J. Electrical Systems 20-9s (2024): 2419-2425

[1] Anirvan B. Gupta
[2] Sandeep Varpe *
[3] S. M. M. Naidu
[4] Prashant Ahire

Investigating Human Responses to Sinusoidal Tones in the Auditory Channel with Emphasis on Individual Resonance Characteristics

Abstract: - The auditory channel plays a pivotal role in human perception, particularly in decoding emotional signals embedded in speech and music. This research investigates the responses of individuals across various age groups when exposed to sinusoidal tones within the human hearing frequency spectrum. Drawing inspiration from mechanical resonant systems, this study explores the resonance exhibited by the human body's internal cavity when subjected to external frequencies matching its natural resonance. The primary objective is to estimate the resonant frequency of individuals, akin to identifying the frequency at which the human body responds with maximum vibrational amplitude. By studying this resonance phenomenon, the research aims to determine the acoustic environments most conducive to inducing states of contentment, particularly within spaces designated for worship or meditation. Furthermore, the findings of this study hold potential implications for the field of medicine, suggesting that acoustical techniques could be leveraged for therapeutic purposes. Understanding individual resonant frequencies may provide medical practitioners with a novel approach to treating individuals through tailored acoustic interventions.

Keywords: auditory channel; sinusoidal tones, resonant frequency, frequency spectrum; hearing range.

I. INTRODUCTION

In the realm of auditory perception, the intricate interplay between sound waves and the human body's response involves a phenomenon known as ‘resonance’. Technically defined as the synchronization of vibrations between two different bodies at the same frequency or a multiple thereof, resonance in the auditory context signifies the compelling influence that one vibrating entity exerts on another, inducing a harmonious synchronization. In this intricate symphony of vibrations, the secondary vibrator, termed a resonator, is set into motion by the primary vibrator, thereby imparting its unique characteristics to the ensuing sound waves [1].

Within the human body, resonance manifests in two distinct forms: sympathetic resonance and forced resonance, each delineating a nuanced response to acoustic stimuli. Sympathetic resonance encapsulates the phenomenon of free resonance, where the inherent vibrational frequencies of the human body align harmoniously with external stimuli. On the other hand, forced resonance, similar to conductive resonance, explains a scenario in which the human body responds to external vibrations by assuming a synchronized state, influenced by the compelling force of the imposed acoustic frequencies [2].

This study delves into the intricate landscape of human responses to sinusoidal tones within the auditory channel, with a particular focus on the individual resonance characteristics that shape and modulate these responses. By unravelling the complexities of sympathetic and forced resonance in the context of auditory perception, we aim to contribute valuable insights into the fundamental mechanisms governing the interaction between sound waves and the human sensory system. Through empirical investigation and analysis, this research endeavors to shed light on the subtle nuances of resonance within the auditory domain, paving the way for a deeper understanding of the intricate relationship between sound and human perception.

II. METHODOLOGY

1. Participant Selection:

---

[1] School of Basic and Applied Sciences, JSPM University, Pune, Maharashtra, India

[2] Associate Professor, Engineering Sciences, International Institute of Information Technology (I^2IT), Pune, Maharashtra, India. sandeepv@isqaureit.edu.in

[3, 4] Electronics and Telecommunication, International Institute of Information Technology (I^2IT), Pune, Maharashtra, India

* Corresponding Author Email: sandeepv@isqaureit.edu.in

Thirty participants, comprising fifteen males and fifteen females, were recruited for the study. The participants were intentionally selected to represent a diverse range of age groups, spanning from 15 to 55 years, to account for potential variations in resonance characteristics across different life stages.

2. Stimulus Presentation:

Participants were asked to listen to sound notes encompassing a range of frequencies within the human audible spectrum (here the frequency range was taken from 100 Hz to 1000 Hz). The stimuli were generated as sinusoidal tones, and the frequencies were systematically varied to cover the relevant range. Each participant was exposed to these tones in a controlled laboratory setting.

3. Individual Frequency Determination:

During the exposure to different frequencies within the given range, participants were asked to identify a frequency when they subjectively experienced peak vibrations in their bodies. This self-reported frequency, denoted as the resonant frequency for each individual, was carefully noted.

4. Data Collection:

The resonant frequencies identified by each participant were recorded, and the data were organized based on gender and age groups. Statistical analyses were then employed to identify any potential patterns or trends in resonant frequencies across the participant group.

5. Correlation with Resonant Frequency of Inner Cavity:

To infer the resonant frequency of the inner cavity of the human body, the self-reported resonant frequencies were examined collectively. By identifying commonalities or trends among the participants, the study aimed to establish a connection between the individual resonant frequencies and the broader resonant characteristics of the human body's inner cavities.

6. Controls and Variables:

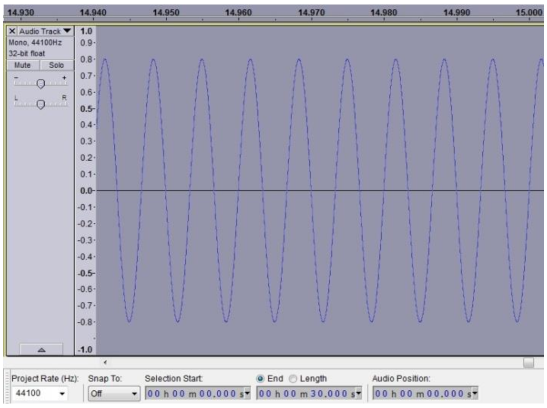
To enhance the rigor of the study, potential confounding variables such as ambient noise levels and individual variations in hearing sensitivity were controlled. Additionally, participants were provided with clear instructions to ensure consistency in reporting their subjective experiences.

7. Ethical Considerations:

This study adhered to ethical guidelines, and informed consent was obtained from all participants. Confidentiality and anonymity of participants were maintained throughout the research process.

8. Data Analysis:

Statistical analyses, including measures of central tendency and dispersion, were applied to examine the distribution of resonant frequencies within the participant group. Correlation analyses were conducted to explore potential relationships between resonant frequencies, gender, and age.



Project Rate (Hz): 44100
Snap To: Off
Selection Start: 00 h 00 m 00.000 s
End: 00 h 00 m 30.000 s
Audio Position: 00 h 00 m 00.000 s

Figure 1: An example of the sinusoidal note illustrating the graphical representation of the sound notes utilized during the experimental process

III. OBJECTIVE MEASUREMENTS

A. Vibratory Sensations within the Human Body

The research began by exposing participants to sinusoidal tones ranging from 100 Hz, using a sampling rate of 44.1 kHz, lasting between 30 and 40 seconds. Notably, subjects were instructed to vocalize the 'OM' sound (or AUM), a ritual linked with stabilizing the brain, clearing unnecessary thoughts, and boosting energy [3]. The act of vocalizing 'OM' triggers vibrations within the body, as airflow manipulated by vibrating vocal cords travels through bones, cartilage, neck and head muscles, and upper chest, causing resonance in these structures [9]. These vibrations act as indicators, providing sensory feedback to the vocalizer regarding the effectiveness of the vocal process. The internal cavity, comprising various vocal resonators, may resonate wholly or partially, and the goal is to determine the specific frequency at which participants feel maximum vibrations.

B. Factors Impacting Vibrational Responses

Various elements can impact the subjective perception of vibrations within the human body. These factors encompass the individual's age, body proportions, emotional state during experimentation, and environmental circumstances. While managing these parameters optimally is complex due to their subjective nature, attempts were made to uphold consistent ambient conditions. Data collection transpired during daylight hours when the sun was at its zenith, and participants were free from physical ailments. Although these factors are not entirely manageable, they could influence the body's cavity, altering its shape, size, and arrangement, potentially leading to fluctuations in resonance frequency.

C. Resonating Structures within the Human Anatomy

The human vocal system encompasses seven distinct resonating chambers: the chest, tracheal tree, larynx, pharynx, oral cavity, nasal cavity, and sinuses [4]. This vocal tract, which is not uniform, spans approximately 175 mm in length in humans and exhibits varying cross-sectional areas controlled during vocalization [7]. Moreover, the nasal passage, with a volume of about 60 cubic centimeters, connects to the vocal tract, where nasal sounds like /m/ and /n/ are produced by the vocal cords and resonate within the nasal cavity. The positions of the tongue and mouth during articulation contribute to distinguishing nasal sounds, with the sealed vocal tract serving as an auxiliary resonator, impacting resonance characteristics for nasal sounds [5]. This intricate anatomical arrangement underscores the complexity of the vocal resonators examined in the study, enriching the investigation of resonant frequencies within the human auditory system.

IV. OBSERVATIONS AND CALCULATIONS

A. Determining the resonant frequency of the human body cavity

In the pursuit of estimating the resonant frequency of the body cavity, a basic model was employed, resembling a hollow tube. This model resembles a tube, which is sealed at one end, specifically the side of the glottis, encompassing the part of the larynx housing the vocal cords and the opening between them, crucial for voice modulation through expansion or contraction. Conversely, the tube remains open at the other end, denoted as the lip end. This simplified representation allows for a focused examination of resonant characteristics.

In this simplified model, the tube is considered narrow relative to the wavelength of sound. This consideration ensures that sound passing through the tube primarily propagates along its length, with negligible spherical propagation effects. By adopting this approach, the study aims to isolate and analyze the resonant frequencies associated with the simplified representation of the body cavity. This focused exploration enables a clearer understanding of the resonance dynamics within the human auditory channel, facilitating the identification of resonant frequencies that may influence individual responses to sinusoidal tones.

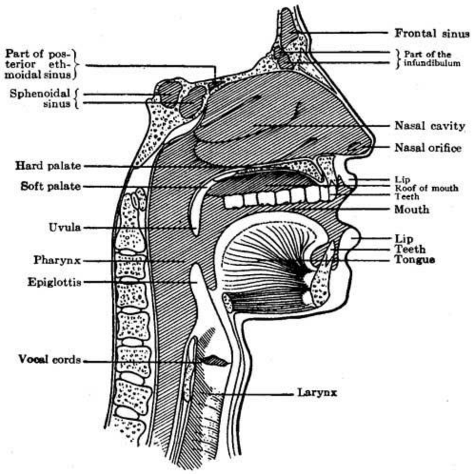


Figure 2: The resonating chamber within the human vocal system [19]

Table 1: Measurement of Resonant Frequency (in Females)

Sr. No.	Height (m)	Weight (kg)	Resonance Frequency (Hz)	Height-to-Weight proportion	Height-to-Resonance Frequency Relation	Weight-to-Resonance Frequency Relation	Body Mass Index (BMI)
1	1.5698	47.3	157	0.0334	0.0100	0.2994	19.0726
2	1.6978	58.4	147	0.0293	0.0115	0.3946	20.1212
3	1.5698	50.1	117	0.0314	0.0134	0.4274	20.2900
4	1.6714	52.6	154	0.0321	0.0109	0.3377	18.6141
5	1.5698	41.2	147	0.0383	0.0107	0.2789	16.6378
6	1.5698	40.3	157	0.0392	0.0100	0.2548	16.2320
7	1.5200	56.3	116	0.0271	0.0131	0.4828	24.2382
8	1.5698	52.5	144	0.0302	0.0109	0.3611	21.1016
9	1.6714	56.6	124	0.0298	0.0135	0.4516	20.0460
10	1.5444	61.1	127	0.0253	0.0122	0.4803	25.5747
11	1.5444	64.7	139	0.0241	0.0111	0.4604	26.8325
12	1.5952	60.2	122	0.0266	0.0131	0.4918	23.5788
13	1.6250	71.3	147	0.0229	0.0111	0.4830	26.8876
14	1.3670	57.0	132	0.0240	0.0104	0.4318	30.5027
15	1.5952	56.2	127	0.0285	0.0126	0.4409	22.0068

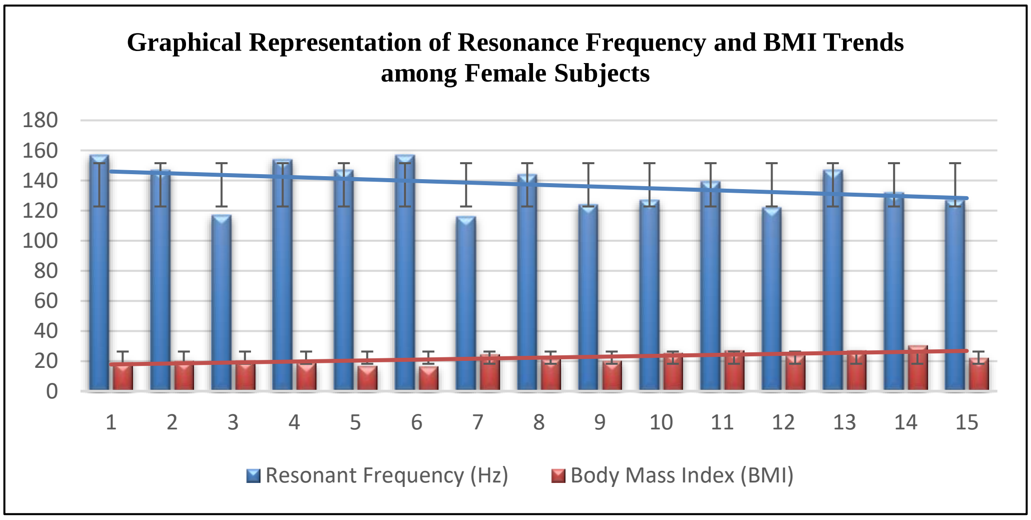


Figure 3: Graphical Representation of Resonance Frequency and BMI Trends among Female Subjects

Table 2: Resonant Frequency Measurement in Males

Sr. No.	Height (m)	Weight (kg)	Resonance Frequency (Hz)	Height-to-Weight proportion	Height-to-Resonance Frequency Relation	Weight-to-Resonance Frequency Relation	Body Mass Index (BMI)
1	1.648	59.3	157	0.0278	0.0105	0.3777	21.8344
2	1.775	72.1	147	0.0246	0.0121	0.4905	22.8843
3	1.7245	70.7	117	0.0244	0.0147	0.6043	23.7735
4	1.7245	73.5	154	0.0235	0.0112	0.4773	24.7150
5	1.707	63.8	147	0.0268	0.0116	0.4340	21.8954
6	1.8005	75.2	157	0.0239	0.0115	0.4790	23.1970
7	1.6228	89.6	116	0.0181	0.0140	0.7724	34.0234
8	1.8005	75.9	144	0.0237	0.0125	0.5271	23.4129
9	1.6735	74.4	124	0.0225	0.0135	0.6000	26.5657
10	1.6735	59.6	127	0.0281	0.0132	0.4693	21.2811
11	1.6735	65.4	139	0.0256	0.0120	0.4705	23.3521
12	1.699	78.8	122	0.0216	0.0139	0.6459	27.2985
13	1.699	92.5	147	0.0184	0.0116	0.6293	32.0446
14	1.699	75.7	132	0.0224	0.0129	0.5735	26.2246
15	1.7245	68.2	127	0.0253	0.0136	0.5370	22.9328

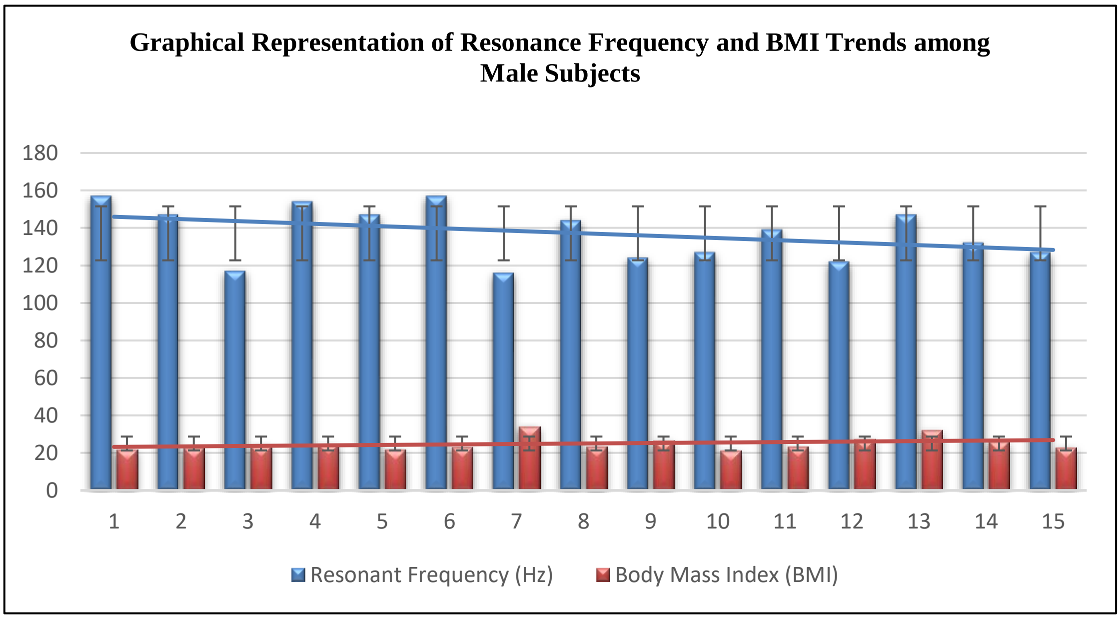


Figure **4:** Graphical Representation of Resonance Frequency and BMI Trends among Male Subjects

B. Mathematical Formulation for Estimation of Resonant Frequency:

The mathematical connection between the wavelength (λ) of sound and its frequency (f) is described by the equation:

$$\boldsymbol{\lambda = \frac{c}{f}}$$

Here, c represents the speed of sound in air, approximately 331 m/s [20].

When considering the body cavity as a closed-end tube, resembling a quarter-wavelength resonator [8], the resonant frequency (f) can be calculated using the formula:

$$f = \frac{c}{\lambda} = \frac{c}{4l}$$

In this formula, (l) denotes the effective length of the tube. For the purposes of this investigation, (l) is estimated as half the distance between the glottis (closed end) and the lips (open end). Upon substituting the provided values:

$$f = \frac{c}{\lambda} = \frac{c}{4l} = \frac{33,100\ cm/s}{4(17.5\ cm)} = 472.86\ Hz$$

It is essential to acknowledge the intricacies of the human vocal tract, which deviate from the simplicity of a closed-end tube. The vocal tract's complexity, shaped by a series of cross-sectional area measurements, introduces modifications that vary across individuals. This variability necessitates a nuanced understanding of the human vocal tract, acknowledging its diverse structures and configurations that contribute to the overall complexity of the resonance dynamics observed in response to sinusoidal tones.

V. RESULTS AND DISCUSSION

The calculated resonant frequencies, as derived from a simplified closed-end tube model, were found to deviate from the resonant frequencies obtained through subjective measurements. This discrepancy suggests that the calculated frequency may represent a harmonic or a multiple of the true resonant frequency observed through individual subjective experiences. Moreover, it is crucial to recognize that the frequencies recorded may encompass either fundamental frequencies or harmonics of the fundamental, with the study's limitations preventing the examination of frequencies below 100 Hz due to constraints in the frequency response of the speakers used.

In the context of the closed-end tube model, where harmonics are odd multiples of the fundamental, the observed resonant frequencies exhibited variation. Figure 3 illustrates a discernible trend, indicating a decrease in resonant frequency with increasing age from 15 to 55 years, coupled with a concurrent rise in body mass index. The x-axis values correspond to distinct age groups, and error bars depict the standard deviation, reflecting the uncertainty or variation associated with the corresponding data points. Additionally, Figure 4 highlights a noteworthy pattern among males, where resonant frequency and body mass index generally increase with age.

Contrary to the anticipated notion that females might exhibit higher tonal frequencies than males, no conclusive evidence supporting this hypothesis emerged from the observations. Further investigation is required to establish any correlation between gender and tonal frequency. Furthermore, tables reveal that an individual's height and weight do not manifest a direct correlation with their resonant frequency.

The study highlights the intricate relationship between sound waves and human perception, with potential implications for various fields. Understanding individual resonant frequencies could give rise to tailored acoustic interventions in medical practices and provide insights into creating acoustically conducive environments for activities like meditation and worship. Further research is warranted to explore correlations between gender, anthropometric parameters, and resonant frequencies in greater depth. The investigation offers valuable insights into the fundamental mechanisms governing human responses to sinusoidal tones and highlights avenues for future exploration in this field of study.

REFERENCES

[1] McKinney, J. C. (1994). *The Diagnosis and Correction of Vocal Faults*. Nashville, Tennessee: Genovex Music Group. ISBN 978-1-56593-940-0.

[2] McCoy, S. (2004). *Your Voice: An Inside View*. Princeton, NJ: Inside View Press.

[3] Gurjar, A., et al. (2009). "*Analysis of Acoustic of OM Chant to Study its Effect on Nervous System.*" International Journal of Computer Science and Network Security, 9(1).

[4] Greene, M. C. L., & Mathieson, L. (1992). "*The Voice and Its Disorders (5th ed).*" Child Language Teaching and Therapy, 8(2), 216–217.

[5] Higashimoto, T., & Sawada, H. (2003). "*A mechanical voice system: construction of vocal cords and its pitch control*."

[6] Institute of Natural Language Processing, University of Stuttgart. [Electronic resource]. Retrieved from https://www.ims.unistuttgart.de/institut/arbeitsgruppen/phonetik/EGG/page10.htm

[7] Fitch, W. (1994). "*Vocal Tract Length Perception and the Evolution of Language.*" Department of Cognitive and Linguistic Sciences, Brown University.

[8] University of Rochester, Department of Physics and Astronomy. [Electronic resource]. Retrieved from http://astro.pas.rochester.edu/~aquillen/phy103/Lectures/C_ColumnAir.pdf

[9] Greene, M. C. L., & Mathieson, L. (2001). *The Voice and its Disorders* (6th ed.). London; Philadelphia: Whurr; John Wiley & Sons. ISBN 978-1-86156-196-1.

[10] Titze, I. R. (1994). *Principles of Voice Production*. Englewood Cliffs, NJ: Prentice Hall.

[11] Sundberg, J. (1987). *The Science of the Singing Voice*. DeKalb, IL: Northern Illinois University Press.

[12] Titze, I. R., & Alipour, F. (2006). *Voice: A Scientific Study of the Human Vocal Instrument*. Salt Lake City, UT: National Center for Voice and Speech.

[13] Kent, R. D., & Read, C. (2002). *Acoustic Analysis of Speech*. Thomson Learning.

[14] Sundberg, J., & Gauffin, J. (1974). "*Articulatory interpretation of the singing formant*." Journal of the Acoustical Society of America, 56(2), 622-630.

[15] Hirano, M. (1981). *Clinical Examination of Voice*. Springer.

[16] Stevens, K. N. (1998). *Acoustic Phonetics*. MIT Press.

[17] Patel, R., & Danis, C. (2006). "*Age and Gender-Related Changes in the Normal Adult Larynx: An Anatomical and Histological Study*." The Laryngoscope, 116(11), 1899-1906.

[18] Jiang, J. J., Zhang, Y., McGilligan, C., & Lim, V. G. (2006). *A study of the complex voice source in running speech*. Journal of the Acoustical Society of America, 119(4), 2262-2271.

[19] Fillebrown, Thomas. (2006) *Resonance in Singing and Speaking.* Boston Oliver Ditson Company, New York, 3rd Ed. pp 7.

[20] Pielemeier, W. (2005). *Velocity of Sound in Air*. The Journal of the Acoustical Society of America. 10 (4). 313-317. 10.1121/1.1915993.