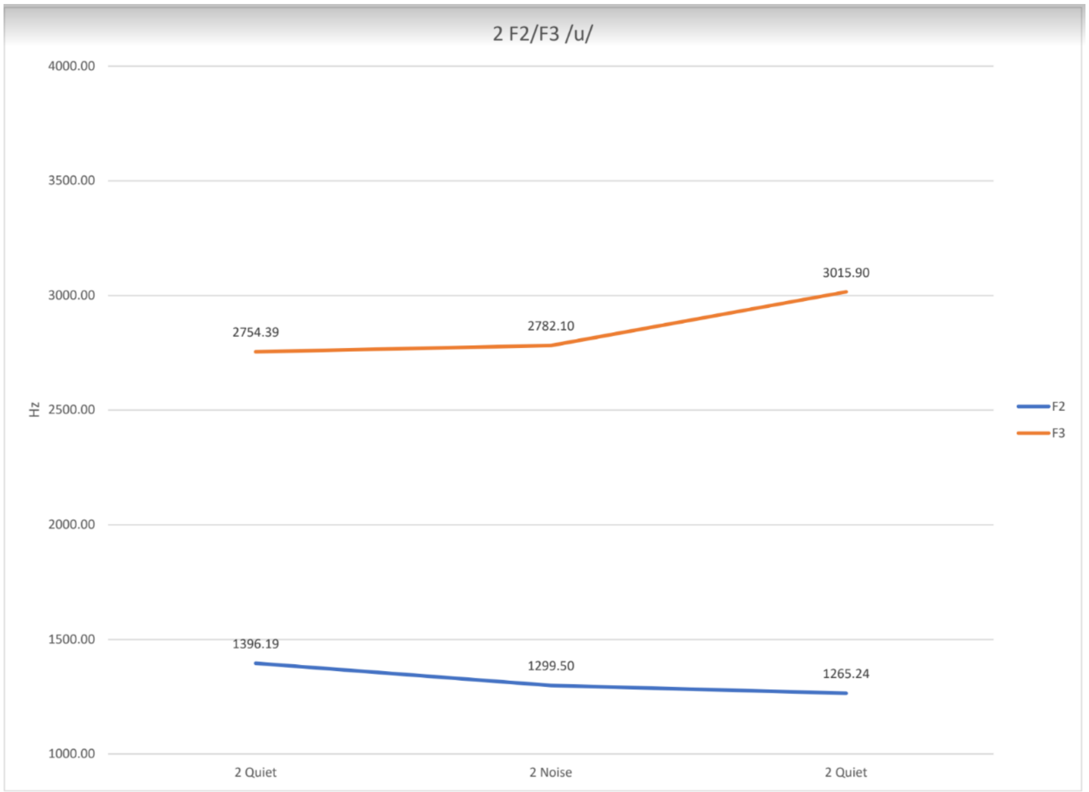
Subject 2:



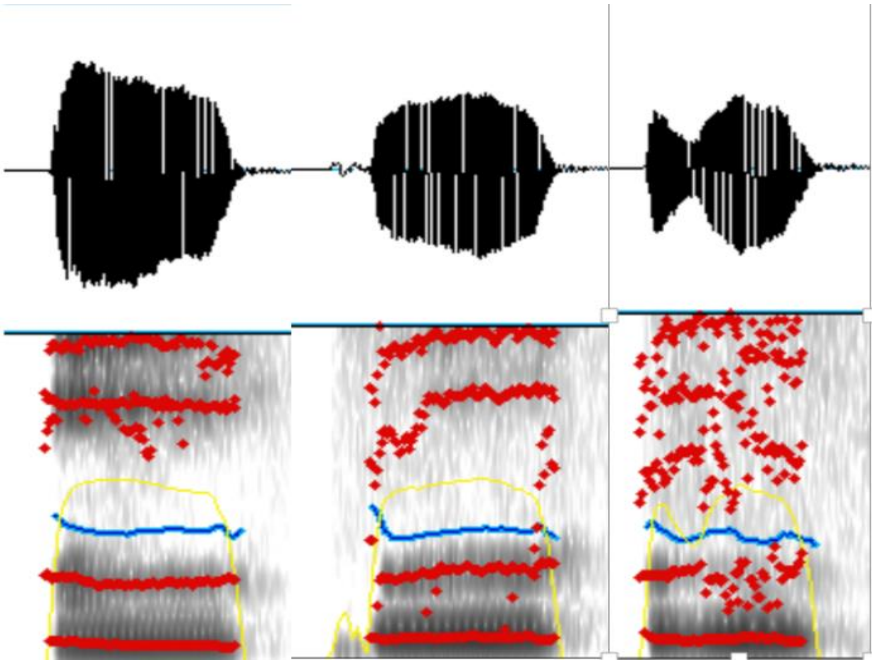
Corresponding line graphs:



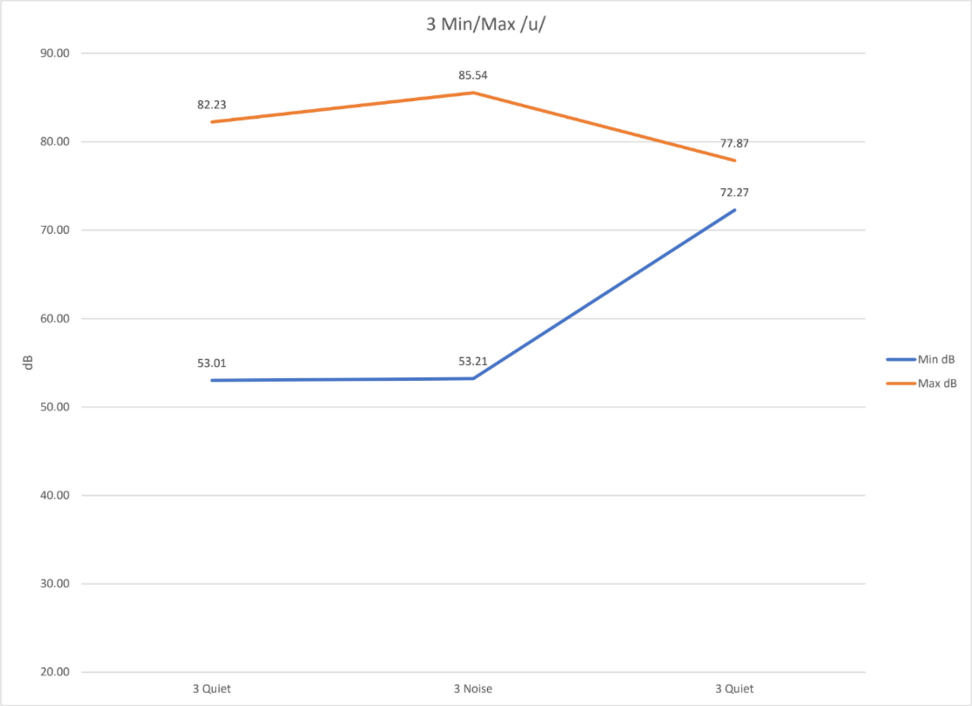

2 FO /u/
295.00
275.00
255.00
235.00
215.00
195.00
175.00
dB
218.49
216.35
207.19
2 Quiet
2 Noise
2 Quiet

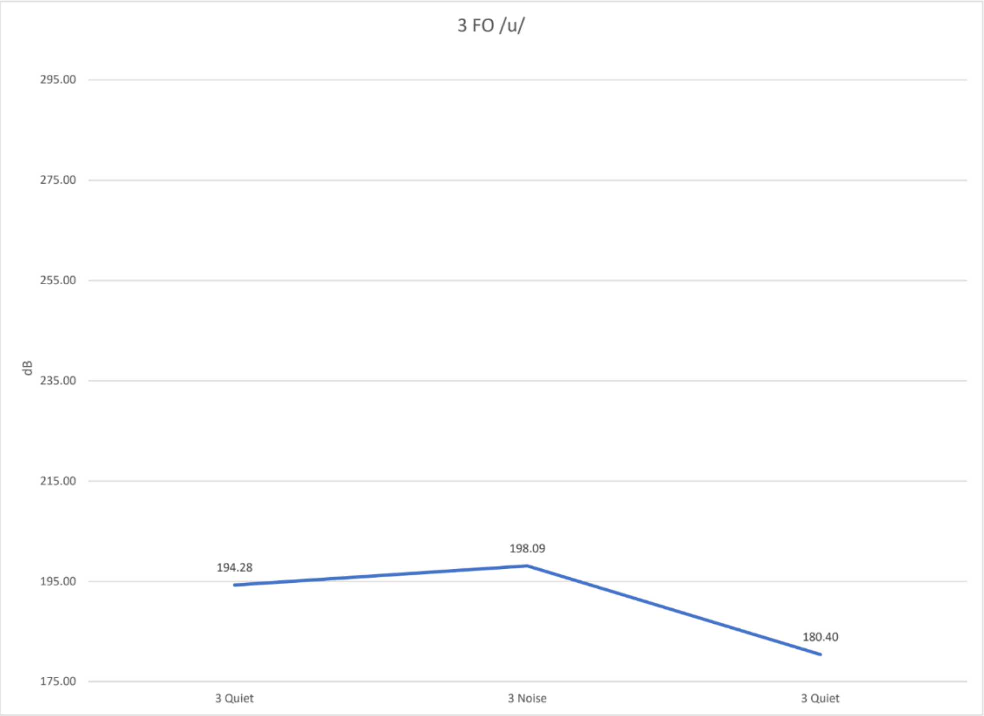

2 F2/F3 /u/
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
Hz
3015.90
2754.39
2782.10
1396.19
1299.50
1265.24
2 Quiet
2 Noise
2 Quiet
F2
F3

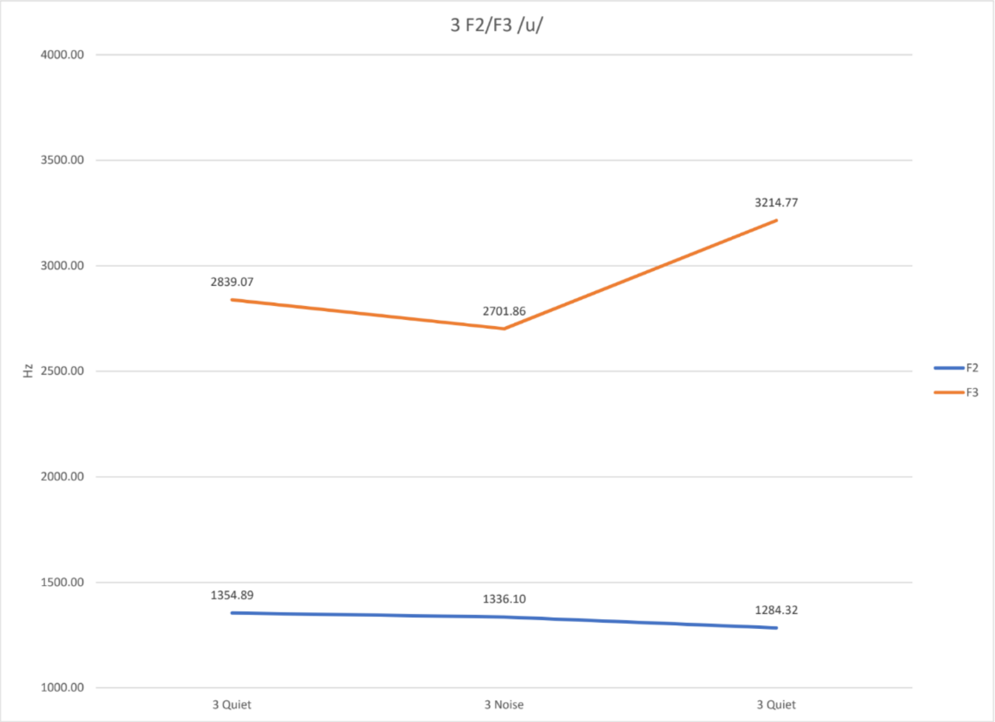
Subject 3:



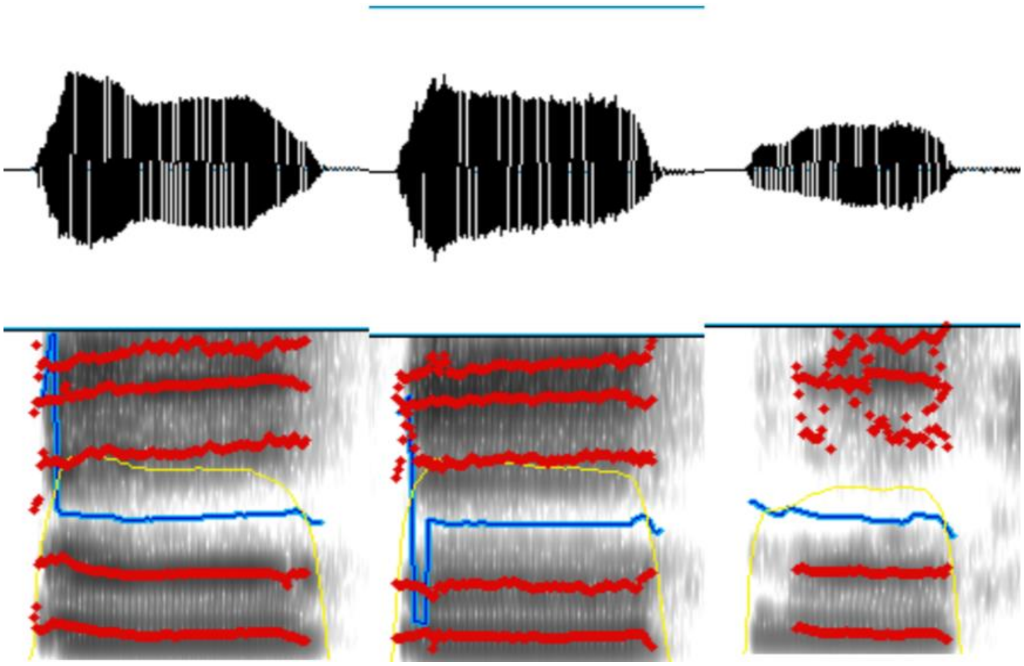
Corresponding line graphs:



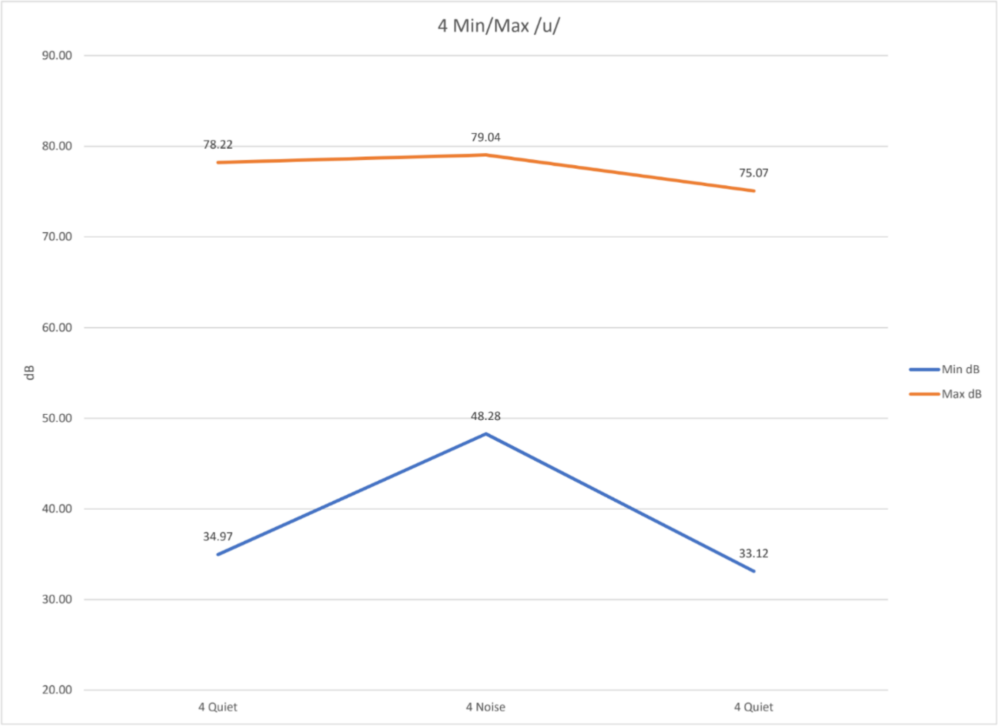

3 FO /u/
dB
295.00
275.00
255.00
235.00
215.00
195.00
175.00
194.28
198.09
180.40
3 Quiet
3 Noise
3 Quiet


3 F2/F3 /u/
Hz
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
2839.07
2701.86
3214.77
1354.89
1336.10
1284.32
3 Quiet
3 Noise
3 Quiet
F2
F3

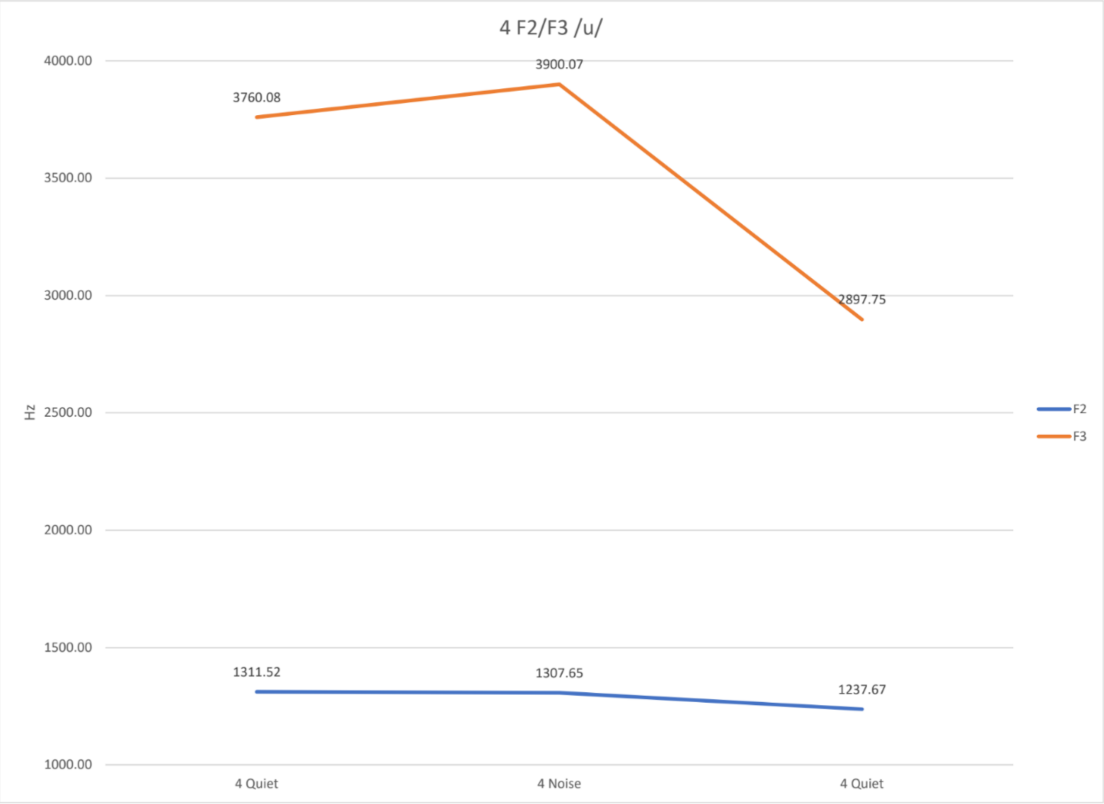
Subject 4:



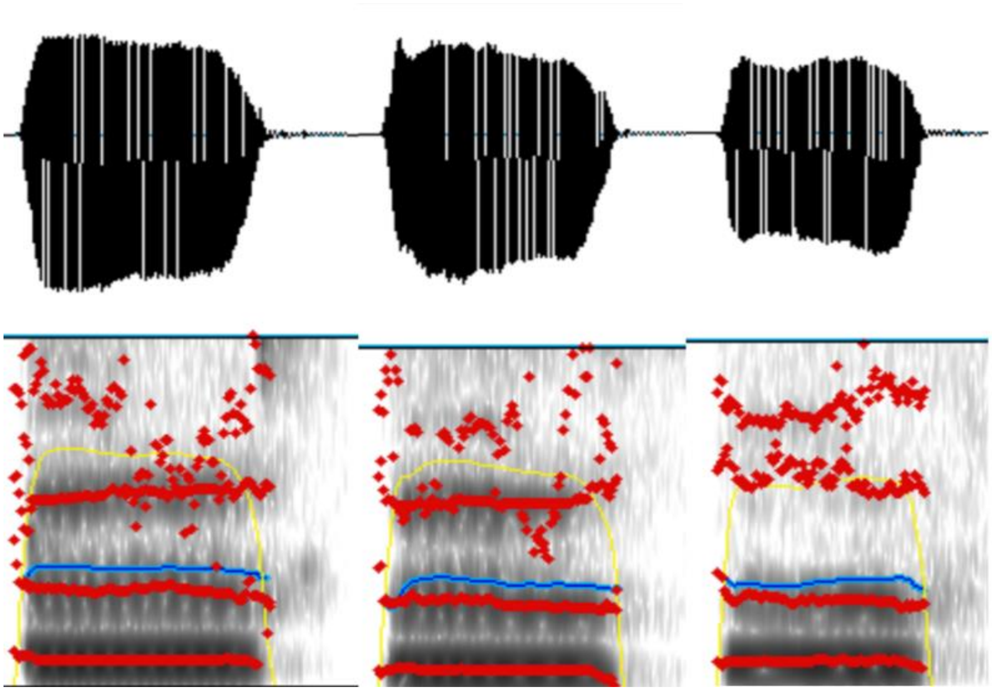
Corresponding line graphs:



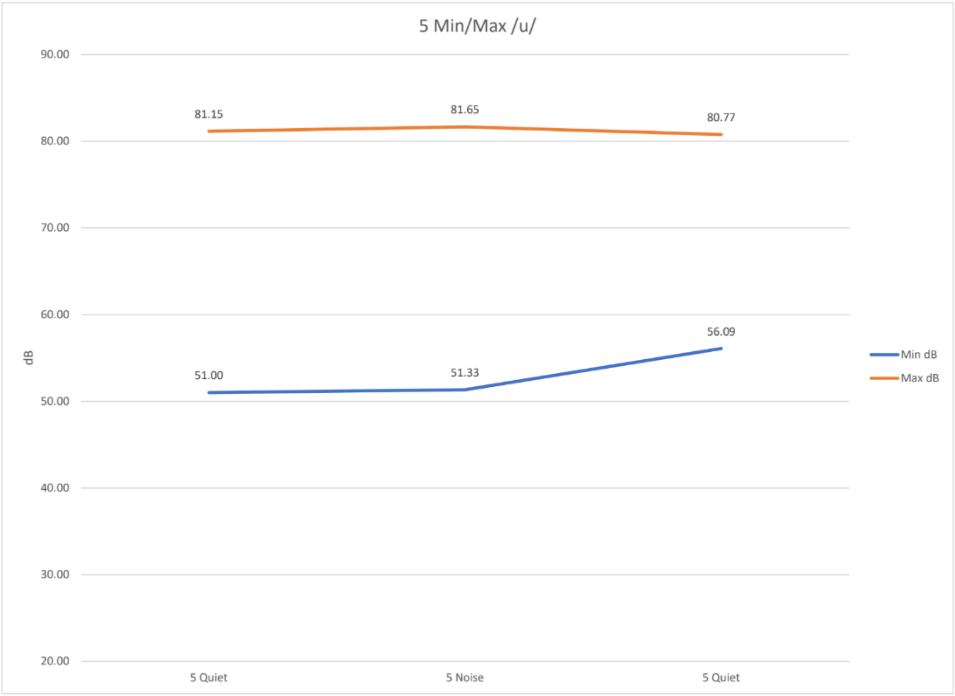

4 FO /u/
295.00
275.00
255.00
235.00
215.00
195.00
175.00
dB
249.11
238.78
227.05
4 Quiet
4 Noise
4 Quiet


4 F2/F3 /u/
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
Hz
3760.08
3900.07
2897.75
1311.52
1307.65
1237.67
4 Quiet
4 Noise
4 Quiet
F2
F3

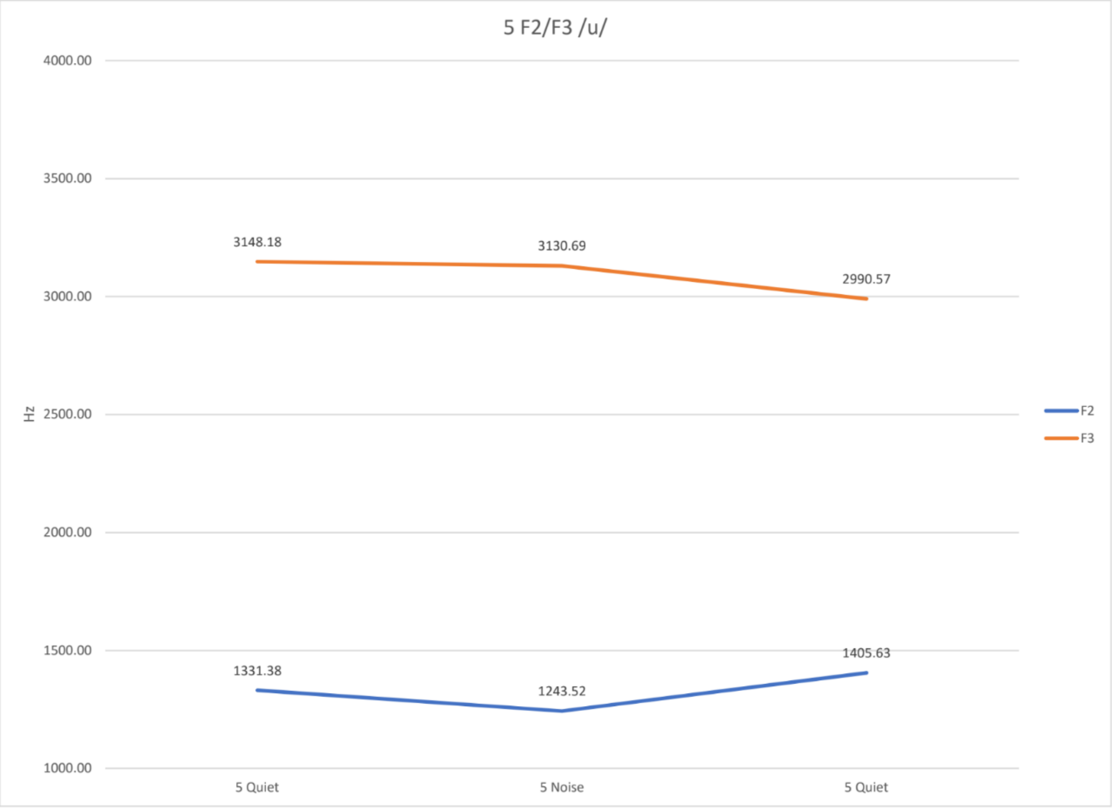
Subject 5:



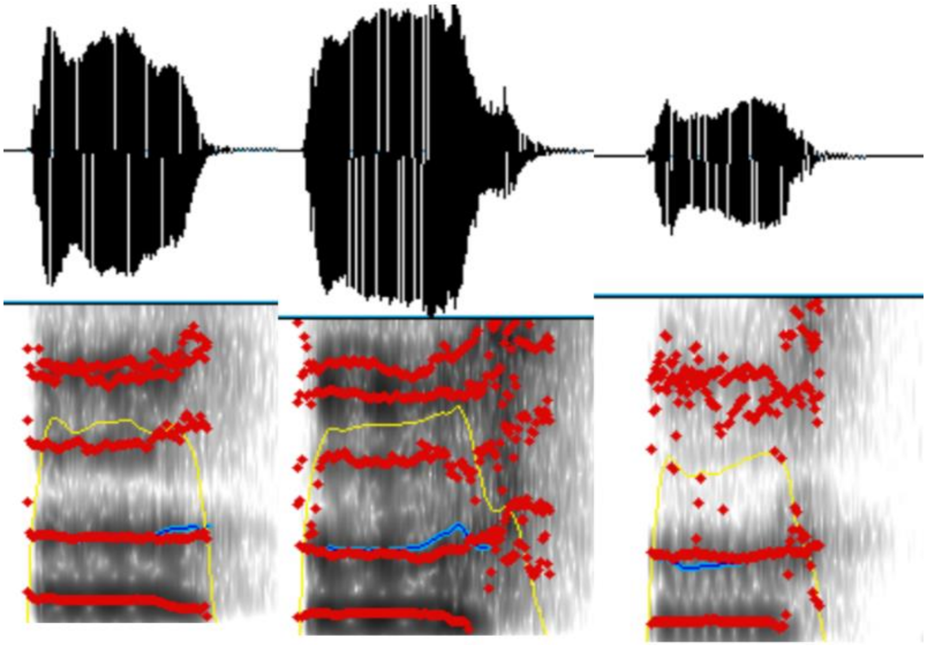
Corresponding line graphs:



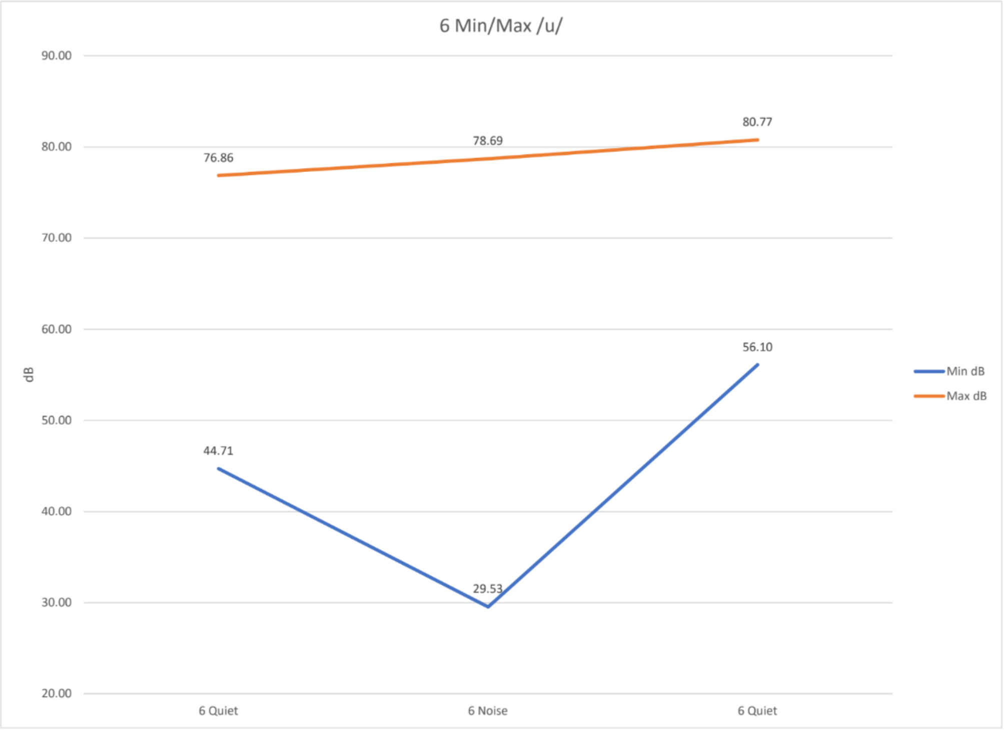

5 FO /u/
dB
295.00
275.00
255.00
235.00
215.00
195.00
175.00
271.12
259.18
245.27
5 Quiet
5 Noise
5 Quiet

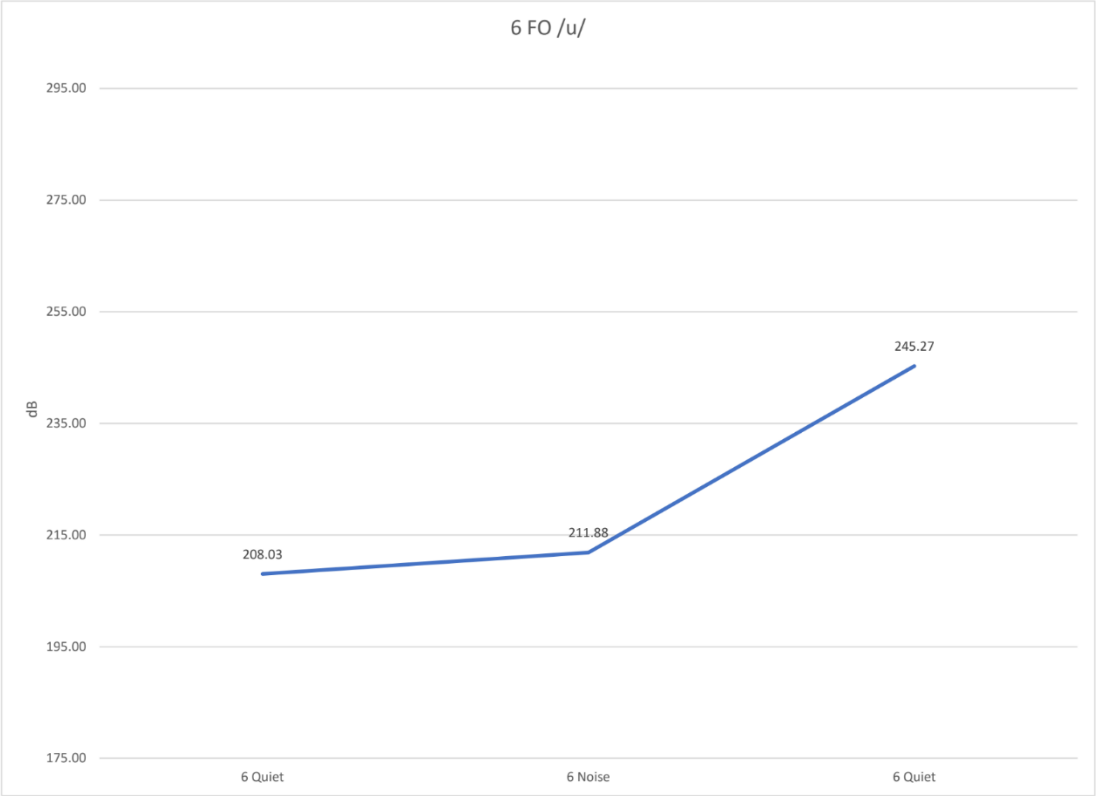

5 F2/F3 /u/
Hz
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
3148.18
3130.69
2990.57
1331.38
1243.52
1405.63
5 Quiet
5 Noise
5 Quiet
F2
F3

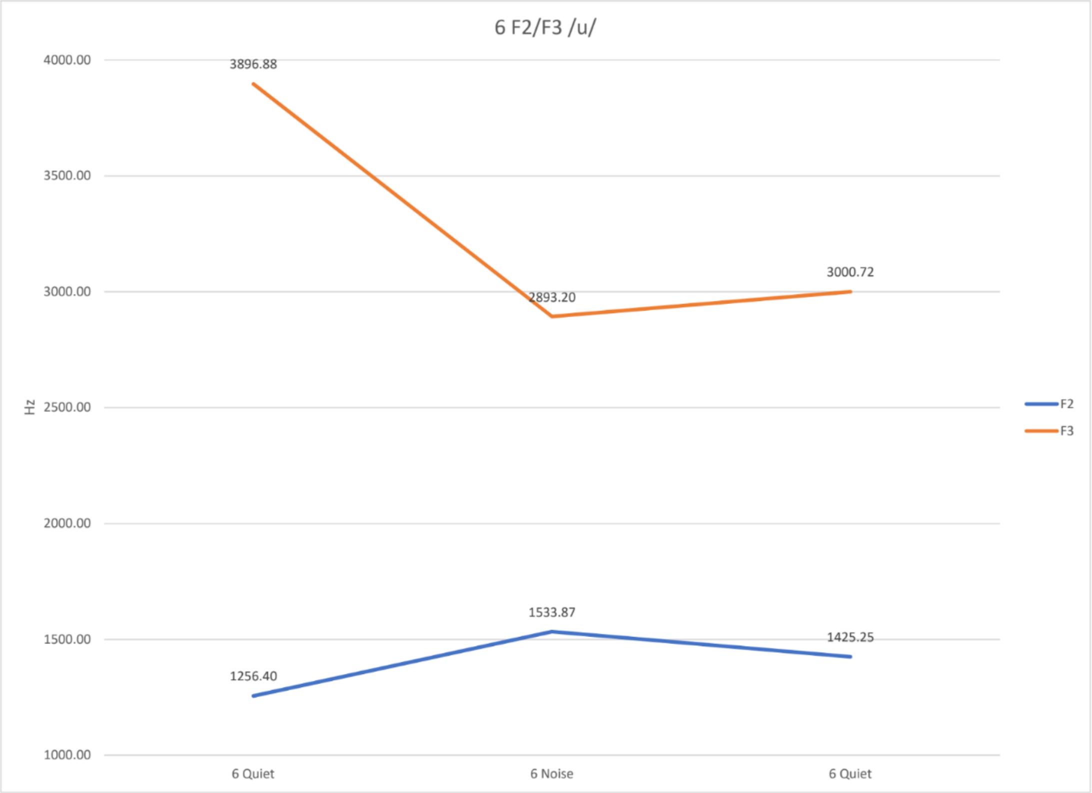
Subject 6:



Corresponding line graphs:




6 FO /u/
dB
295.00
275.00
255.00
235.00
215.00
195.00
175.00
208.03
211.88
245.27
6 Quiet
6 Noise
6 Quiet


6 F2/F3 /u/
Hz
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
3896.88
2893.20
3000.72
1256.40
1533.87
1425.25
6 Quiet
6 Noise
6 Quiet
F2
F3

Works Cited

American National Standards Institute (1991). Maximum Permissible Ambient noise for audiometric test rooms. ANSI S3.1-1991 New York: American National Standards Institute.

American National Standards Institute (2004). American National Standard Specification for Audiometers. ANSI S3.6-2004. New York National Standards Institute.

Boersma, Paul and Weenink, David (2005). *Praat: Doing Phonetics by Computer*. Retrieved March 2018 from http://www.fon.hum.uva.nl/praat/.

Lin, J., & Staecker, H. (2006, July). “Nonorganic hearing loss”. Retrieved March 5, 2019, from https://www.ncbi.nlm.nih.gov/pubmed/16791778

Martin, Frederick N. and Clark, John Greer. (2015). *Introduction to Audiology* (12th ed.) Upper Saddle River, NJ: Pearson.

Rosen, Kristin (1997). *The Role of Auditory Feedback in Automatized and Unautomatized Phonemes.* University of Wyoming, School of Speech Language Pathology and Audiology.

Siegel, Sidney (1988). *Nonparametric Statistics for the Behavioral Sciences*. (2nd ed.) Mc-Graw Hill Inc.

Silman, Shlomo and Silverman, Carol A. (1991). *Auditory Diagnosis: Principles and Applications*. San Diego, CA: Academic Press, Inc.

Stach, Brad A. (2010). *Clinical Audiology: An Introduction.* Clifton Park, NY: Delmar, Cengage Learning