WIDEBAND POWER REFLECTANCE AND THE MINIMUM AUDIBLE PRESSURE CURVE

by

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As members of the Audiology Doctoral Project Committee, I certify that I have read the Audiology Doctoral Project prepared by Sarah Morris, titled Wideband Power Reflectance and the Minimum Audible Pressure Curve and recommend that it be accepted as fulfilling the Audiology Doctoral Project requirement for the Degree of Doctor of Audiology.

David Velenovsky, Ph.D. Date: April 6, 2020

James Dean, Au.D. Date: April 6, 2020

Michael Hartley, Ph.D. Date: April 6, 2020

Brad Story, Ph.D. Date: April 6, 2020

Final approval and acceptance of this Audiology Doctoral Project is contingent upon the candidate's submission of the final copies of the Audiology Doctoral Project to the Graduate College.

I hereby certify that I have read this Audiology Doctoral Project prepared under my direction and recommend that it be accepted as fulfilling the Audiology Doctoral Project requirement.

David Velenovsky, Ph.D. Date: April 6, 2020
Audiology Doctoral Project Committee Chair
Department of Speech, Language, and Hearing Sciences

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Abstract

The peripheral hearing mechanism, which involves structures and mechanisms that exist between the pinna (part of the ear I can see) and the brainstem, consists of the outer, middle and inner ears. The purpose of this study was to examine the natural resonances of our outer and middle ears and what role they play in determining an individual's hearing thresholds. This was done through middle ear reflectance and Békésy audiometry.

Middle ear reflectance permits the opportunity to see how the outer and middle ears affect the acoustic signal across frequency (200-6000 Hz). Minimum audible pressure thresholds differ as a clinical tool in that they are a behavioral response that reflects the participant's perception of the acoustic signal across frequency. Threshold refers to the softest sound that a person can hear at any given frequency. Minimum audible pressure thresholds can be determined at static octave intervals (250, 500, 100, 2000, 4000, and 6000 Hz) or through Békésy Audiometry, which involves a sweeping of frequencies from 125 Hz to 8000 Hz at much smaller frequency. This process results in a minimum audible pressure (MAP) curve made up of more discrete frequency intervals.

I hypothesize that the MAP curve will correlate strongly with the middle ear reflectance curve, suggesting that the natural resonances of the outer and middle ears account for our varying sensitivity across frequency. To my knowledge, these correlations have not yet been examined.

Introduction

The purpose of this project is to examine the effect of the ear canal and middle ear transfer functions on audiometric thresholds across frequency. Transfer functions refer to the natural boosts in sound energy as a result of the mass and stiffness (resonant) properties of our outer and middle ears (Møller, 1963; Mehrgardt & Mellert, 1976). Beginning from the outer ear to the middle ear, ear canal transfer functions show peaks between 1000 and 3000 Hz, and 8000 and 11000 Hz (Mehrgardt & Mellert, 1976). Previous studies have shown that human eardrum has resonance peaks between 3000 and 6000 Hz (Geffcken, 1934; Onchi, 1961). The impedance at the ear drum can be used to determine the middle ear transfer function (Møller, 1963). More recent studies of this function demonstrate a 20-23 dB peak gain around 1000 Hz that rolls off at a slope of approximately -6 dB/octave (Aibara, Welsh, Puria, & Goode ,2001). Static measures show peak gains of approximately 20 dB at 2000 Hz and 12 dB at 4000 Hz. This information demonstrates a natural amplifying effect of mid-range frequencies most often associated with speech signals. Essentially, mid to high-frequency information gains a natural boost as it travels through the outer and middle ears. While humans do have varying sensitivity across frequency, clinically, these differences are not seen as important and the thresholds are normalized to 0 dB HL as a matter of convenience. Average human hearing thresholds across frequency are illustrated in Table 1 as measured during my experiment.

Table 1: Threshold Across Frequency, dB SPL vs. dB HL

Frequency (Hz)	250	500	1000	2000	4000	8000
Intensity (dB SPL)	12.6	4.6	-1.3	2.0	3.2	1.6
Hearing Level (dB HL)	0	0	0	0	0	0

For many years, acoustic immittance measurements (tympanometry, multi-frequency tympanometry and acoustic reflex) have been the clinical tools used to evaluate middle ear function (Metz, 1946; Møller, 1962; Emanuel, Henson, & Knapp, 2012). These measures comprise tympanograms (displays of eardrum mobility measured at various pressures) and acoustic reflex measures, which are changes in eardrum mobility that result from the stiffening of the middle ear system in response to middle ear muscle contraction elicited by moderately loud sounds presented through earphones (Luscher, 1929; Borg, 1968). These tests are all performed while the subject has a measurement probe fit to either the right or left ear canal using a soft rubber or foam tip. A low frequency probe tone (226 Hz) is presented to the ear at a comfortable level (Rosowski & Wilber, 2015). This probe tone is then used to measure information about the ear's static acoustic admittance, volume, and pressure.

More recently, wideband reflectance technology has allowed researchers and clinicians to understand how the outer and middle ears respond to a broad range of frequencies (200-6000 Hz) during middle ear status testing (Feeney, Keefe, & Sanford, 2004). This can be measured in the presence of the acoustic reflex or in its absence, which could be considered a passive state. Middle ear reflectance permits the opportunity to see how a broad range of frequency energy interacts with the outer and middle ears. Similar to conventional methods, a wideband chirp is used to measure energy within the ear canal. More specifically, the wideband chirp stimulus ranges from 200-6000 Hz, which allows investigators to observe transmittance (derived from wideband reflectance) of sound energy into the ear across a broad range of frequencies. The information garnered from transmittance measures informs us about the energy transfer through the outer and middle ear as it relates to mass and stiffness of the system. This would, essentially, define the unique natural resonances of an individual's ear canal and middle ear.

Minimum audible pressure (MAP) thresholds are another clinical tool, but they differ from immittance measures in that they depend on the participant's perception of sound (Sivian &

White, 1933). These measures, typically performed by a clinician, involve a subject responding to a variety of frequencies at varying levels of intensity presented through supra-aural or insert earphones. The purpose is to determine the lowest (softest) level at which a person can hear a particular frequency. This can be done in static octave intervals (250, 500, 100, 2000, 4000, and 6000 Hz) or through Békésy Audiometry (Békésy, 1947) which involves sweeping frequency from 125 Hz to 8000 Hz at much smaller frequency intervals, while subjects control the increases or decreases in intensity in order to determine their hearing thresholds. These data points can then be used to derive a minimum audible pressure curve made up of more discrete frequency intervals than found in static octave testing. A MAP curve demonstrates an individual's lowest threshold across frequencies. Further, previous data show that MAP curves show a differential sensitivity in thresholds across frequency in human beings.

While both minimum audible pressure curves and the presence of natural resonances within the outer and middle ear are well established, it is my understanding that the relationship between these two phenomena is unexamined. I hypothesize that the MAP curve will correlate strongly with the middle ear transmittance curve, suggesting that the natural resonances of the outer and middle ears are mostly responsible for our varying thresholds across frequency.

Methods

I tested 19 adult participants, male and female, and accepted 10 left and 10 right ears. Eighteen ears were excluded from the study due to low-acoustic reflex thresholds and/or cerumen impaction. Each participant first completed a screening battery comprising otoscopy, pure tone audiometry at 20 dB HL, tympanometry, and ipsilateral acoustic reflex thresholds. Testing was completed in a sound treated booth. Immittance measures were recorded with a Grayson-Stadler TympStar™ Middle Ear Analyzer, audiometry measures were obtained with a

Madsen Astera Audiometer, and wideband power reflectance measures (transmittance) were recorded using a Mimosa Acoustics HearID® 5.1 system.

Elicitation of stapedius muscle contraction directly changes the middle ear's acoustic impedance (Geffcken, 1934), thus, participants were screened to ensure that transmittance measures were recorded in a passive state. That is, they were recorded without activation of the acoustic reflex. If subjects had an acoustic reflex threshold at or below 62 dB SPL they were excluded from the study as this was the stimulus level used for the wideband chirp. In normal hearing individuals the reflex response threshold is between 85 and 100 dB SPL (Gelfand & Piper, 1984). Sixty two dB SPL was chosen for the reflectometry stimulus level because it was the softest intensity that could be delivered without contamination from the noise floor.

Investigative measures included Békésy Audiometry and transmittance measures via wideband power reflectance under ER3 or ER-10C insert earphones, respectively. The inserts for both were equal in length and diameter. Probe insertion distance was marked on the extruding portion of the foam tip to ensure equal insertion depth between measures.

Békésy Audiometry was completed for each accepted ear. Participants began with a practice trial from 125 Hz to 1000 Hz and were instructed to hold a response button when they heard the tone and release the button once they no longer heard the tone. Hearing thresholds were defined by the Astera software as the dB SPL immediately preceding a release of the button, however, the traces between thresholds were also recorded. For each tested ear, a pulsed stimulus and steady stimulus trial were completed for 125 Hz to 8000 Hz. For exact frequency steps tested please see Table 2a at the end of this section. At the end of this portion subjects were asked whether pulsed tones or continuous tones were easier to respond to.

Reflectometry was completed for each accepted ear. A 62 dB SPL wideband chirp stimulus was delivered via an ER 10C insert probe and transmittance measures were recorded for frequencies 210 Hz to 6000 Hz. For exact frequency steps tested please see Table 2b. Each participant was instructed to sit still and quietly while six repeated measures were recorded. The results of the examination were discussed with the participants. No specific ethnicity or gender was targeted or excluded. As instructions were given in English, only English speakers were recruited. The study did not involve vulnerable populations such as children, pregnant women, prisoners, or cognitively impaired subjects, or populations at risk of transitioning into one of these vulnerable categories during the course of the study. All participants were recruited voluntarily. All methods were approved by the University of Arizona Institutional Review Board, Project #1808887280.

Table 2a: Complete List of Frequencies Tested in Békésy Audiometry (Hz)

125	230	425	775	1400	2580	4750
128	236	437	800	1450	2650	4870
132	243	450	825	1500	2720	5000
136	250	462	850	1550	2800	5150
140	258	475	875	1600	2900	5300
145	265	487	900	1650	3000	5450
150	272	500	925	1700	3070	5600
155	280	515	950	1750	3150	5800
160	290	530	975	1800	3250	6000
165	300	545	1000	1850	3350	6150
170	307	560	1030	1900	3450	6300
175	315	580	1060	1950	3550	6500
180	325	600	1090	2000	3650	6700
185	335	615	1120	2060	3750	6900
190	345	630	1150	2120	3870	7100
195	355	650	1180	2180	4000	7300
200	365	670	1220	2240	4120	7500
206	375	690	1250	2300	4250	7750
212	387	710	1280	2360	4370	8000
218	400	730	1320	2430	4500	
224	412	750	1360	2500	4620	

Table 2b: Complete List of Frequencies Tested in Transmittance (Hz)

210.9375	1054.688	1898.438	2742.188	3585.938	4429.688	5273.438
234.375	1078.125	1921.875	2765.625	3609.375	4453.125	5296.875
257.8125	1101.563	1945.313	2789.063	3632.813	4476.563	5320.313
281.25	1125	1968.75	2812.5	3656.25	4500	5343.75
304.6875	1148.438	1992.188	2835.938	3679.688	4523.438	5367.188
328.125	1171.875	2015.625	2859.375	3703.125	4546.875	5390.625
351.5625	1195.313	2039.063	2882.813	3726.563	4570.313	5414.063
375	1218.75	2062.5	2906.25	3750	4593.75	5437.5
398.4375	1242.188	2085.938	2929.688	3773.438	4617.188	5460.938
421.875	1265.625	2109.375	2953.125	3796.875	4640.625	5484.375
445.3125	1289.063	2132.813	2976.563	3820.313	4664.063	5507.813
468.75	1312.5	2156.25	3000	3843.75	4687.5	5531.25
492.1875	1335.938	2179.688	3023.438	3867.188	4710.938	5554.688
515.625	1359.375	2203.125	3046.875	3890.625	4734.375	5578.125
539.0625	1382.813	2226.563	3070.313	3914.063	4757.813	5601.563
562.5	1406.25	2250	3093.75	3937.5	4781.25	5625
585.9375	1429.688	2273.438	3117.188	3960.938	4804.688	5648.438
609.375	1453.125	2296.875	3140.625	3984.375	4828.125	5671.875
632.8125	1476.563	2320.313	3164.063	4007.813	4851.563	5695.313
656.25	1500	2343.75	3187.5	4031.25	4875	5718.75
679.6875	1523.438	2367.188	3210.938	4054.688	4898.438	5742.188
703.125	1546.875	2390.625	3234.375	4078.125	4921.875	5765.625
726.5625	1570.313	2414.063	3257.813	4101.563	4945.313	5789.063
750	1593.75	2437.5	3281.25	4125	4968.75	5812.5
773.4375	1617.188	2460.938	3304.688	4148.438	4992.188	5835.938
796.875	1640.625	2484.375	3328.125	4171.875	5015.625	5859.375
820.3125	1664.063	2507.813	3351.563	4195.313	5039.063	5882.813
843.75	1687.5	2531.25	3375	4218.75	5062.5	5906.25
867.1875	1710.938	2554.688	3398.438	4242.188	5085.938	5929.688
890.625	1734.375	2578.125	3421.875	4265.625	5109.375	5953.125
914.0625	1757.813	2601.563	3445.313	4289.063	5132.813	5976.563
937.5	1781.25	2625	3468.75	4312.5	5156.25	6000
960.9375	1804.688	2648.438	3492.188	4335.938	5179.688	
984.375	1828.125	2671.875	3515.625	4359.375	5203.125	
1007.8125	1851.563	2695.313	3539.063	4382.813	5226.563	
1031.25	1875	2718.75	3562.5	4406.25	5250	

Analysis

Data were prepared for analysis in the following ways:

Békésy thresholds.

1. All Békésy threshold data were originally recorded in dB HL as is conventional for clinical audiometers and all reflectometry data were recorded in dB SPL as is conventional for investigative wideband power reflectance procedures. Thus, the dB HL data had to be converted to dB SPL data. A Larson Davis Model 821 Type 1 sound level meter (and an AEC203 insert coupler) was used to measure dB SPL output at discrete frequencies from the insert earphone transducers used for Békésy audiometry. Table 3 provides a complete list of the frequencies measured and their corresponding dB HL to SPL conversion factors. To complete the conversion, these data were resampled with a shape-preserving cubic spline interpolation [Fritsch & Carlson (1980), specifically the "pchip" algorithm available in MATLAB (Mathworks, 2019)] to provide dB HL values at each of the Bekesy frequencies shown previously in Table 2a.

Table 3: Measured Frequencies and Corresponding Conversion Factors

Hz	**212**	**230**	**250**	**272**	**300**	**325**	**355**	**387**	**425**	**462**	**500**	**545**
dB	15.5	14.0	12.6	12.4	12.1	11.5	10.3	8.8	7.1	5.7	4.6	3.7
Hz	**600**	**650**	**710**	**775**	**850**	**925**	**1000**	**1500**	**2000**	**3000**	**4000**	**6000**
dB	3.2	2.6	1.5	0.9	0.6	-0.5	-1.3	0.8	2.0	2.6	5.2	1.6

2. Békésy Audiometry data were recorded in two conditions for each ear: pulsed and steady. The pulsed and steady runs were preserved as such and not combined for any of the analysis.

Reflectance data.

1. Wideband power reflectance was used to derive transmittance data of sound energy into each participant's ear. While reflectance measures the percent of sound energy reflected off of the tympanic membrane, transmittance can be understood as the amount of sound in dB SPL that is admitted into the middle ear space. Six runs at 62 dB SPL were completed and the average transmittance value in dB SPL for each frequency was used for statistical analysis.
2. Transmittance testing and Békésy audiometry both involve measures of dB at discrete frequency intervals. However, the exact frequencies differed between the two measures. This can be attributed to two separate manufacturer systems being required to complete this study. Transmittance data were resampled at the overlapping Békésy frequencies (between 212 Hz and 6000 Hz) using the same "pchip" spline interpolation described previously so that a direct comparison could be achieved.

Ears.

Not all subjects had both ears accepted into the study. When both ears were accepted their data were collapsed to assess data by subject.

Results

All data were statistically analyzed with the dependent variables as Békésy thresholds in dB SPL in the pulsed and continuous paradigms. These were assessed separately so distinctions could be made between the Békésy pulsed and continuous conditions. Fixed variables were ear, gender, intercept, Hz, Transmittance and combinations of those variables.

First, two-tailed testing was completed for group and individuals to assess correlations between the dependent and continuous variables with correlation significant at the 0.01 level.

Results from two-tailed testing showed that Békésy pulsed, Békésy continuous, and Transmittance relate significantly to changes in Hz. The two Békésy results are correlated at a Pearson Correlation level of 0.733, suggesting that they are similar in measurement of thresholds. In addition, the transmittance correlates strongly with the Békésy indices at a Pearson Correlation level of 0.429 and 0.419 for Békésy pulsed and continuous, respectively. When combined with the visual representations shown below, this demonstrates that along frequencies there are varying levels of correlation. It should also be noted that for both the Békésy indices the following coefficients were significant at the 0.01 level: Hz, Transmittance, Ear, Ear*Transmittance.

I then analyzed the data by a Linear Mixed Model approach to understand the relationship between the previously mentioned variables. First, I will discuss the results for the Békésy continuous paradigm, as shown in Table 4.

Békésy Continuous

Table 4: Type III Test of Fixed Effects

	Hz	***Transmittance***	***Gender***	***Ear***	***Hz*Transmittance***
F-Value	50.505	25.825	0.031	8.478	42.793

A regression analysis (estimates of fixed effects) assessed the linear relationship between all variables and the Békésy continuous data. From this assessment it was demonstrated that the variability seen in the Békésy data can be accounted for by the frequency and transmittance data, which both had large magnitudes of significance as shown by the F-Value. Covariance Parameters for Random Effects can be seen in Table 5, suggesting that the means of subjects differ overall, as expected, but that the Transmittance, again, is significant in accounting for the changes in threshold seen for the Békésy data.

Table 5: Estimates of Covariance Parameters

	Estimate	***Standard Error***
Residual	39.6	1.17
Intercept	46.3	21.15
Transmittance	0.64	0.30

Grand Means of the dB SPL data were also obtained. Overall Grand Mean was 7.085 dB. Left and right ear Grand Means were 7.249 dB and 6.921 dB, respectively. Female Grand Mean was 6.198 dB and male Grand Mean was 7.972 dB.

Finally, the residuals were examined and found to be normal implying that the statistical decisions are correct and that significance results are robust.

Békésy Pulsed

A regression analysis (estimates of fixed effects) assessed the linear relationship between ear variable and the Békésy pulsed data. From this assessment it was demonstrated that the variability seen in the Békésy data can be accounted for by the Hz and Transmittance data, which both had large magnitudes of significance. Covariance Parameters for Random Effects can be seen in Table 6, suggesting that the means of subjects differ overall, as expected, but that the Transmittance, again, is significant in accounting for the changes in threshold seen for the Békésy data.

Table 6: Type III Test of Fixed Effects

	Hz	***Transmittance***	***Gender***	***Ear***	***Hz*Transmittance***
F-Value	54.318	23.730	0.147	6.403	60.934

When compared to results from the Békésy continuous paradigm, it is evident that both test procedures resulted in robust and significant effects for Hz, Transmittance, and Hz*Transmittance. However, the Békésy pulsed condition yielded even greater F-Values for all variables. This suggests that the threshold results I see in the pulsed condition are even less related to variability between subjects and more strongly correlated to frequency and transmittance values.

Again, a regression analysis (estimates of fixed effects) assessed the linear relationship between ear variable and the Békésy continuous data. From this assessment it was demonstrated that the variability seen in the Békésy data can be accounted for by the Hz and transmittance data, which both had large magnitudes of significance. Covariance Parameters for Random Effects can be seen in Table 7 suggesting that the means of subjects differ overall, as expected, but that the transmittance, again, is significant in accounting for the changes in threshold seen for the Békésy data.

Table 7: Estimates of Covariance Parameters

	Estimate	***Standard Error***
Residual	32.8	0.96
Intercept	34.82	15.91
Transmittance	0.64	0.29

Grand Means of the dB SPL data were also obtained. Overall Grand Mean was 7.350 dB. Left and right ear Grand Means were 7.249 dB and 7.446 dB, respectively. Female Grand Mean was 7.197 dB and male Gran Mean was 7.502 dB.

Finally, the residuals were again examined and found to be normal implying that the statistical decisions are correct and that significance results are robust.

The following figures illustrate the results across all subjects as a group and for each subject individually. Visually, it is apparent that there is variability between subjects, which was also suggested by my statistical analysis. Yet, it can also be seen that there is a strong correlation between the dB SPL that is transmitted into the ear and the recorded thresholds in each condition.

Eight of the twelve subjects reported that the Békésy pulsed condition was easier to follow than the Békésy continuous condition.

Figure 1: Overall group data plotted in dB SPL across frequency

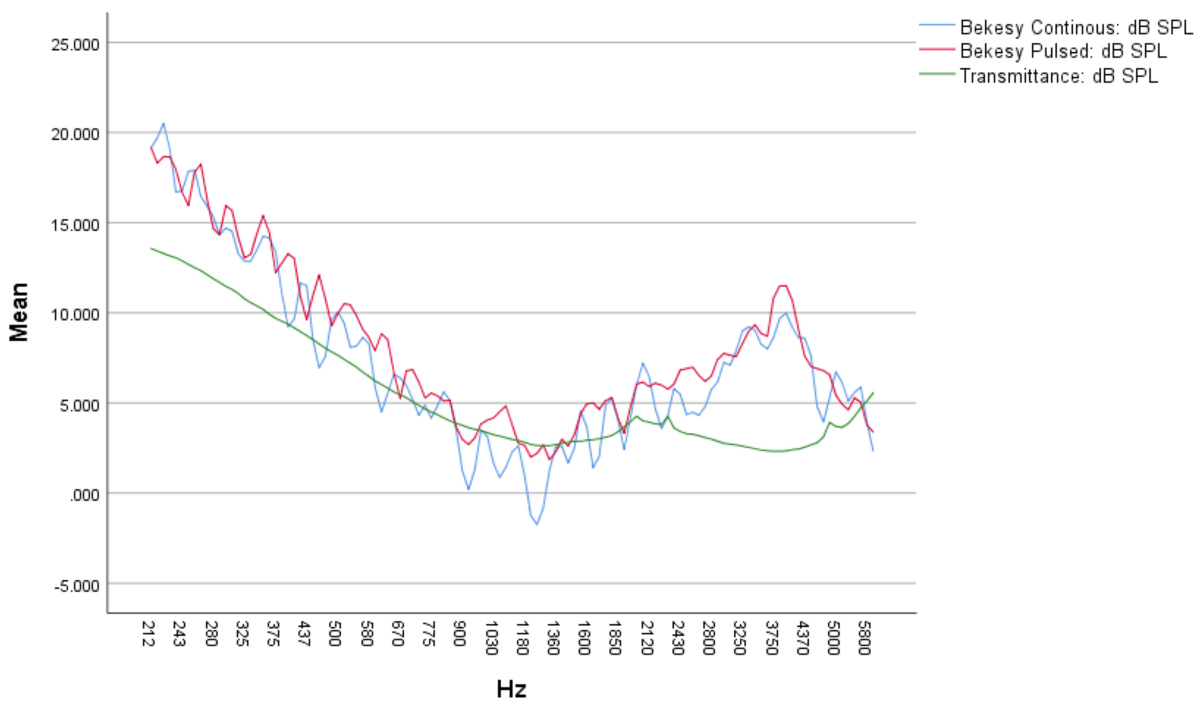


Figure 2: Subject 1 data plotted in dB SPL across frequency.

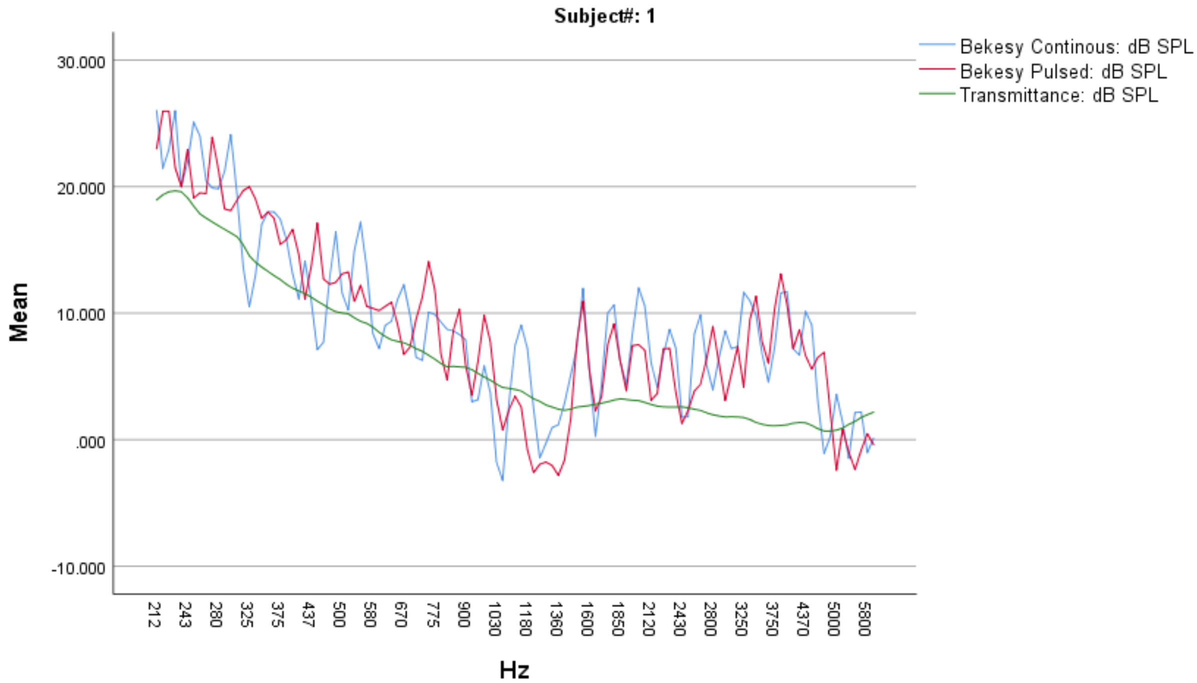


Figure 3: Subject 2 data plotted in dB SPL across frequency.

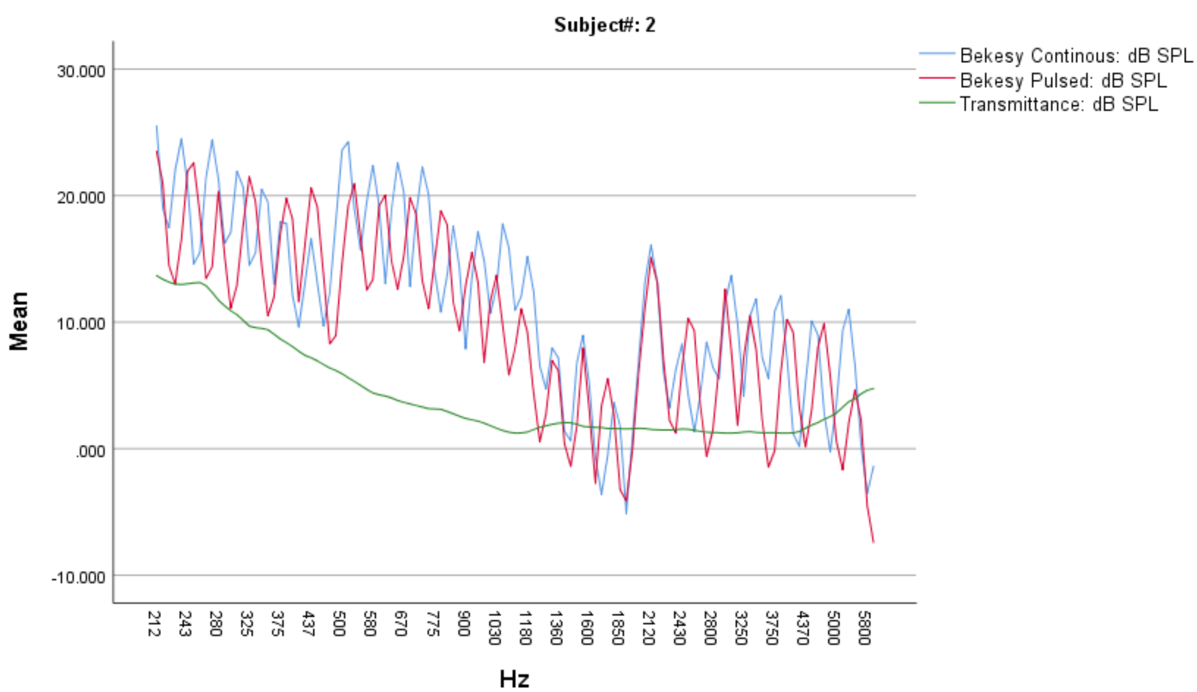


Figure 4: Subject 3 data plotted in dB SPL across frequency.

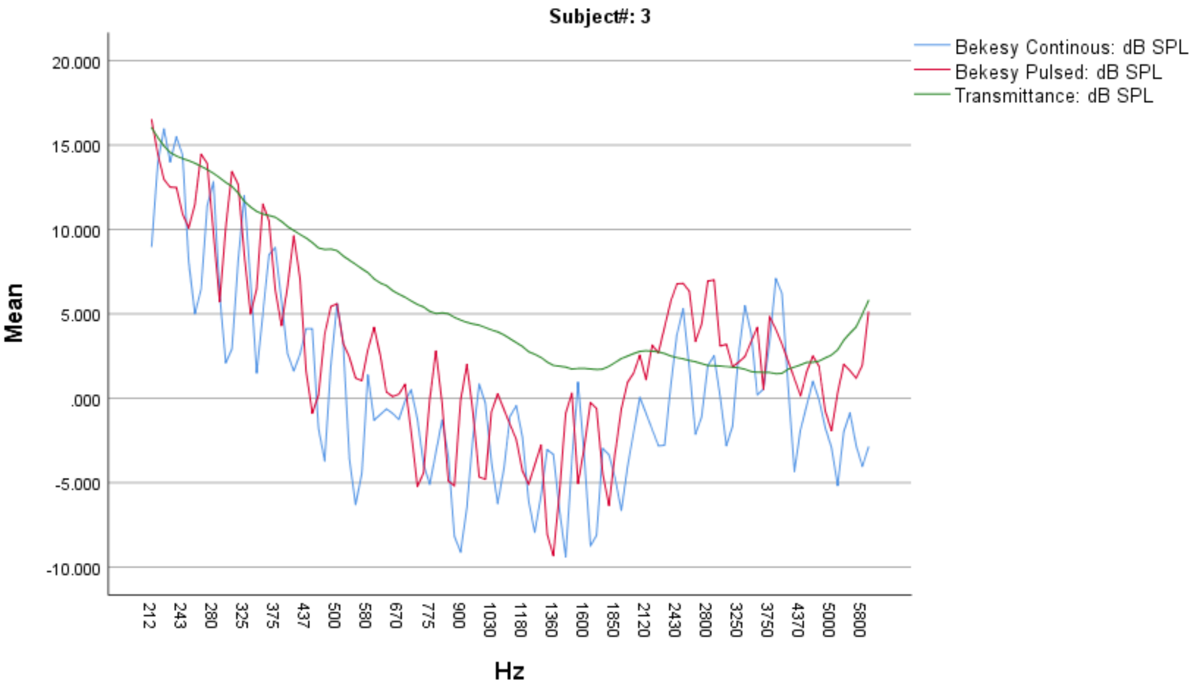


Figure 5: Subject 4 data plotted in dB SPL across frequency.

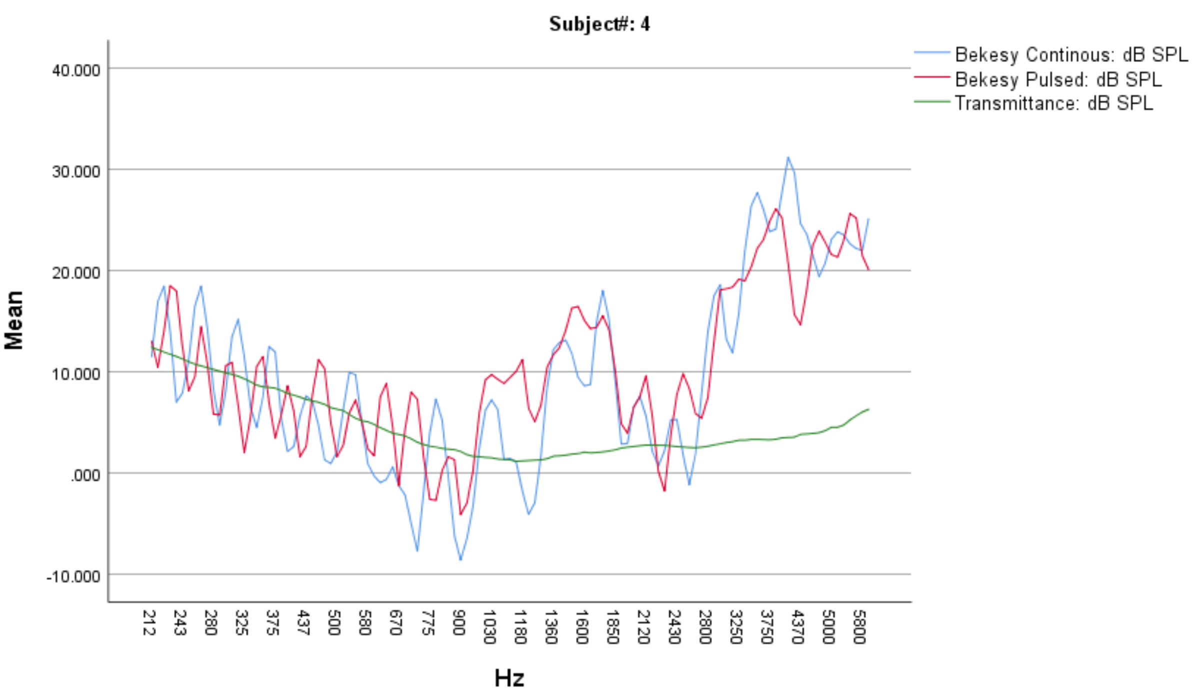


Figure 5: Subject 4 data plotted in dB SPL across frequency.

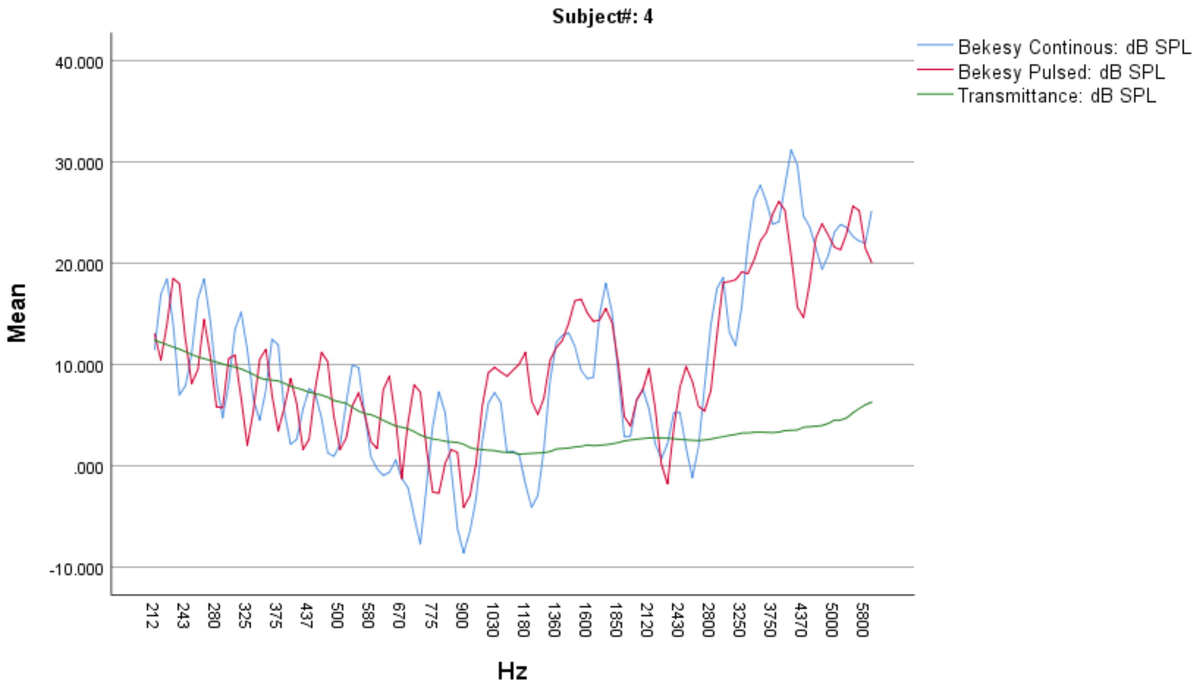


Figure 6: Subject 8 data plotted in dB SPL across frequency.

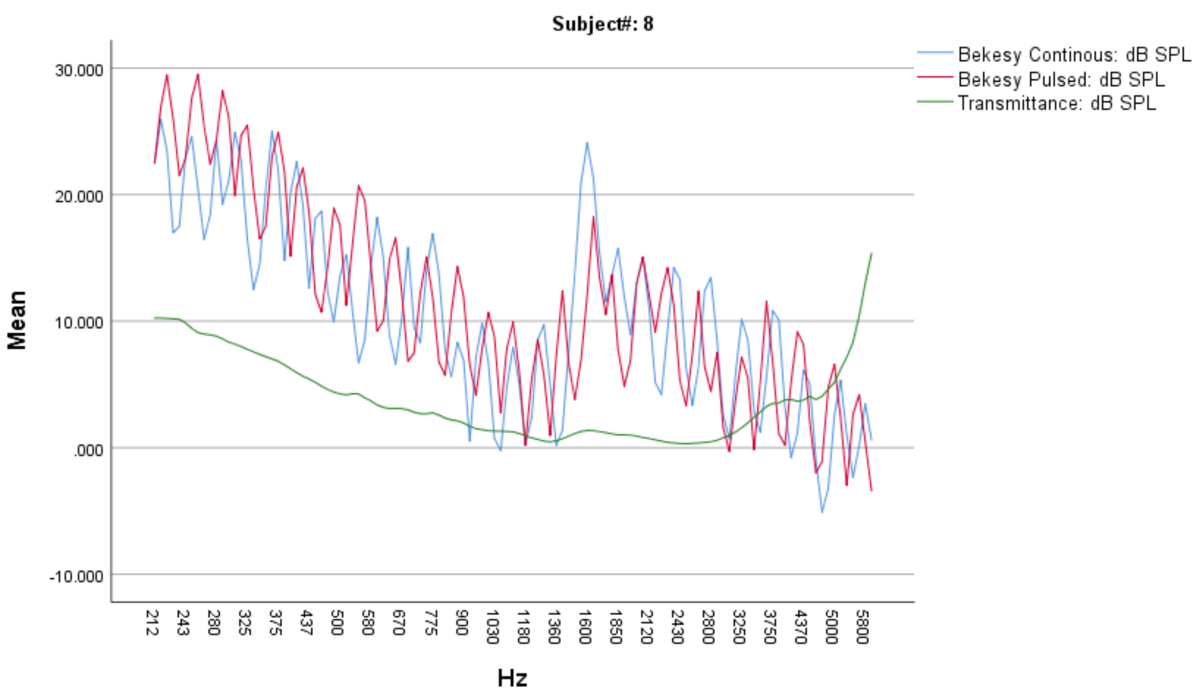


Figure 7: Subject 10 data plotted in dB SPL across frequency.

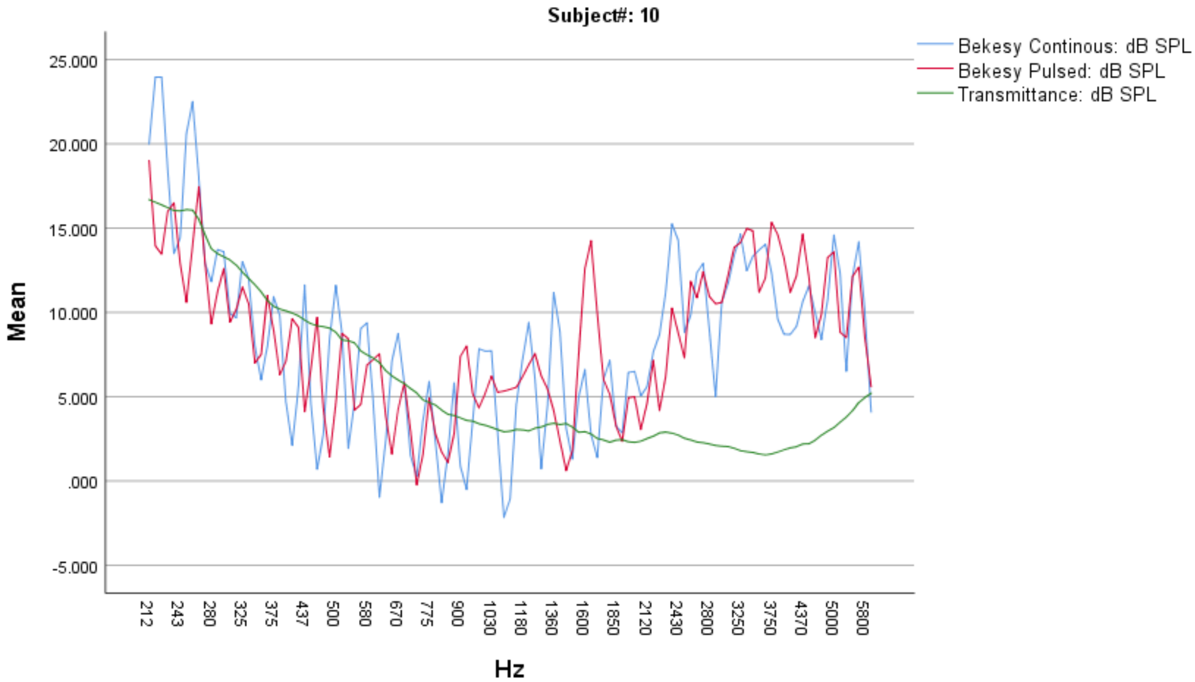


Figure 8: Subject 14 data plotted in dB SPL across frequency.

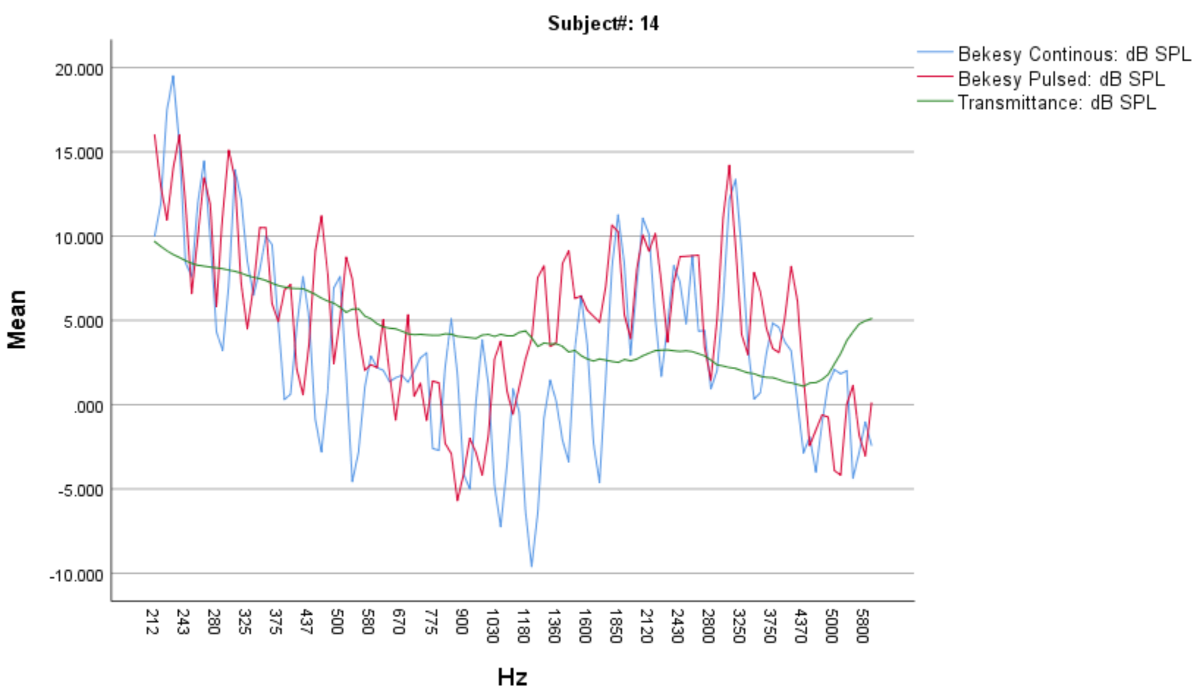


Figure 9: Subject 15 data plotted in dB SPL across frequency.

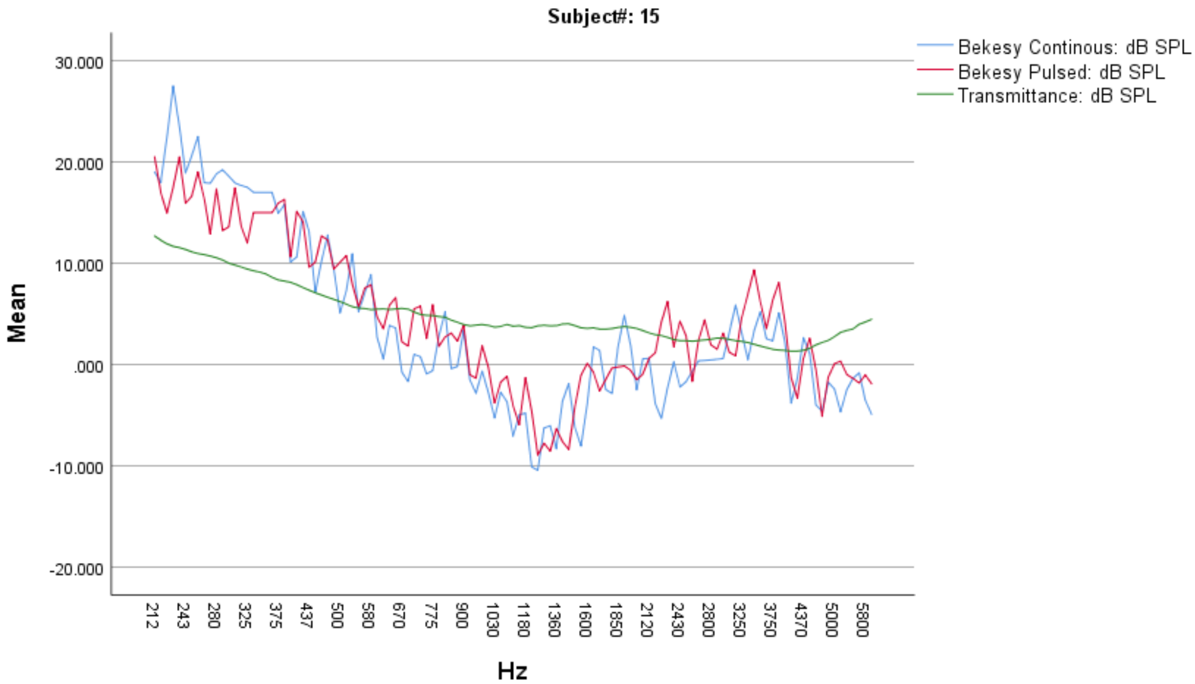


Figure 10: Subject 16 data plotted in dB SPL across frequency.

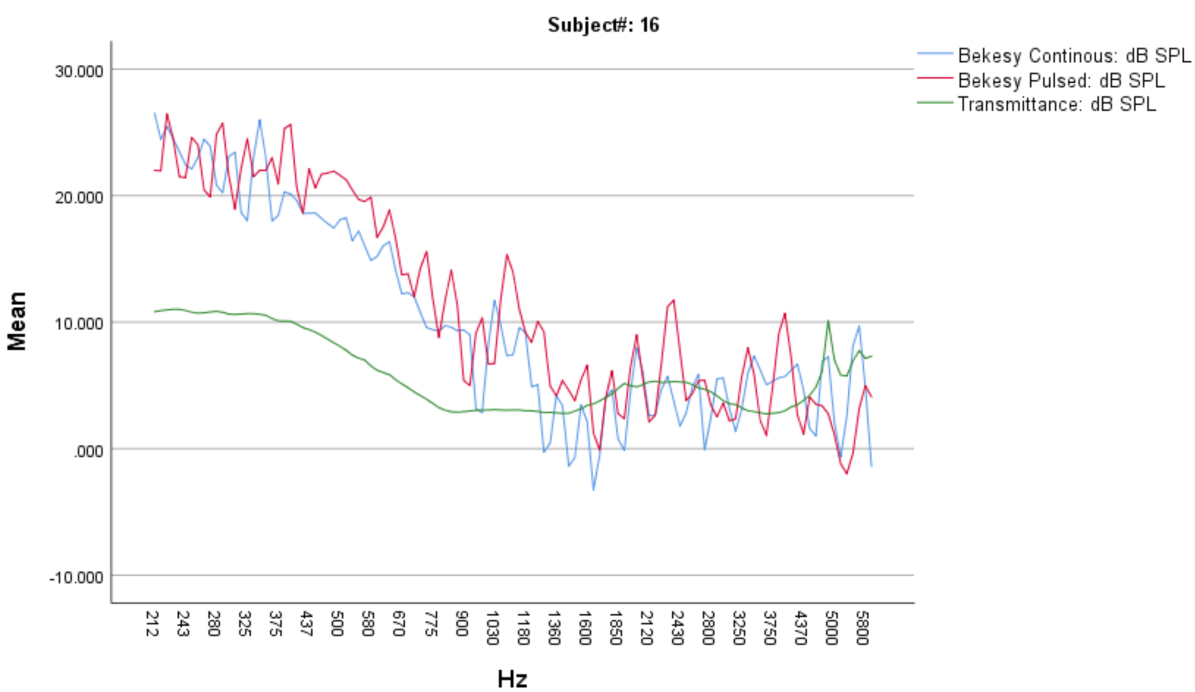


Figure 11: Subject 17 data plotted in dB SPL across frequency.

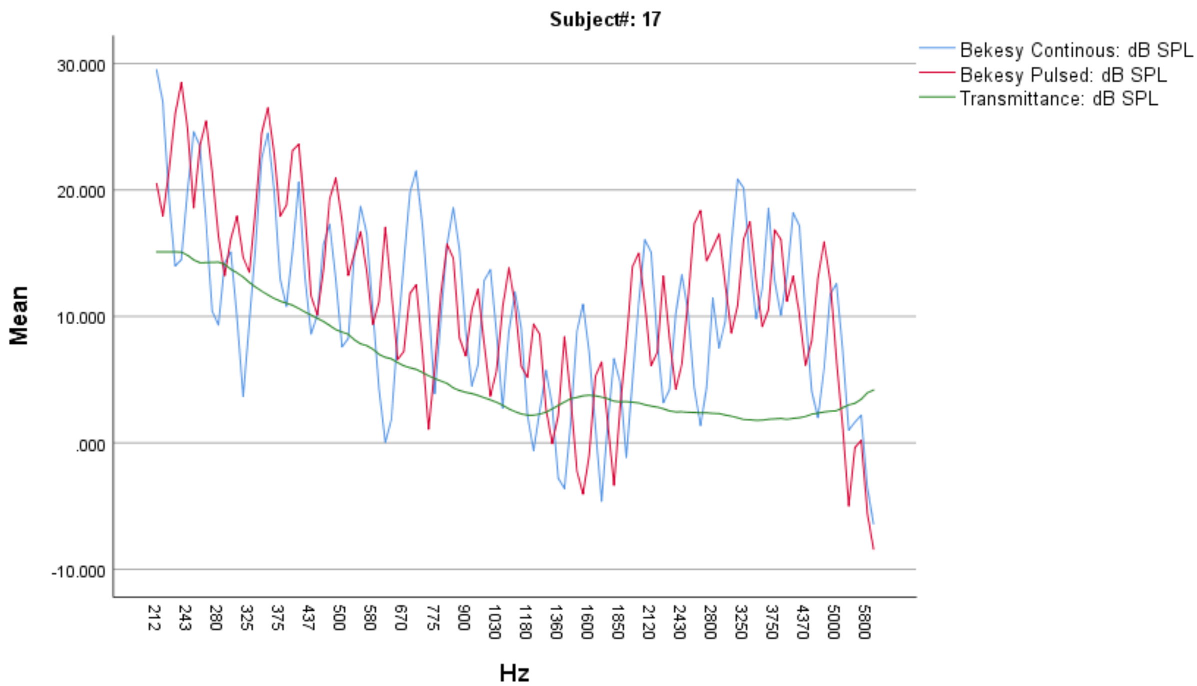


Figure 12: Subject 18 data plotted in dB SPL across frequency.

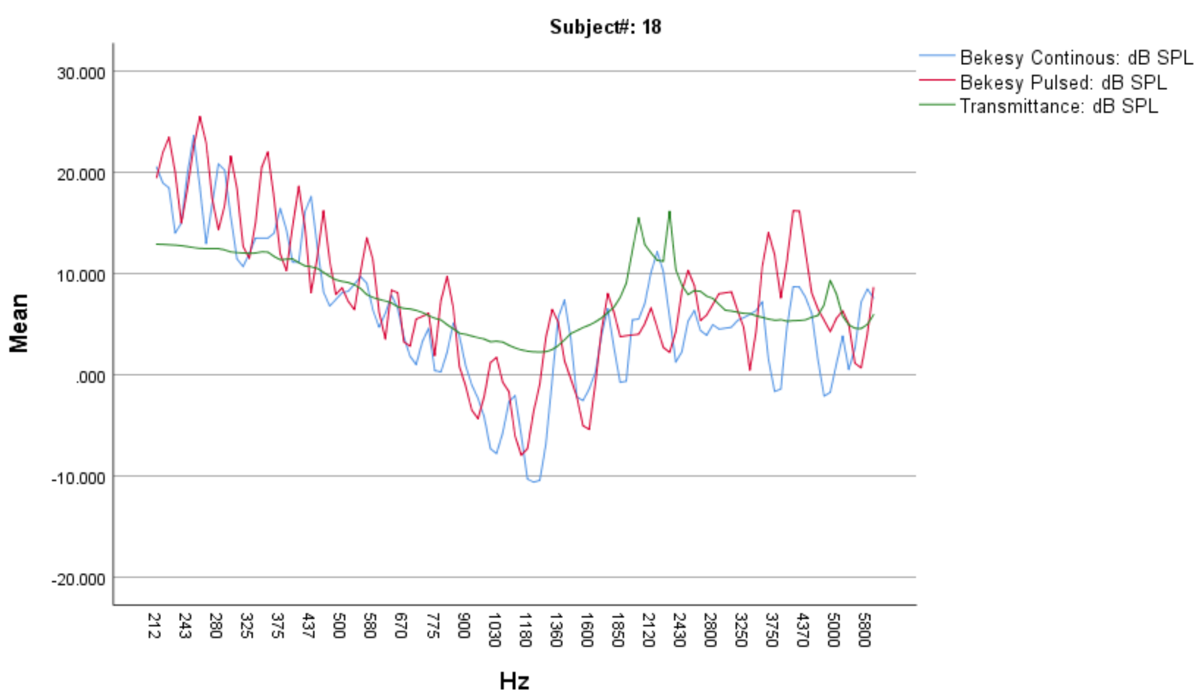
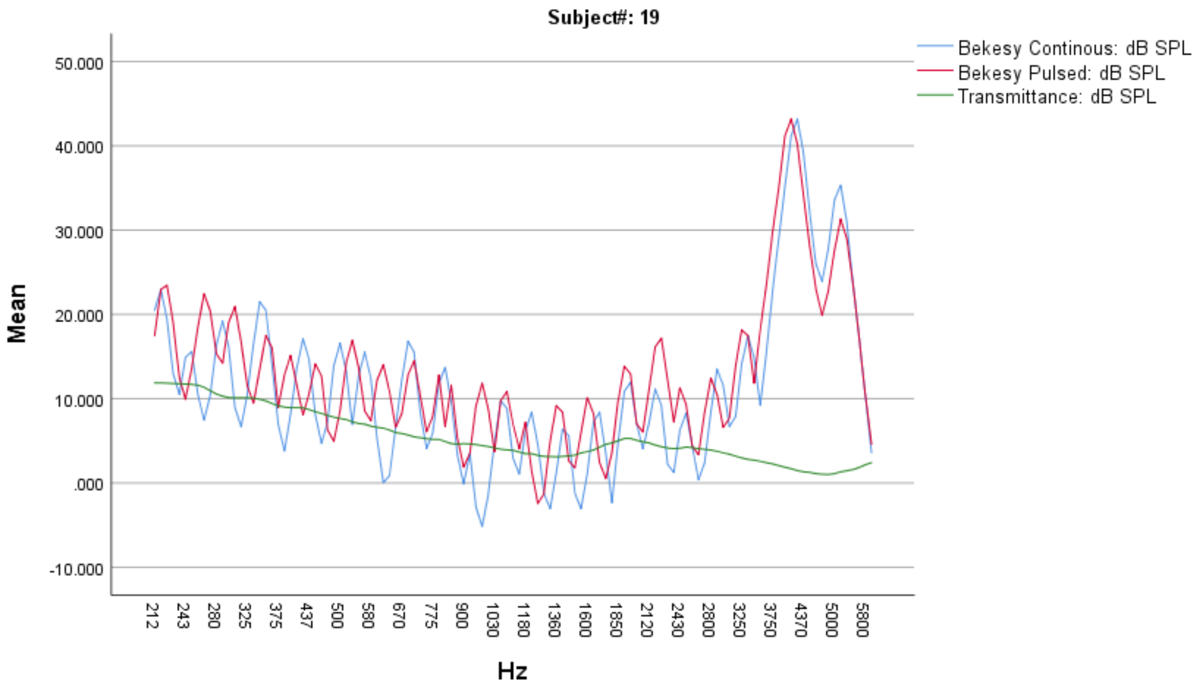


Figure 13: Subject 19 data plotted in dB SPL across frequency.



Discussion

This study examined the relationship between minimum audible pressure curves obtained using Békésy audiometry and transmittance curves obtained using reflectometry. The resulting Békésy data, both in the continuous and puled conditions, can be interpreted as the minimum audible pressure curve for each individual. Similarly, the resulting transmittance curves demonstrate how each participant's ears filtered the broadband stimulus resulting in varying degrees of transmittance across frequency. My data demonstrate that there is a significant relationship between derived minimum audible pressure curves and each individual's natural resonances, as well as when assessed as a group. The MAP curve can thus be interpreted as largely resulting from the influences of the ear canal, tympanic membrane, and middle ear resonances. This would be true for normal hearing individuals.

When examining the data there were several aspects necessitating further explanation. First, the limitations of this study will be discussed in respect to participant-limitations and equipment limitations. It was noted during testing that some participants subjectively appeared more alert than others. The results of those with diminished attention may be seen as the larger excursions for the Békésy traces. Larger excursions in the tracings result in less accurate results, however, as was demonstrated above, the significance of the data is overwhelming. Future investigations in this topic should consider participant rest periods and clear instructions in order to avoid listening fatigue. Additionally, several participants who confirmed that they experienced tinnitus noted that during portions of the Bekesy testing that it was difficult to distinguish the stimulus from their tinnitus. In future studies tinnitus matching procedures may be helpful in assuring accurate threshold measurement or exclusion of participants with tinnius.

Equipment limitations related to several parts of this study. First, my experiment used insert earphones for both the transmittance and the Békésy recordings. It is known that the pinna also contributes to outer ear transfer functions (Møller, 1963), however, due to the limitations in the transmittance equipment's transducer, supra-aural headphones could not be used. Finally, this study was limited to my ability to non-invasively measure outer and middle ear resonance. However, the cochlea and the basilar membrane that resides within it are physical structures that also have mass and stiffness properties that affect the transmittance of sound energy. It would be clarifying to understand how the outer, middle, and inner ears all contribute to the filtering of incoming auditory signals.

Related to the limitations of the transmittance transducer, it is possible that the separation in Bekesy thresholds and the transmittance curve seen in the group data figure as well as several of the individual participant's figures is due to nodes created by the widedband chirp. This can occur at high-frequencies within a closed-closed system, such as an ear canal fit with an insert earphone. Further investigation would be needed to confirm whether this occurs within the ear canal and if it is contributable to the lack of correlation seen between 2500 Hz and 4500 Hz. It should be noted that the internal processing algorithms for the MIMOSA Acoustics HearID® 5.1 system claim that this phenomenon is accounted for during measures.

Interestingly, it appeared that the Békésy pulsed more highly correlated with the transmittance data than the continuous Békésy stimuli. In addition, of the 12 participants whose data were accepted, eight of them reported that the Békésy pulsed condition was easier than the Békésy continuous condition to follow. Also, informal visual assessment of the figures above shows smaller excursions for the Békésy pulsed condition than the Békésy continuous condition. However, these results were not formally assessed and therefore remain as an observation of the investigator. It should also be noted that while the Grand Means across the two conditions were not equal, there is little clinical significance of these differences as the means fall within five dB of one another. It could be helpful in the future to re-examine the Bekesy threshold data with a best-fit polynomial line to address the phase-shifts seen between pulsed and continuous recordings as well as the “chatter” from extraneous excursions.

Future investigations in this topic should consider the speech recognition abilities of individuals with and without activation of the acoustic reflex (AR), as well as how the activation of the AR affects transmittance of sounds into the middle ear. The acoustic reflex refers to the contraction of the stapedius muscle in response to moderately loud sounds (Luscher, 1929; Borg, 1968). The contraction of this muscle changes the stiffness properties of the tympanic membrane and middle ears such that mid and high-frequency sounds are more easily transmitted (Møller, 1962). Further, it can be understood that contraction of this reflex filters out low-frequency sounds in loud environments. It would thus follow that the contraction of the stapedius muscle positively supports speech understanding in noise by decreasing the amount of low frequency interference. Therefore, transmittance curves during activation of the AR should be examined to understand how it contributes to our ability to understand speech when background or other loud noises are present.

In summary, the natural resonances of our outer and middle ears affect the level of incoming acoustic signals across frequency. It is clearly demonstrated by my data that there is a strong relationship between the natural resonances of a person's ear and their hearing thresholds across frequency. It would appear then that our variation in threshold sensitivity across frequency is largely dependent on the resonant properties of the outer and middle ears.

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