Acoustical Resonance in Humans through Determination of Individual Natural Frequency

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Abstract: ***In the auditory channel, humans are highly attuned to emotional signals in speech and music that arise from shifts in the frequency spectrum and intensity of sound. In this study, responses of human beings from various age groups were observed by exposing them to sinusoidal tones of frequency within human hearing range. Similar to a mechanical resonant system, human body also has an internal cavity, which, when exposed to an external frequency equal to its natural frequency, vibrates with maximum amplitude. An attempt was made to estimate the resonant frequency of an individual. The study is expected to throw light on acoustic environment most suited for an individual to make him realize a state of contentment when he is in an enclosure meant for worship or meditation. The study may also support people from medical background to treat a person through acoustical techniques.***

Keywords: auditory channel; frequency spectrum; hearing range; sound intensity; resonance

1. Introduction

In technical sense, resonance is a relationship that exists between two bodies vibrating at the same frequency or a multiple thereof. In other words, the vibrations emanating from one body cause the other body to start vibrating in tune with it. A resonator may be defined as a second vibrator which is set into motion by the main vibrator and which adds its own characteristics to the generated sound waves [1]. Two kinds of resonance that may occur in human body are: the sympathetic resonance and forced resonance. Sympathetic refers to free resonance while forced resonance refers to conductive resonance [2].

2. Methodology

Thirty subjects, fifteen males and fifteen females, from various age groups from 15 years to 55 years were exposed to sound notes of frequencies in the human audible range. A particular frequency at which an individual experiences maximum vibrations from within was noted. This frequency could then be related to the resonant frequency of the human body's inner cavity.

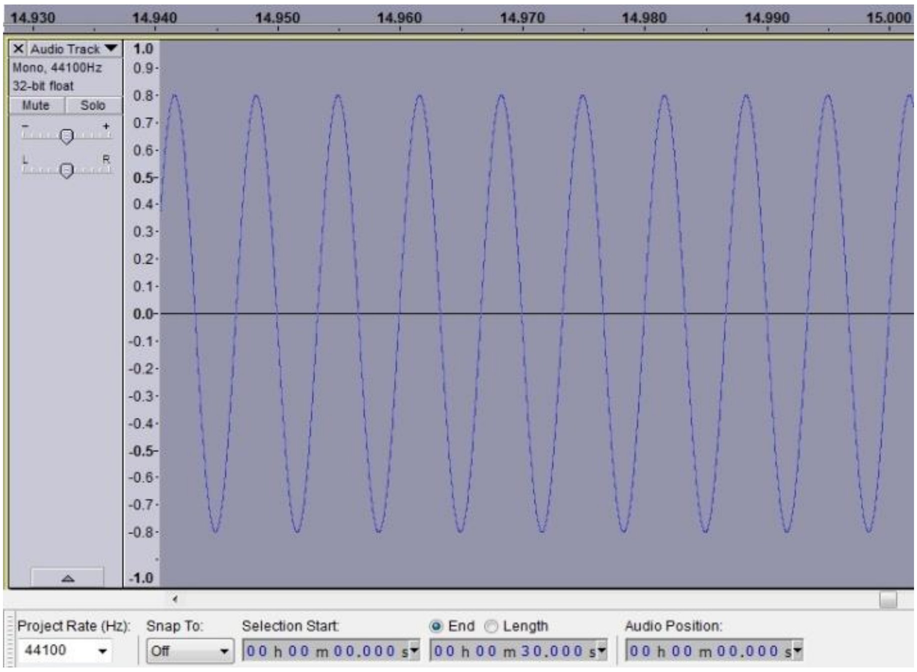

Figure 1: An illustration of the graphical representation of sound note used during experimentation

3. Objective Measurements

3.1 Vibrations within human body

The subjects were exposed to sinusoidal tones of frequency in the range starting from a frequency of 100 Hz. The sampling rate used was 44.1 kHz and lasting for 30 seconds. The subjects were asked to enchant the sound of 'OM' (or AUM). The acoustical significance of enchanting 'OM' lies in the fact that it results in stabilization of brain, removal of unnecessary thoughts and increase of energy [3]. Since subjects were asked to enchant the OM sound, the vibrations felt from within must be forced vibrations. The waves originated by the airflow modulated by the vibrating vocal folds travel along the bones, cartilages, muscles of neck and head, and upper chest, causing them to vibrate by forced resonance [9]. These same forced vibrations may serve as sensation guides for the person, regardless of their effect on external sound. These sensations may provide evidence to the enchanter that their vocal folds are forming strong primary vibrations which are being carried through the chest and head. Thus, these vibratory sensations can supply sensory feedback about the efficiency of the whole phonetory process to the person [6]. The inner cavity may therefore vibrate as a whole or in any of its parts. The vibrations may take place in several ways, all at once. The objective is to find a particular frequency at which maximum vibrations is felt by the subjects.

3.2 Factor affecting vibrations

There are many factors which may affect the vibrations in the human body. Few of them are age of the person, height, weight, physical and emotional condition, season, weather, time of the day, and temperature. Although these parameters are subjective and may not be controlled during experimentation, it has been tried to keep the ambient conditions as close as possible. For this purpose, all the observations were carried out during afternoon, 12.00 pm to 4.00 pm with subjects not suffering from any health ailment during experimentation. These factors would also affect the physical structure of the body cavity such as its shape, size, composition etc. The frequency of resonance may appreciably change by rather small variations in these conditions and parameters.

3.3 Vocal resonators in a human body

There are possible seven vocal resonators in a human body. These are the chest, the tracheal tree, the larynx, the pharynx, the oral cavity, the nasal cavity, and the sinuses [4]. The human vocal tract is a non-uniform tube about 175 mm long in man (this gives the distance between the glottis and the lips) [7]. Its cross-sectional area varies from 0 to 20 cm^2 under the control for vocalization [5]. A nasal tract with a total volume of 60 cm^3 is coupled to the vocal tract. Nasal sounds such as /m/ and /n/ are normally excited by the vocal cords and resonated in the nasal cavity. The soft palate and lips are closed to generate nasal sound. In such cases, sound resonates in the nasal cavity. The closed vocal tract works as a lateral branch resonator and also has effects of resonance characteristics to generate nasal sounds. Based on the difference of articulatory positions of tongue and mouth, the /m/ and /n/ sounds can be distinguished with each other [5].

4. Observations and Calculations

4.1 Estimation of resonant frequency of the body cavity

To estimate the resonant frequency of body cavity, a simplified version of the cavity in the form of a hollow tube, closed at one end (the glottis end - the part of the larynx consisting of the vocal cords and the opening between them. It affects voice modulation through expansion or contraction) and open at other end (the lip end) is approximated. The diameter of such a tube may be considered small compared to the wavelength of sound. Hence, sound through this tube will only propagate down the length of the tube, and any spherical propagation may be ignored.

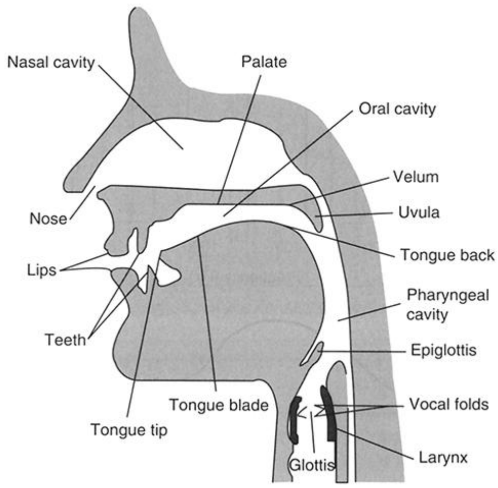

Figure 2: Vocal resonating cavity of a human body (Source :http://www.mtosmt.org/issues/mto.16.22.1/heidemann_examples.php?id=1&nonav=true)

Table 1: Resonant Frequency Measurement in Females

Sr. No.	Height (m)	Weight (kg)	Resonant Frequency (Hz)	Height to Weight Ratio	Height to Resonant Frequency Ratio	Weight to Resonant Frequency Ratio	Body Mass Index (BMI)
1	1.5748	45	155	0.03	0.01	0.29	18.15
2	1.7018	57	145	0.03	0.012	0.393	19.68
3	1.5748	49	115	0.03	0.014	0.426	19.76
4	1.6764	51	152	0.03	0.011	0.336	18.15
5	1.5748	40	145	0.04	0.011	0.276	16.13
6	1.5748	39	155	0.04	0.01	0.252	15.73
7	1.55	55	114	0.03	0.014	0.482	22.89
8	1.5748	51	142	0.03	0.011	0.359	20.56
9	1.6764	55	122	0.03	0.014	0.451	19.57
10	1.5494	60	125	0.03	0.012	0.48	24.99

11	1.5494	63	137	0.02	0.011	0.46	26.24
12	1.6002	59	120	0.03	0.013	0.492	23.04
13	1.63	70	145	0.02	0.011	0.483	26.35
14	1.397	56	130	0.02	0.011	0.431	28.69
15	1.6002	55	125	0.03	0.013	0.44	21.48

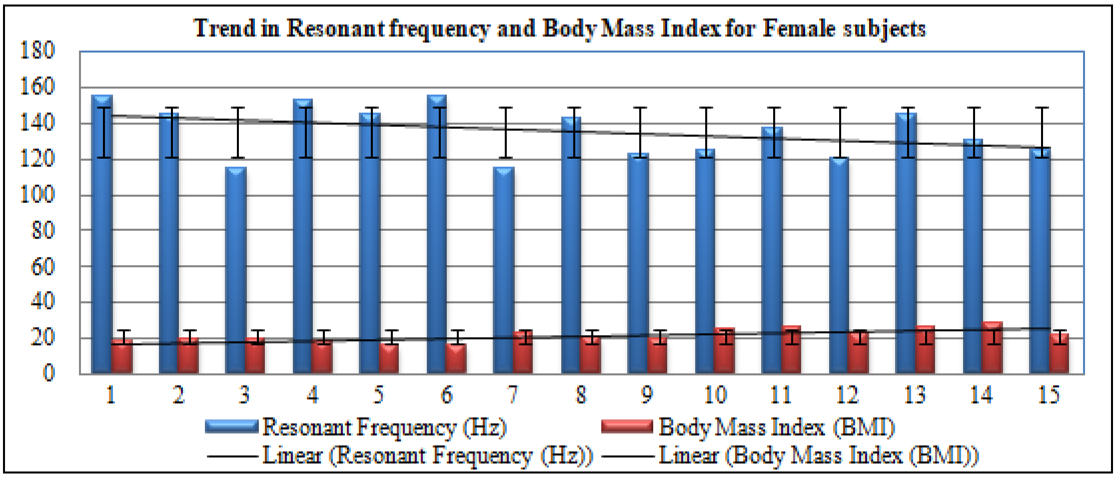

Figure 3: Trend in Resonant frequency and BMI for female subjects

Table 2: Resonant Frequency Measurement in Males

Sr. No.	Height (m)	Weight (kg)	Resonant Frequency (Hz)	Height to Weight Ratio	Height to Resonant Frequency Ratio	Weight to Resonant Frequency Ratio	Body Mass Index (BMI)
1	1.651	57	130	0.03	0.013	0.438	20.91
2	1.778	70	144	0.03	0.012	0.486	22.14
3	1.7272	68	154	0.03	0.011	0.442	22.79
4	1.7272	71	127	0.02	0.014	0.559	23.8
5	1.71	61	152	0.03	0.011	0.401	20.86
6	1.8034	73	153	0.02	0.012	0.477	22.45
7	1.6256	87	145	0.02	0.011	0.6	32.92
8	1.8034	73	138	0.02	0.013	0.529	22.45
9	1.6764	72	144	0.02	0.012	0.5	25.62
10	1.6764	57	155	0.03	0.011	0.368	20.28
11	1.6764	63	145	0.03	0.012	0.434	22.42
12	1.7018	76	153	0.02	0.011	0.497	26.24
13	1.7018	90	155	0.02	0.011	0.581	31.08
14	1.7018	73	128	0.02	0.013	0.57	25.21
15	1.7272	66	141	0.03	0.012	0.468	22.12

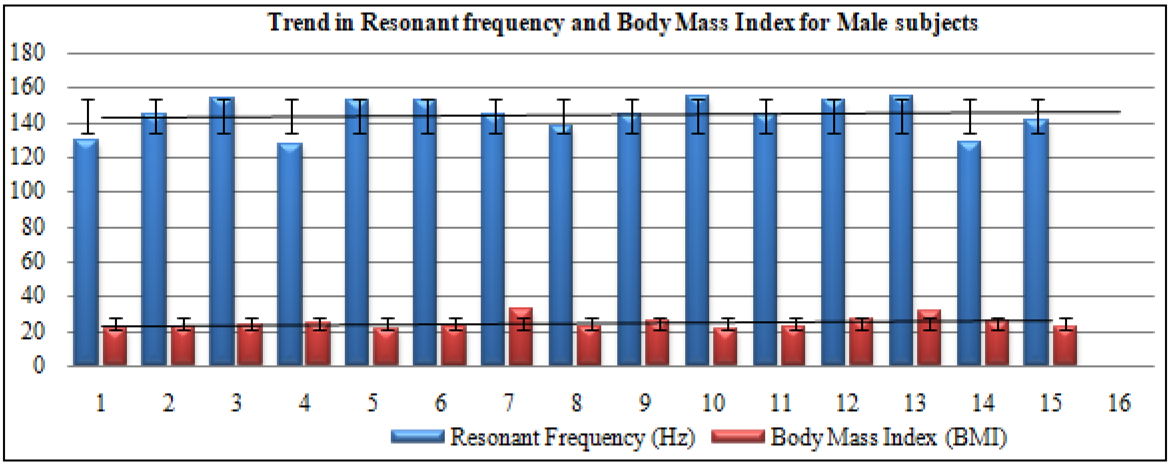

Figure 4: Trend in Resonant frequency and BMI for male subjects.

4.2 Mathematical Formulation

The relation between wavelength of sound and its frequency is given by

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

where,cis the speed of propagation of sound in air (approximately 335 m/s).

Approximating the cavity to be a tube closed at one end, that is a quarter-wavelength resonator [8], the frequency of resonance may be given by

$$f = \frac{c}{\lambda} = \frac{c}{4l} = \frac{33,500\ cm/s}{4(17.5\ cm)} = 478.57\ Hz$$

However, it has to be noted that the human vocal tract is a complex structure, and not a simple tube closed at one end. Its complexity in shape may be described as a series of cross-sectional area measurements. This can be modified in a variety of ways in humans.

5. Results and discussion

It is observed that, the resonant frequencies are different from the above-calculated value. This frequency may be a harmonic to the resonant frequency actually obtained through subjective measurements. It is also to be noted that the frequencies obtained may be either fundamental or any harmonic of the fundamental. Due to limitation on the frequency response of the speakers used, frequencies lower than 100 Hz could not be checked. In case of consideration of tube closed at one end model, the harmonics are all odd multiples of fundamental.

From figure 3 it is observed that the trend for resonant frequency is to decrease with age from 15 years to 55 years, while the body mass index tends to increase. The numbers indicated on the x-axis correspond to age groups of the subjects. The error bar gives the standard deviation of the data sets and represents the uncertainty or variation of the corresponding coordinate of the points. Figure 4 indicates that for males, the resonant frequency and the body mass index generally increases with age.

It is also believed that females in particular, have a tonal frequency higher than males. However, such conclusion could not be drawn from the observations. The tables also show that height and weight of a person do not have a direct correlation to the resonant frequency of an individual. More complex study is needed to develop any correlation between these parameters.

6. Acknowledgement

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