International Baccalaureate

EXTENDED ESSAY

Subject: Physics HL

Biomechanical Aspects of the Human Voice Production

Research Question

What are the frequency levels of the head, mixed, and chest voice in individuals, and how can the biomechanical aspects be interpreted based on these frequencies, utilizing voice analysis and existing biomechanical research?

Word Count: 2923

Table of Contents

Introduction

In this Extended Essay, I explore the nexus between speech analysis, human physiology, and biomechanics. By delving into previous biomechanical studies, I aim to extract interpretations and formulas, which will serve as the foundation for my research. My primary objective is to investigate the frequency levels of head, mixed, and chest voices in individuals, and decipher the biomechanical implications inherent in these frequencies.

With a cohort comprising 10 females and 10 males proficient in utilizing their voices professionally, totaling 20 subjects, I will gather 10 samples each of head, mixed, and chest vocalizations from every participant. These vocal samples will undergo meticulous frequency measurements, facilitating the extraction of biomechanical insights regarding the subjects' vocal production mechanisms.

The overarching aim of this study is to ascertain whether it is feasible to delineate a human's vocal tract map solely through the analysis of voice frequencies. However, owing to constraints in resources, the inferences drawn from these measurements will not be supplemented by technical measurements for validation.

The genesis of this research lies in the convergence of my cumulative and specific interests in both art and science. From an early age, I have been deeply involved in acting and vocal arts, with the majority of my future aspirations revolving around these fields. Additionally, my formative experiences have profoundly shaped my worldview. Born prematurely and grappling with health challenges such as HSP disease and a myriad of sports-related injuries, including spine issues and bone fractures, I have developed a deep empathy for individuals facing disabilities. These experiences have fostered within me an erudite fascination with biomechanics, as I seek to comprehend the intricacies of the human body and explore avenues for its enhancement through technology and scientific inquiry.

Literature Review

Previous Studies on Biomechanical Aspects of Vocal Production

Previous studies have investigated the frequency levels of head, mixed, and chest voice in individuals, as well as the biomechanical aspects of these voice types. According to a study published in ScienceDirect, the middle voice (mixed) had greater fundamental-frequency energy than the chest but had less high-frequency harmonic energy than the chest[1]. Another study on the mixed voice explains that it is not a mixture of head and chest, nor is it a separate vocal register. Instead, it is a technique used in the middle of the range to disguise the transition from one vocal mechanism to another[2].

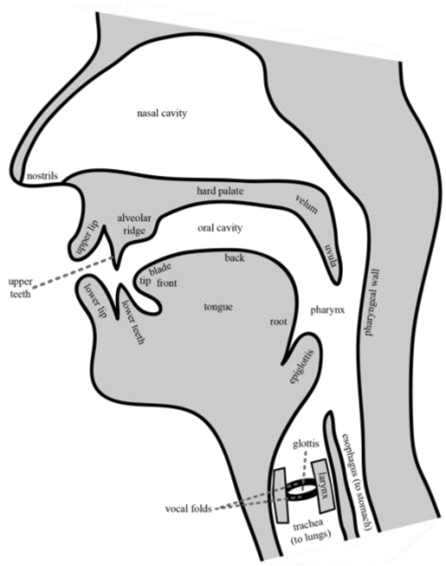

Figure 1: Midsagittal diagram of the human vocal tract.

The biomechanical aspects that affect the frequency of voice include the length, tension, and mass of the vocal folds, the subglottal pressure, the resting glottal angle, and the cricothyroid muscle (CT) and lateral cricoarytenoid (LCA) muscles[3]. The CT muscle, when contracted, pulls the thyroid cartilage, which in turn pulls the vocal folds longer, thinner, and more taut, causing them to vibrate faster and produce higher frequencies[4]. Increasing subglottal pressure can also increase the vibration amplitude and glottal flow amplitude, leading to increased noise production and a reduction in HNR (harmonic-to-noise ratio)[5]. The anterior-posterior (AP) stiffness of the vocal folds can also affect the frequency of voice, with higher stiffness leading to improved excitation of higher-order harmonics in the resulting voice spectra[5]. Additionally, the vocal folds' mass and stiffness can vary along the superior-to-inferior direction, which can affect the frequency and quality of the voice[6].

Deriving Insights from Previous Theses for Application in the Current Study

The Ishizaka and Flanagan biomechanical model (two-mass-model) [7] and its variants have been extensively used to study vocal fold vibrations. It represents each vocal fold as two coupled oscillators. We are using one simplified version, the two-mass-model (2MM) by Steinecke and Herzel [8]. The 2MM accounts for both myoelastic and aerodynamic properties of the vocal folds. Aerodynamic forces from subglottal pressure, described by Bernoulli's law, induce vibrations in masses on both sides. This model simplifies by ignoring interactions of glottal flow with vocal tract structures above and below the glottis, a simplification supported by excised larynx experiments. It also neglects small nonlinear elastic forces and assumes Bernoulli flow predominates beneath the narrowest part of the glottis [8]. Viscous losses within the glottis are disregarded in this simplified model.

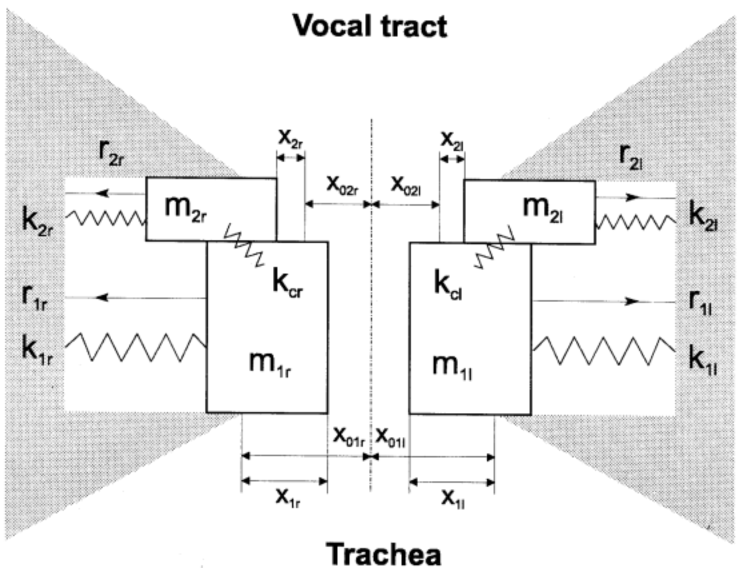

Figure 2: Steinecke and Herzel two-mass-model

The 2MM reflects the most important vibratory patterns of vocal fold oscillations when using the standard parameters presented by Ishizaka and Flanagan [6]. Asymmetry can be imposed by expressing the parameters $m_{i\alpha}$, $k_{i\alpha}$, … in terms of the standard parameters $m_{i\alpha 0}$, $k_{i\alpha 0}$, … by introducing factors Q_r and Q_l which influence the masses and the spring constants [6]. They are defined as follows:

(1)

$$k_{i\alpha} = Q_\alpha k_{i\alpha 0}, \qquad k_{c\alpha} = Q_\alpha k_{c\alpha 0},$$
$$c_{i\alpha} = Q_\alpha c_{i\alpha 0}, \qquad m_{i\alpha} = m_{i\alpha 0}/Q_\alpha.$$

The parameters $c_{i\alpha}$ represent additional stiffness coefficients describing the influence of the impact of the left and right masses [6]. Using the representation from above, the vibratory pattern of the vocal fold oscillations can be described by a set of three parameters: (Q_l, Q_r, P_s).

If Q_l and Q_r are equal, masses and spring constants are symmetric resulting in regular oscillations. If Q_l and Q_r differ from each other oscillations may become asymmetric [6].

As a first approximation for Q_r, Q_l it is possible to use a simple mass-spring oscillator, with mass m, spring constant k, and frequency f [6].

(2)

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}.$$

To adapt the parameters of (2) to the 2MM, we use k1a, m1a, and fa instead of k, m, and f. Additionally, using the relations from (1) we obtain [6]

(3)

$$f_\alpha = \frac{1}{2\pi}\sqrt{\frac{k_{1\alpha}}{m_{1\alpha}}},$$

$$= \frac{1}{2\pi}\sqrt{\frac{Q_\alpha * k_{1\alpha}}{\frac{m_{1\alpha}}{Q_\alpha}}} \Leftrightarrow Q_\alpha = f_\alpha * 2\pi\sqrt{\frac{m_{1\alpha}}{k_{1\alpha}}}.$$

For the sake of this Extended Essay, we will be making our interpretations by using (2), accepting that all the vocal samples represent "healthy voice" with complete laryngeal symmetry ($Q_l^s = Q_r^s = 1$)[6]. Also, to simplify the interpretations (and because we didn't have access to the necessary tools for the measurement) , we will be using the global minimum parameters for airflow and subglottal pressure as 100 m/l and 6.5 cmH_2O respectively.[6] Further development of the research is open for the usage of (3) with the airflow and subglottal pressure parameters being reviewed subject by subject as well, given that the necessary techniques are available. It would benefit for precise estimations of voice disorders.

Methodology

Selection Criteria for Research Subjects

To ensure the reliability and validity of our findings, stringent selection criteria are applied in the recruitment of research subjects. The following criteria delineate the characteristics sought in potential participants:

1. Completion of Vocal Tract Development: Subjects must have completed the developmental stage of their vocal tract, ensuring stability in vocal anatomy and

physiology. It is crucial that participants' vocal mechanisms have reached maturity to minimize variability in vocal production. Given that vocal tract development typically concludes between the ages of 20 to 21, individuals aged 22 and above are considered for participation. This age threshold ensures that participants have reached a stage of vocal maturity conducive to the study's objectives.

2. Absence of Vocal Disorders: Individuals with any vocal disorders or abnormalities are excluded from participation to maintain consistency and accuracy in vocal measurements. This criterion ensures that the data collected accurately reflects the typical functioning of the vocal tract.
3. Professional Voice Utilization: Prospective participants should actively utilize their voices in a professional capacity, such as opera singers, actors, or trained vocalists. This criterion ensures that subjects possess the requisite vocal skills and proficiency necessary for the study's objectives.
4. Training or Experience in Vocal Arts: Preference is given to individuals who have received formal training or education in vocal arts disciplines, such as vocal performance, opera, theater, or singing. This criterion ensures that participants have a foundational understanding of vocal technique and anatomy, enhancing the quality of data collected.

By adhering to these selection criteria, the research aims to recruit a cohort of participants who possess the requisite vocal expertise and physiological characteristics necessary for the comprehensive analysis of vocal frequency levels and biomechanical implications.

Data Collection Process for Vocal Samples

The collection of vocal samples for frequency measurement was conducted meticulously to ensure accuracy and reliability. The following outlines the step-by-step process employed:

1. Selection of Recording Equipment: A semi-professional USB microphone was utilized in conjunction with the "Spectroid" Android application for capturing vocal samples. This combination of hardware and software facilitated precise frequency analysis and data collection.
2. Recording Procedure: Each vocalization, including head, mixed, and chest voices, was recorded for a duration of 5 seconds per instance. This recording duration was chosen to capture a sufficient sample of vocalization while minimizing participant fatigue.
3. Repetition and Consistency: To enhance the robustness of the data set, each vocalization was repeated 10 times by each participant. This repetition ensured consistency in vocal production and provided multiple data points for analysis.
4. Environment Considerations: All recordings were conducted in a controlled environment characterized by minimal background noise and absence of reverberation. This ensured that extraneous factors did not influence the recorded frequencies and maintained the integrity of the data.
5. Data Recording: Following each recording session, the frequencies of the vocal samples were analyzed using the "Spectroid" application in real-time. The frequency measurements for each vocalization were meticulously noted down to facilitate subsequent data analysis.

6. Participant Instructions: Participants were provided with clear instructions regarding vocalization techniques and were encouraged to produce each voice type (head, mixed, chest) with consistency and clarity. Any concerns or queries raised by participants were addressed promptly to ensure optimal recording conditions.

By adhering to this systematic data collection process, the research aims to generate a comprehensive dataset of vocal samples with accurate frequency measurements. This dataset will serve as the basis for the subsequent analysis of biomechanical factors associated with vocal production.

Data Analysis

Presentation of Frequency Measurements for Head, Mixed, and Chest Voices

Table i. - Voice Frequency Table: 10 Male Research Subjects

Individual's Age	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
22	123	170	214
23	132	183	227
26	102	153	198
28	128	177	215
28	137	151	238
31	88	146	184
31	134	179	215
34	94	149	216
35	148	195	253
37	113	157	204
Average Value	≈120, 119.9	166	≈216, 216.4

Table ii. - Voice Frequency Table: 10 Female Research Subjects

Individual's Age	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
23	114	163	215
25	137	197	253
26	142	185	248
26	186	220	274
27	158	208	265

27	145	198	255
27	193	236	291
33	137	174	219
35	161	212	267
36	149	194	248
Average Value	≈152, 152.2	≈199, 198.7	≈254, 253.5

Comparison of Frequency Levels Between Genders

The analysis of frequency levels between genders reveals notable differences in vocal characteristics. Among the male participants, the average frequencies for chest, mixed, and head voices were 120 Hz, 166 Hz, and 216 Hz, respectively. In contrast, female participants exhibited higher average frequencies across all vocal registers, with chest, mixed, and head voices averaging at 152 Hz, 199 Hz, and 254 Hz, respectively. While these values provide insights into gender-specific vocal profiles, it is essential to acknowledge the limitations of the small sample size. General assumptions about gender differences in vocal frequencies should be approached with caution due to the relatively small pool of test subjects. Further research with larger and more diverse participant groups is warranted to validate these findings and elucidate the nuances of gender-related differences in vocal production.

Interpretation of Biomechanical Implications Based on Frequency Data

With the (2), we can interpret the rate of mass to stiffness coefficient of the vocal folds for each individual.

Table iii. – Mass ratio to stiffness coefficient Table: 10 Male Research Subjects

Individual's Age	Chest Voice Ratio	Mixed Voice Ratio	Head Voice Ratio
22	$1.674 * 10^{-6}$	$8.765 * 10^{-7}$	$5.531 * 10^{-7}$
23	$1.454 * 10^{-6}$	$7.564 * 10^{-7}$	$4.916 * 10^{-7}$
26	$2.435 * 10^{-6}$	$1.082 * 10^{-6}$	$6.461 * 10^{-7}$
28	$1.546 * 10^{-6}$	$8.085 * 10^{-7}$	$5.480 * 10^{-7}$
28	$1.350 * 10^{-6}$	$1.111 * 10^{-6}$	$4.472 * 10^{-7}$
31	$3.271 * 10^{-6}$	$1.188 * 10^{-6}$	$7.482 * 10^{-7}$
31	$1.411 * 10^{-6}$	$7.906 * 10^{-7}$	$5.480 * 10^{-7}$
34	$2.867 * 10^{-6}$	$1.141 * 10^{-6}$	$5.430 * 10^{-7}$
35	$1.156 * 10^{-6}$	$6.661 * 10^{-7}$	$3.957 * 10^{-7}$

37	$1.984 * 10^{-6}$	$1.028 * 10^{-7}$	$6.087 * 10^{-7}$

Table iv. – Mass ratio to stiffness coefficient Table: 10 Female Research Subjects

Individual's Age	Chest Voice Ratio	Mixed Voice Ratio	Head Voice Ratio
23	$1.949 * 10^{-6}$	$9.534 * 10^{-7}$	$5.480 * 10^{-7}$
25	$1.350 * 10^{-6}$	$6.527 * 10^{-7}$	$3.957 * 10^{-7}$
26	$1.256 * 10^{-6}$	$7.401 * 10^{-7}$	$4.118 * 10^{-7}$
26	$7.322 * 10^{-7}$	$5.234 * 10^{-7}$	$3.374 * 10^{-7}$
27	$1.015 * 10^{-6}$	$5.855 * 10^{-7}$	$3.607 * 10^{-7}$
27	$1.205 * 10^{-6}$	$6.461 * 10^{-7}$	$3.895 * 10^{-7}$
27	$6.800 * 10^{-7}$	$4.548 * 10^{-7}$	$2.991 * 10^{-7}$
33	$1.350 * 10^{-6}$	$8.366 * 10^{-7}$	$5.281 * 10^{-7}$
35	$9.772 * 10^{-7}$	$5.636 * 10^{-7}$	$3.553 * 10^{-7}$
36	$1.141 * 10^{-6}$	$6.730 * 10^{-7}$	$4.118 * 10^{-7}$

With these calculations, because the mass stays constant, we can write the formula (2) as

(4)

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}},$$

$$2\pi f = \sqrt{\frac{k}{m}}, \qquad 4\pi^2 f^2 = \frac{k}{m}, \qquad m = \frac{k}{4\pi^2 f^2},$$

$$\frac{k_c}{4\pi^2 f_c^2} = \frac{k_m}{4\pi^2 f_m^2} = \frac{k_h}{4\pi^2 f_h^2}.$$

k_c, k_m, and k_h representing the stiffness coefficient and f_c^2, f_m^2, and f_h^2 representing the frequency of chest, mixed, and head voice state respectively. We can simplify the formula as

(5)

$$\frac{k_c}{f_c^2} = \frac{k_m}{f_m^2} = \frac{k_h}{f_h^2}$$

Thus, the gradient of the graph of k and f^2 gives the mass of vocal folds for each individual.

Discussion of any Observed Patterns or Correlations

The observed patterns and correlations suggest that biomechanical factors estimated using consistent methodology exhibit similarities between similar and near frequency levels. However, the most significant correlation identified was with age, indicating that there is almost no relationship between frequency rate and age for an individual.

Discussion

Analysis of the Limitations and Challenges Encountered in the Study

Throughout the research process, several limitations and challenges emerged, impacting various facets of the study. One significant hurdle was the absence of access to specialized technical equipment commonly used in professional voice analysis. This limitation restricted the depth and accuracy of the data collected, as advanced devices were unavailable for precise frequency measurements. Consequently, the estimations made in this research paper couldn't be validated by technical methods and recordings. Another challenge stemmed from the need to coordinate participant availability to ensure an environment conducive to accurate vocal measurements. While a wide network within the performing arts community facilitated the recruitment of suitable participants, scheduling mutually convenient times and locations for data collection sessions proved to be a logistical challenge. This constraint imposed difficulties in data collection efficiency and may have impacted the timeliness of the study. The complexity of the research topic posed inherent challenges in comprehension and analysis. With its focus on biomechanical aspects of voice production and frequency analysis, the subject matter demanded a nuanced understanding of complex theoretical frameworks. The absence of direct access to experts in the field hindered opportunities for clarification and guidance, necessitating self-directed learning and reliance on literature review for comprehension. This limitation may have constrained the depth of analysis and interpretation of findings.Furthermore, the specificity and complexity of the research topic limited access to individuals with expertise who could provide guidance and consultation. The absence of direct access to knowledgeable mentors or collaborators restricted opportunities for discussion, feedback, and validation of methodologies and findings.

Further Implications of the Findings

The research findings could lead to transformative advancements in vocal analysis and diagnostics. If validated, estimations derived from frequency measurements could revolutionize vocal tract modeling and diagnostics. By using artificial intelligence (AI) algorithms, vocal tract maps could be modeled solely based on voice frequencies, streamlining the diagnosis of vocal disorders without the need for specialized equipment. Integration of AI-driven vocal tract modeling into clinical practice could democratize access to voice diagnostics, potentially leading to personalized interventions and improved outcomes for individuals with voice-related concerns.

Conclusion

Summary of Key Findings

The analysis of frequency levels across different vocal registers - chest, mixed, and head voices - revealed distinct characteristics among both male and female participants. On average, male participants demonstrated lower frequencies, with chest voice averaging around 120 Hz, mixed voice at approximately 166 Hz, and head voice at 216 Hz. In contrast, female participants exhibited higher average frequencies, with chest voice around 152 Hz, mixed voice at 199 Hz, and head voice at 254 Hz. These findings suggest gender-based differences in vocal characteristics, with females generally producing higher-pitched voices compared to males. However, the small sample size necessitates caution in making broad generalizations about gender-related differences in vocal production.

Further insights into the biomechanical aspects of vocal production were gained through the interpretation of mass-to-stiffness coefficient ratios. Variations in these ratios across different vocal registers indicate differential stiffness properties of vocal folds during phonation, influencing the observed frequency differences. This highlights the complex interplay between vocal fold structure and function in determining voice characteristics. The interpretation of these ratios provides valuable insights into the underlying biomechanical mechanisms governing vocal frequency production, shedding light on the intricate dynamics of vocal fold oscillations.

The study's methodological rigor ensured the accuracy and reliability of frequency measurements, with meticulous attention to recording procedures, environmental considerations, and participant instructions. By employing a systematic data collection process, the study aimed to minimize variability and bias, thus enhancing the validity of the findings. However, the study's reliance on a relatively small sample size underscores the need for future research with larger and more diverse participant cohorts to validate these findings and explore additional factors influencing vocal biomechanics. Overall, the study contributes to our understanding of the biomechanical aspects of vocal production, laying a foundation for further investigation into the complex dynamics of voice production and its implications for vocal health and performance.

Closing Remarks

Exploring the intricate connection between speech analysis, human physiology, and biomechanics has been a fascinating journey, blending my passions for art and science. By delving into previous studies and employing meticulous methodologies, I've uncovered insights into vocal production mechanisms and gender-specific vocal profiles. Though challenges like limited resources and logistical hurdles arose, the commitment to thoroughness remained steadfast. Despite these obstacles, I hope that this study paves the way for future advancements in vocal analysis and diagnostics.

As I conclude this exploration, I'm reminded of the joy found in unraveling the mysteries of the human voice. This journey has not only deepened my understanding of biomechanics but also highlighted the synergy between art and science.

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Appendices

Raw Data Tables

A. Male Measurements

Table v. - Voice Frequency Table: 22 years old male

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	124	173	211
2	119	168	216
3	126	167	213
4	123	171	213
5	121	169	212
6	127	172	211
7	122	171	216
8	118	169	214
9	125	168	215
10	120	168	215
Average Value	≈123	≈170	≈214

Table vi. - Voice Frequency Table: 23 years old male

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	130	181	230
2	133	184	229
3	128	185	227
4	135	178	224
5	127	187	227
6	134	186	223
7	131	186	231
8	129	179	228
9	136	181	225

10	126	183	226
Average Value	≈132	≈183	227

Table vii. - Voice Frequency Table: 26 years old male

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	97	157	198
2	103	155	201
3	101	152	202
4	100	152	195
5	99	152	197
6	104	154	200
7	98	155	196
8	105	153	199
9	102	152	202
10	96	154	197
Average Value	≈102	≈153	≈198

Table viii. - Voice Frequency Table: 28 years old male - 1

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	130	174	210
2	127	181	216
3	131	178	220
4	123	175	212
5	129	173	214
6	133	179	213
7	126	177	209
8	129	182	217
9	127	176	219
10	122	180	218
Average Value	≈128	≈177	≈215

Table ix. - Voice Frequency Table: 28 years old male - 2

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	136	152	242
2	139	153	233
3	140	150	235
4	138	150	239
5	135	148	241
6	137	149	240
7	134	152	236
8	136	153	237
9	135	151	243
10	137	150	234
Average Value	137	≈151	≈238

Table x. - Voice Frequency Table: 31 years old male - 1

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	87	145	187
2	84	148	183
3	88	142	180
4	86	144	185
5	92	151	182
6	90	144	189
7	86	148	178
8	89	149	183
9	84	141	186
10	91	146	183
Average Value	≈88	≈146	≈184

Table xi. - Voice Frequency Table: 31 years old male - 2

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	129	180	218
2	136	182	214
3	133	175	214
4	130	178	210
5	138	183	220
6	132	176	216
7	135	181	2218
8	131	177	212
9	137	184	211
10	134	173	217
Average Value	134	≈179	≈215

Table xii. - Voice Frequency Table: 34 years old male - 1

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	90	150	219
2	91	146	217
3	96	148	211
4	93	151	222
5	95	148	214
6	94	147	220
7	89	153	213
8	92	149	217
9	96	150	216
10	90	146	218
Average Value	≈94	≈149	≈216

Table xiii. - Voice Frequency Table: 35 years old male

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	147	196	256
2	152	195	252
3	150	194	254
4	147	196	251
5	150	1998	253
6	146	193	252
7	149	197	252
8	152	194	255
9	150	199	251
10	146	196	254
Average Value	≈148	≈195	253

Table xiv. - Voice Frequency Table: 37 years old male

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	111	156	200
2	112	159	205
3	114	158	206
4	113	155	208
5	116	158	201
6	115	154	203
7	114	159	202
8	112	153	209
9	111	161	202
10	110	157	203
Average Value	≈113	157	≈204

B. Female Measurements

Table xv. - Voice Frequency Table: 23 years old female

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	112	164	213
2	117	163	212
3	113	160	217
4	116	166	216
5	110	164	211
6	111	162	219
7	114	165	214
8	119	161	215
9	115	166	216
10	110	162	214
Average Value	≈114	≈163	≈215

Table xvi. - Voice Frequency Table: 25 years old female

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	132	195	253
2	140	196	251
3	135	198	252
4	130	193	256
5	140	194	247
6	130	199	257
7	135	200	249
8	138	196	250
9	142	195	255
10	135	201	254
Average Value	≈137	≈197	253

Table xvii. - Voice Frequency Table: 26 years old female - 1

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	139	183	250
2	141	185	244
3	138	188	252
4	142	181	249
5	143	186	247
6	140	183	252
7	144	189	249
8	141	186	245
9	146	186	246
10	144	184	253
Average Value	≈142	≈185	≈248

Table xviii. - Voice Frequency Table: 26 years old female - 2

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	181	224	279
2	184	219	273
3	185	223	270
4	187	217	280
5	188	221	273
6	185	218	277
7	182	224	268
8	187	216	277
9	189	222	268
10	186	220	276
Average Value	≈186	≈220	≈274

Table xix. - Voice Frequency Table: 27 years old female - 1

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	160	207	265
2	155	209	267
3	161	212	266
4	157	209	262
5	154	206	264
6	162	204	263
7	160	209	263
8	157	210	267
9	159	204	267
10	155	213	265
Average Value	158	≈208	≈265

Table xx. - Voice Frequency Table: 27 years old female - 2

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	147	197	257
2	144	199	257
3	146	202	255
4	144	200	256
5	145	195	255
6	143	196	252
7	146	201	254
8	145	200	253
9	145	198	253
10	147	196	257
Average Value	≈145	≈198	≈255

Table xxi. - Voice Frequency Table: 27 years old female - 3

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	192	241	293
2	192	235	288
3	193	232	288
4	192	234	289
5	201	236	290
6	194	234	292
7	189	236	289
8	191	235	293
9	193	236	291
10	195	238	294
Average Value	≈193	≈236	≈291

Table xxii. - Voice Frequency Table: 33 years old female

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	137	173	217
2	138	175	219
3	141	175	218
4	140	172	222
5	139	175	221
6	137	176	219
7	136	172	221
8	136	174	220
9	138	175	219
10	132	173	217
Average Value	≈137	174	≈219

Table xxiii. - Voice Frequency Table: 35 years old female

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	160	213	267
2	159	211	263
3	162	208	271
4	162	214	261
5	157	207	270
6	159	212	271
7	156	213	269
8	164	210	267
9	162	215	272
10	165	213	262
Average Value	≈161	≈212	≈267

Table xxiv. - Voice Frequency Table: 36 years old female

Measurement Number (#)	Chest Voice (Hz)	Mixed Voice (Hz)	Head Voice (Hz)
1	147	192	244
2	150	192	251
3	149	195	245
4	152	194	246
5	146	196	247
6	149	196	248
7	153	191	250
8	151	194	248
9	150	194	245
10	146	197	253
Average Value	≈149	≈194	≈248