Experiments in Psychoacoustics

Jason E. Mock
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Professor Steve Errede
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Introduction

Most people tend to take their senses for granted. Most people can see, hear, touch, taste, and smell fairly well. It is not until ability of one of the senses begins to deteriorate does one typically begin to appreciate the value of that sense. One sense that people begin to appreciate earliest in this way is their sense of hearing. Whether the cause is wind, a nearby explosion, or a rock concert, one's sense of hearing is often at least temporarily effected from time to time, giving a person cause to appreciate the quality of hearing he or she typically has.

As with all of the other senses, the sense of hearing is an incredibly complex system. It takes in many stimuli to produce the final sensation experienced by a person. Pitch, direction, intensity, timbre, duration are just a few elements that give any sound, musical or not, its characteristic.

This study covers a few of the basic aspects of the human ear and the brain's perception of sound. These experiments barely scratch the surface of the wonders of information contained in these fields, but they do begin to shed some light on the details concerning the sense of hearing. Using headphones and a personal computer, these experiments were able to begin to do this.

The first experiment deals with the ear's frequency response, or sensitivity to specific frequencies. This experiment provides some idea of what frequencies the human ear is better at perceiving, possibly shedding some light on a person's preference for certain graphic equalizer settings.

The second experiment tests the brain's ability to perceive pitch from increasingly small durations of sensation. At some shortness of duration, any given frequency is no longer recognized as a pitch, but rather as a click sound. This study sought to find those limits.

The last experiment works with the ability of the brain to take two slightly different stimuli from each the left and the right ear, and analyze those differences to determine the direction from which the sound came. The first half of this experiment tested the participants' ability to localize a stationary sound source, which the second half added in the additional auditory cue of motion.

Together, these three experiments sought to test and explain a little bit of how the human mind understands the waves detected by the hear. The process of conducting these experiments was a lengthy and trying one, but a worthwhile one nonetheless.

The Experiments

Frequency Response Experiment

This experiment deals with the ear's frequency response, or sensitivity to specific frequencies. This experiment provides some idea of what frequencies the human ear is better at perceiving, possibly shedding some light on a person's preference for certain graphic equalizer settings.

Development

Not only does the response of human hearing depend upon frequency, but it also depends upon volume. The original idea behind this experiment was to measure a person's response to a given frequency at a variety of intensities in order to create a "map" of that person's entire frequency response. My idea was then to take that data and apply it to a specialized graphic equalizer, which would then output sound accordingly, in order to compensate for an individual's areas of weaker hearing.

My original design was to test each participant's hearing at ten different volumes, each at ten different frequencies. After a little thought, research, and input, I saw two possibilities I could pursue as a medium for this experiment: a frequency generator or a computer equipped with a sound card. Considering the number of times the same test would be given to a single participant at different volumes and the number of participants I hoped to have in this experiment, I quickly settled on using creating wave files on the computer. This would allow me to quickly load each pitch and intensity from a corresponding file without having to repeatedly adjust the controls of a frequency generator.

However, the amount of data to be collected combated against the limited time available to do such tests on students already busy with their own projects quickly destroyed any hopes of completing such a thorough experiment. My next revision of the experimental design limited the range of volumes to five different amplitudes. This, too, turned out to take too long for the satisfaction of the participants. Finally, I resolved myself to only using one amplitude as my test volume for frequency response.

I then created the wave files using a wave-editing program. My first design was to create a series of "pings," or short pulses at a specific frequency, of increasing amplitude starting with an amplitude approaching zero. Each ping would last one-quarter of a second and be followed by one-quarter of a second of silence. Each subsequent ping would have slightly greater amplitude than the previous one, resulting in a "ramp of pings." These pings would then be superimposed against a background of white noise. The intensity of this white noise would correspond to the volume I wished to test. Ideally, a participant would only hear a ping if the level he or she perceived the ping to be at exceeded the level of the white noise.

This experimental design turned out to be a failure because of the laws of physics. The superimposing of any wave with another will result in an amplitude that is the sum of the amplitude of the two superimposed waves. For my experiment, this meant that my first ping at –36 dB superimposed against background noise of –18 dB would result in a ping that would be perceived as louder than –36 dB. This was discovered when I listened to the ramp of pings and could hear the pings after five seconds in the absence of background noise. However, when I listened to the same ramp of pings with a significant amount of background noise, I heard the pings much earlier at approximately three or four seconds. This failure in my experimental design was beneficial in proving that a sound that is naturally below the threshold of human hearing can actually become audible in the presence of background noise.

This "discovery" ruined my original idea for testing frequency and amplitude response. It was then that Professor Errede suggested creating a "song" which would present each of the test frequencies at constant amplitude for an identical duration of time. This file could then be looped to allow the participant to adjust the volume of each frequency using a graphic equalizer.

That idea appealed to me and I produced a "song" composed of each of the frequencies integrated into the graphic equalizer of the wave-editing program. However, the result of adjusting the graphic equalizer to compensate for lesser or greater perceived volume of a particular frequency also resulted in a distortion of the frequencies other than the desire one. After much consideration, it was deemed that this error was the result of a poorly written subroutine in the wave editing software for the graphic equalizer. These setbacks resulted in nearly two months of lost work. Even so, I was able to find an adequate solution within the time limitations of the semester.

I discovered that the graphic equalizer found within the free .mp3 player, WinAmp, while not perfect, would suffice for my intentions. The distortions created by the WinAmp graphic equalizer only effected the other frequencies when the initial amplitude of the wave file was above –18 dB. As I had already decided to limit myself to a single initial amplitude, I wisely chose one less than –18 dB, specifically –24 dB. In addition, I was required to create wave files with a sampling of 96 kHz to avoid sampling errors that could occur at higher frequencies.

Experimental Procedure

For this experiment, the participant was instructed to listen to a looped wave file played through the WimAmp program. This wave file contained a series of pings, one at each frequency for each of the equalizer bars of the WinAmp graphic equalizer (60 Hz, 170 Hz, 310 Hz, 600 Hz, 1 kHz, 3 kHz, 6 kHz, 12 kHz, 14 kHz, and 16 kHz). Each ping was followed by a moment of silence. When the series reached the highest frequency, the series would reverse, progressing down the scale of tones, then repeat.

The participant was instructed to first decide which tone was perceived to be the loudest. The corresponding equalizer bar was then reduced to its lowest level. The task for the participant was then to adjust the remaining equalizer bars such that each frequency was perceived to be the same volume. The participant could each keep track of the frequency of the current ping by following the labels for the graphic equalizer with the mouse pointer as each ping passed. This process typically took less than five minutes.

Results

As can be seen from the data and corresponding graphs for this experiment, most participants found the midrange frequencies, specifically 1 kHz or 3 kHz, to be the loudest. This would correspond to the ear's increased sensitivity to these frequencies. Most participants also found the extreme high and extreme low frequencies to be difficult to hear. In most cases, the graphic equalizer did not allow them enough freedom to adjust the volume for those frequencies in order to match them to the volume of the other pitches.

The end result of this experiment found that most participants had very similar response curves to each other and, consequentially, to the class average. Some exceptions to this were quite interesting. One subject not only found the 60 Hz frequency difficult to hear, but also the 600 Hz frequency, despite the fact that he was able to readily hear the frequencies in-between (170 Hz and 310 Hz). This shows that it is possible to have good hearing, but have a localized deafness or decrease of response around a certain frequency. I found that I had an overall good response curve, however I have a very distinct and sharp drop-off in response right at four kHz. Ten hertz above or below that value and I can hear the pitch just fine, however it is nearly impossibly for me to hear any sound generated at a frequency of 3995 to 4010 Hz.

As most participants had very similar response curves, it is easier to believe that each participant can hear any given sound approximately the same. However, when applying a graphic equalizer corresponding to each participant's response curve, subtle differences can be heard when listening to the same sound, such as an orchestra.

Possibilities for Future Exploration

While I was overall pleased with the results of my experiment, it would be quite interesting to see this experiment taken to the next step. Namely, this experiment could be most interesting if it could indeed be applied to various volume levels in order to create a 3-D mapping of the frequency and amplitude response of the human ear.

In addition, I had once envisioned creating a response mapping for each ear. Studying the differences in these maps for a given individual would be very interesting, especially if there was a systematic degradation of response in one ear over the other.

These more detailed studies could be very interesting if applied to the hearing aid industry. It would be very fascinating to develop a hearing aid that not only systematically boosts the volume of sound entering the ear canal, but boosts extra the frequencies which an individual has a harder time hearing. A hearing aid could then be configured to match a response curve of the same individual when he or she was younger, thus restoring to some degree the very hearing he or she once enjoyed.

Additionally, much finer measurements would be useful for this experiment. WinAmp's graphic equalizer used inconsistent increments of approximately 1.6 dB. Finer and more consistent increments would increase the validity of this study.

The most disappointing aspect of using the WinAmp software for this experiment was the choice of values for the graphic equalizer. The spacing of these frequencies follows no discernible pattern and is tight at the high and low ends while widely spaced at the midrange. This choice of values seems illogical and highly disturbing from a data evaluation standpoint. The use of an equalizer with standard values would result in data more practical to possible applications.

Click-Tone Threshold Experiment

This experiment tests the brain's ability to perceive pitch from increasingly small durations of sensation. At some shortness of duration, any given frequency is no longer recognized as a pitch, but rather as a click sound. This study sought to find those limits.

Development

I was inspired to do this experiment after listening to a wave file found on the Internet in which a given pitch was repeated in successively shorter durations until at a point the tonality of the pitch was lost. At that point, each instance was perceived as a "click" sound of no definable pitch. My idea was to test the timescale in which this change in perception takes place.

Rather than having each participant listen to the same file I found on the Internet, I decided to create my own wave file. I preferred not to have each iteration become shorter as the participant's mind may trick them into believing that they could still discern a pitch even when it sounds like a click. To defeat that possibility, I sought to reverse the procedure. I created a wave file in which the sound was absurdly short in duration (approximately 0.001 seconds), guaranteeing that the sound would be perceived as a click. Then I made each succession slightly longer than the previous instance. Then, by making note of how many evenly spaced clicks passed before the participant could discern a pitch, I was able to translate that into the duration of the sound at that point.

In the end, I created six files for each of the following frequencies: 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, and 4 kHz. Each instance of sound in a given file was 0.002 seconds longer in duration than the previous one. Thus by counting the number of instances before a pitch could be detected, I was able to calculate the duration of that instance.

This method proved to be reliable and required little alteration from its original design.

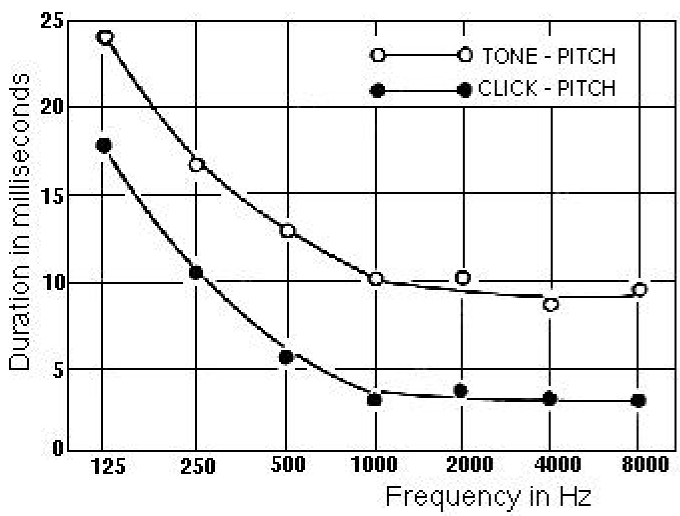
Experimental Procedure

Each participant was first primed by listening to a file containing each of the possible pitches to come as a gentle ping. These pitches were then grouped as "high," "medium," and "low." Once primed, the participant was instructed to listen to each file. As the file was being played, as soon as the participant could recognize the pitch as one of the groupings described earlier, he or she was to immediately indicate it as such. The issue here was not to test pitch recognition, but rather to ensure the participant was actually detecting a pitch and not merely "blindly" indicating ability to detect any pitch.

This procedure was repeated for each of the six files. The total duration for this experiment for each participant was approximately two minutes.

Results

The results of this experiment were highly correlated with the results of previous studies. This graph, from the results of such studies as found in the Handbook for Acoustic Ecology (1999) is very similar to the graph of each participant's click threshold from my experiment. There were two cases (Pioia and Gary) in which there seemed to be no correlation between frequency and click threshold. Aside from these instances, all of the results closely paralleled this graph. Most of the participants found around 22 ms for the 125 Hz frequency. In addition, the durations required to discern pitch from the one kHz, two kHz, and four kHz were nearly identical, each averaging 10 ms, which is very consistent with the previously recorded data.



In the end, I found this experiment to be a simply yet effective one in testing the click threshold of human hearing and I was very pleased that the data from the participants in this study paralleled previous studies very well.

Possibilities for Future Exploration

This experiment would have benefited greatly from repeated trials. Due to time constraints, especially at the end of the semester, each participant typically completed only one trial of each frequency. Several trials averaged together for each participant would have been useful. Additionally, the pool of subjects for this experiment was extremely small (eleven). A larger subject pool would likely increase the reliability of this study.

If this study were carried on in the future, it would be interesting to explore the a much more fine timescale. Whereas each of the increments in this experiment were 2 ms, perhaps 1 or 0.5 ms would yield data that are more precise.

Along the same lines of this experiment might be an interesting study in finding how close together successive clicks need to be before it sounds like a continuous sound. Even more interesting might be exploring the possibility that if these clicks were close enough, they might be perceived as a pitch, even though each individual click is too short to be perceived as such.

Sound Localization Experiment

The last experiment works with the ability of the brain to take two slightly different stimuli from each the left and the right ear, and analyze those differences to determine the direction from which the sound came. The first half of this experiment tested the participants' ability to localize a stationary sound source, which the second half added in the additional auditory cue of motion.

Development

With only two weeks left in the semester, I sought to use my time by developing another experiment. However, because of the lack of time in which to execute this experiment, it proved to be only somewhat insightful.

I wanted to study how the human brain can detect a phase difference between signals received from the left and the right ears, and assign a direction to the source of that signal. Creating the wave files was fairly easy using the wave editing software I had been using all semester. I first created a single click with a phase difference of 40 ms, right leading left. Then I created more clicks, each with the left gaining the right channel by 5 ms until the left led the right channel by 40 ms. The use of short clicks, however, made it very difficult for participants to localize the direction the source might be coming from. I tried to correct this by simply tripling the number of clicks at each phase position. This did increase the ability for participants to localize the sound.

I then broke each of the sets of clicks into separate wave files, one for each phase position. The idea behind this was to test each subject randomly with each phase position. Without the auditory cue of a sense of motion, this experiment would be testing more specifically the brain's ability to detect and make sense of phase information alone in localizing a sound.

Here, again, I found the clicks to be insufficient in determining direction. Therefore, I created a file for each phase position using a one-half second sustained pitch. This greatly increased the ability of participants to determine the direction of the sound.

Experimental Procedure

I first started with the file that involved a gradual shift from 40 ms to –40 ms of left leading right channels. Each participant would listen to the file once through to become used to the conditions. Then, the second time the participant listened to the file, he or she was to indicate when the sound seemed to begin moving from the right to the left, be at about a 45 degree angle to the right, be about straight ahead, be at about a 45 degree angle to the left, and finally completely to the left.

For the second part, the participant was asked to listen to each of the eighteen randomly ordered files corresponding to a particular phase. The participant was then asked to first state if the sound seemed to be coming from the left or the right and then identify a particular angle from which it was coming. The participant was given a paper with degree markings on it for reference.

Results

The results from the phase of a moving source experiment were very good. All participants were able to detect the apparent motion of the sound source, and to a fairly high degree of accuracy. The results from the stationary source experiment were quite disturbing, however. I found a 0.0053 correlation between the phase information for each file, and the participant's perception of if it came from the left or the right. The explanation of this is not entirely clear.

One part that might have contributed to such terrible results is the range of phase separation I used. Based on a slightly incorrect equation I received from a previous work, I used a phase of 40 to –40 ms for each the stationary and motion files. However, the proper equation to calculate interaural time difference, Δt, is

$$\Delta t = \frac{3a}{c}\sin q$$

where a is the radius of the head (approximately 8.75 cm) and c is the speed of sound (34,400 cm/s) (Physics Today, Nov. 1999). With this in mind, Δt should have ranged from 7.63 ms to –7.63 ms, rather than the 40 to –40 ms range I used in creating this file. Unfortunately, by time I detected this error, it was far too late in the semester to consider recreating the wave files I would need and retest all of the participants.

Possibilities for Future Exploration

Indeed, it would be worthwhile for this experimented to be repeated in the future with a range of phasings from –8 to +8 ms, perhaps using increments as small as 0.01 ms. In the future, it would be interesting to see the limit to which human hearing can differentiate between two increasingly close sound sources. Discovering how small a variance of Δt that the ear can detect would answer that question. It would be especially beneficial to study sound localization when tested without the assistance of the motion cue.

It would also be quite interesting to explore all of the means by which the human ears can discern direction. If understood well enough, and equipped with the proper software, one very enticing application for this study would be in introducing the proper phase information into any given sound or channels of sound so that sound localization could take place anytime someone listened to a song while using headphones. I would be most interested in studying the cues by which azimuthal angle can be discerned. With this information, midi composers could create a virtual orchestra in which a song could be written where a certain instrument is located beside the listener, another above, below, and behind, or possibly in motion all around the listener.

Resources

I found the following websites to be of extreme value:

http://gyronymo.free.fr/audio3D/the_experimenter_corner.html
http://www.ie.ncsu.edu/kay/msf/sound.htm
http://ear.berkeley.edu/auditory_lab/
http://www.sfu.ca/sonic-studio/index.html
http://www.usd.edu/psyc301/localize.htm

Most interesting was the Berkeley sight in which the sound localization, as well as other experiments, could actually be carried out on-line.

Also incredibly useful was the article handed out in class, "How We Localize Sound" from Physics Today on the Web, November 1999.

Moreover, my utmost thanks go to Professor Steve Errede and Dan Finkenstadt for their continuous input, ideas, and inspirations.

Experimental Data

Frequency Response Experiment

Top half of table is in units of decibels. Bottom half is in units of inverse decibels.

Fre-quency (Hz)	Dan	Steve	Bill	Joe	Pioia	Tim	Chris	Jared	Gary	Angie	Average
60	-4.0	-4.0	-4.0	-4.0	-7.9	-4.0	-5.9	-4.0	-4.0	-4.0	-4.6
170	-4.0	-19.2	-18.6	-9.7	-21.8	-24.0	-14.8	-11.0	-9.7	-4.0	-13.7
310	-4.0	-24.0	-24.0	-21.1	-21.1	-24.0	-19.2	-18.6	-12.3	-12.9	-18.1
600	-4.0	-33.2	-24.0	-26.9	-19.2	-19.2	-12.3	-21.1	-4.0	-18.6	-18.3
1000	-44.0	-44.0	-25.6	-44.0	-44.0	-40.2	-44.0	-33.2	-33.2	-31.9	-38.4
3000	-4.0	-42.1	-43.4	-38.3	-42.7	-44.0	-40.2	-33.2	-44.0	-44.0	-37.6
6000	-4.0	-32.6	-43.4	-31.3	-39.6	-37.0	-26.9	-42.1	-4.0	-26.9	-28.8
12000	-4.0	-4.0	-15.4	-24.1	-35.7	-37.0	-12.3	-44.0	-4.0	-19.9	-20.0
14000	-4.0	-4.0	-4.0	-8.4	-22.4	-4.6	-9.7	-4.0	-4.0	-4.0	-6.9
16000	-4.0	-4.0	-4.0	-5.3	-4.0	-4.0	-4.0	-4.0	-4.0	-4.0	-4.1
60	-0.2500	-0.2500	-0.2500	-0.2500	-0.1266	-0.2500	-0.1695	-0.2500	-0.2500	-0.2500	-0.2183
170	-0.2500	-0.0521	-0.0538	-0.1031	-0.0459	-0.0417	-0.0676	-0.0909	-0.1031	-0.2500	-0.0731
310	-0.2500	-0.0417	-0.0417	-0.0474	-0.0474	-0.0417	-0.0521	-0.0538	-0.0813	-0.0775	-0.0552
600	-0.2500	-0.0301	-0.0417	-0.0372	-0.0521	-0.0521	-0.0813	-0.0474	-0.2500	-0.0538	-0.0548
1000	-0.0227	-0.0227	-0.0391	-0.0227	-0.0227	-0.0249	-0.0227	-0.0301	-0.0301	-0.0313	-0.0260
3000	-0.2500	-0.0238	-0.0230	-0.0261	-0.0234	-0.0227	-0.0249	-0.0301	-0.0227	-0.0227	-0.0266
6000	-0.2500	-0.0307	-0.0230	-0.0319	-0.0253	-0.0270	-0.0372	-0.0238	-0.2500	-0.0372	-0.0347
12000	-0.2500	-0.2500	-0.0649	-0.0415	-0.0280	-0.0270	-0.0813	-0.0227	-0.2500	-0.0503	-0.0499
14000	-0.2500	-0.2500	-0.2500	-0.1190	-0.0446	-0.2174	-0.1031	-0.2500	-0.2500	-0.2500	-0.1447
16000	-0.2500	-0.2500	-0.2500	-0.1887	-0.2500	-0.2500	-0.2500	-0.2500	-0.2500	-0.2500	-0.2421

Click-Tone Threshold Experiment

All values in units of seconds unless otherwise noted

File	Frequency	Dan	Steve	Bill	Joe	Pioia	Tim	Chris	Jared	Quinn	Gary	Angie	Aver-age	Theo-retical
B	125 Hz	0.032	0.038	0.014	0.020	0.004	0.024	0.030	0.016	0.034	0.010	0.020	0.022	0.024
E	250 Hz	0.016	0.014	0.010	0.012	0.006	0.020	0.018	0.020	0.020	0.008	0.022	0.015	0.016
D	500 Hz	0.014	0.014	0.014	0.018	0.012	0.020	0.018	0.018	0.018	0.018	0.014	0.016	0.013
F	1000 Hz	0.006	0.010	0.004	0.010	0.006	0.012	0.014	0.008	0.014	0.012	0.012	0.010	0.010
C	2000 Hz	0.012	0.012	0.010	0.012	0.004	0.014	0.014	0.010	0.012	0.008	0.006	0.010	0.009
A	4000 Hz	0.006	0.012	0.010	0.010	0.004	0.012	0.014	0.010	0.010	0.010	0.010	0.010	0.009

Moving Source Sound Localization Experiment

All values in units of seconds of left-channel leading right-channel phase unless otherwise noted

	Dan	Steve	Bill	Joe	Pioia	Tim	Chris	Jared	Quinn	Gary	Angie	Average	Theoretical
90º	-0.0325	-0.0275	-0.0375	-0.0300	-0.0375	-0.0150	-0.0325	-0.0175	-0.0225	-0.0125	-0.0125	-0.0252	-0.0010
45º	-0.0150	-0.0125	-0.0300	-0.0200	-0.0200	-0.0075	-0.0250	-0.0050	-0.0100	-0.0025	-0.0075	-0.0141	-0.0005
0º	0.0025	0.0000	-0.0125	-0.0025	-0.0025	-0.0025	-0.0125	-0.0025	0.0000	0.0025	0.0025	-0.0025	0.0000
-45º	0.0075	0.0100	0.0025	0.0125	0.0050	0.0075	0.0000	0.0000	0.0050	0.0050	0.0075	0.0057	0.0005
-90º	0.0200	0.0250	0.0125	0.0275	0.0175	0.0150	0.0050	0.0025	0.0100	0.0100	0.0125	0.0143	0.0010

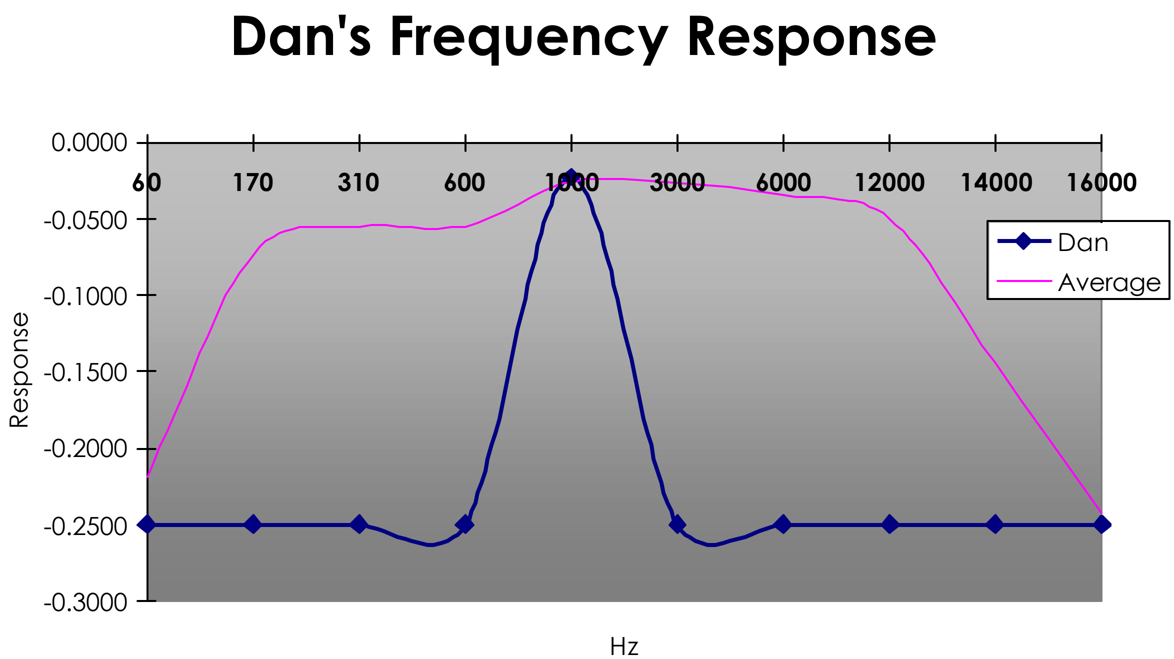
Stationary Source Sound Localization Experiment

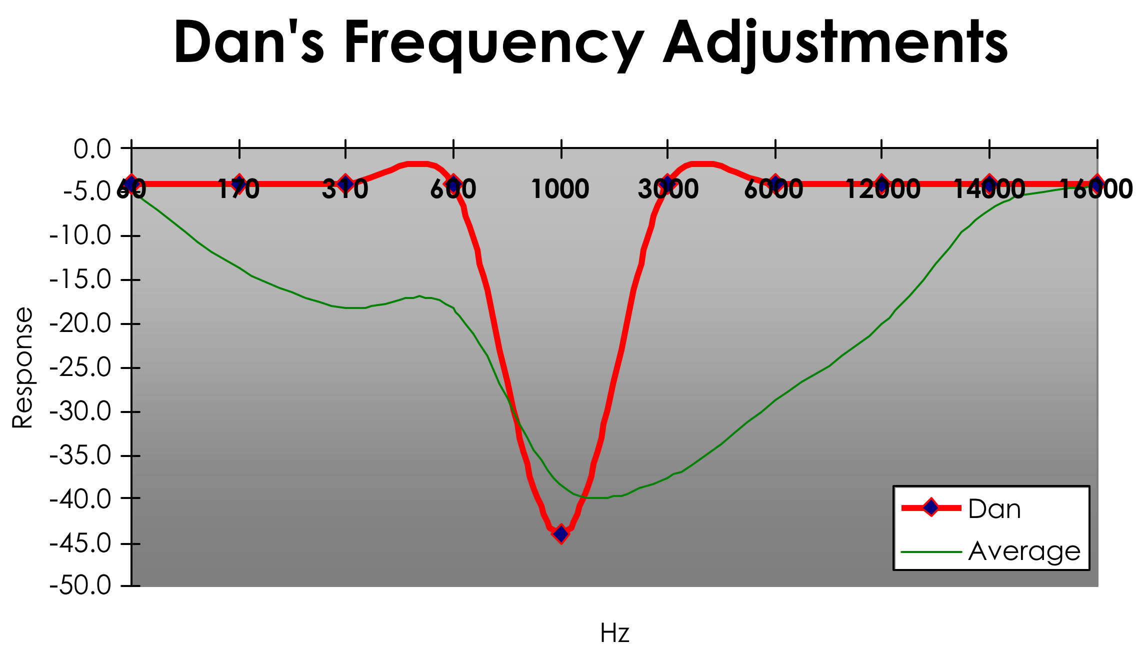
+1 for positive correlation in distinguishing left from right sound source.
0 if subject responded with "center" or actual location was centered and response was other than center.
-1 for negative correlation in distinguishing left from right sound source.

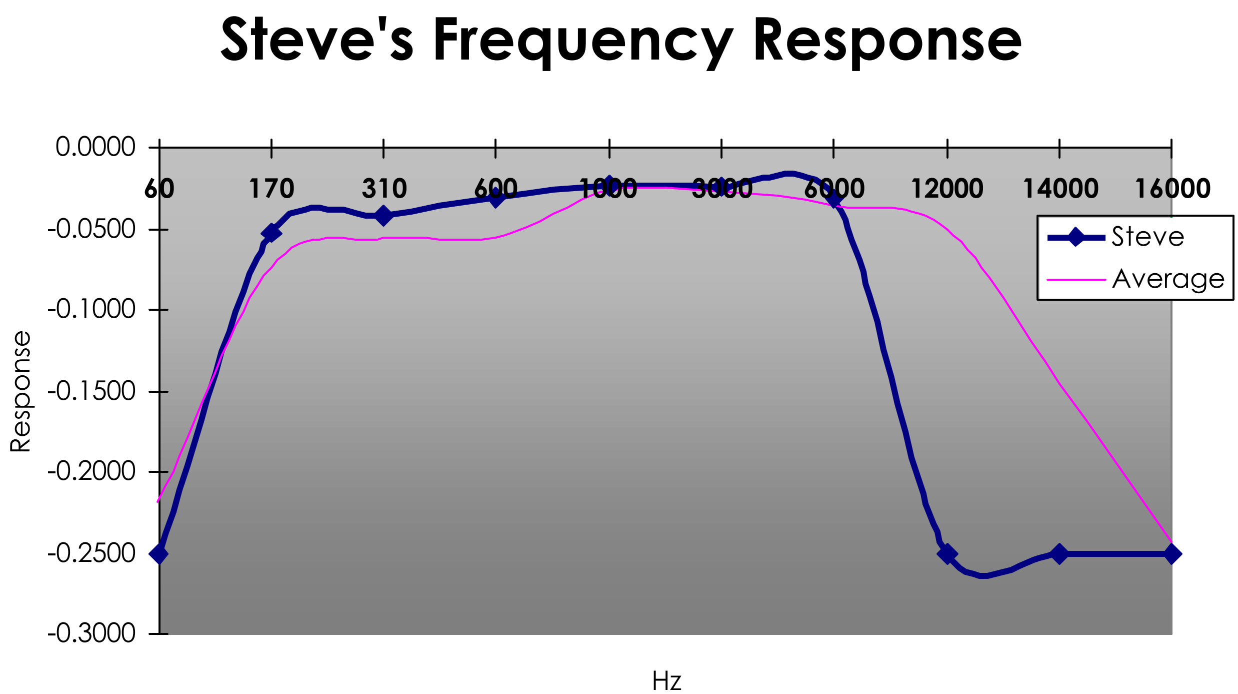
File	Seconds Leading	Dan	Steve	Bill	Joe	Pioia	Tim	Chris	Jared	Quinn	Gary	Angie	Average	Theo-retical
A	-0.0040	-1	-1	0	1	0	1	-1	0	0	0	1	0.00	1
I	-0.0035	-1	1	-1	0	-1	-1	-1	-1	-1	-1	-1	-0.73	1
G	-0.0030	1	0	-1	1	1	1	1	1	1	1	-1	0.55	1
E	-0.0025	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1.00	1
M	-0.0020	-1	1	-1	-1	-1	1	-1	-1	-1	-1	-1	-0.64	1
N	-0.0015	1	-1	1	1	1	1	1	1	1	1	1	0.82	1
B	-0.0010	-1	1	-1	0	-1	-1	-1	-1	-1	-1	-1	-0.73	1
C	-0.0005	1	-1	1	1	1	1	-1	1	1	1	-1	0.45	1
J	0.0000	0	0	0	0	0	1	0	1	0	0	0	0.18	1
O	0.0005	1	-1	1	1	1	1	1	1	1	1	1	0.82	1
K	0.0010	-1	-1	-1	-1	-1	-1	0	-1	-1	0	1	-0.64	1
H	0.0015	1	1	0	1	0	0	0	1	1	1	1	0.64	1
Q	0.0020	-1	-1	1	1	1	0	1	0	1	1	1	0.45	1
L	0.0025	1	1	-1	-1	-1	-1	-1	-1	0	0	1	-0.27	1
F	0.0030	1	1	1	1	1	1	1	1	1	1	-1	0.82	1
D	0.0035	1	-1	-1	-1	0	-1	0	-1	-1	-1	-1	-0.64	1
P	0.0040	1	0	-1	1	-1	1	0	1	-1	0	-1	0.00	1
Correlation		**0.1176**	**-0.1176**	**-0.2353**	**0.2353**	**-0.0588**	**0.1765**	**-0.1176**	**0.0588**	**0.0000**	**0.1176**	**-0.1176**	**0.0053**	**1.0000**

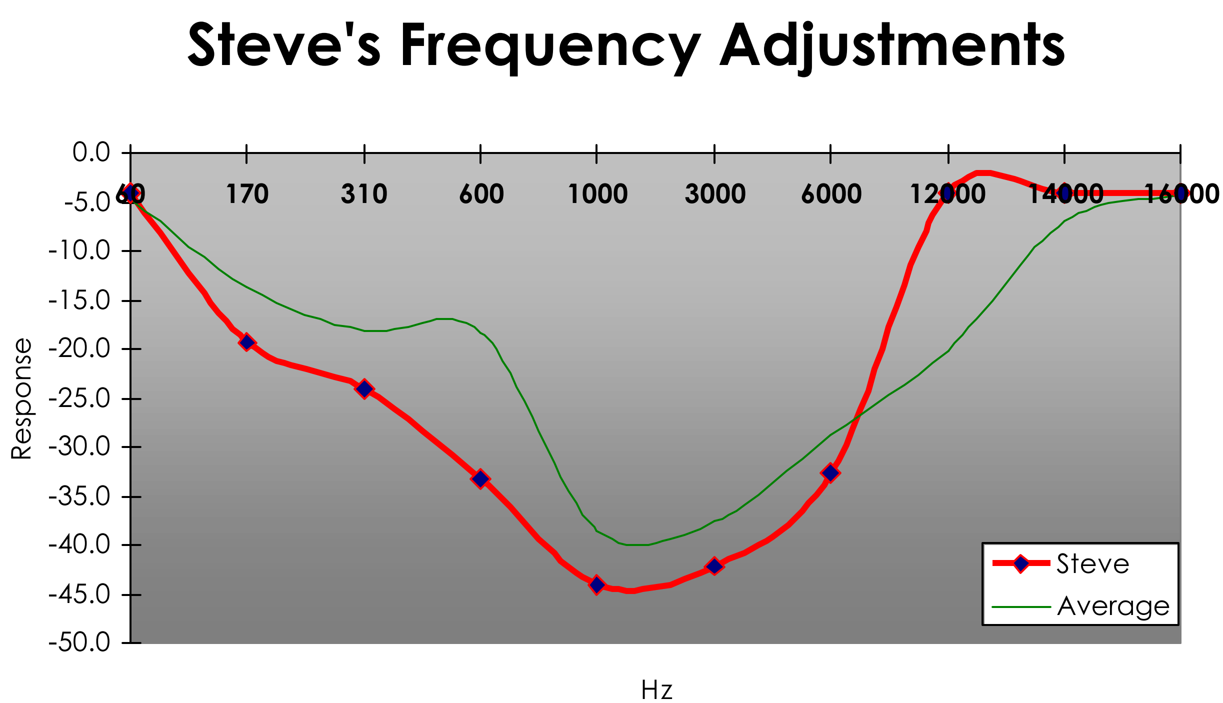
Data Plots

Frequency Response Experiment

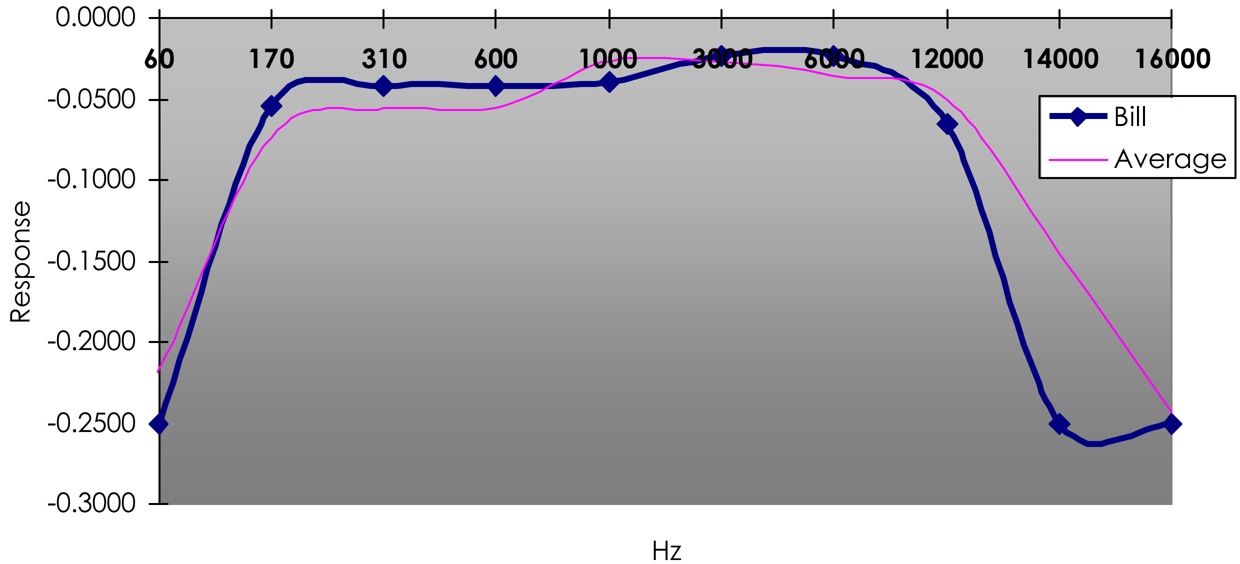




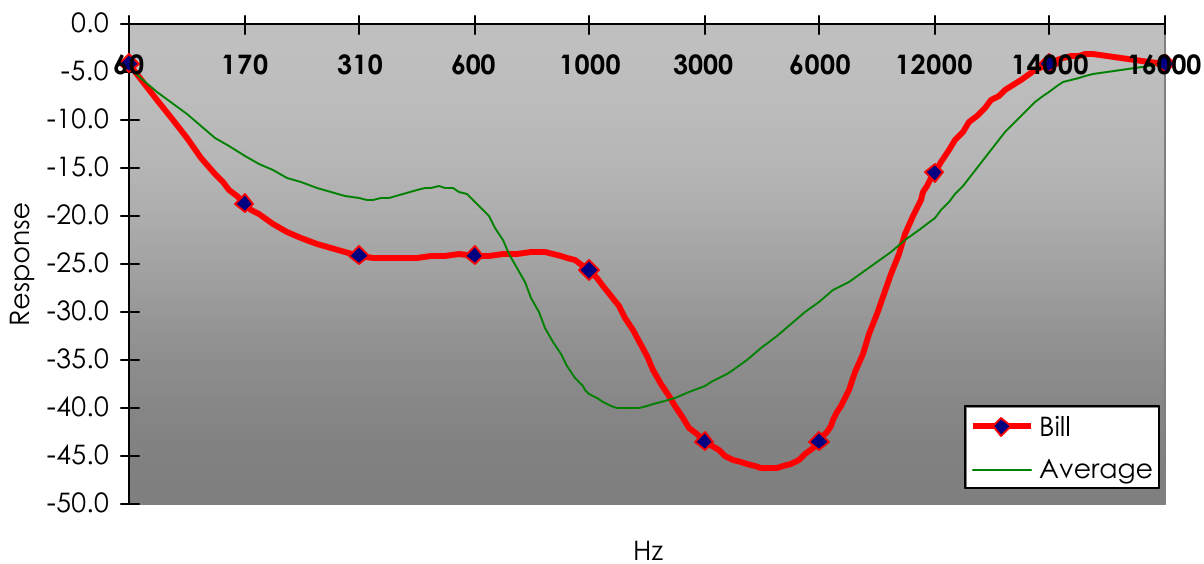

Steve's Frequency Response
0.0000
-0.0500
-0.1000
-0.1500
-0.2000
-0.2500
-0.3000
Response
60
170
310
600
1000
3000
6000
12000
14000
16000
Hz
Steve
Average


Steve's Frequency Adjustments
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
Response
60
170
310
600
1000
3000
6000
12000
14000
16000
Hz
Steve
Average

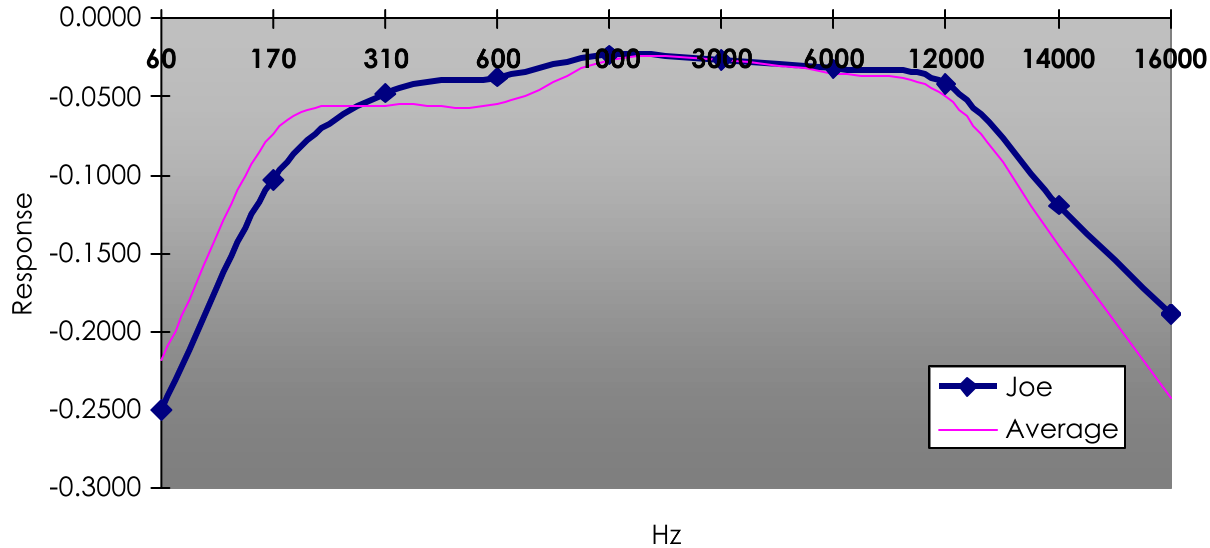
Bill's Frequency Response



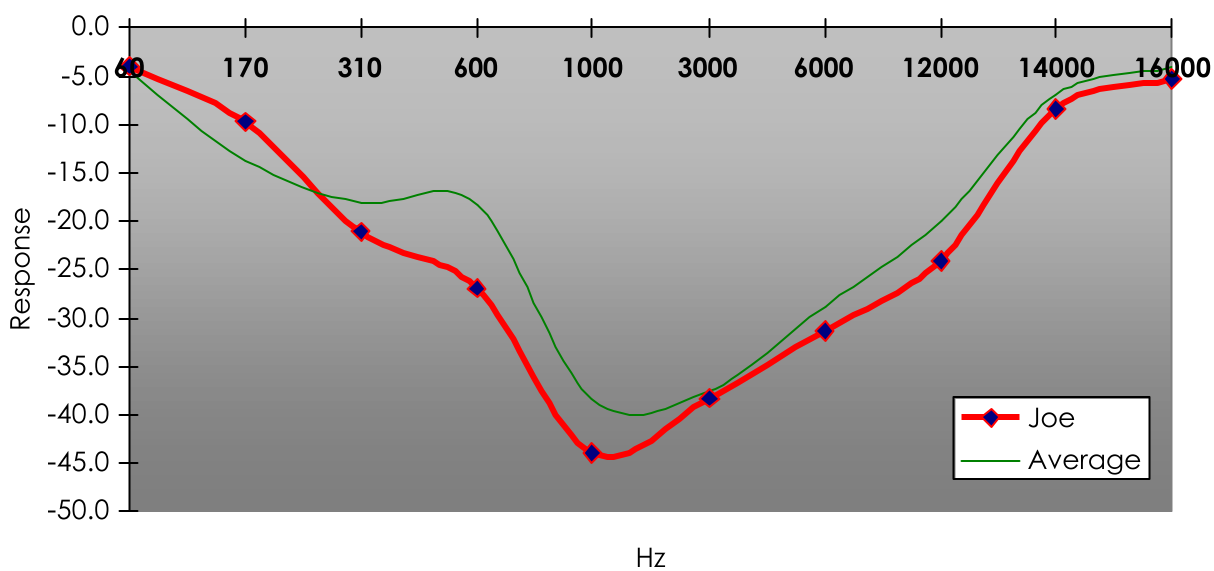
Bill's Frequency Adjustments



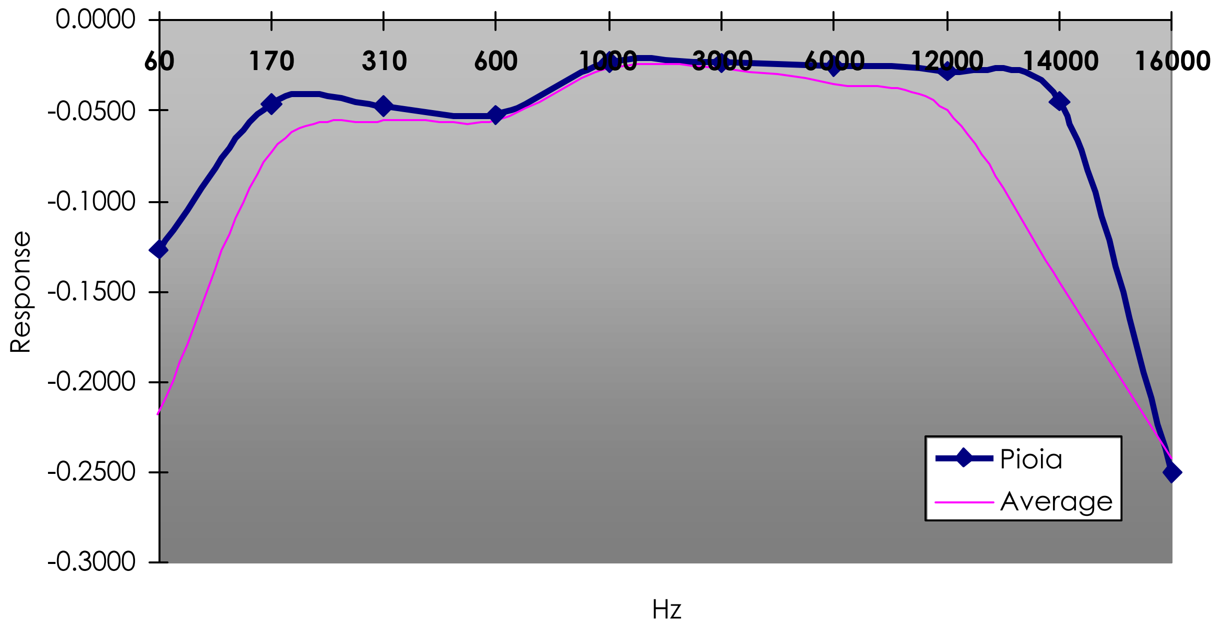
Joe's Frequency Response



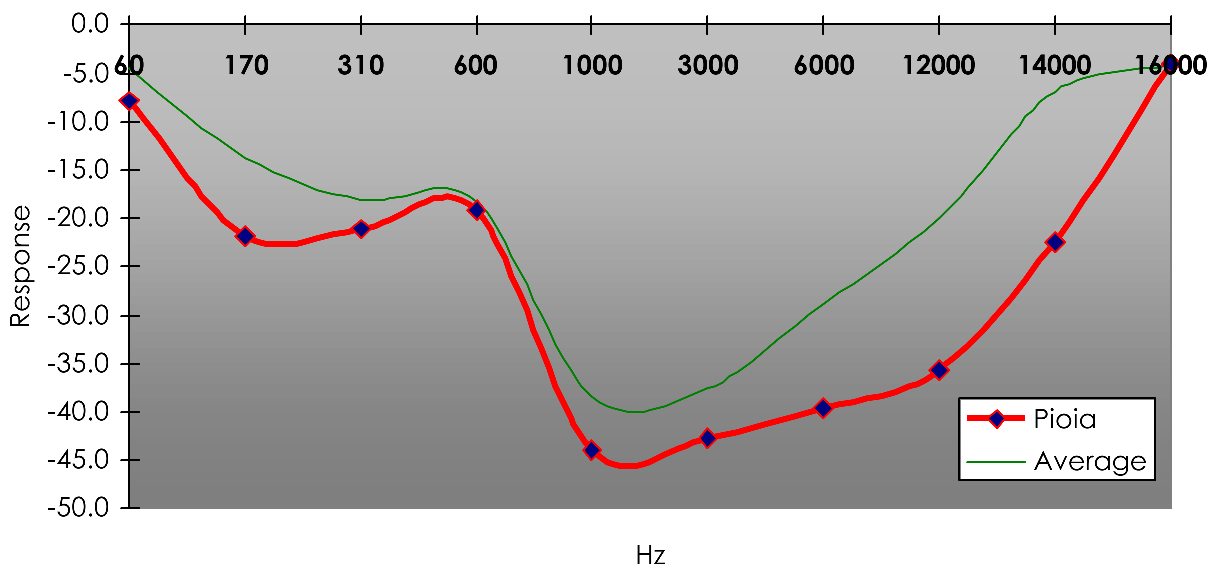
Joe's Frequency Adjustments

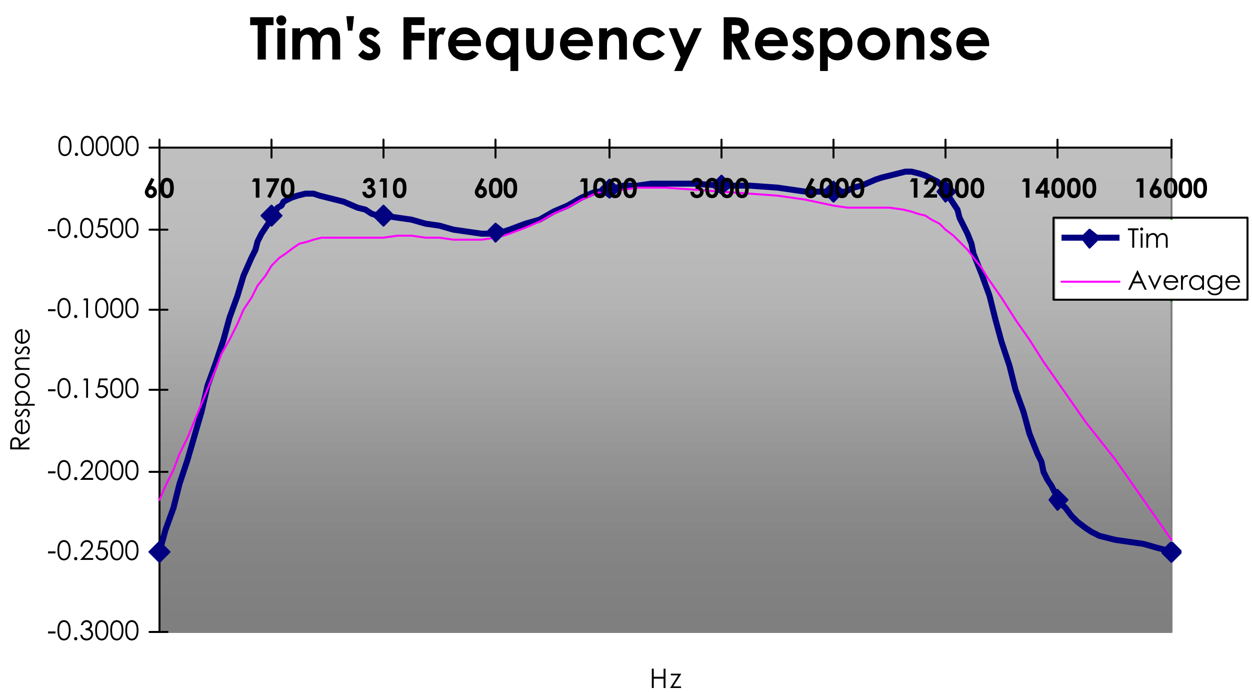


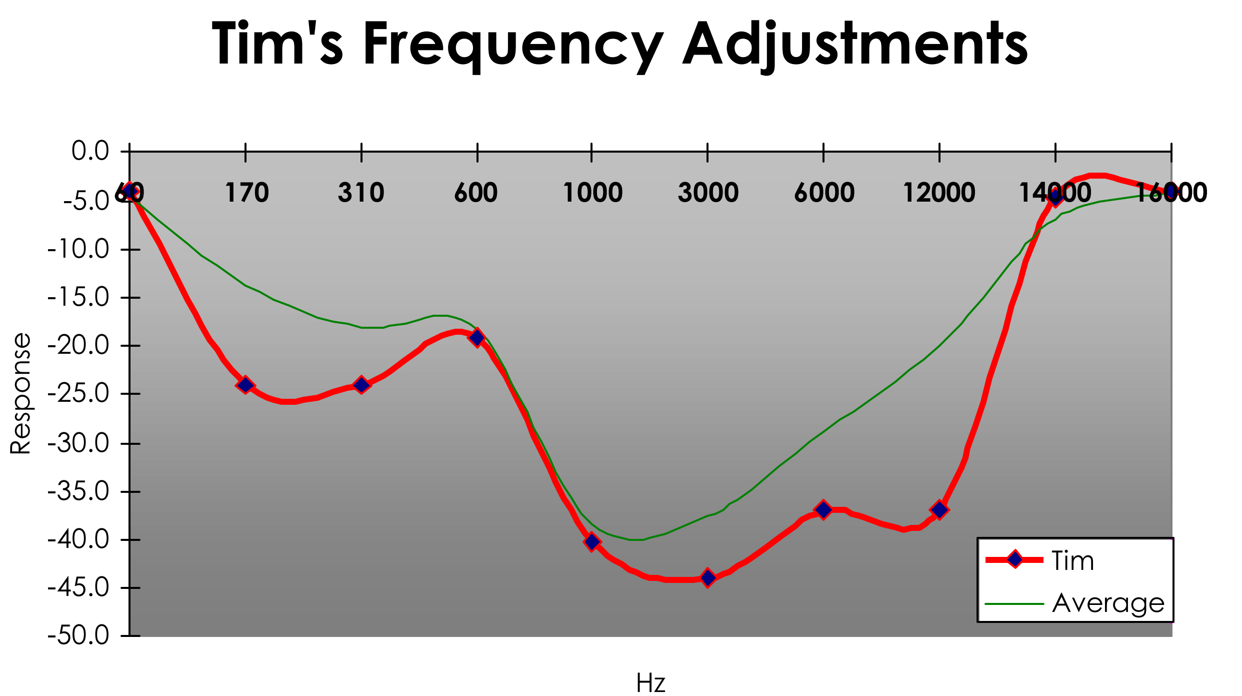
Pioia's Frequency Response

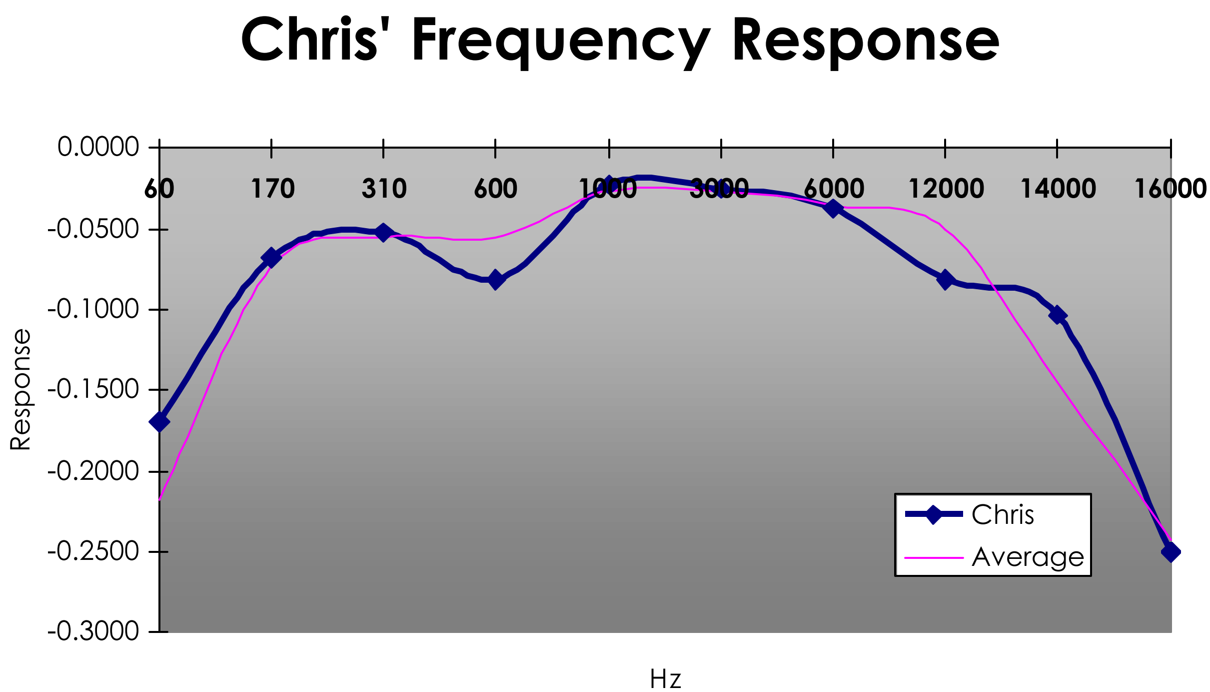


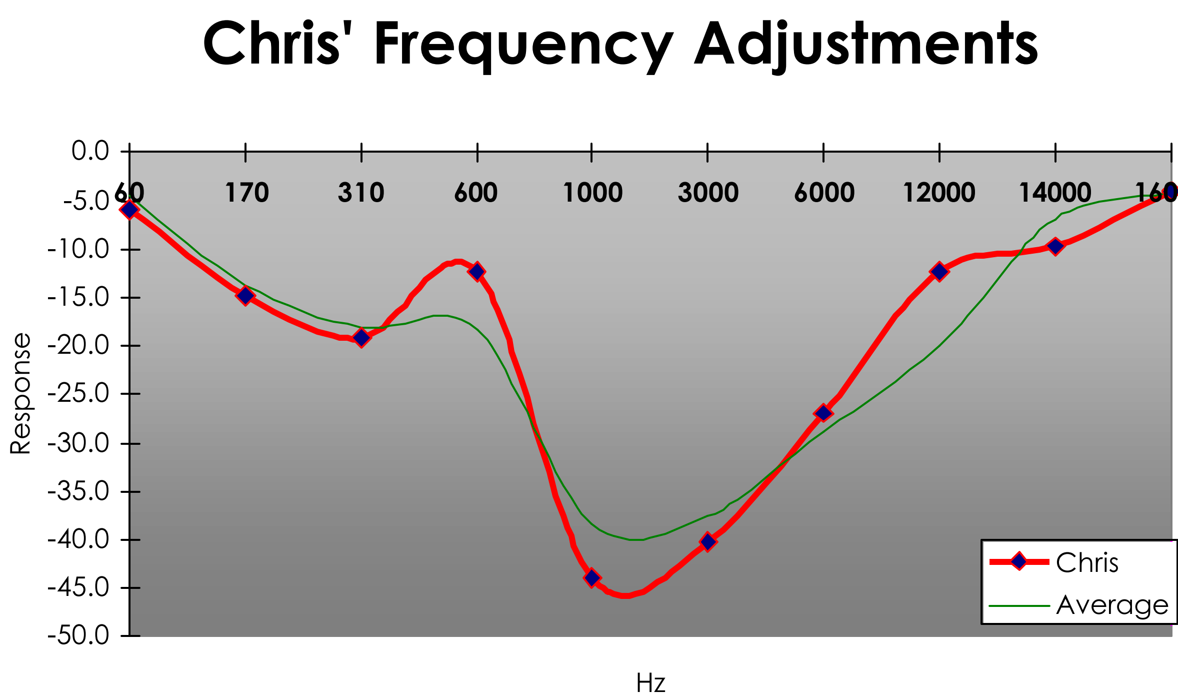
Pioia's Frequency Adjustments



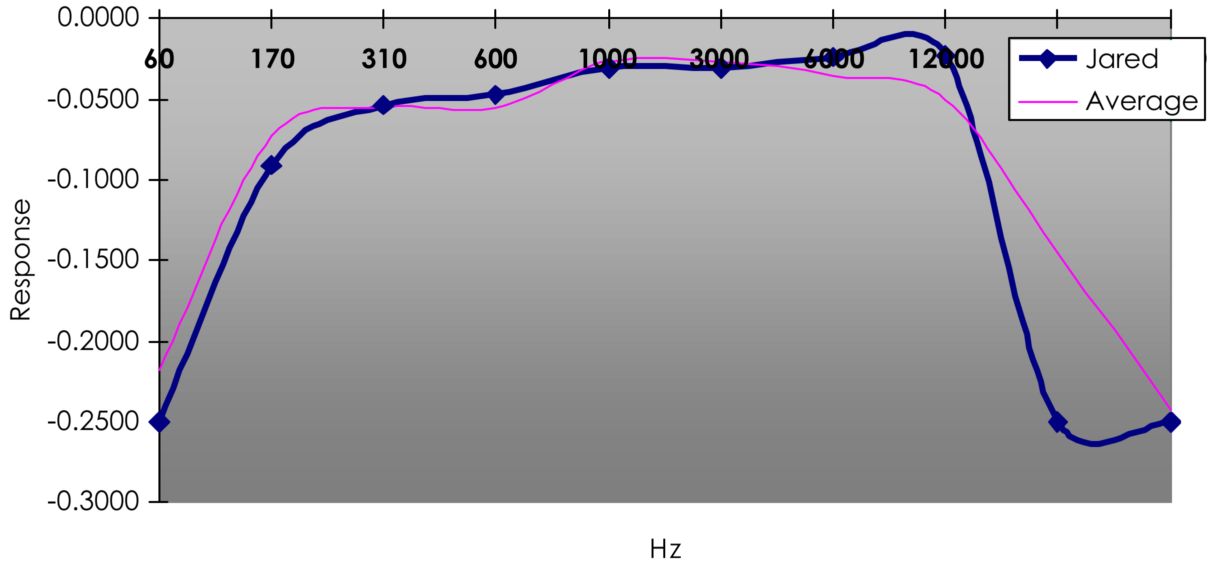

Tim's Frequency Response
0.0000
-0.0500
-0.1000
-0.1500
-0.2000
-0.2500
-0.3000
Response
60
170
310
600
1000
3000
6000
12000
14000
16000
Hz
Tim
Average


Tim's Frequency Adjustments
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
Response
60
170
310
600
1000
3000
6000
12000
14000
16000
Hz
Tim
Average

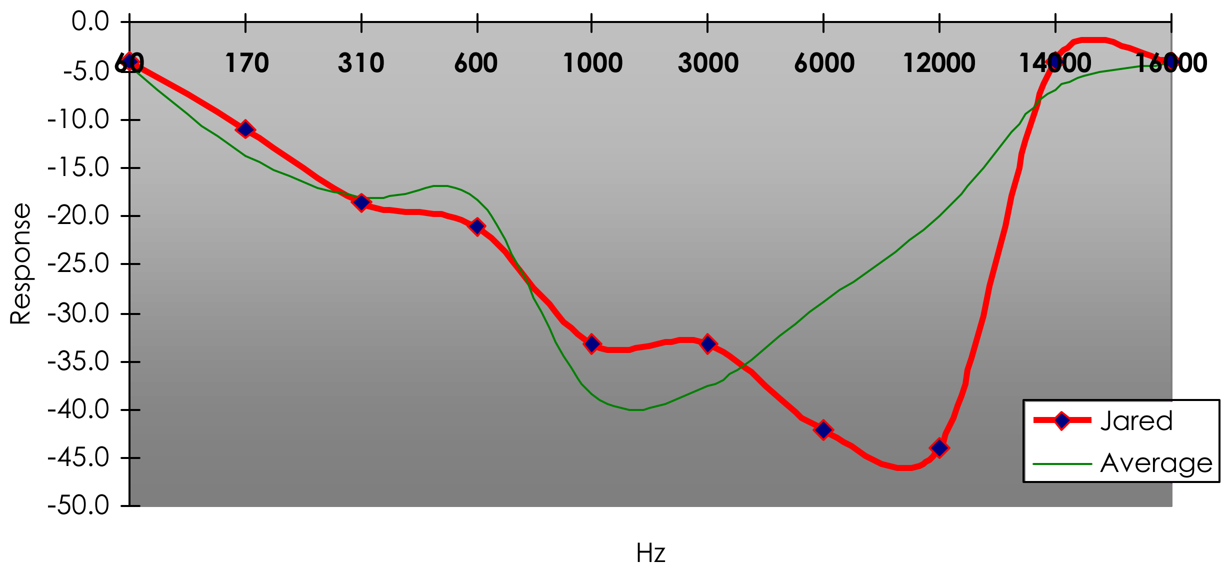

Chris' Frequency Response
0.0000
-0.0500
-0.1000
-0.1500
-0.2000
-0.2500
-0.3000
60
170
310
600
1000
3000
6000
12000
14000
16000
Response
Hz
Chris
Average


Chris' Frequency Adjustments
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
60
170
310
600
1000
3000
6000
12000
14000
16000
Response
Hz
Chris
Average

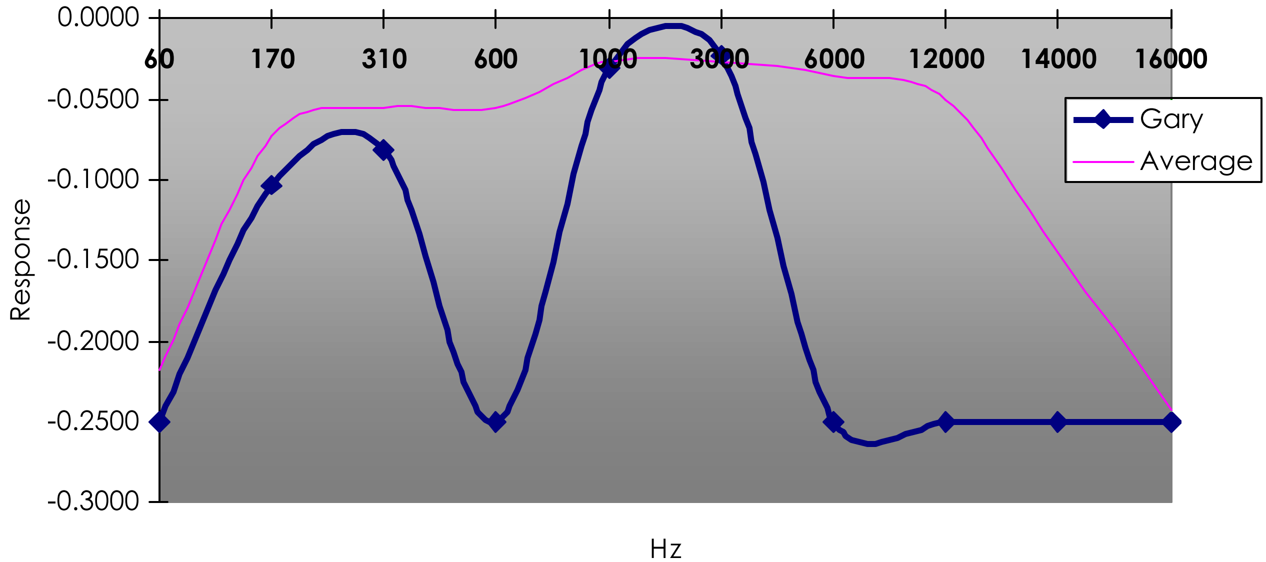
Jared's Frequency Response



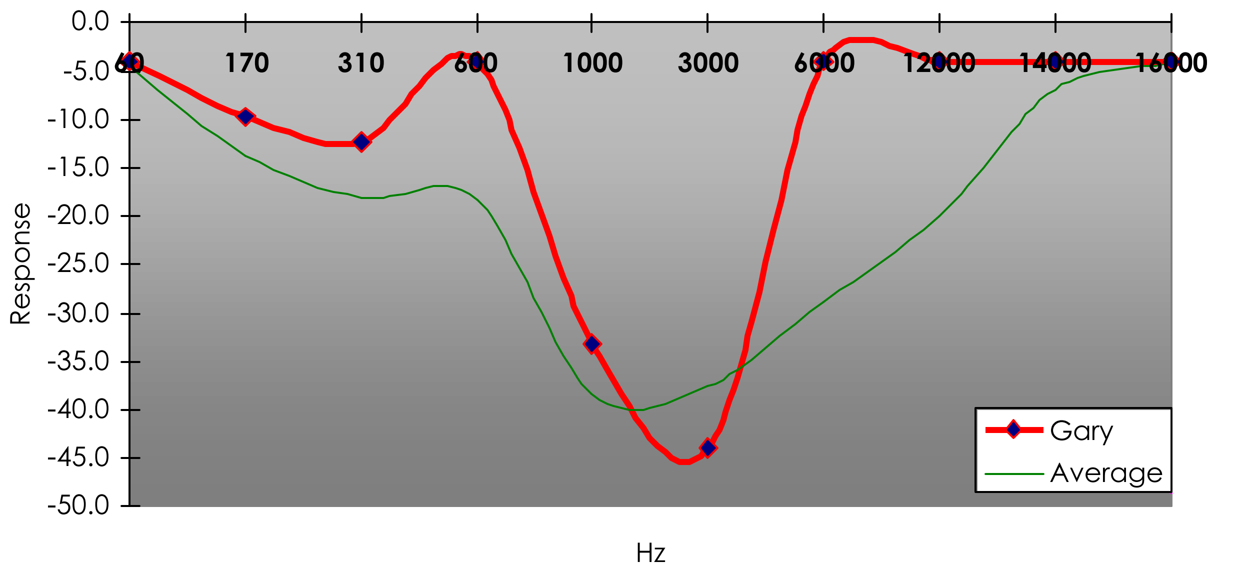
Jared's Frequency Adjustments



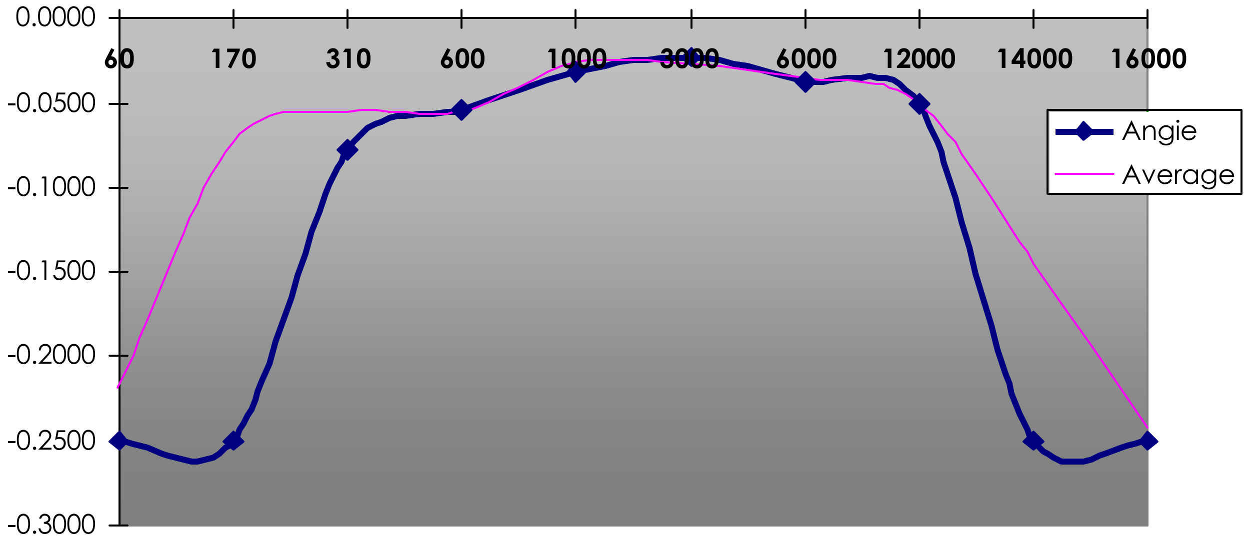
Gary's Frequency Response



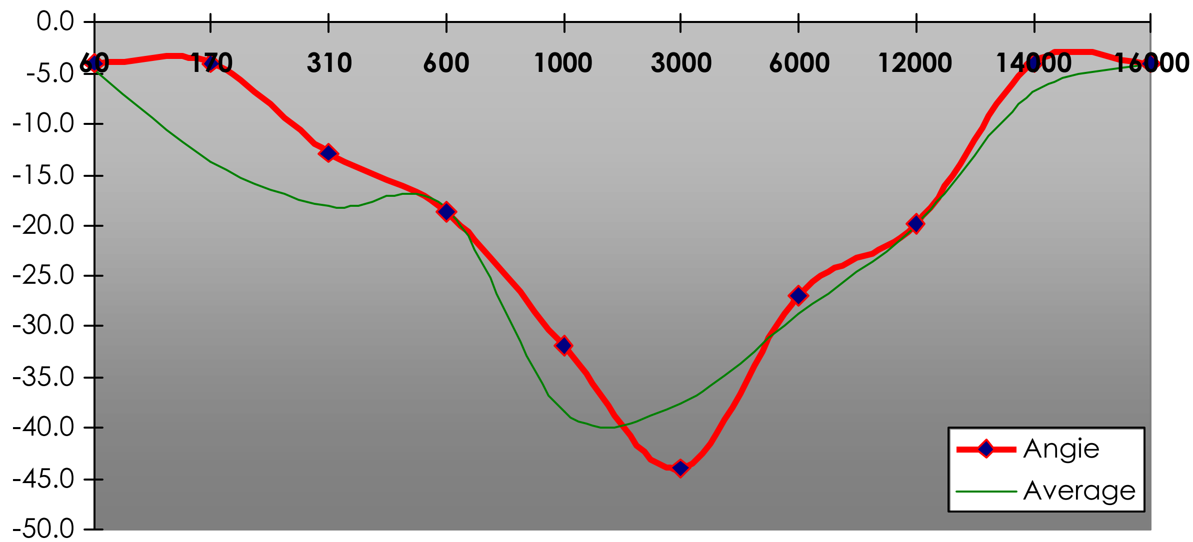
Gary's Frequency Adjustments

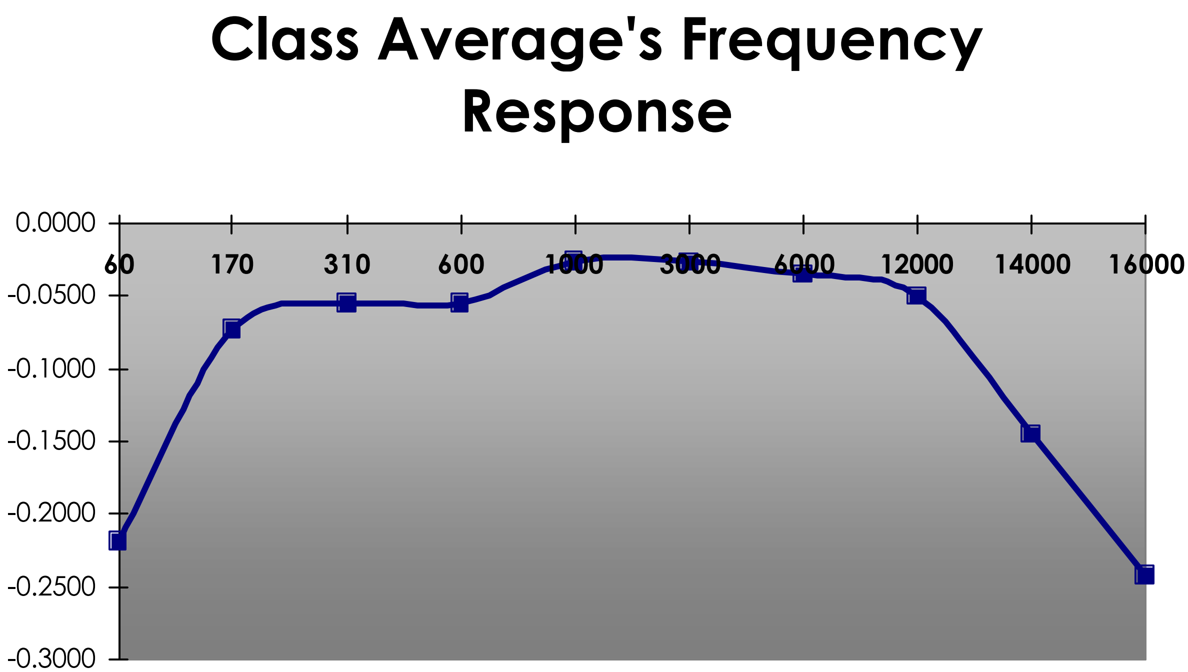


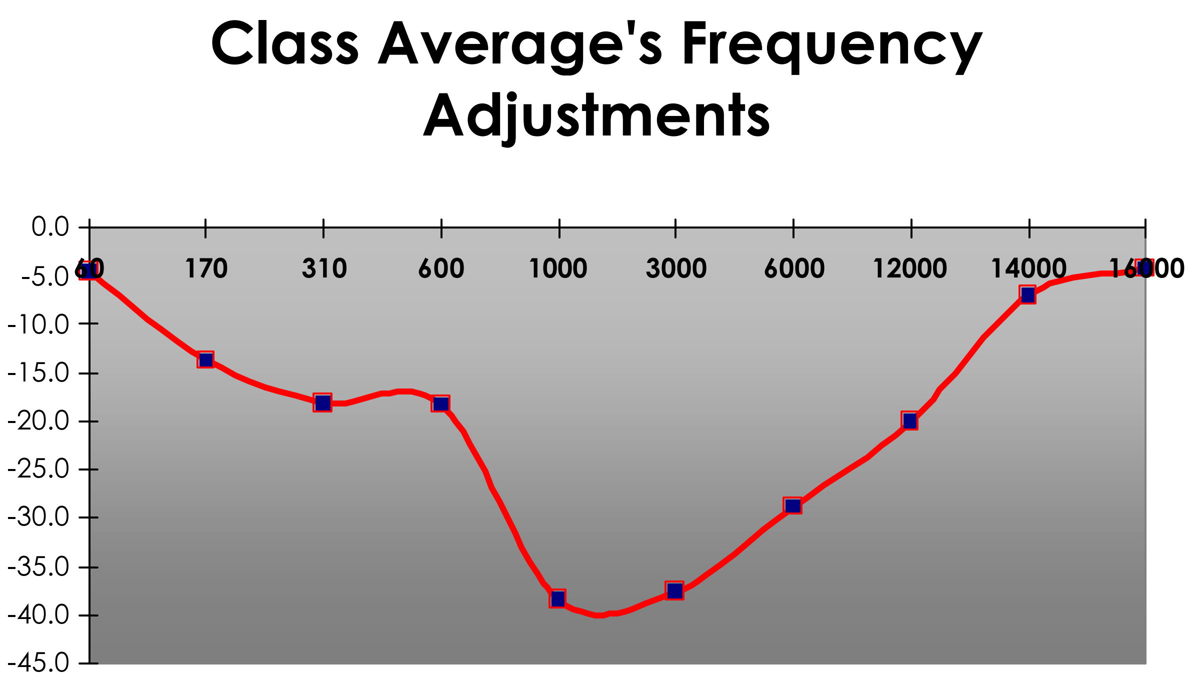
Angie's Frequency Response



Angie's Frequency Adjustments

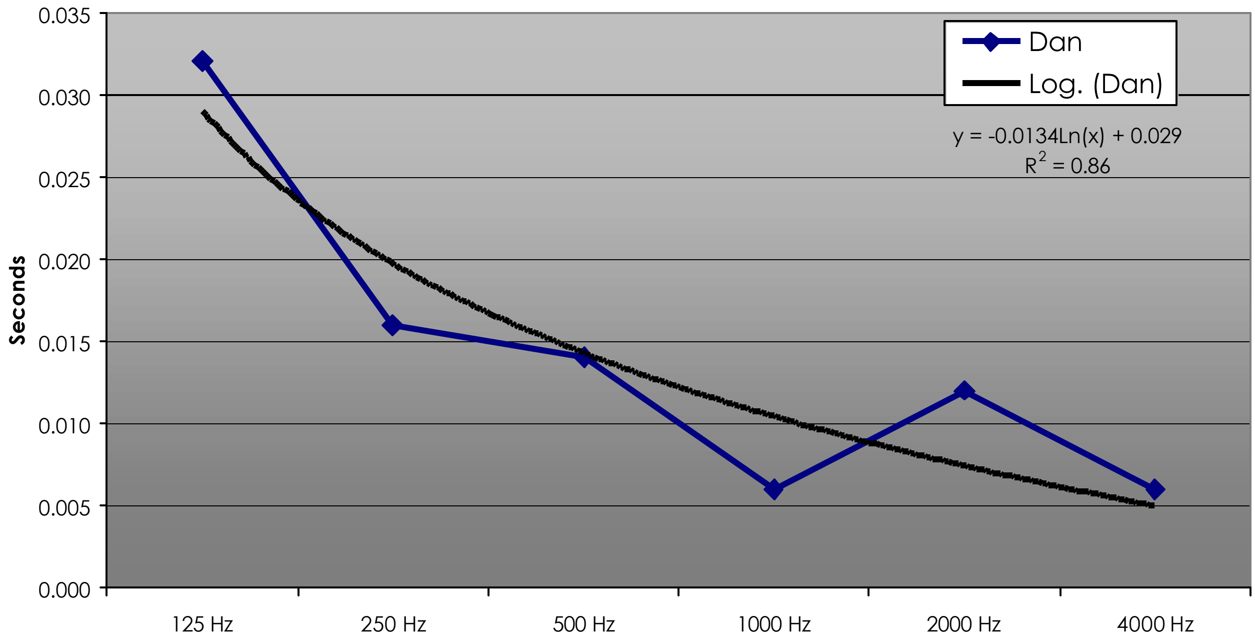



Class Average's Frequency Response
0.0000
-0.0500
-0.1000
-0.1500
-0.2000
-0.2500
-0.3000
60
170
310
600
1000
3000
6000
12000
14000
16000

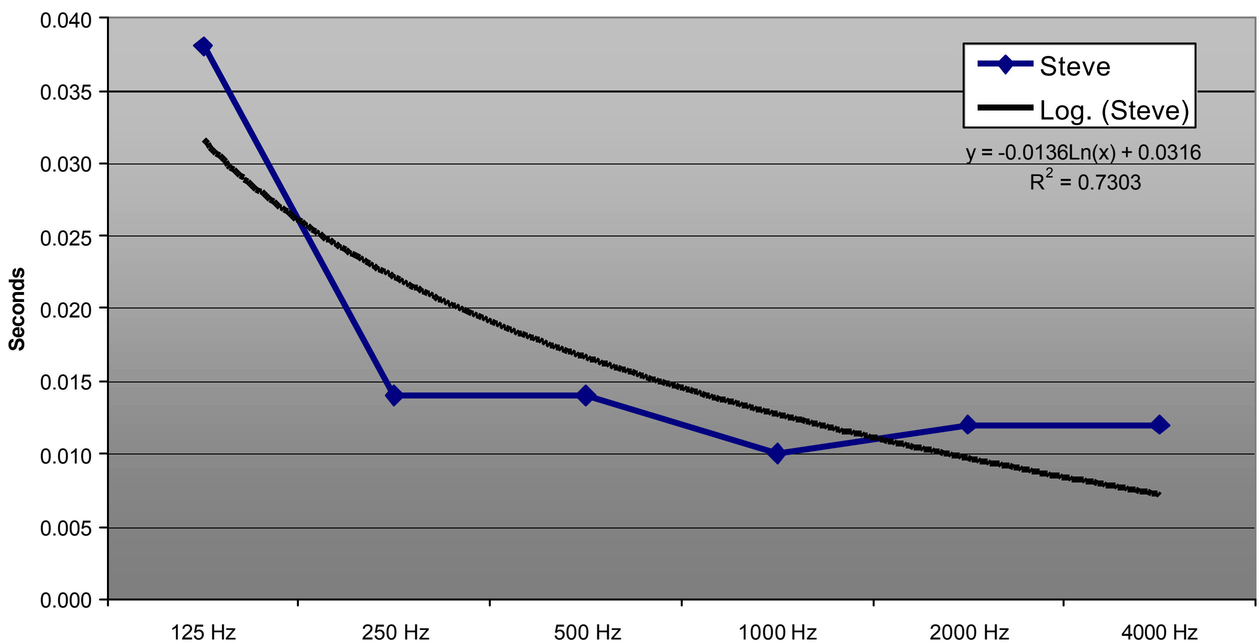

Class Average's Frequency Adjustments
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
60
170
310
600
1000
3000
6000
12000
14000
16000

Click-Tone Threshold Experiment

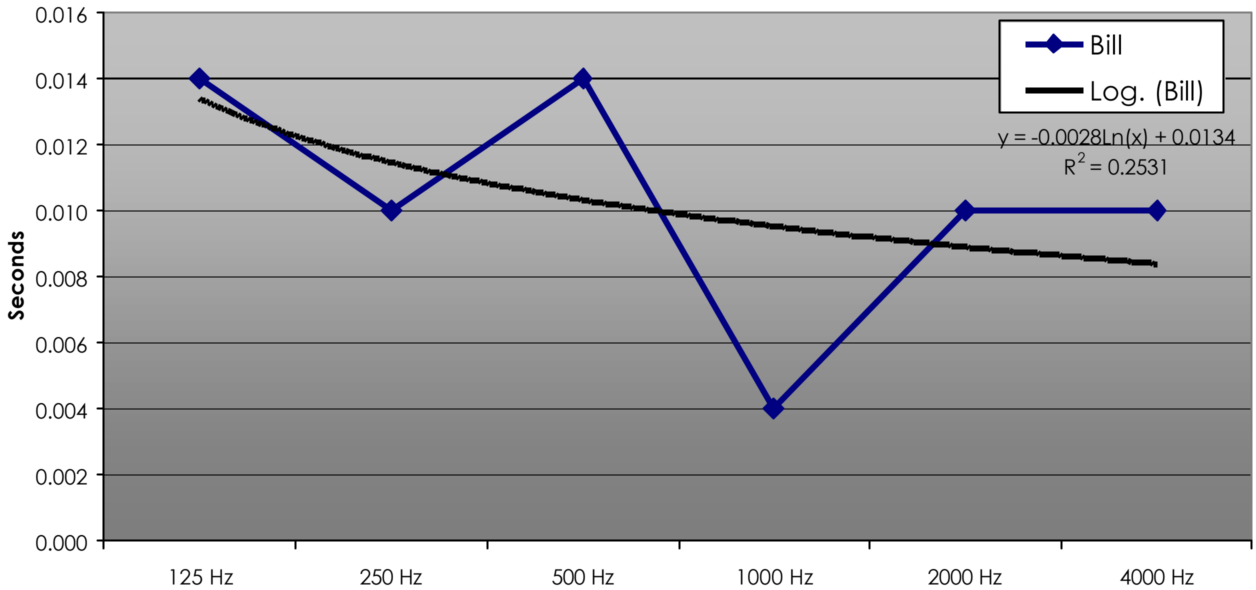
Dan's Click Threshold



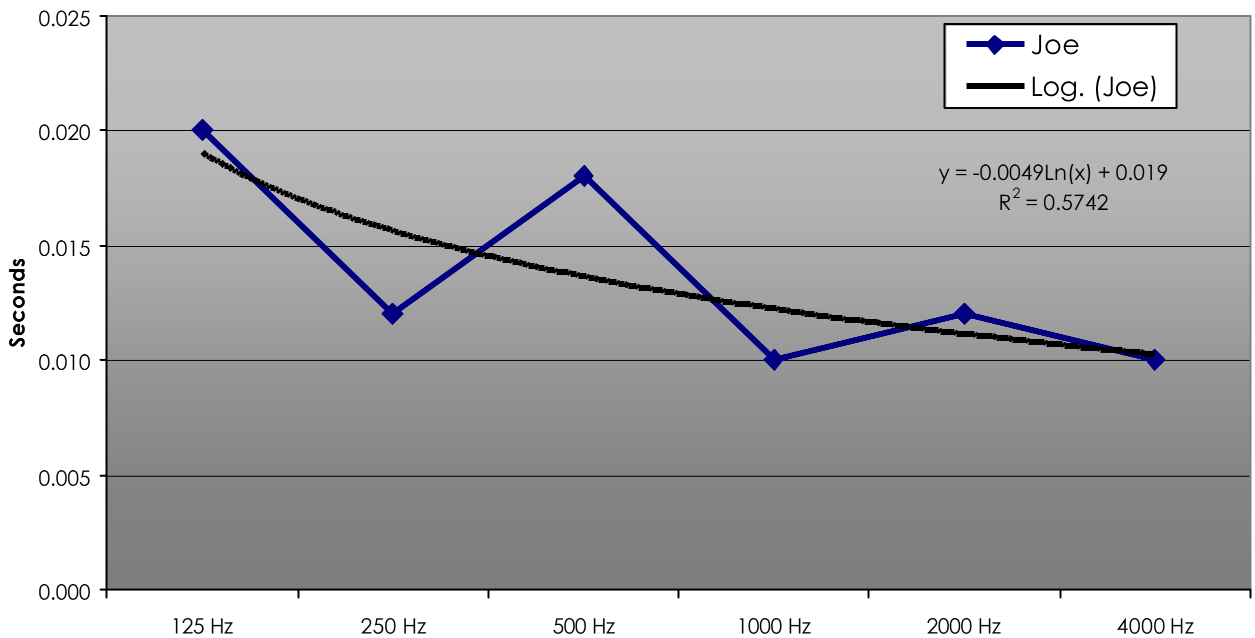
Steve's Click Threshold

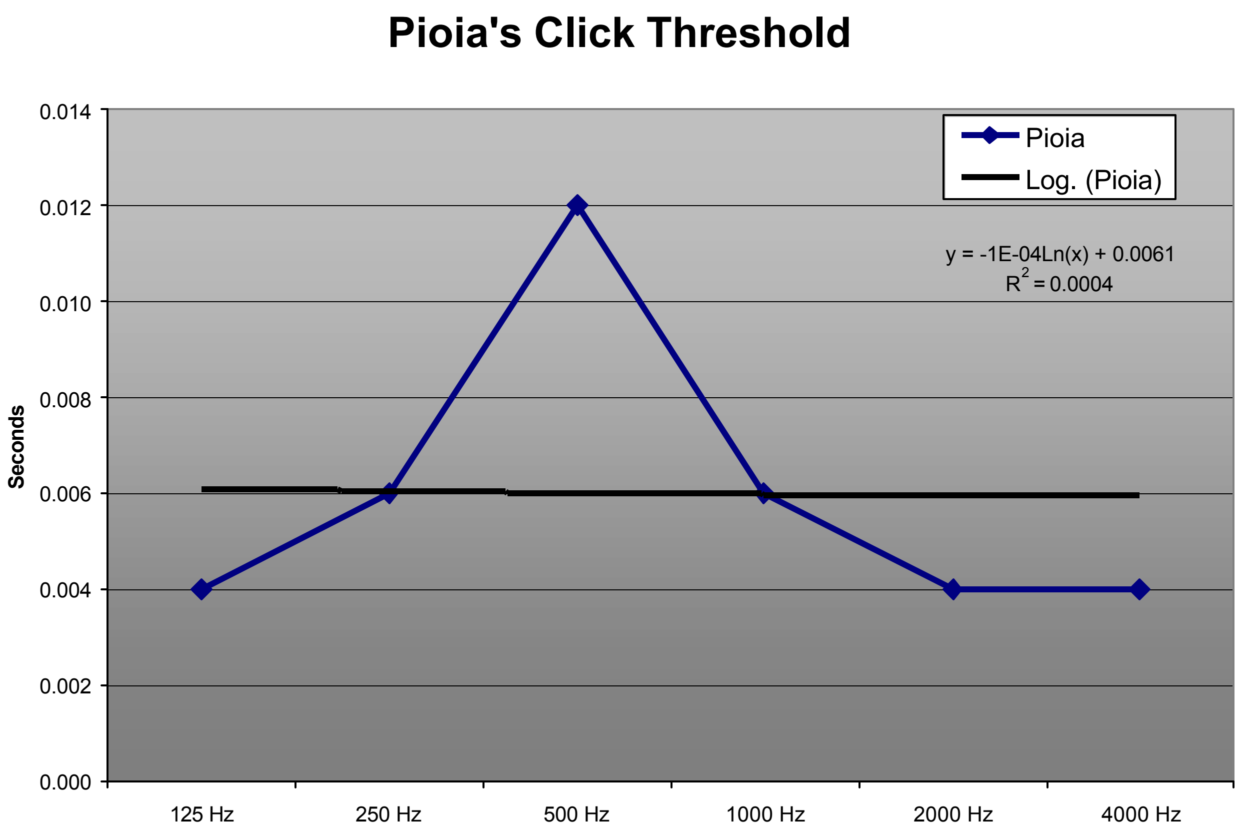


Bill's Click Threshold

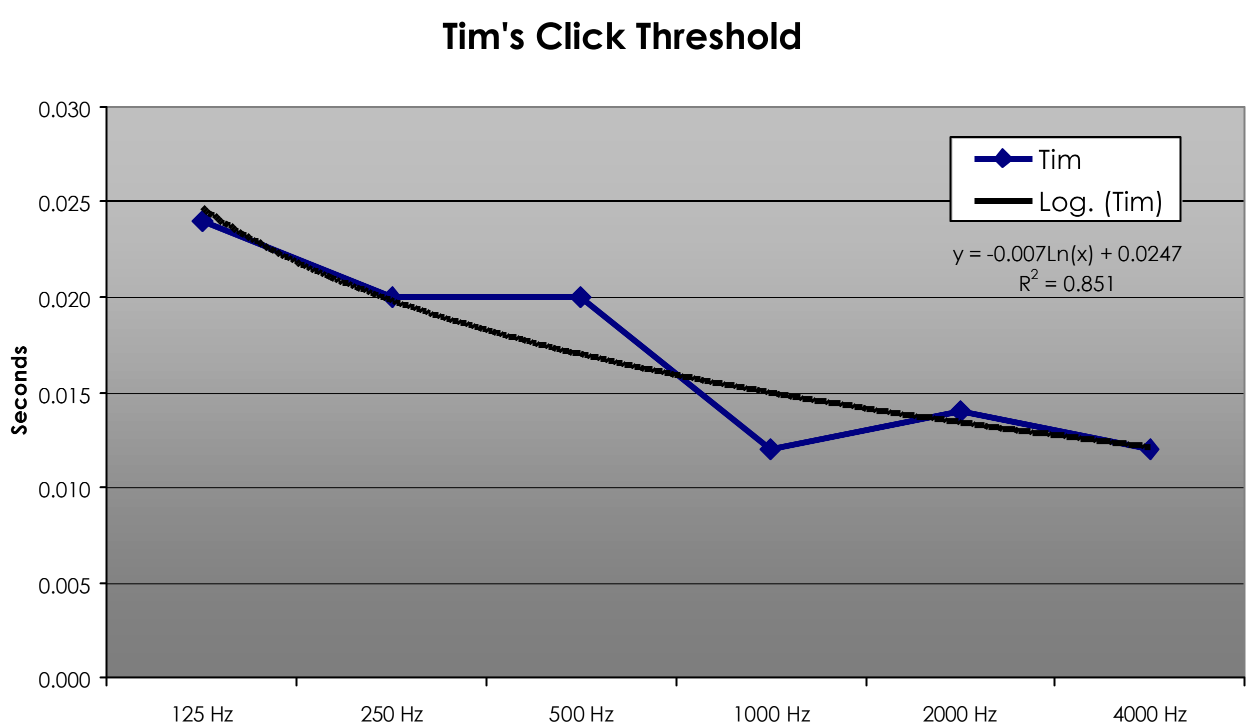


Joe's Click Threshold



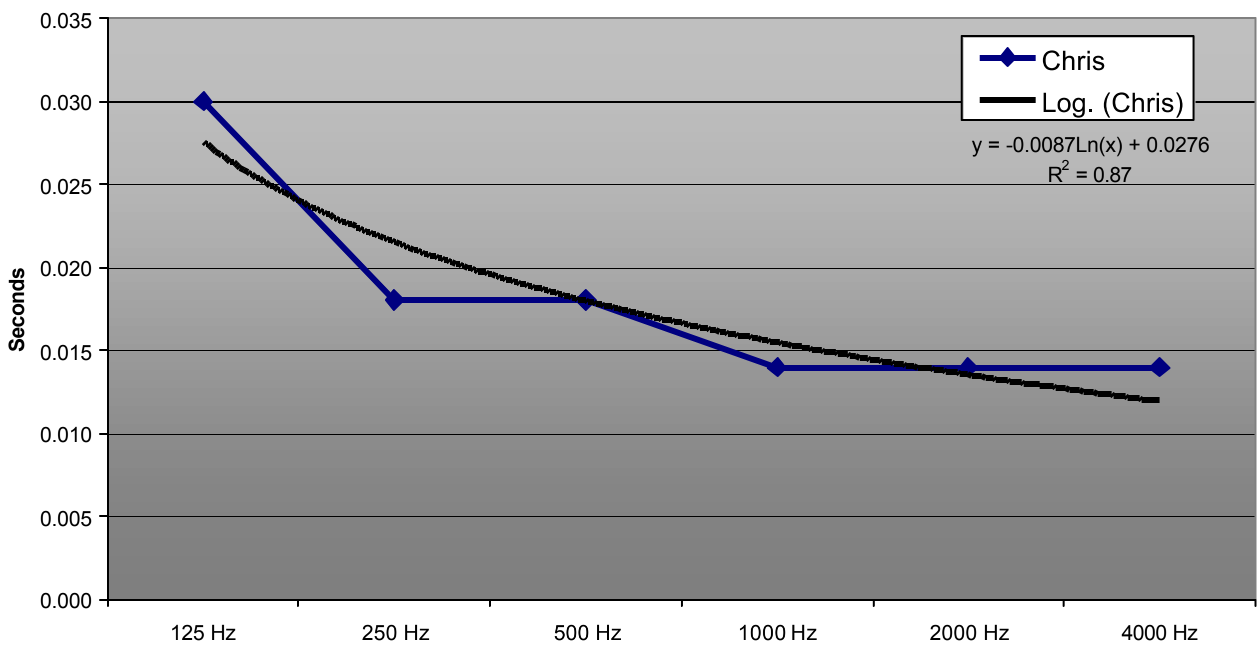


Pioia's Click Threshold
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Seconds
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
Pioia
Log. (Pioia)
y = -1E-04Ln(x) + 0.0061
R2 = 0.0004

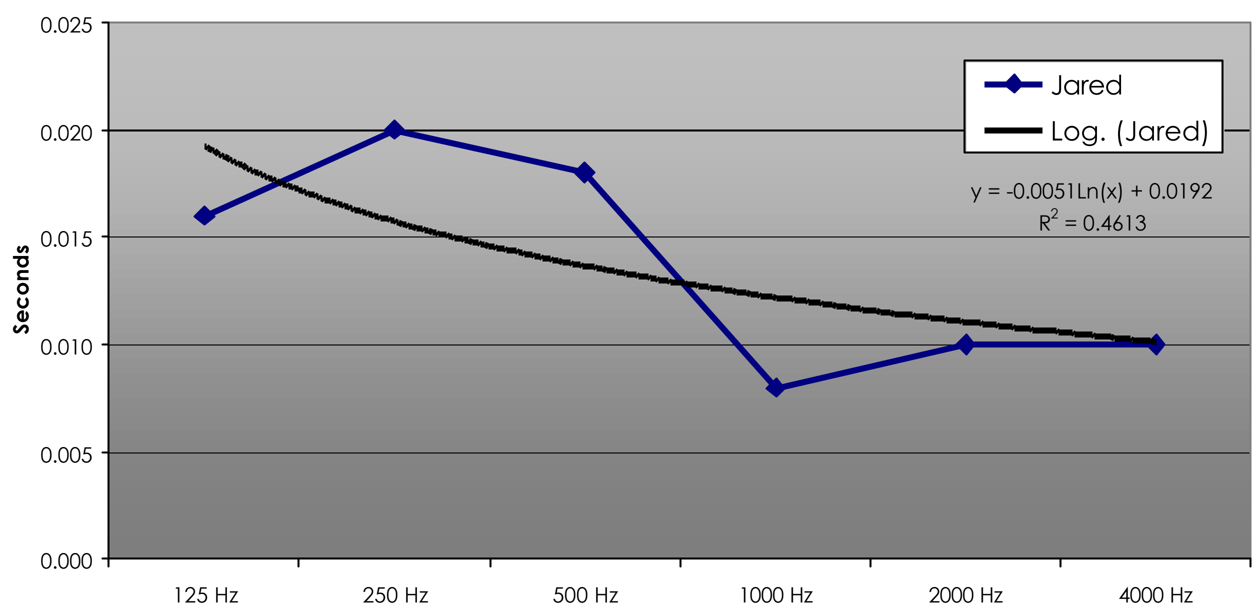


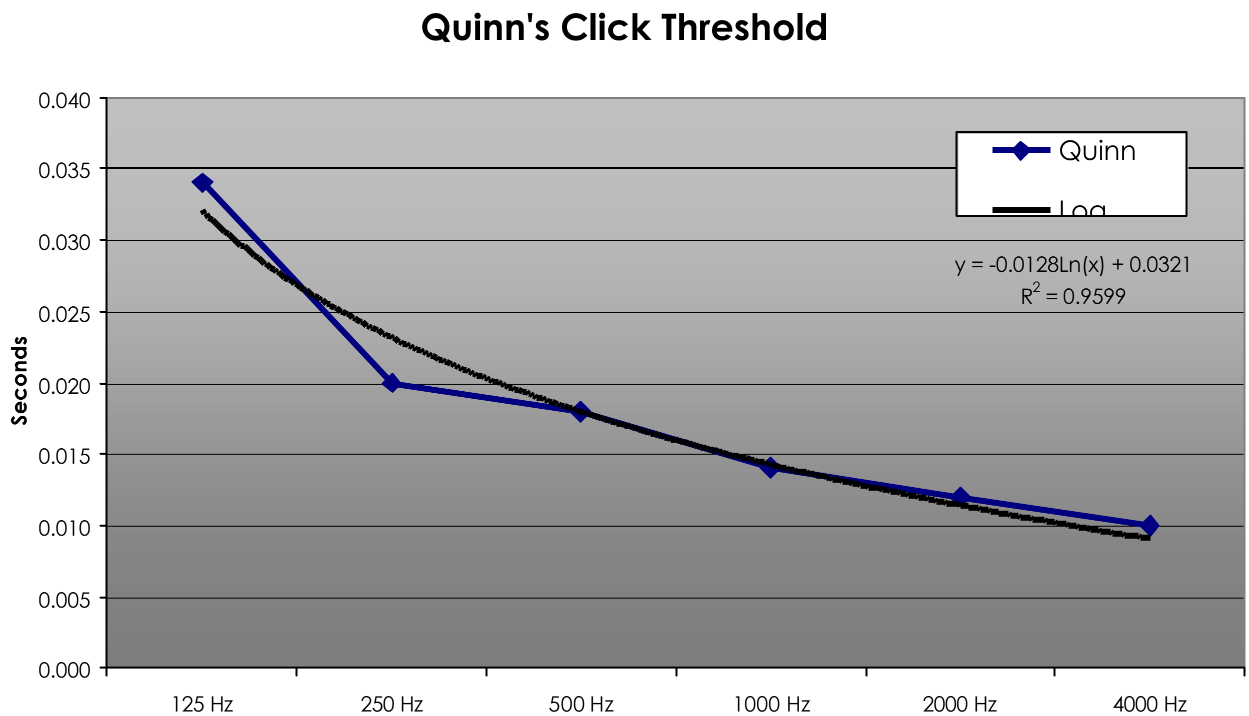
Tim's Click Threshold
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Seconds
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
Tim
Log. (Tim)
y = -0.007Ln(x) + 0.0247
R2 = 0.851

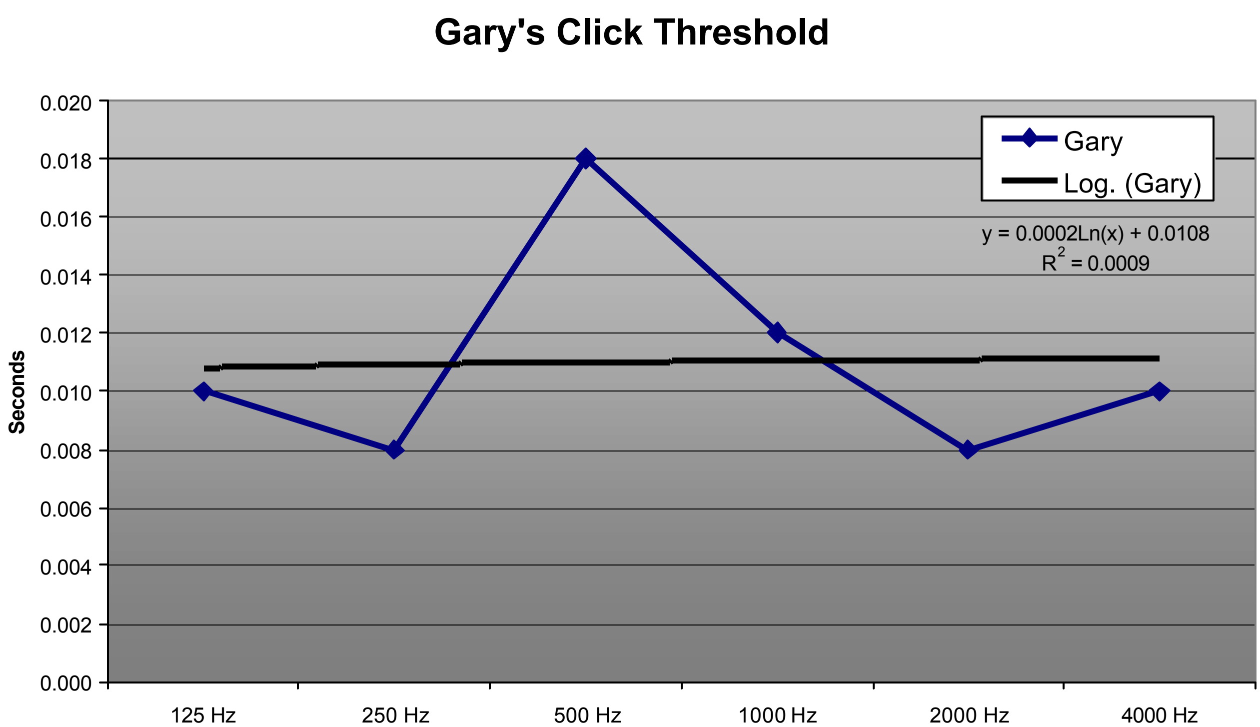
Chris's Click Threshold



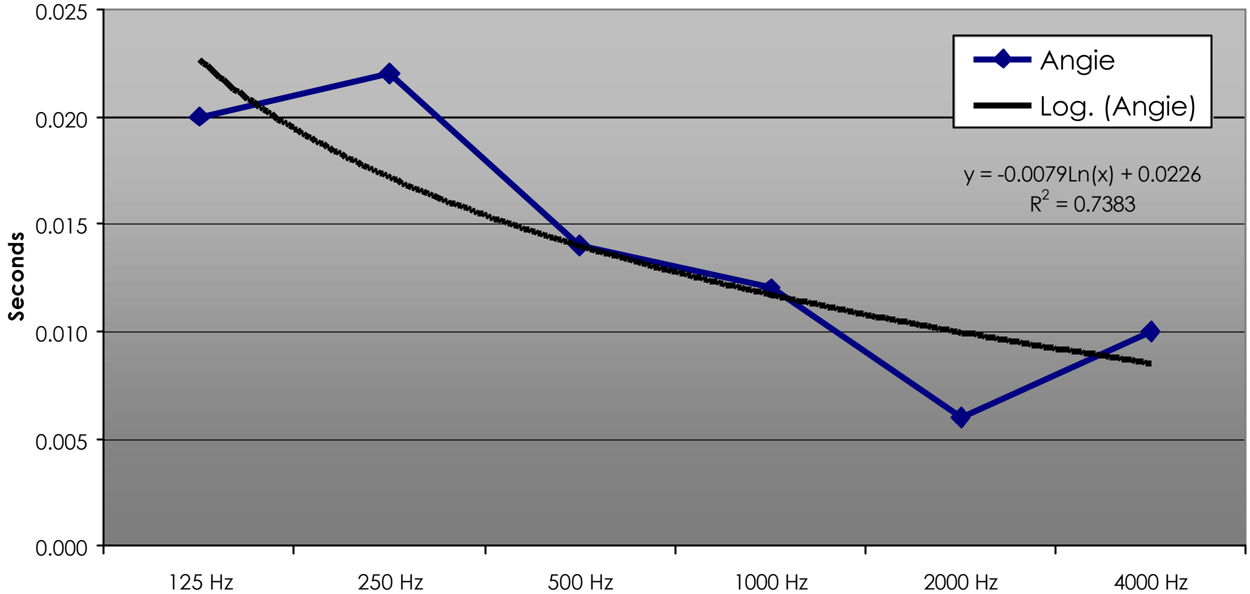
Jared's Click Threshold



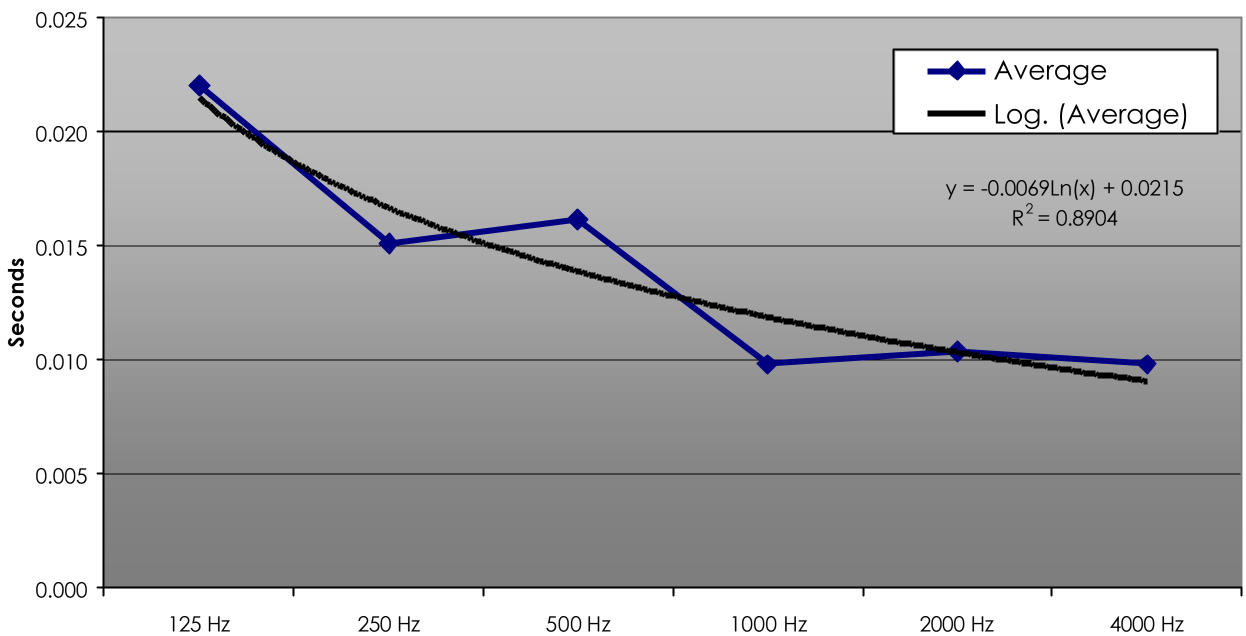

Quinn's Click Threshold
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Seconds
Quinn
y = -0.0128Ln(x) + 0.0321
R2 = 0.9599
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz


Gary's Click Threshold
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Seconds
Gary
Log. (Gary)
y = 0.0002Ln(x) + 0.0108
R2 = 0.0009
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz

Angie's Click Threshold

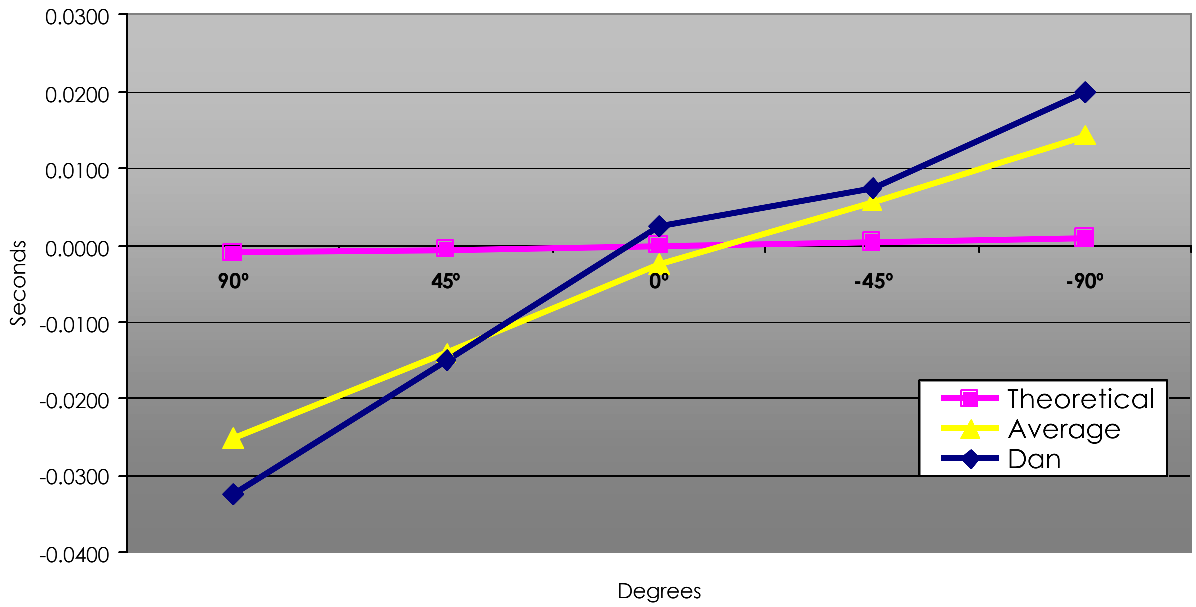


Subject Pool Average Click Threshold

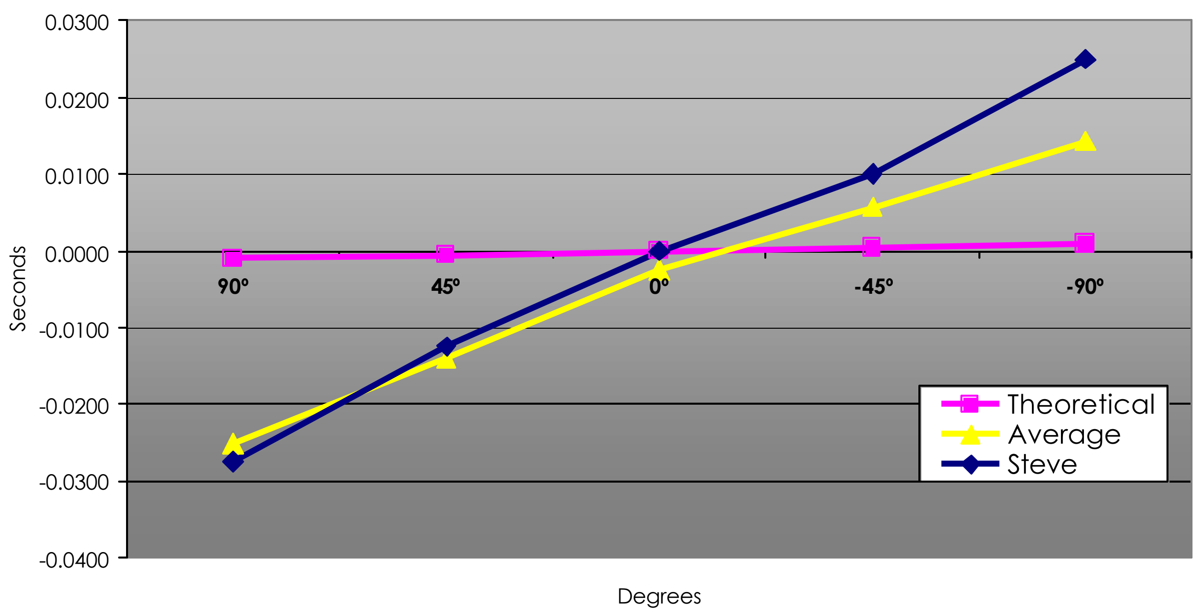


Moving Source Sound Localization Correlation

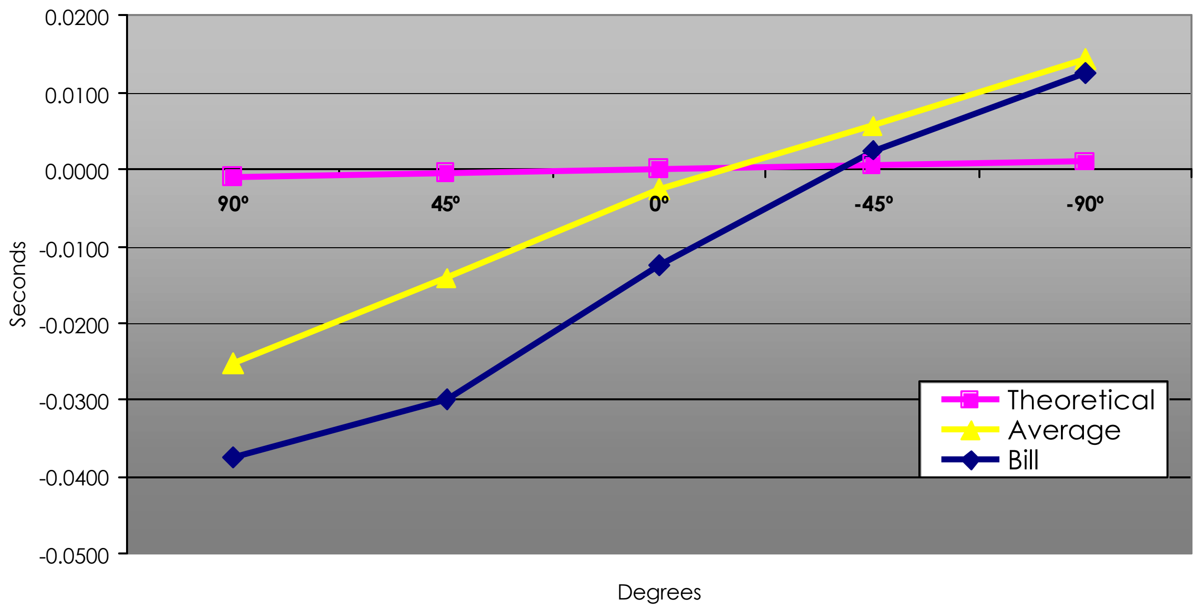
Dan's Localization Response



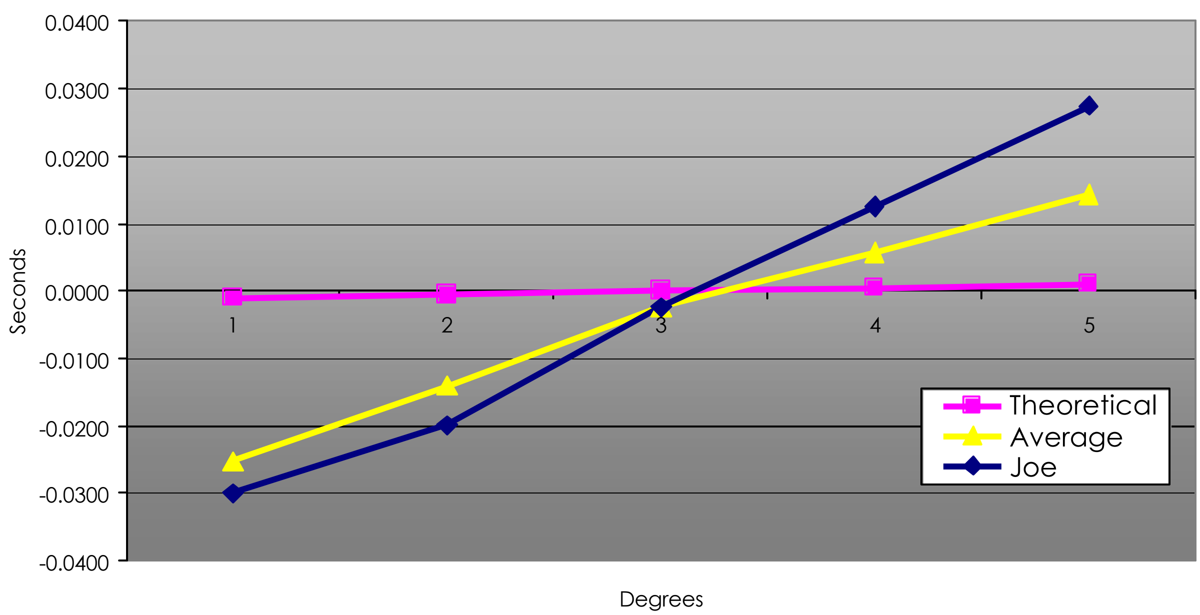
Steve's Localization Response



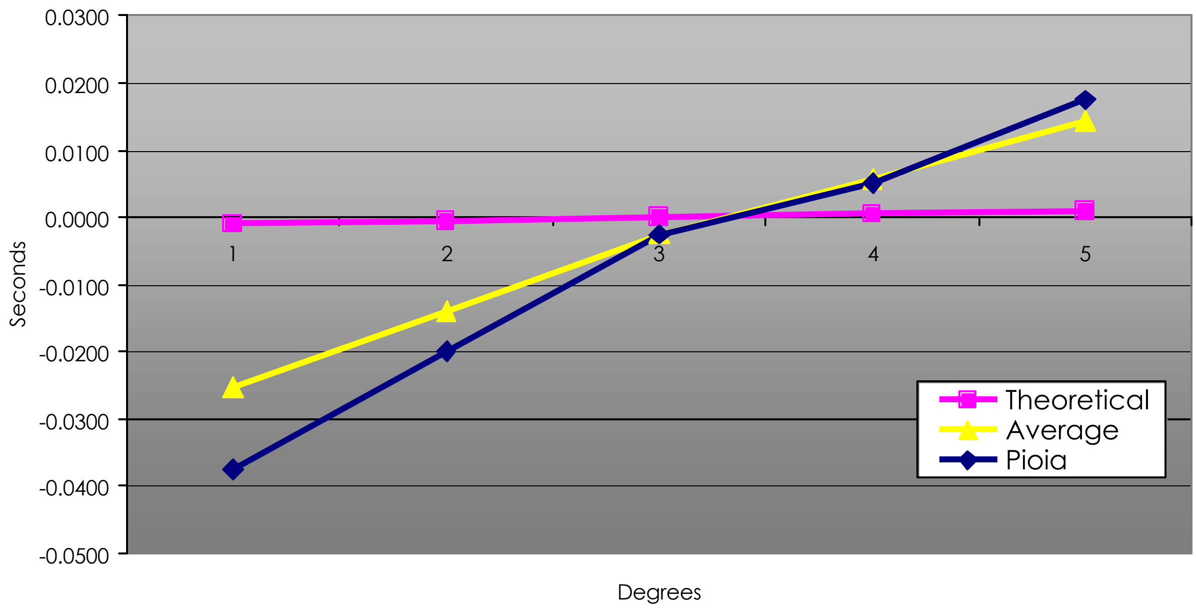
Bill's Localization Response



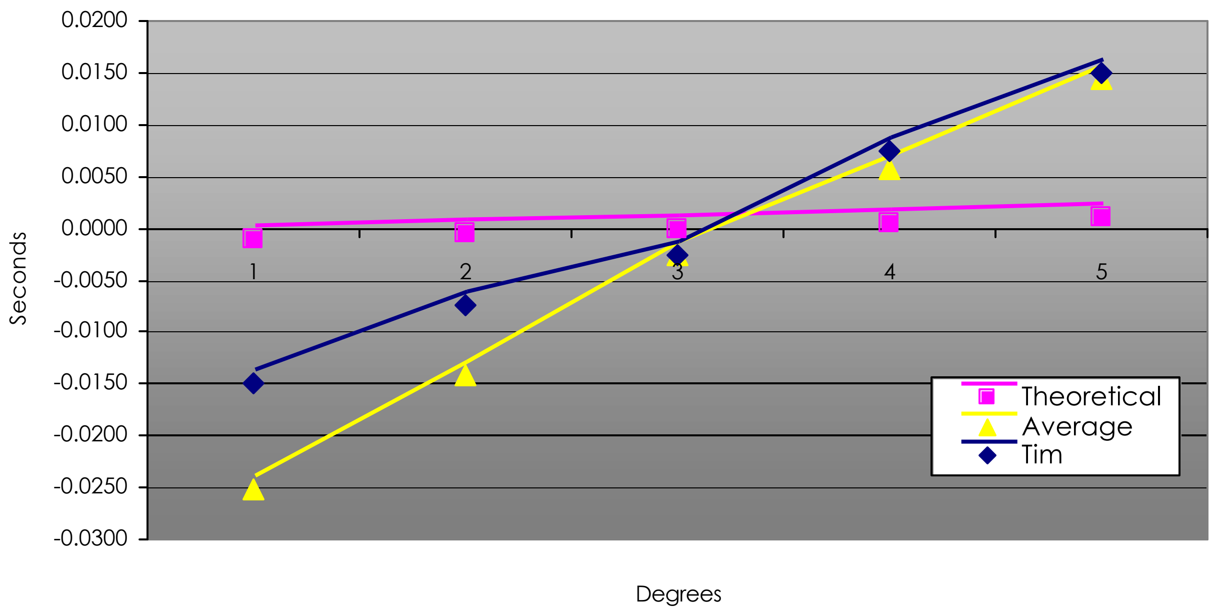
Joe's Localization Response

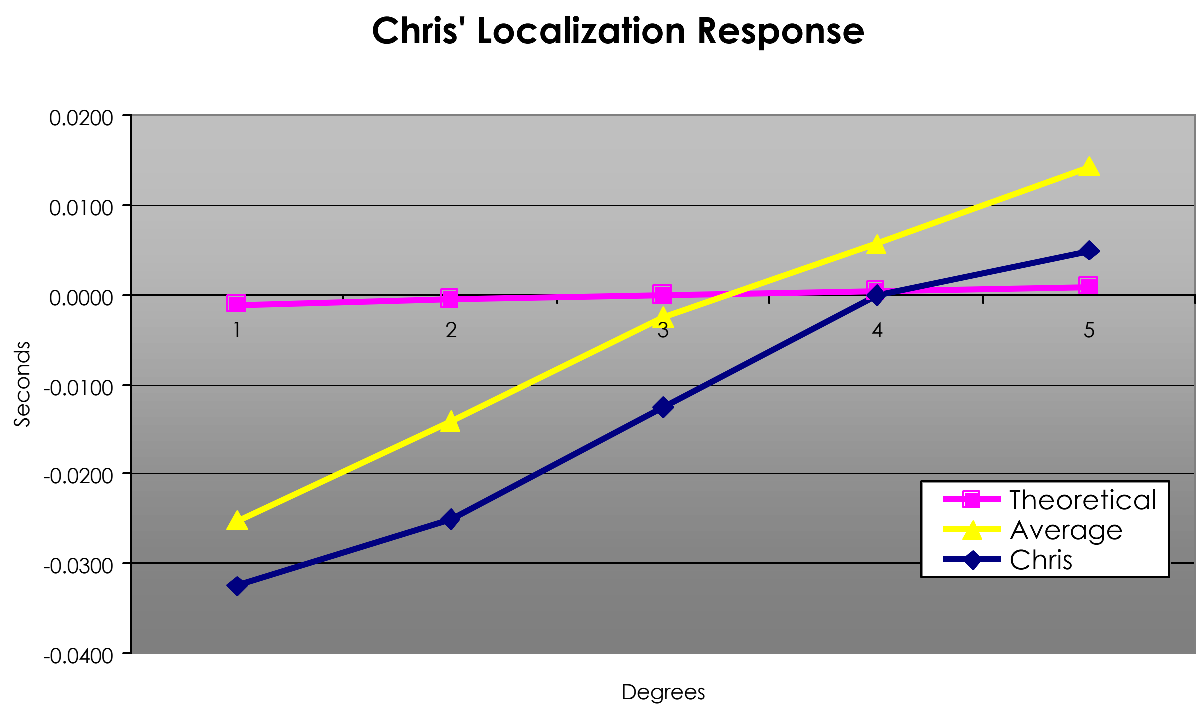


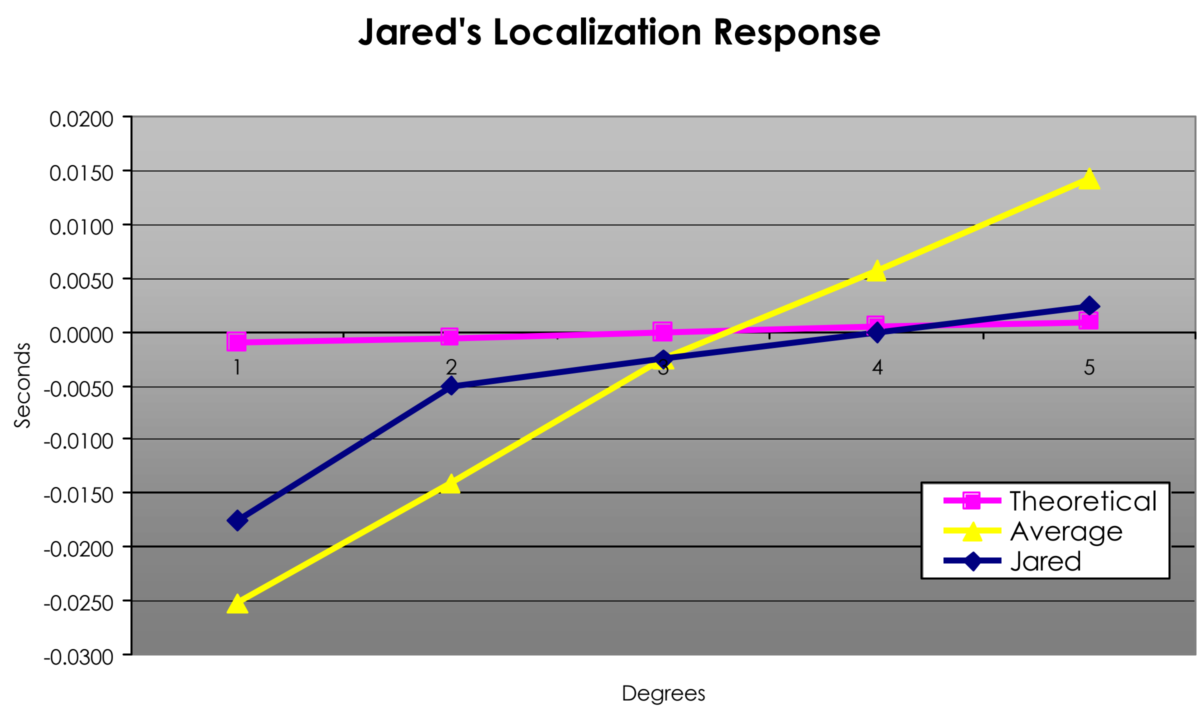
Pioia's Localization Response



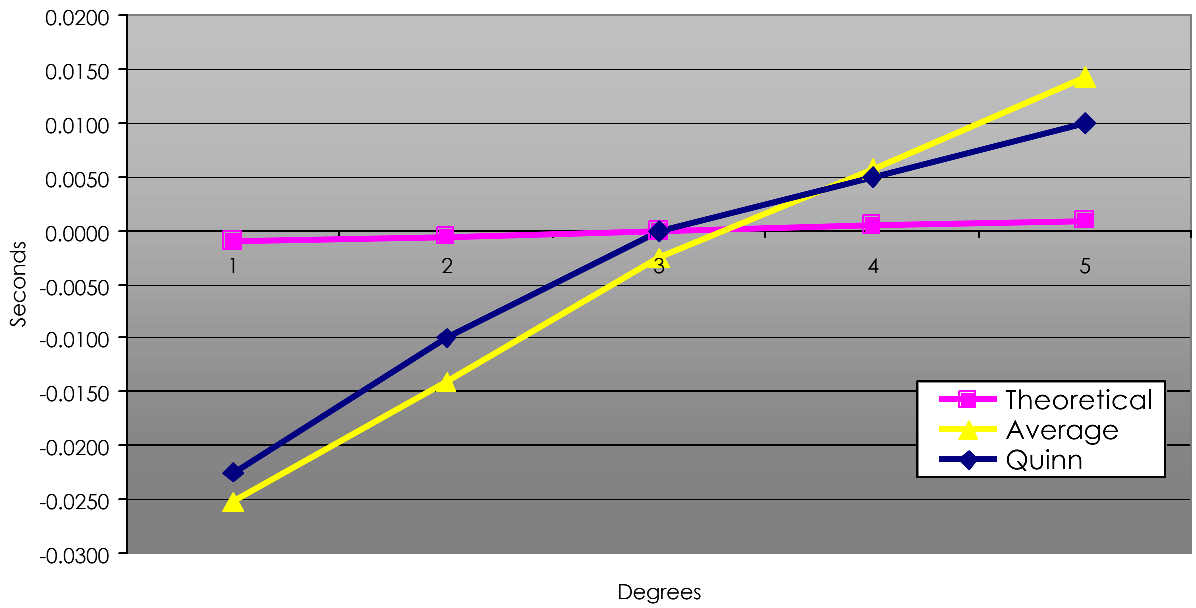
Tim's Localization Response



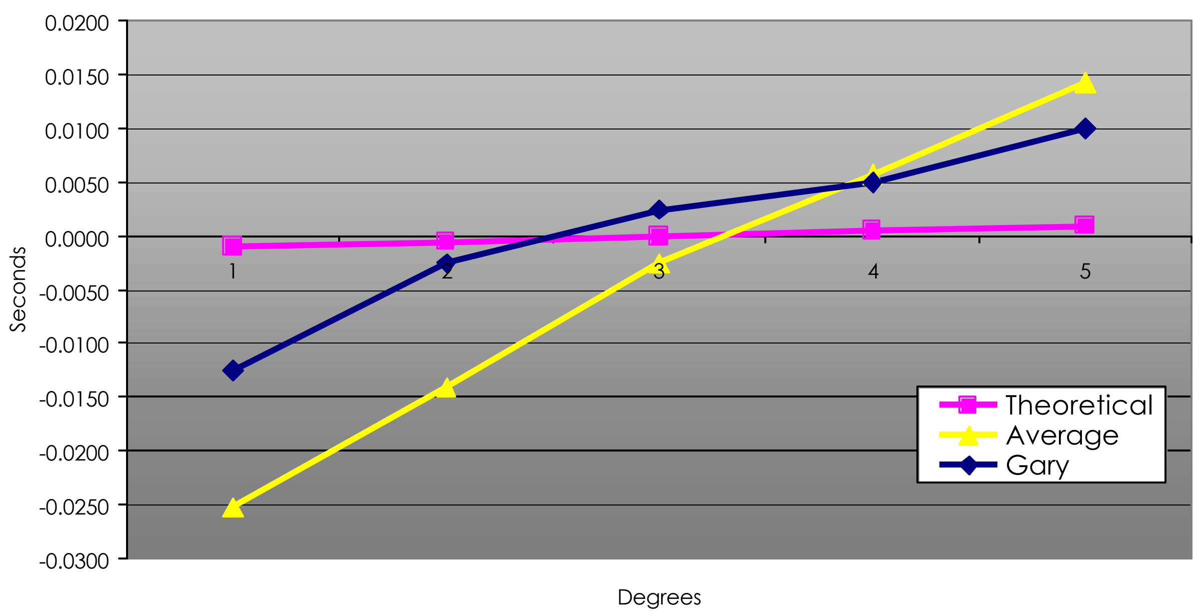

Chris' Localization Response
0.0200
0.0100
0.0000
-0.0100
-0.0200
-0.0300
-0.0400
Seconds
1
2
3
4
5
Degrees
Theoretical
Average
Chris


Jared's Localization Response
0.0200
0.0150
0.0100
0.0050
0.0000
-0.0050
-0.0100
-0.0150
-0.0200
-0.0250
-0.0300
Seconds
1
2
3
4
5
Degrees
Theoretical
Average
Jared

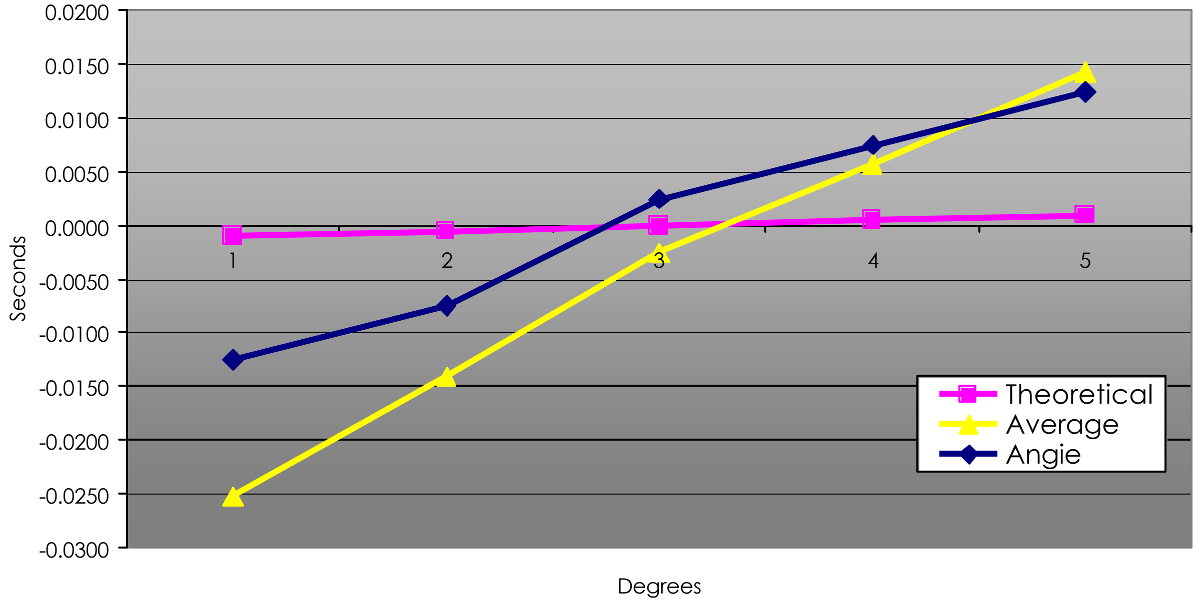
Quinn's Localization Response



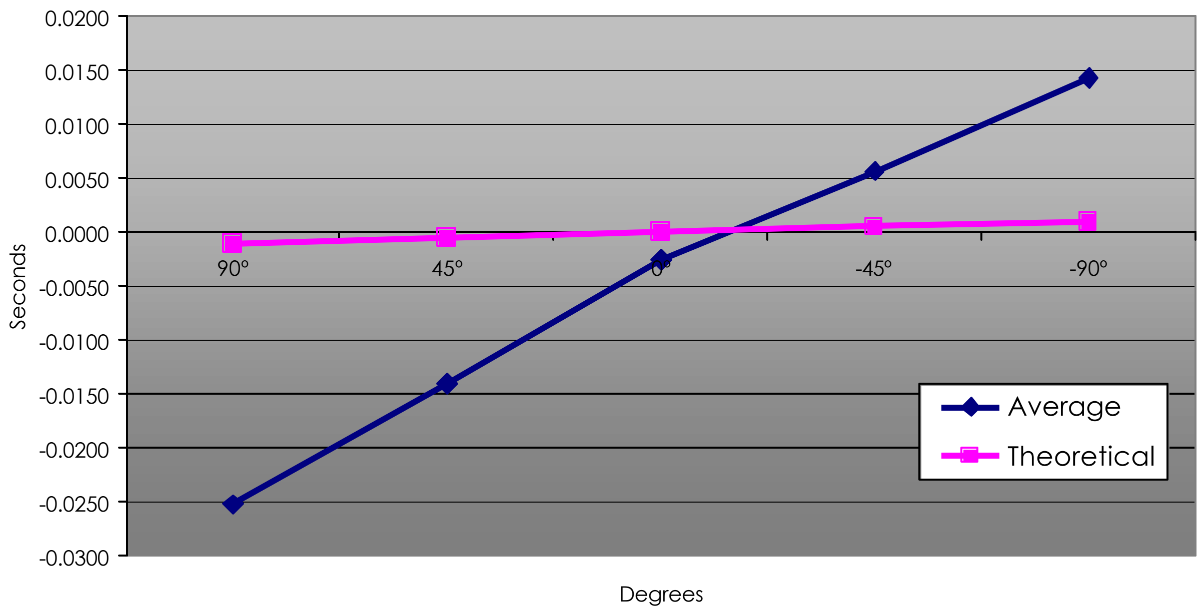
Gary's Localization Response



Angie's Localization Response



Class Average's Localization Response



Stationary Source Sound Localization Correlation