BODY MASS INDEX (BMI) AND ACOUSTIC VOICE PARAMETERS IN INDIAN FEMALES: A CORRELATION STUDY

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A dissertation submitted as a part of fulfillment for the degree of

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CERTIFICATE

This is to certify that this dissertation entitled **"Body Mass Index (BMI) and Acoustic Voice Parameters in Indian Females: A Correlation Study"** is a bonafide work submitted as a part of fulfillment for the Degree of Master of Science (Speech-Language Pathology) of the student with the Registration Number: 18SLP032. This has been carried out under the guidance of a faculty of this institute and has not submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"Body Mass Index (BMI) and Acoustic Voice Parameters in Indian Females: A Correlation Study"** has prepared under my supervision and guidance. It is also been certified that this has not submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"Body Mass Index (BMI) and Acoustic Voice Parameters in Indian Females: A Correlation Study"** is the result of my study under the guidance of Dr. R. Rajasudhakar, Reader in Speech Sciences, Department of Speech-Language Sciences, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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Chapter I

Introduction

Aronson and Bless (2011) defined voice as an "audible sound produced by the larynx, which embodies such parameters as pitch, loudness, quality, and variability." Voice is affected by most of the body systems. Among all the structures, larynx receives the best interest due to its vulnerable characteristics. This cartilaginous structure, the larynx, consists of intrinsic and extrinsic muscles, skeleton and mucosa, and also constitutes vascular, neurological, and other connected structures. Lungs provide a source of air that passes between the vocal folds and supply power for life and voice. The supraglottic cartilaginous structures such as lips, tongue, palate, pharynx, sinuses, and nasal and oral cavity act as resonators for sounds produced at the level of vocal folds. Minor changes in these structures and their interconnections could turn out extensive changes in the quality of voice.

"Your body is the baggage you must carry through life. The more excess the baggage, the shorter the trip" – (Glasgow, 2010)

The human body is composed of many kinds of tissues, as lean or fat; each will change significantly in a brief time, counting on exercise and diet. Once the energy intake exceeds the energy output for an extended period, then the amount of body fatty (adipose) tissue will increase. Lack of exercise in addition to excessive intake of high- energy food is an apparent reason behind fat (Handan et al., 2019). Obesity is considered as a metabolic syndrome; one intriguing potential explanation is that the balance between omega- 6 and omega-3 fatty acid polyunsaturated within the popular food chain has modified (Petersen, 2007). Maintaining a person's weight within 20% of ideal weight is recommended to maintain good health. Above 20%, the increasing weight represents the increase of risk to our body, physically and mentally (Sataloff, 2017). Physiologically, with the impact of estrogen hormone, body fat tissue will increase in females in line with muscle mass at the start of the adolescence period. With aging, a variety of factors like physiological condition (gestation) and climacteric condition (the period of life when fertility and sexual activity are in decline in women, i.e., menopause) may contribute to the current weight increase (Aslan et al., 2019). The prevalence of Obesity condition in the world ranges between 29.4% for men and 53.1% for women (Aslan et al., 2019 and Ogden et al., 2015). The prevalence of fatness is higher among urban populations, high socioeconomic status, and conjointly in South Asian countries. From 1998 to 2018, the incidence of fatness is rapidly increasing as a result of an inactive lifestyle and consumption of high calories food (Ahirwar and Mondal, 2019). Mishra et al. (2018) found urban population was at a higher risk of obesity as compared to the rural community.

Obesity and Voice

The weight will interfere with abdominal breath support for voice production due to elevated adipose tissue around the abdomen and ribs, which results in reduced strength of the respiratory muscle and compliance of chest (Souza and Santos 2018). The deposition of adiposity, and reduction in lumen diameter, cause an endocrine reaction, which increases free fatty acid accumulation in the skeletal muscles resulting in the decrease of glucose intake, conjointly affects endurance and fatigue. In some cases, it's going to conjointly change vocal resonance because the further pounds may considerably reduce the size of the lumen of the pharynx higher than glottis (Takaki et al., 2016). Likewise, being underweight isn't thought of healthy. It will cause poor circulation and psychological distress. Low and high weight usually raises the symptom (Sapienza et al., 2016). Even a moderate degree of obesity could affect the respiratory system adversely, undermining support for speech (Sataloff, 2017). The increase in tissue bulk in the chest wall, neck, and laryngeal airway regions results in excessive fat deposition, i.e., obesity leads to impaired vocalization (Acurio et al., 2014). Also, interfere with the acoustics features of voice (Souza et al., 2014), i.e., fall in fundamental frequency (Souza and Santos, 2018) in obese individuals, but results are contradictory (Acurio et al., 2014).

Takaki et al. (2016) assessed the relationship between BMI and acoustic voice parameters in male and female adults. One hundred and twenty-four individuals between 18 and 45 ages were selected randomly. The BMI (by measuring height and weight) and speech formants (sustained vowels /a/, /i/ and /ɛ/ analyzed using spectrography) were analyzed. They found a direct correlation between BMI and F_3, even though the degree of correlation was low. Also, the association was not significant; the authors believed that there is a relationship that leads to alteration in speech patterns with an increase in body weight. The limited sample size and its inadequate number of subjects in each group were the limitations of the study, as pointed out by the authors.

Souza et al. (2014) found an insignificant difference in mean fundamental frequency in morbidly obese women and control groups. Still, there was a considerable difference between the two groups concerning the maximum phonation time parameter. The authors concluded that increased adipose tissue interfered with vocal parameters in the vocal tract. A similar study carried out in eighty- four adult females aged between 18 and 40 years grouped normal, underweight, overweight, and obese based on BMI classification (Eveleth, 1996) by Souza and Santos (2018). The authors found a statistical difference in the average fundamental frequency between underweight, overweight, and obese and also between normal (non-obese, healthy) and obese participants. The participants in the underweight, normal, and overweight showed higher maximum phonation time than obese with statistical significance. The authors concluded that decreased F_0 values were affected by body weight in obese and overweight individuals. Individuals with obese BMI showed lower MPT, which could have been affected by the enhanced adiposity around the ribs and abdomen, favoring a substantial decrease of this parameter.

Need for the Study

The vocal tract plays an essential role in forming speech sounds; by amplifying specific harmonics and dampening others, which results in the resonance of the sound according to an individual's configuration. Certain factors like body volume or weight and height can influence voice production and cause a change in acoustic parameters. Specifically, individuals with obesity have an abnormal fat deposition in the upper airway, which impedes characteristics of voice (Souza et al., 2014). People with Obese BMI display the following changes in speech characteristics: hoarseness, whispering, vocal instability, modified jitter and shimmer, and the existence of speech strangulation at the end of the emission (Da Cunha et al., 2011). Individual voices with morbid obesity differ from individual voices without obesity and show essential changes in vocal features in both genders (Da Cunha et al., 2011). Individuals with overweight and obesity, a change in acoustic characteristics, mainly decreased F_0 and MPT values have been noticed (Souza and Santos 2018).

In contrast, Mass doesn't contribute to change in F_0 because the vibratory pattern of the vocal folds occurs as a wave, so the movement of the vocal fold is not uniform, and therefore the center of mass cannot be definite. The length, thickness, and depth are the dimensions of the vocal folds, which affect F_0 (Titze, 2011). This view of Titze is supported by other researchers as well. Souza et al., 2014 found a statistically insignificant difference in F_0 of the voice in morbidly obese women and control groups. Similarly, Solomon et al., 2011 did not detect changes in laryngeal airway resistance, and airflow, acoustics, and maximum phonation time for sustained vowel tasks for either group comprising non- obese and obese adults who underwent bariatric surgery.

With the aforementioned review of literature on acoustic parameters and body size, there is a lack of agreement on the absence or presence of a relationship between vocal parameters and body mass or size. Further, studies exploring the influence of obesity on voice features in the Indian population are very spare; particularly, there is a remarkable difference in the physical stature of Indians from the western population. The voice clinician or voice researcher needs to be aware of this relationship for learning and service. Hence the, need for the present study arose. The present study is aimed to investigate the correlation between voice parameters and body mass index in Indian females.

Chapter II

Review of Literature

Phonation is typically due to aerodynamic forces acting at inherently elastic tissue of vocal folds, placing the vocal folds into vibration and developing acoustic energy that's known as 'voice.' The vibration of the structure changes by muscular forces that affect the effective mass and tension of vibrating vocal folds. Phonation for speech is a voluntary behavior, but our body includes continuous modifications in aerodynamic and muscular forces, involuntary reflexes mediated through the nervous system underlying the production of voice ensuing in variations of pitch and loudness produced in non-dysphonic speech and singing. According to Shewell (2009), "Voice is the sound that emerges from the nose or mouth, mechanized by breath, produced by vibration, and shaped by the vocal tract." VOICE is also; shaped by the physical and emotional state of an individual and the situation they speak. In this study, the influence of the physical state is the focus.

Developmental Changes in the Larynx

Various researches are contributing to the adjustments within the larynx throughout the existence span from pediatrics to adulthood and geriatrics. The pediatric larynx is located higher in the neck than an adult, which descends after puberty. Subsequently, the lengthening and widening of the pharynx contribute to modifications in the resonance of the voice. The entire laryngeal framework in children is much softer than in adults, which makes it less vulnerable to blunt trauma. Still, the larynx has a higher risk of disintegrating and leading in the compromise of the airway. The pediatric hyoid bone assumes a much decrease in the vertical role and may overlap the thyroid cartilage. There is no thyroid prominence (Adam's apple) that does not appear until puberty. The angle of the thyroid laminae in the newborn is about 120^0, close to that of an adult female.

Additionally, the cricothyroid space within the developing larynx is a narrow slit and hard to comprehend with palpation. Finally, the length of the vocal fold in the newborn is 2.5 to 3.0 mm (0.1 to 0.2 inches), developing rapidly with puberty and achieving an adult length of about 17 to 21 mm (0.7 to 0.8 inches) in adult men and 11 to 15 mm (0.4 to 0.6 inches) in adult females (Hirano, 1983). The membranous portion of the vocal fold is similar because of the cartilaginous portion. There is no vocal ligament in newborns, with an immature one growing between the ages of 1 to 4 years. The vocal mucosa is thinner in newborns and young children. The lamina propria is a single layer; layers seem between the ages of 6 and 12 years, and an utterly differentiated covering is only apparent after puberty.

As an individual reaches his or her Sixties and beyond, there are structural changes throughout physiological systems, and these changes affect the accuracy, speed, range, endurance, coordination, stability, and strength of muscular movements. A number of the age-associated modifications encompass hardening of the laryngeal cartilages, atrophy, and degeneration of the intrinsic laryngeal muscular tissues, cricoarytenoid joint, glands in laryngeal mucosa, lamina propria, and alterations in the conus elasticus and reduced laryngeal blood flow. These modifications are collectively known as presbylarynx.

Voice Changes across the Life Span

The infant's voice has been advised to generally have expected fundamental frequency within the variety of about 400 to 600 Hz, without a massive, determined difference amongst sexes in the fundamental frequency. Pitch and fundamental frequency gradually lower in each sex in the direction of infancy and through the early life years with the fast adjustments in fundamental frequency taking place in the course of the first four months and 2 to 13 years of age. Fundamental frequency (F_0) generally becomes distinguishable by sex at approximately 11 years and certainly by 13 years. Among females, the F_0 lowers about one octave from birth to puberty, but for males, it drops two octaves. The change in F_0 in males is the result of increased length and mass of the vocal folds. The growth modifications that occur in the larynx at some point of puberty (referred to as a mutation, wherein the neck lengthens, and the larynx descends and grows in length) are accountable for changes in F_0 in both sexes with full variation taking place within 3 to 6 months. As females pass from adolescence into adulthood, mean F_0 tends to be relatively stable within the range of 180 to 230 Hz until the onset of menopause because of hormonal changes, variations in both pitch and the F_0 documented by various authors. Watts and Awan (2019) found females of 18 to 30 years had significantly higher mean F_0 than females in their age of 40s, 50s, 60s, and 70s. At the side of developmental changes, other elements reason changes in a female voice, the maximum frequent of the other reason encompass vocal abuse, allergic reaction, upper respiratory tract infection, and hormonal effect. In conjunction with these causes, the increase in body weight/obesity causes changes in voice, increasing the instability/ variability. Obesity is a result of a long-time discrepancy between energy intake and energy expenditure, which results in the storage of non-essential lipids in adipose cells (American Psychiatric Association, 2013).

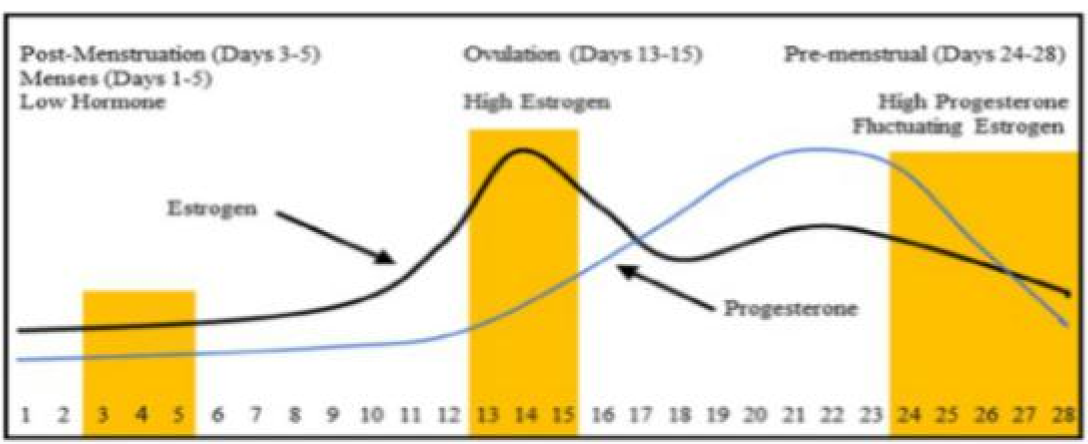
Dynamic Characteristics of the Female Voice

Voice changes associated with sex hormones are frequent in both the sexes and occur throughout life. In females, cyclic voice change and laryngeal change occur with each menstrual cycle, and permanent modifications occur at menopause; hence the prevalence of voice changes and complaints are higher in females. Males undergo a more dramatic initial pubertal voice change, but they have relatively stable circulating levels of sex hormones across the life span and undergo fewer subsequent voice changes. In females, at puberty estrogen and progesterone levels rise, secondary sex characteristics develop, and the menstrual cycle initiated. Throughout a woman's productive life, their voice has cyclic changes in the relative serum concentration of estrogen and progesterone that affects the functions of the larynx. A menstrual cycle is a phenomenon that naturally occurs in females due to changes in hormones, and these changes occur continuously for 28 days (Figure 1). This cycle controlled by a decrease or increase of sex hormones, with primary involvement of estrogen and progesterone hormones.

An increase in the estrogen hormone level produces a hypertrophic effect (increase in muscle mass), increases capillary permeability (and in turn increases the chance of bleeding), and the mucous secretion thickens. The concentration of the hormone estrogen gets decreased at the time of menses duration (days one to four), post-menstrual stage (days five to ten), and pre-menstrual stage (days twenty- three to twenty-eight). The drop in estrogen hormone results in a physiological change through raised tissue permeability, which is mostly edema of the tissues, and this occurs at the initiation and following menses stage (days one to ten). Hormone Progesterone functions as a competitor (an antagonist) of estrogen hormone; it inhibits capillary permeability. As a result of this antagonistic function, cellular congestion increases by trapping intracellular fluids created by estrogen. Hormone Progesterone will increase after ovulation stage (ovulation occurs fourteen days before the menses stage if an individual's average menstrual cycle is twenty- eight days, in that case, that individual will ovulate at around day fourteen) than at the time of menses, and also has an ability of diuretic impact because of its composition it moves on sodium metabolism, consequently decreases secretions ensuing in dryness. Because of the successive pattern and changing concentration of the hormones, the impact on the vocal folds vibratory characteristics will be temporary and mostly evolve all through at particular time intervals of the cycle.

Figure 1

Representation of the Menstrual Cycle.



Source: Kunduk, M., Vansant, M. B., Ikuma, T., & McWhorter, A. (2017). The effects of the menstrual cycle on vibratory characteristics of the vocal folds investigated with high-speed digital imaging. Journal of Voice, 31(2), 182-187.

Kunduk et al. (2017) used digital imaging to investigate the effect of the menstrual cycle on the vocal fold functions in females. The authors collected samples from thirteen female participants aged between 20 and 28 years using the HSV (High-Speed film and Video) equipment. Authors considered samples collected at different stages of the menstrual cycle: pre-menstruation (one to five days before the expected onset of menses; at ovulation stage (between days thirteen and fifteen of the cycle); and post menstruation stage (three to five days of the cycle). A 70° rigid laryngoscope (Model 9106, KayPentax, Montvale, NJ) with HSV system (Model 9700, KayPentax) and a 300-W cold light source (CLV-U20, Olympus America, Center Valley, PA) used for laryngeal examination; the recordings captured at 2000 frames/second for 8 seconds. Participants produced and held /i/ vowel at comfortable pitch and loudness during the examiner positioned the laryngoscope for examination. The acoustic parameters such as Fundamental frequency (F_0 in Hz), Fundamental frequency deviation (F_0 SD in Hz), Harmonics-to-Noise Ratio (HNR in dB), Harmonic Richness Factor (HRF in dB) were analyzed.

Additionally, the authors investigated the interaction between reduced reflux and vocal fold function, using the Reflux Symptoms Index (RSI), and self-rated Perceptual Voice quality Ratings (PVR).   RSI is the 1–10 analog rating scale (where, 1 = best, 10 = worst), and self-rated PVR is a visual analog scale that scores between 0 and 100 (where

100 is the most severe). The authors found young female's vocal cord vibratory behavior did not have a significant difference from one menstrual cycle to the other.

A similar study was carried out by Abitbol et al. (1999), where they aimed at studying voice characteristics at the time of the pre-menstrual phase and ovulation in young women aged between 23 to 26 years. The authors used Spectrographic analysis with the vocal sample of vowel /i/; Stroboscopy for analyzing vibration of the vocal mucosa, and Electrolaryngogram for visual examination of the vocal folds. The authors found the following findings;

- Hypersecretion of mucus on vocal folds of three subjects which caused frequent throat clearing for three to four days at the ovulation phase; this was absent in the rest of the ninety- four participants.
- Mucosal signs (including edema of the vocal mucosa, reduced supraglottic and subglottic secretions which resulted in the dryness of the larynx due to thickened, and diminished glandular and alteration in amplitude).
- Vascular signs noticed among 71 percent of total subjects (including pre-menstrual dilation of micro-ovaries, reactionary edema, submucosal vocal fold hematoma).
- Muscular and mucosal signs in 60% of the subjects (including a decrease in muscle tone, the reduced power of vocal muscle contraction, vocal fold nodule, and posterior chink).
- The loss of harmonics from spectrographic analysis.

Abitbol et al. (1999) documented vocal syndrome in hundred menopause females. They found seventeen subjects had menopause syndromes, including lowered vocal intensity, decreased phonatory range with the inability to produce high notes, vocal fatigue, and loss of timbre in speech and singing. Remaining eighty- three participants showed a slight manifestation of the syndrome mentioned above. The symptoms found in seventeen subjects were progressive and specifically noticed in professional voice users. The stroboscopy findings of these subjects showed unilateral muscular atrophy (in eight out of seventeen participants), vocal fold mucosa thinning, bilateral atrophy (in nine out of seventeen participants), there is a decline in the amplitude of phonation and finally, asymmetry of both vocal folds.

Voice Change and Pregnancy

Disturbances of voice during pregnancy are not uncommon, which is mostly due to sexual hormonal imbalance. The fast-bodily changes that arise all through pregnancy cause significant voice modifications. Estrogen and Progesterone hormones are utmost during the third trimester causing changes in the nasal cavity, gingival region, and laryngeal mucosa. Excessive levels of progesterone decrease the lower esophageal sphincter and gastric motility; and higher intra-abdominal pressure, which tends to exacerbate laryngopharyngeal reflux. Illness of vomiting at some point of the primary trimester also exposes the larynx to belly contents. Abdominal distention all through the later stages of pregnancy interferes with gastric muscle function and interferes in vocal production. Laryngopathia gravidarum is an unprecedented voice disorder of pregnancy-related to preeclampsia. The reason is incompletely understood. The progressive hoarseness in laryngopathia gravidarum is due to edema of the superficial layer of lamina propria, and it resolves unexpectedly after parturition.

According to Shiny Sherlie and Varghese (2012), voice changes during pregnancy are collectively known as Laryngopathia Gravidarum. During pregnancy, abdominal distension interferes with functions of abdominal muscles, which alters phonation mechanics, and creates overuse/ abusive injuries. The primary vocal symptoms include loss of voice and hoarseness. Specifically, singers exhibit a diminished range of pitch and a deeper voice. During this stage, management could be mainly focused on supportive mechanisms (like hydration), and usually, singers advised to refrain from singing till functions of abdominal muscles get back to normal. Laryngopathia Gravidarum typically gets resolved naturally at postpartum due to endocrinologic alterations and return abdominal functions to baseline.

Breastfeeding reasons excessive levels of circulating prolactin, which suppresses healthy female sex hormones. In women who breastfeed, the circulating levels of estrogen and progesterone are similar to the ones observed during menopause. As the frequency of breastfeeding decreases, the prolactin level drops, and the normal menstrual cycle resumes. Common symptom encountered in the course of breastfeeding is mucosal modifications, which include mucous membrane dryness.

Ghaemi et al. (2018) evaluated the vocal changes in three trimesters of Iranian pregnant women. Participants in this study were ninety- three Women in the gestational/ pregnancy period and thirty-one women in the non-gestational period between the ages ranges of 23 to 36 years. Among ninety-three Women in the gestational period, thirtythree were in the first trimester, thirty-one in the second trimester, and twenty-nine in the third trimester of their gestational periods. Exclusion factors for the participants included a history of upper and lower respiratory tract infection, laryngeal surgery, head, and neck radiotherapy, smoking, and endocrinological issues. Among the 93 Women in the gestational period, five in the first trimester, four in the second trimester, and ten in the third trimester had Gastroesophageal reflux disorder (GERD), and nausea was common in the first trimester. In this study, authors have carried out both subjective and objective evaluation. In this study, authors have used a rigid 70^0 telescope (KarlStorzTelecamDXII, Tuttlingen, Germany) for endoscopic examination, including vocal fold and its closure patterns and mobility span of the vocal folds. They recorded vocal signals using an AKGD5 dynamic microphone (AKG, Vienna, Austria) placed at 10 cm distance from the mouth, and subjects produced the vowel /a/ as long as possible twice. The authors have taken the longest duration among them for MPT.

Similarly, subjects produced /s/ and /z/ with two repetitions, the analysis had done with the longest among them. Subsequently, the subjective evaluation was done using the Persian versions of VHIP-30, which consists of 30 questions and scored between 0 (meaning never) and 4 (meaning always). Authors have used SPSS Version17.0 (IBM, USA) for statistical analysis.

From this study, authors have found, the absence of significant difference among women of the control group, first-trimester, and second-trimester groups, and, but decreased MPT showed a substantial difference between third-trimester women and other groups. In laryngeal findings, the authors found diffuse laryngeal edema and vocal fold edema, and it was not significant. They did not see a difference in acoustic measures (F_0, jitter, shimmer, and HNR) between the groups. This acoustic finding is in high consensus with other supporting studies documented in their work. In subjective evaluation, authors used a self-rated questionnaire, Persian versions of VHIP-30; the result revealed that women in the third trimester had a higher score with a significant difference as they reported more difficulties than other groups due to their voice quality. This study directs to investigate further voice changes across the span of pregnancy, carrying out a longitudinal study. In parallel to the changes as mentioned above, women develop vocal changes due to constriction of the airway at the level of source and passage by varying reasons among which Obesity is common in the present scenario.

Obesity

Obesity is one of the globally faced significant problems of well- being or health. The rise in obesity is a severe rising concern, especially in developing and underdeveloped nations. In the last 30 years, the rate of obesity has increased by 40% (Engin, 2017). Because of differences in behavioral characteristics (e.g., unavailability of meals for the duration of childhood and inadequate physical activity) and organic characteristics (e.g., hormonal imbalance), females are at higher risk of being underweight, obese and overweight in comparison to their male opposite numbers (Kanter and Caballero, 2012). The percentage of overweight/obesity in women is increasing in the maximum among the Low- and Middle-Income Countries (LMICs) (Ng et al., 2014). The prevalence of obesity/overweight in the Bangladesh population varied from 9 to 39% (Chowdhury et al., 2018). The socio-demographic factors such as education, watching television, marital status, age, wealth index, the status of employment, and residency are associated with increased overweight and obesity. The effect of extreme obesity on mortality is more significant among younger than older adults. Obesity is associated with an elevated risk of several cancer types. The co-morbidities associated with obesity are cardiovascular, musculoskeletal, metabolic, endocrine, psycho-emotional diseases, and undoubtedly many more. Henceforth, obesity is associated with a substantial reduction in life expectancy as a result of this obesity gains the attention of medical requirements at foremost to attain medical stability for livelihood.

Further, the human body is composed of many kinds of tissues, as lean or fat; each will change significantly in a brief time, counting on exercise and diet. Once the energy intake exceeds the energy output for an extended period, then the amount of body fatty (adipose) tissue will increase. Lack of exercise in addition to excessive intake of high- energy food is an apparent reason behind fat (Handan et al., 2019). Obesity is a metabolic syndrome; one intriguing potential explanation is that the balance between omega- 6 and omega-3 fatty acid polyunsaturates within the popular food chain has modified (Petersen, 2007). For an individual to be healthy, the weight maintained within 20% of the ideal weight is optimal. Above 20 %, the increasing weight represents the increase in risk to our body, physically and mentally (Sataloff, 2017). Physiologically, with the impact of estrogen hormone, body fat tissue will increase in females in line with muscle mass at the start of the adolescence period. With aging, a variety of factors like physiological condition (gestation) and climacteric condition (menopause is the period of life when fertility and sexual activity declines in women) may contribute to current weight increase (Aslan et al., 2019).

The weight will interfere with abdominal breath support for voice production as a result of increased adipose tissue in and around the abdomen and ribs, also reduction in the compliance of chest wall movement and strength of the respiratory muscle (Souza and Santos, 2018). The fatty adiposity deposition, along with the decrease in the diameter of the lumen, results in an endocrine reaction, which raises the accumulation of fatty acid in skeletal muscles resulting in the reduction of glucose intake, conjointly affects endurance and fatigue. In some cases, it is going to conjointly change vocal resonance because the further pounds may considerably scale back lumen of the pharynx higher than glottis (Takaki et al., 2016). Likewise, being underweight is not thought of healthy. It will cause poor circulation and psychological distress. Low and high weight usually intensities the symptom (Sapienza et al., 2018). Even a moderate degree of obesity could affect the respiratory system adversely, undermining support (Sataloff, 2017).

Prevalence Studies

Hah et al. (2015) intended to establish the prevalence of laryngeal disease and risk factors in the general population; and also, to compare the incidence of vocal complaints between both sexes individually for the different laryngeal disease. Data collected from the Korean National Health and Nutrition Examination Surveys (KNHANES) during 2008– 2011 by the Centers for Disease Control and Prevention of Korea population using stratified, multistage clustered sampling. Out of 31,217 participants, individuals below nineteen and young children (n =57,778) were missing cases as their data was not part of the survey. The participants who declined to undergo laryngoscopy examination (n=53,803) and those individuals who did not provide data about education, income status, smoking, alcohol consumption, pulmonary tuberculosis, asthma, and allergic rhinitis history (n=5,597) were excluded from the study. Hence, the authors continued this study with 19,039 participants (8,195 males and 10,844 females) between 19 to 97 years. By using KNHANES's weighted values from the data, authors estimated the prevalence and odds ratios (AORs), representing a total of 30,471,019 subjects (15,101,064 males, 49.6% and 15,369,955 females, 50.4%). An Otolaryngologist examined each participant using a 70^0 rigid endoscope. The organic laryngeal conditions evaluated include epiglottic cyst, vocal nodule, vocal polyp, vocal cord paralysis, vocal cyst, Reinke's edema, sulcus vocalis, contact granuloma, hyperkeratosis, laryngitis, laryngeal papilloma, and laryngeal cancer. Related factors included in this study are as follows

- Body mass index (BMI)**:** BMI groups devised as low BMI, <18.5 kg/m^2; normal BMI, 18.5–25 kg/m^2; and high BMI, -25 kg/m^2 based on The Asia-Pacific perspective: Redefining Obesity and its Treatment (WHO, 2000)
- Monthly income: Based on Organization for Economic Cooperation and Development, 2009, participant's household income divided by the square root of the number of household members; monthly income subdivided into lowest, low-middle, upper-middle, and highest quartile
- Educational level: This factor classified as low education group (Uneducated and those who had graduated only from elementary or middle schools) the middle group (with high school and junior college graduation) and the high group (graduate school and college graduates)

- Alcohol consumption: Alcohol consumption was divided into the following three categories: < once a month; 1–4 times a month; and >twice per week
- Smoking status: was divided into < 5-lifetime packs (100 cigarettes) smoked, and ≥5-lifetime packs smoked,
- History of pulmonary tuberculosis, asthma, and allergic rhinitis evaluated with a questionnaire and based on the diagnostic history provided by a medical doctor.

The authors found that Laryngitis was a common disease, followed by Reinke's edema, vocal nodules, and vocal polyp. The laryngeal disorders' significance was higher in males than in females; < 35% of patients had voice problems with the history of laryngeal disease. But, participants' subjective voice complaints were significantly higher in females than in males concerning laryngitis, vocal nodules, Reinke's edema, hyperkeratosis, and vocal cyst. And the male population showed a higher number concerning laryngeal cancer. The authors found a Reinke's edema, vocal cyst, vocal fold palsy, sulcus vocalis, laryngitis, and laryngeal cancer were positively associated with aging. Even though females were negatively associated with laryngitis, the adjusted prevalence and odds ratios (AORs) for gender did not show the significance of other diseases. Authors also found the association between BMI and smoking and various laryngeal conditions namely

- Low BMI group and vocal nodules are inversely associated
- The low BMI group had decreased airway resistance (where the air passes through the cavity with ease)

- High BMI group and laryngitis are positively associated. And further, as obesity increased the risk of laryngopharyngeal reflux increased causing inflammation of the larynx (Saruc et al., 2012), thus increasing laryngitis risk
- Smoking is positively associated with an epiglottic cyst, Reinke's edema, vocal polyp, hyperkeratosis, and laryngeal cancer
- History of tuberculosis adversely associated with Reinke's edema; allergic rhinitis was positively related to vocal nodules, laryngitis, and epiglottic cyst and negatively associated with the vocal polyp
- A higher educational level and vocal nodules were positively associated
- Alcohol consumption was not associated with any laryngeal condition
- Authors have pointed absence of association between asthma and laryngeal diseases;
- Formation of the vocal nodule and epiglottic cyst due to allergic rhinitis, which induces throat clearing and chronic upper airway irrigation

The limitations of this study are the lack of objective voice analysis and participant medication history. Additionally, the authors could have considered occupation as one of the related variables and the psychological factors as well. They should have included self- reporting questionnaire. As the age group is large from 19 to 90 years, neurological aspects (including degenerative condition, autoimmune conditions, and other related elements) should have taken into consideration.

Parimalavalli and Kowsalya (2015) conducted a cross-sectional study using anthropometric measurements to find the overweight/ obese prevalence in adolescents between 11- 15 years in rural and urban areas of Salem District, Tamil Nadu.

Anthropometric measurements are a series of quantitative measures of the bone, muscle, and adipose tissue, which used to assess the body composition. The core factors of anthropometry are body circumference (waist, hip, and limbs), height, weight, BMI, and skinfold thickness. In this study, subjects were grouped based on age and specific percentile of BMI using the CDC (Centers for Disease Control and Prevention) BMI-Age growth chart (Mei et al., 2002). Based on this chart, underweight is less than or equal to age-specific 5th percentile; normal weight is between 5th and 85th age-specific percentile; overweight is between 85th and 95th percentile, and Obesity is at 95th percentile and above. Circumference measure of waist and hip obtained using a measuring tape to calculate Waist Hip Ratio. This study has indicated a higher prevalence of overweight/obesity found in rural girls (15.88%) than urban girls (13.74%) than boys (12.18%) in rural areas and (10.45%) metropolitan areas. The authors also found a lower prevalence of overweight/ obesity in boys than girls. The highest prevalence of overweight/obese noticed in 14 years in rural boys (15.76%) and 13 years (12.40%) in urban boys.

On the contrary, the highest prevalence of overweight/obesity seen in urban girls at fourteen years (22.72%) and thirteen years (20.83%) in rural areas. They concluded that weight had a significant positive correlation with BMI, and other anthropometric measurements had no significant relation with BMI of the urban overweight /obese girls. The height and weight of rural overweight/obese girls had a significant positive correlation with BMI. However, waist circumference, hip circumference, and Waist Hip Ratio (WHR) had no significant association with BMI.

Al Kibria et al. (2019) studied the prevalence and elements related to underweight and overweight or obesity among the Indian women between 15 to 49 years. The data for this study obtained from the National Family Health Survey (NFHS- 4) (2015- 2016). Authors have used BMI cut-offs of the World Health Organization and BMI for the Asian population (WHO, 2004). Based on Asian cut-offs, the prevalence of underweight, overweight and obesity was 22.9%, 22.6% (95% CI: 22.5–22.8), 10.7% (95% CI: 10.5–10.8), respectively. Based on WHO cut-offs, 15.5% (95% CI: 15.4–15.7) was underweight prevalence, and 5.1% (95% CI: 5.0–5.3) overweight prevalence. Compared to Asian and WHO cut-offs, the Asian cut-offs are more apt to use in the Indian scenario as the range of each severity is lower, which would help to identify risk factors much earlier. The underweight prevalence declined with an increase in age, while obese/ obesity prevalence increased with age as per each cut- off. They observed a higher incidence of overweight and obesity among using hormonal contraceptive users; at the underweight prevalence was better hormonal contraceptive non- users. The three backward classes (i.e., scheduled caste, scheduled tribe, and other backward classes) showed an increased occurrence of underweight. However, other backward classes showed an increase in the prevalence of obesity, according to both Asian and WHO cut-offs. The people with overweight/weight problems were higher in urban areas than rural areas as per each cut-off. The underweight prevalence was higher in rural areas as compared to urban areas (26.8% vs. 15.5%).

Magnetic Resonance Imaging (MRI) and Fat Deposition

Many researchers studied vocal tract shape in subjects with obesity based on the information of the pathogenic role of Obesity among patients with Obstructive Sleep

Apnea (OSA). Horner et al. (1989) compared the deposition of fat around the upper airway among individuals with obese BMI with a positive history of OSA and weight-matched control individuals without OSA using MRI, considering the site(s) and size(s) of fat deposits. The authors found excessive fat deposition at various locations of the vocal tract was lesser in individuals without OSA. MRI showed the absence of fat deposition in the oropharyngeal region. But, they found adiposity deposition in areas of the palate, pharyngeal region, and anterior to the laryngopharyngeal space in all subjects; additionally, this was significantly higher for individuals with obesity. Also, the fat found within the tongue was 40% to 50% of the total participants with OSA.

Obesity and Voice

Bosso et al. (2019) aimed to find the voice characteristics of individuals with morbid obesity. In this study, the authors have grouped the participants under two groups, namely, the Obese group and the Control group. The first (Obese) group consisted of twenty- seven women selected between the age of 26 to 59 years, were chosen for bariatric surgery whose BMI was above 35 kg/m^2 or 40 kg/m^2, which was one of the inclusion Standard established by the Federation Medical Committee. Similarly, the second (control) group consisted of twenty- seven women with ideal height and weight, who’s BMI, was less than 24.99 kg/ m^2. Each participant underwent an audiological evaluation; participants with a threshold below 40 dB NA and tympanometric curve type A were included in this study. Exclusion criteria included any laryngeal trauma or lesions and with the history of smoking. In this study, authors have investigated the following voice characteristics using four parameters:

- Questionnaire: This parameter contained information on demographic data, co-morbid features, everyday health habits, profession, vocal, and respiratory symptoms.
- Voice self-assessment: For self- evaluation authors have used Voice Related Quality of Life (VRQOL), which consisted of 10 questions, answers recorded from 1 (never happens and not a problem) to 5 (it always happens and is a bad problem). The questionnaire rating ranged from 0 to 100; higher scores indicate poor quality of life. And the Voice Disadvantage Index questionnaire (VDI) was used; it consists of 30 items, the highest rating of the VDI is 120 points, and the higher the score indicates a greater handicap.
- Auditory-perceptual vocal evaluation: Authors used the GRBASI scale to evaluate the vocal perceptual parameters such as Grade (G), Roughness (R), Breathiness (B), Asteny (A), Strain (S), Instability (I). Three independent Voice assessment specialists who were blind in this study analyzed the samples. The score given for the sample was between 0 (no change) and 3 (severe change) for each of the parameters.
- Acoustic vocal analysis: For acoustic analysis authors recorded, the voice of the participants with a microcomputer in the Multidimensional Voice Program software (Kay- PENTAX), Tokyo (Japan), fixed to the standard sound table. The voice sample collected was prolongation of vowel / a /, / i /, / s / and / z / for the maximum duration that they are able to prolong.
- Video-laryngoscopic evaluation: An Otorhinolaryngologist measured this parameter, using the rigid telescope (Asap), 70°, 8 mm in diameter coupled

with a multifunctional system (video system type XE-30, Eco X -TFT / USB, Germany) with image registration.

The authors found the participants in the control group had no co-morbidities or clinically noticeable symptoms. The results have shown the prominent clinical signs found in the obese group were voice and gastroesophageal symptoms. Some of the recorded vocal symptoms were secretion, tiredness when speaking, chronic cough, the effort to speaking and difficulty in high pitched sounds. The VRQOL and VDI questionnaires did not indicate any negative impact of voice on self, others, and everyday activities. In the auditory -perceptual evaluation, scores of the participants in the obese group were between 0 and 1, wherein the participants of the control group scored 0 in all the parameters except the 'grade' parameter. Roughness, breathiness, strain, and instability parameters showed a difference between the groups, which was statistically significant. The s / z index for the obese group is 1.03, and for the control group is 0.89 because the duration of /z/ was different among groups. In acoustic voice measure, the obese group had lower values, which was statistically insignificant. But the SPI and NHR parameters had a significant difference between the groups. The video laryngoscopy examinations showed the normal study in 92.5% of participants in the control group, and only 55.5 % of participants in the obese group (remaining 44.5% had posterior commissure hypertrophy, mid-posterior bowing vocal fold, and vocal fold edema).

To conclude, the authors found GERD symptoms as the main co-morbidity reported by 22% of individuals with obesity and is associated with increased abdominal pressure. The gastric content, composition of pepsins and acid, arises at esophagus and larynx, resulting in inflammation of the mucosal membranes, occurrence of infections, and mucosal erosion lining. Posterior pachydermia (posterior commissure hypertrophy) finding was present in most of the participants in the obese group (33.3%). The auditory-perceptual voice analyses showed worsening scores for the participants in the obese group, especially for the parameters R, B, S, and I parameters, due to the compensation mechanism of the larynx and vocal tract, certainly for the continuous emission of airflow. The participants in the obese group have more difficulty in producing and maintaining airflow due to adiposity deposition in the cervical and abdominal circumference. The participants in the obese group have higher values of NHR and SPI parameters than the control group. As noticed above, obesity has an adverse reaction to respiratory performance, resulting in shorter respiratory cycles with reduced expiratory capacity. The tension of the neck, tongue, pharynx, and larynx musculature; compensates the raised subglottal pressure and thus increasing vocal emission breathiness.

Solomon et al. (2011) investigated the influence of overweight and reduction of weight on vocal characteristics using auditory- perceptual, acoustic, and aerodynamic measures. The participants were classified based on standards reported by the World Health Organization (WHO) (1995), where BMI of 25 to 30 kg/ m^2 is overweight, and BMI of >30 kg/m^2 is obese. Eight participants selected for the obese group had a BMI higher than 35 kg/ m^2, and they had bariatric surgery. For the non- obese group, eight participants were chosen as carefully as possible for sex and age with BMI $\leq$ 30 kg/m^2. The total participants selected in this study were 16 adults, eight in each group (obese and non- obese group) planned for surgery except for the complications of head or neck. All the participants were arranged for laparoscopic procedures under general anesthesia with endotracheal intubation for the bariatric procedure or other abdominal procedures. The authors collected the data before schedule surgery (within one week, i.e., pre-treatment recording) and repeated by two weeks, three months, and six months after surgery. The following tests and procedure administered in this study:

- Visual–Perceptual: In this study, laryngeal imaging carried out using a fiber-optic endoscopic laryngoscope (Pentax FNL- 10RP3; Kay Pentax, Lincoln Park, NJ). Participants got examined under topical anesthesia administered in the nasal cavities. During this procedure, the fiber- optic endoscope passed transnasally; the participants were seated and positioned the instrument below the rim of the epiglottis to achieve a clear visualization of the vocal folds. The tasks performed were prolonged vowels at different pitch and loudness levels, pitch glides, syllables, and sentences. Images were recorded and rated using a 4-point rating scale.
- Acoustic: Voice recordings were taken in a sound-treated and electrically shielded booth. The authors used a head-mounted microphone (AKG C 420; AKG; Vienna, Austria) positioned at 4 to 5 cm from the lips coupled with the KayPentax Computerized Speech Laboratory (CSL 4500, Lincoln Park, NJ). The tasks were to sustain vowels /i/ and /u/ for approximately 3 seconds, each at comfortable pitch and loudness and was given six sentences from Consensus Auditory-Perceptual Evaluation of Voice [CAPE- V] (Wuyts, De Bodt, Molenberghs, et al., 2005). Highest and lowest fundamental frequencies (F_0) in Hertz and semitones, as well as minimum and maximum vocal intensities in decibels (dB), were recorded over multiple trials using the KayPentax Voice Range Profile (4326) and its supplied table-mounted microphone (Shure SM48), positioned 15 cm from the

lips was measured. Three trials of Maximum Phonation Time (MPT) measured, among these, the longest was considered. The acoustical analysis was done by extracting the middle portion of the sustained vowel. Using the KayPentax, Multidimensional Voice Program (Model 5105) Jitter, Shimmer, and Noise-Harmonic Ratio (NHR) was obtained. And authors used the Dysphonia Severity Index (DSI), the weighted algorithm that considered to reflect vocal function and, to a lesser degree, quality.

- Auditory – Perceptual: The sustained vowel (/i/ and /a/) and sentence samples were rated by three Speech-Language Pathologists using CAPE- V where the domains measured were severity, roughness, breathiness, strain, pitch, and loudness. Raters were blinded, and they rated under randomized conditions.
- Aeromechanic: Initially, participants sustained vowel /a/ for approximately 3 seconds at 30% of the F_0 range (F_0 range is the percentage of the total F_0 range in semitones and selected to represent a comfortable pitch) for determination of airflow. Later, each participant repeated the syllable /pI/ seven times slowly at the rate of 1.5 syllables per second and in a sustained and connected fashion. To determine laryngeal airway resistance (R_{law}), the participant produced the syllable at a comfortable level. To obtain Phonation Threshold Pressure (PTP), each participant repeated syllables as quietly as possible, among these whispering was eliminated. The aerodynamic assessment continued with either KayPentax Phonatory Aerodynamic System (PAS Model 6600) or its accompanying software or Glottal Enterprises Aerodynamic system (Syracuse, NY) (MS-100) coupled with DATAQ data acquisition hardware and WINDAQ data analysis software.

The authors reported the following findings;

- Visual – perceptual: Three participants with obesity had partially obstructed views of the vocal folds due to supraglottic constriction or inadequate illumination of vocal folds, vocal fold edema, or thick mucus. One of them had ventricular phonation while sustaining phonation and mediolateral and anteroposterior constriction preoperatively. Over time with a decrease in his BMI, the supraglottic constriction was reduced and resulted in the absence of ventricular phonation. Three participants in both groups exhibited anteroposterior constriction during the first session, which persisted during subsequent sessions. No other participants rated as having excessive mediolateral constriction for any course.
- Acoustic: Authors did not find the difference (significant) between groups for any acoustic variables namely Relative Average Perturbation (RAP), i.e., jitter, Amplitude Perturbation Quotient (APQ), i.e., shimmer, Noise-to- Harmonics Ratio (NHR), Semitone (ST), sound pressure level (SPL), Dysphonia Severity Index (DSI) and Maximum Phonation Time (MPT). Similarly, in longitudinal analysis, there was no significant effect or interaction except for the interaction for NHR.
- Auditory- Perceptual: The authors have highlighted that the rating for each parameter from each sample indicated voice characteristics with the absence of significant differences between groups. And the longitudinal analysis showed statistically significant effects for loudness parameters between groups and noticeable changes in strain and pitch across sessions.

- Aeromechanic measures**:** Longitudinal analysis data of twelve participants who completed the study revealed a significant effect for PTP, both at 30% and 80% of the F_0 range. Reanalysis carried to find the influence of BMI, considering it as a covariate factor. The main effect for the session was no longer significant for PTP 30% [$F(3, 27) = 1.497$, $p = 0.238$], or PTP 80% [$F(3, 27) = 0.427$, $p = 0.736$], indicating that BMI explained some of the variances in the data. PTP 30% consistently decreased as BMI decreased for three participants (who participated in three sessions); PTP 30% inconsistently decreased for the other three participants, and inconsistently increased for one participant.

To conclude, this study examined the influence of body weight on vocal quality between the participants in the non-obese and obese groups. They found an insignificant difference in perceptual voice quality, acoustic measures, or aeromechanic measures in both groups at the beginning of this study. But a longitudinal analysis indicated auditory-perceptual (especially, strain) and aeromechanic differences. Both the groups differed in perceived loudness and pitch in longitudinal analysis, which was statistically significant; however, the difference was small. They found a significant difference for PTP across sessions for vocal production at both comfortable and high pitches (30% and 80% of the F_0, respectively). Results showed that PTP 30% and 80% dropped over time, but PTP 30% was prominent in the obese group, and the variation within the group was relatively small especially, for the non- obese group. The obese group exhibited raised PTP 30% data, marked variability, and decreasing PTP 30% values over the first three sessions. The authors had proposed, the amount of tracheal pressure required to set the vocal folds into oscillation was enormous when structures had obesity, and the necessary force decreases to some extent as they proceeded to lose weight. The limitations of this study are its less number of participants, heterogeneous group, and the visual – perceptual ratings are not well explained.

Barsties et al. (2013) studied voice quality, phonatory range, and vocal aerodynamics across different bodyweight groups in females. The twenty-nine participants were divided into underweight (UW- <18.5 kg/m^2), normal weight (18.5-24.99 kg/m^2) and obese (OB- 25- 29.99kg/m^2) groups (WHO, 1995). The authors anthropometrically determined the participant's body fat. And the volume of fat was quantified with RH15 9LB Harpenden Skinfold Caliper (Baty International, West Sussex, UK). Other parameters analyzed by authors are as follows;

- Acoustic*:* The phonatory range acquired using Voice Profiler for the production of vowel /a/ at softest intensity, loudest intensity, lowest F_0, highest F_0, F_0 range, and intensity range. The analysis was done for the middle- three-second portion selected from phonation. Voice quality in time- domain and frequency- domain (jitter (local), jitter (rap), jitter (ppq5), shimmer (local), shimmer (local dB), shimmer (apq11) and mean harmonic to noise ratio (HNR) measured using Praat (Paul Boersma & David Weenink, Institute of Phonetic Sciences, Amsterdam, The Netherlands) software. Also, Cepstral Peak Prominence (CPP) and smoothed peak prominence (CPPs) was estimated using the Speech Tool program. The acoustic Voice Quality Index (AVQI) obtained using the Praat and Speech Tool. The effect of confounding variable on frequency analyzed by asking the subject to match the F_0 of their /a/ with a note of Speaking Fundamental Frequency (SFF_0).

Further, the result of post hoc analysis of mean loudness of sustained vowel, showed absence of difference between groups, thus confirming the validity of the acoustic measure. Sixty seconds of running speech used as a measure of habitual/ comfortable Speaking Fundamental Frequency (SFF_0).

- Auditory- Perceptual: Two Speech-Language Pathologists analyzed the speech sample based on Hoarseness (H), Roughness (R), and Breathiness (B) using a four-point equal, in which 0 is normal, one is slightly disordered, two is moderately disordered, and three is severely disordered, and the inter-rater reliability was assessed.
- Aerodynamic: Relative measure of Vital Capacity, which is the difference between VC_M and VC_E (where VC_M is measured VC and VC_E is the expected VC)), Maximum Phonation Time (MPT) as the longest duration of three sustained phonations produced comfortably. The voice recording has taken using Praat software to measure the initiation and end of phonation accurately, and Phonation Quotient (PQ in mL/s) calculated as the ratio between VC and MPT.

The results reported by the authors are;

- On observation of the data, the groups were significantly different in weight, BMI, relative adiposity, and age. The height measurement is the same in both groups. The participants in the OB group were older with the mean age of 25 years than other groups. For relevant habits and conditions, the participants in the OB group had the highest Reflux Symptom Index (RSI) value, and the participants in the UW group had the lowest RSI value. Normophonic subjects have not reported any impact of allergy and had fever spring, gastric ulcer, and any general diseases.

- Acoustic measures of phonatory range: Only for I- min (Intensity minimum), I-max (Intensity maximum), and SPL, the participants in the OB group had a significantly higher value than the participants in the UW and NW groups. Further, the F_0- low was considerably higher in the UW group than in the NW group.
- Auditory – perceptual and acoustic measures of voice quality: Both groups failed to differ significantly in any measure except in shimmer, in which the OB group had significantly lower shimmer than the NW group. Interestingly the participants in the OB group scored better on most of the measures except for CPP and the perception of H and R.
- Vocal aerodynamic measures: The UW group had significantly lower VC_M and VC_{M-E} (V_E is the expected Vital Capacity) than OB and NW groups. NW group had a substantially higher value than the other two groups for MPT.

The authors concluded that shimmer values were significantly lower in the OB group than the other two groups, which would be indirectly sensitive to body weight, and this is not much defined. They have pointed out that shimmer and SPL, gender, and F_0 are not directly associated. From sustained vowel production, the perturbation measures did not differ among groups, and henceforth the difference noticed in this cannot be wholly accepted as variability. They found that participants in the OB group showed significantly higher I-min, I-max, and habitual SPL in connected speech, indicating the ability of participants in this group to produce vocal output at higher habitual intensity levels and higher maximal voice. But they cannot phonate as softly as other participants due to raised resistance due to additional mass of the vocal folds or surrounding tissues

(Solomon et al., 2011), especially in the supralaryngeal regions resulting in increased pharyngeal resistance. In the aerodynamic measures, the V_{CM} was lowering (significant), and MPT was shorter (significantly) in the UW group than in NW and OB groups, this would be the effect of lesser movement, weight, and strength of abdominal muscles in UW group. In the OB group, V_{CM} was higher, and MPT was shorter when compared to the NW group. Authors mentioned that the bodyweight does not alter voice quality and other parameters significantly; however, some patterns do exist, i.e., bodyweight influences specific features associated with amplitude perturbation, intensity, F_0, VC, and MPT of voice. Limitations pointed by the authors are small sample size as it fails to establish causality between voice and weight gain, absence of laryngeal imaging (which strengthens information regarding laryngeal structure and physiology), and absence of self- evaluation report.

Need for the Study

Those mentioned above developmental, climacteric, and gestational changes are a normal process in women. However, there are few descriptions given to an ideal or healthy vocal behavior. According to Wilson (1987), a pleasant voice has "pleasing voice quality, a proper balance in nasal and oral resonance, appropriate loudness, appropriate voice fluctuations using pitch and loudness and age, size, and gender-appropriate speaking fundamental frequency." Additionally, the voice will not comprise noise (Hollien, 2000)). Shewell (2009) emphasizes the following aspects of free voice;

- Body: Body, which is as free of inappropriate postures and excess tension. An adequate amount of muscle tension is essential.

- Breath: This gives the best support to voice when it is not higher within the torso, which ensures the involvement of abdominal muscles than accessory muscles to provide better airflow.
- Channel: Comprises the structures from the level of vocal cords to the lips and nose. The typical voice should lack inappropriate or inadequate or excess muscular tension of the vocal tract. The excess or low tightness of the channel negatively affects the airflow, voice or sound quality, and the structures.
- Phonation: Highlights the vibration and vibratory pattern of the vocal fold. It also accounts for phonation stamina or resistance or endurance during vocal activities.
- Voice approach: Includes various registers, namely, head, oral, and chest. If there is too much focus on one rather than another in vocal production, it results in imbalance.
- Pitch: Free voice will comprise a comfortable pitch appropriate for age, gender, and personality.
- Loudness: Free voice has a variety of loudness required to emphasize words when necessary. The loudness is associated with breath in the absence of an excess of laryngeal constriction.
- Articulation: Free voice is the result of the precise audible pronunciation of each sound with adequate fluency, pace, pause, and rhythm.

As observed from the literature, the vocal tract plays are crucial in the production of speech sounds, which amplifies specific harmonics and dampens others depending on individual configuration. Certain factors like body volume or weight and height can influence voice production and cause a change in acoustic parameters. Specifically, individuals with obesity have an abnormal fat deposition in the vocal tract, which might hinder the production of acoustic measures (Souza et al. 2014). People with obese BMI display the following changes in speech characteristics: hoarseness, whispering, instability, modified jitter and shimmer, and the existence of speech strangulation at the end of the emission (Da Cunha et al., 2011).

Individual voices with morbid obesity differ from people's voices without obese BMI and show essential changes in vocal features in both genders (Da Cunha et al., 2011). Significant changes noticed in individuals with overweight and obese BMI are having decreased F_0 and MPT values **(**Souza & Santos, 2018).

In contrast, mass is not the only contributor for changing F_0 because the vibratory pattern of the vocal folds is a wave phenomenon of itself and its associated structures. Therefore structural mass cannot be defined as the only reason for the vibratory pattern. Vocal fold dimensions influence F_0, but it depends on the length, thickness, and stiffness of the structure (Titze, 2011). This view of Titze is supported by other researchers as well. The authors did not find a significant difference between the voice in morbidly obese women and control groups (Souza et al., 2014) considering fundamental frequency. Solomon et al. (2011) did not find vocal changes across the different time of recording for acoustic, maximum phonation time, laryngeal measures in groups comprising non- obese and obese adults who underwent bariatric surgery (Solomon, 2011).

Hence, it draws the attention of voice clinician or voice researcher to be aware of this relationship. Because of the aforementioned reports on vocal parameters and body weight, there is a lack of consensus on the absence or presence of a relationship between vocal parameters and body mass or size. Hence, the need for the present research is to study the relationship between BMI and acoustic voice parameters in Indian females.

Null Hypothesis

- There is no significant difference in acoustic parameters and Body Mass Index (BMI) between groups
- There is no correlation between acoustic parameters and Body Mass Index.

Aim

- To determine the effect of BMI on acoustic voice parameters
- To establish the relationship between BMI and acoustic voice parameters in young female adults

Objectives

- To measure and document the acoustic voice parameters in females with normal BMI
- To measure and profile the acoustic voice parameters in females with obese BMI (BMI greater than 25 kg/m^2)
- To compare the acoustic voice parameters between non- obese and obese groups
- To determine a correlation (if any) between BMI and acoustic voice parameters in females with normal and obese BMI.

Chapter III

Method

This study is a standard- group comparison research in which groups are formed based on an independent variable; to compare the groups based on the same independent variable and other dependent variables. In standard group comparison, there is no manipulation of the independent variable, and only the dependent variables are measured.

Participants

A total of fifty- one female participants between the age range of 22- 35 years without any previous history of vocal complaints were considered for the study. The selected participants were grouped based on BMI variable according to work published by Misra et al., 2011, 'The Revised Consensus of BMI guidelines for Indians'. The participants in this study allocated to the non- obese (Group I) whose BMI ranged between 18.5- 22.9 kg/m^2 and the obese group (Group II) whose BMI was ≥ 25 kg/m^2. Group I consisted of 24 participants, and group II consisted of 27 participants. Further, the participants who fulfilled the below-mentioned inclusion and exclusion criteria were selected to measure the acoustic parameters.

Inclusion Criteria for Participants in Group I and II

- Participants without the history of vocal complaints, dysphonia or other laryngeal pathology
- Participants without the history of smoking and alcohol consumption

- Based on 'The Revised Consensus of BMI guidelines for Indians', female participants whose BMI varies between 18.5 – 22.9 kg / m^2 allocated to the Non-Obese group (Group I).
- Similarly, for female participants whose BMI is higher than 25 kg / m^2 allocated to the Obese group (Group II)
- Participants with normal speech, language and hearing, communication, and cognitive skills were selected.

Exclusion Criterion for Participants in Group I and II

- According to Koufman & Isaacson (1991) classifications of professional voice users; the individuals who were Elite Vocal Performer (including actor and singer) and the professional voice users (especially teachers)
- Individuals with a history of voice disorders, allergies, Gastroesophageal Reflux Disorder (GERD), upper and lower respiratory tract disorders at the time of data
- Individuals with syndromes or malformations, physical or intellectual disability, and who underwent surgical procedures to the head or neck and those with orofacial myofunctional alterations
- Individuals with neurological impairment
- Individuals who have an irregular menstrual cycle and Polycystic ovarian syndrome
- Individuals under the Pre-Menstrual Syndrom (PMS) period and menstruation
- Individuals who were in the third trimester of gestation

Procedure

The participants were explained about the aim and objectives of the study, and written informed consent (Appendix A) was obtained. Each participant was evaluated individually. Each participant's height and weight were measured to establish BMI. Their height was measured using a flexible measuring tape (in centimeter unit and converted to meter unit). Weight was measured using a digital personal weighing machine (in Kilogram unit) for the human body with participants positioned with their back and head straight in Frankfurt horizontal plane, feet barefoot and parallel, and placed in the mid-line of the platform of the device. The BMI was calculated using the below-mentioned formula by Groff and Gropper (2009).

$$\text{BMI (in SI units):} \quad \text{Weight (kg)/ Height } (m^2)$$

The participants were seated on a chair comfortably with head and back erect in a noise-free room. The vocal signal was recorded using Olympus Multi-Track Linear PCM recorder LS-100 (Olympus Imaging Corp. designed by Olympus in Tokyo). The recorder was placed at a distance of 10 cm from the mouth. The participants were instructed to perform the following tasks;

- Participants were instructed to phonate the vowel /a/ for 3-5 seconds for three trials. Three trials were recorded with a rest period between the trials, and intake of water was encouraged if required by participants**.** Among the three trials, the sample with steady phonation and minimal instability selected for further analysis. The dependent variables Phonation Fundamental Frequency, Jitter, Shimmer, Noise to Harmonic Ratio, and Harmonic to Noise Ratio, were measured.

- Participants were instructed to count numbers from 1 to 10 in any language (participants' mother tongue was Kannada and Hindi) at their comfortable pitch and loudness. The Speaking or Counting fundamental frequency extracted from this sample.
- In order to obtain respiratory efficiency, Maximum Phonation Duration (MPD) was obtained. Participants were instructed to prolong the vowel /a/ as long as possible by taking a deep breath prior to the phonation. A digital stopwatch and Praat software were used to obtain the duration measure in seconds. Three trials were recorded with a rest period between the trials and intake of water was encouraged if required by participants, among these three samples, the sample with maximum duration and least variability was considered for final analysis.

Instruments and Software's Used

Instrumentation

- Digital weighing machine for the human body was used to obtain weight
- Olympus Multi-Track Linear PCM recorder LS-100 (Olympus Imaging Corp. designed by Olympus in Tokyo) was used to record the vocal samples
- The recorded sample was transferred on to the computer memory and was displayed as a waveform.
- Praat software (v. 5.3.56) {(Boersma & Weenink, 2013), [Amsterdam, Netherlands]} was used to measure the acoustic parameters

Analysis

1. From the recorded phonation sample, the steady portion was extracted from the midpoint, and the investigation was carried out for following acoustic measures
    i. Phonation Fundamental Frequency (PFF0)
    ii. Jitter (Ji)
    iii. Shimmer (Shi)
    iv. Noise to Harmonic Ratio (NHR)
    v. Harmonic to Noise Ratio (HNR)
2. From the recorded speech sample of counting numbers from 1 to 10, the mid-portion of the sample with minimal pitch and loudness variation was considered to measure Speaking Fundamental Frequency (SFF0)
3. Maximum Phonation Duration (MPD): The participants were guided to prolong the vowel /a/ for as long as possible at a comfortable pitch and loudness. MPD was measured using a stopwatch, this test was repeated three times, and the longer time was taken into consideration for analysis.

Statistical Analysis

A commercially available standard statistical package (SPSS software: Statistical Package for Social Sciences, Version 22) was used for statistical analyses. The raw data Phonation Fundamental Frequency (PFF_0), Speaking Fundamental Frequency (SFF_0), Jitter (Ji), Shimmer (Sh), Noise to Harmonic Ration (NHR), Harmonic to Noise Ratio (HNR) and Maximum Phonation Duration (MPD) were subjected to Shapiro - Wilk test of normality. The acoustic parameters PFF_0, SFF_0 & HNR satisfied the standard distribution criteria; hence One Way ANOVA parametric test was done for these parameters. The other variables MPD, Ji, Sh & NHR, did not meet the standard distribution criteria; accordingly, a Mann Witney, non- parametric test, was done. And the non- parametric Spearman's Correlation Test was done for correlation analysis between BMI and acoustic parameters.

Chapter IV

Results

The present study aimed to investigate the correlation between BMI and acoustic voice parameters (if any) and to compare the acoustic voice characteristics among individuals with normal and obese BMI. The voice samples collected from fifty- one phono- normal individuals (twenty- four participants in non- obese group and twenty-seven participants in obese). The vocal tasks used in this study is (a) phonation of vowel /a/ for three-five seconds at comfortable pitch and loudness (b) counting numbers from 1 to 10 at comfortable pitch and loudness and (c) prolonging /a/ as long as possible at comfortable pitch and loudness. The recorded vocal samples were analyzed from the steady portion of the voice output. Phonation Fundamental Frequency (PFF_0), Jitter (Ji), Shimmer (Shi), Noise to Harmonic Ratio (NHR) and Harmonic to Noise Ratio (HNR) were extracted from the vocal tasks '(a)'; Speaking Fundamental Frequency (SFF_0) was extracted from task '(b)'; and Maximum Phonation Duration (MPD) was calculated from task '(c).' Statistical analysis, including descriptive and inferential statistics, were carried out using SPSS software version 21.

The test of Normality showed a skewed curve, indicating that the data did not follow the normal distribution. From the Shapiro Wilk test, outliers were noticed in both the groups, the removal of those outliers from both the groups did not result in a normal distribution with the remaining data. Hence, further statistical analysis carried out by considering all the obtained fifty-one samples.

In descriptive statistics, the mean and standard deviation was calculated for both groups. Inferential statistics were further carried out using parametric, one way ANOVA test and non- parametric, Mann- Whitney U test. The results are discussed under the following sections;

Comparison of BMI between the groups

Comparison of acoustic voice parameters between the groups

Correlation between BMI and acoustic voice parameters

Comparison of BMI between Groups

The mean age of the non- obese and obese groups is 25.96 and 29.67 years, respectively. Table 1 shows the age and BMI of both groups. The mean BMI of non- obese and obese groups is 21.12 and 31.12 kg/ $m^{2,}$ respectively. Table 1 reveals that the BMI of the participants in group II is higher than in group I.

Table 1

Mean (M) and Standard Deviation (SD) of Age and BMI of Group I and II

Group	n	Age (Years)		BMI (kg/m^2)	
		M	SD	M	SD
Group I (Non- obese)	24	25.96	3.80	21.12	1.60
Group II (Obese)	27	29.67	4.40	31.12	5.25

Comparison of Acoustic Voice Parameters between the Groups

From table 2, it is observed that the mean PFF_0 and Ji values are higher in group II than group I. The mean Shi, HNR, and SFF_0 are higher in group I than group II. The mean NHR is similar in both groups. Lastly, the MPD of the participants in group I is longer than group II. The standard deviation of the fundamental frequency, both in phonation and speaking tasks, is higher in group II (obese) compared to group II (non-obese). Overall the observation of higher standard deviation in group II indicates that it is heterogeneous.

Table 2

The Mean (M) and Standard Deviation (SD) of Acoustic Parameters of Group I and II

Acoustic Parameters (Units)	**(Group –I) Non- obese**		**(Group- II) Obese**	
	M	**SD**	**M**	**SD**
PFF_0 (in Hz)	215	22.53	218	23.29
Ji (in %)	0.28	0.12	0.33	0.24
Shi (in %)	3.29	2.04	2.72	1.34
NHR	0.00	0.00	0.00	0.00
HNR (in dB)	22.42	3.25	21.59	3.40
SFF_0(in Hz)	224	23.46	219	26.98
MPD (in sec)	12.50	2.55	11.44	2.19

Note. Hz- Hertz, %- Percentage, dB- Decibel, secs- Seconds

Results of One Way ANOVA, the parametric test revealed that there is no significant difference between group I and II on the acoustic parameters such as PFF0, HNR, and SFF0. Table 3 shows the results of one way ANOVA for between-group comparison.

Results of the Mann Whitney U test, non- parametric analysis revealed that there is no significant difference between group I and II on the acoustic parameters such as Ji, Shi, and NHR. Similarly, there is no significant difference found for MPD measure between groups I and II. Table 4 shows the results of the Mann Witney U test for between-group comparison.

Table 3

Results of One Way ANOVA for Between-Group Comparison

Acoustic Parameters (Units)	df	F	Sig (p-value)
PFF_0 (in Hz)	1	0.15	0.69
HNR (in dB)	1	0.79	0.37
SFF_0 (in Hz)	1	0.56	0.45

Note. df- degree of freedom, F- Variation between samples/ variation within sample and Sig- the level of significance.

Table 4

R*esult of the Mann- Whitney U Test for Between-Group Comparison*

Acoustic Parameters (units)	/z/	Sig (p-value)
Ji (in %)	0.22	0.82
Shi (in %)	0.10	0.27
NHR	0.36	0.71
MPD (in secs)	0.66	0.09

Correlation between BMI and Acoustic Voice Parameters

Results of Spearman's correlation revealed the acoustic parameters PFF_0, Shi, HNR does not correlate with the BMI. Ji shows a moderate positive correlation, and SFF_0 shows a strong negative correlation, which is not significant. Similarly, MPD shows a weak- negative correlation, but it is not statistically significant. Table 5 shows the results of Spearman's correlation test

Table 5

Result of Spearman's Correlation Test

Acoustic parameters (units)	**BMI**	
	Correlation Co-efficient	**Sig (2 tailed) p-value**
PFF_0 (in Hz)	0.06	0.64
Ji (in %)	0.32	0.82
Shi (in %)	-0.15	0.27
NHR	0.05	0.71
HNR (in dB)	-0.12	0.39
SFF_0(in Hz)	-0.99	0.49
MPD (in sec)	-0.23	0.09

To summarize, the mean and standard deviation of age and BMI is high in group II (obese). The acoustic voice parameters PFF_0 and Ji are higher in group II (obese); and Shi, HNR, SFF_0& MPD are higher in group I (non- obese), but these differences in acoustic characteristics are not statistically significant. Also, there is no statistically significant correlation between acoustic parameters and BMI.

Chapter V

Discussion

This study aimed to investigate the relationship between acoustic voice parameters and body weight in Indian females. This study focused on females because females are susceptible to changes in voice throughout life (Souza and Santos, 2018), the higher prevalence rate of obesity in females than in males (Al Kibria et al., 2019) and vocal complaints reported being more elevated in females than in males (Hah et al., 2015). Chowdhury et al. (2018) investigated the obesity prevalence using the data of Bangladesh Demographic and Health Survey (BDHS) conducted at three years interval from 1993. For the current study, authors have taken data from 1999 to 2014; data consisted of 58,192 women between 15 years to 45+ years. They found between 1999 and 2014, the rate of obesity and overweight raised significantly in women of Bangladesh due to the increasing trend of watching television, the use of contraceptive pills, age, education, and wealth index factors. Also, this rise in rate was more in females residing in urban regions than in the rural regions. Also, another factor to be considered is the relation between the structural/bodily changes across the life span and vocal changes in females has gained attention in some studies, signifying individuals with overweight or obesity is anticipated to have diverse acoustic characteristics (Barsties et al., 2013, Bosso et al., 2019, Da Cunha et al., 2011, Souza and Santos, 2018).

The individuals with obesity may exhibit changes at three significant systems of voice, namely the respiratory system (characterized by accretion of adiposity in the thoracic and abdominal region), phonatory system (characterized by a rise in the mass of the vocal fold structures) and resonatory system (characterized by accretion of adiposity at the upper airway region, causing changes in the resonators). These modifications contribute to resultant acoustic changes [Barsties et al. (2013), Busetto et al. (2009), Celebi, et al. (2013), and Souza et al. (2014)]. Horner et al. (1989) investigated the site and size of adipose deposition at the level of the upper airway in individuals with obesity using MRI; they observed greater accretion of adiposity in the laryngopharyngeal airspace, the posterolateral region of the oropharynx, at soft palate level, tongue, and submental areas. Busetto et al. (2009) studied body fat distribution (BMI) and its proportion with the pharyngeal region, in women with obesity. The authors found the size of the upper airway is inversely related to visceral fat and adiposity. According to Da Cunha et al. (2011), vocal characteristics of individuals who were morbidly obese is hoarseness (62%), murmuring (27%) and vocal instability (44%); the increase in vocal complaints is related to an imbalance in the phonatory subsystem due to the deposition of fat in the larynx and vocal tract.

Few studies suggest acoustic characteristics of voice, exceptionally fundamental frequency, may be closely related to body weight/body size. But, Titze (2011) suggests that mass is not the only contributor for changing F_0 because of the vibratory movement pattern of vocal folds occurs like a wave, so the movement of the vocal folds is not uniform along with the structure. Therefore, the center of mass cannot be defined.

From the previous studies, the prevalence of vocal complaints is high in females, and the occurrence of obesity is significant as the age increases so that obesity may be one of the reasons for voice alterations. In the present study, individuals were grouped based on BMI, the females with normal BMI between 18.5 to 22.9 kg/m^2 assigned to Group I (non- obese group), and females with obese BMI greater than 25 kg/m^2 assigned to Group II (obese group). The findings are discussed based on the comparison of acoustic and aerodynamic characteristics between groups and the relationship between them which are as follows;

Comparison of BMI between the Groups

The mean and standard deviation of age factor of individuals in the obese and non- obese groups is 29.67 (± 1.60) and 25.96 (± 3.80) years, respectively. Similarly, the mean and standard deviation of BMI of individuals in the obese and non- obese groups is 31.12 (± 5.25) and 21.12 (± 4.40) kg/ m^2, respectively. This result suggests that individuals in Group II, the obese group, have relatively higher age and high BMI value than the individuals in Group I, the non-obese group. This pattern similar to the findings of the literature, as mentioned above. Table 6 shows the mean age of individuals with and without obesity in different studies.

Table 6

Summary of Study Findings Related to the Mean Age of Individuals

Sl.No.	Author and Year	Number of Participants	The Age Range of Participants (in Years)	Mean Age (in Years)	
				Obese Group	Non-obese Group
1.	Solomon et al. (2011)	16	26-64	53.1	49.8
2.	Barsities et al. (2013)	91	17-31	24.57	21.38
3.	Present study	51	22-35	29.67	25.96

From the above table, the individuals in the obese group have a comparatively higher mean age than the individuals in the non-obese group. Results of the current study are in accord with the findings of Barsities et al. (2013) and Solomon et al. (2011), in terms of the mean age of becoming obese happens late in life instead of at a very young age. That is, the obese features might emerge in the later stage of young-middle age rather than at a very young adolescent or early adulthood period. The possible reason might be relatively less physical activity, more screen time, reduced daily activities, and excessive intake of high energy food in middle-age individuals when compared to very young individuals.

Comparison of Acoustic Voice Parameters between the Groups

The acoustic findings are as follows;

1. PFF_0 found for the obese group is 218 (±23.29) Hz, and for the non-obese group is 215 (± 22.53) Hz. The fundamental frequency is relatively higher for individuals in the obese group than the individuals in the non-obese group, with an insignificant difference. Similarly, Celebi et al. (2013) found a fundamental frequency of 236 (±24) Hz for the individuals in the obese group and 221 (±27) Hz for the individuals in non- obese groups, without significant differences. The mass would play a role in the vibration of vocal folds where the accretion of adipose tissue and others might be present in obese individuals. This might lead to a reduction of the fundamental frequency.

   Contrary to this, mass is not the only contributing factor for fundamental frequency, which includes laryngeal activity, vocal fold length, and biomechanical mechanism (Titze, 2011). For instance, it is possible that in individuals with obesity, the supra-laryngeal resistance increase due to the lessened size of the pharyngeal cavity. Thus, increasing the need for high subglottal pressure against the damping effects of added resistance to the pharyngeal cavity; therefore, raising subglottal pressure results in high voice (Barsities et al., 2013).

2. Similar to PFF_0, the perturbation measures had insignificant differences among the groups, the mean jitter for the obese and non- obese groups is 0.33 (±0.24) % and 0.28 (±0.12)%, with the absence of significant difference. The present findings are in concordance with the study by Celebi et al. (2013), who found that the jitter is 0.4 (±0.4)% for the obese group and 0.3 (±0.1) % for the non- obese group. On the other hand, Barsities et al. (2013) observed relatively higher jitter in the non- obese group than the obese group without significant difference. The results of the present study align with the findings of Celebi et al. (2013) and Barsities et al. (2013), where they did not find any difference in jitter value between obese and non-obese individuals. A similar jitter value in both groups can be due to the factor that 'obesity' did not influence the pitch related voice quality parameter such as F_0 and jitter. This needs to be further substantiated with more individuals in the obese group.
3. Celebi et al. (2013) found lower amplitude perturbation in individuals with normal BMI than individuals with obese BMI, which was insignificant. But Barsities et al. (2013) found lower shimmer value in the obese group than in non-obese, which is still negligible. In the present study, the shimmer was 2.72 (±1.34) % and 3.29 (±2.04) % for the obese and non- obese group. Though, the shimmer is different between the groups and found it is not a statistically significant difference between the groups. Hence, the present study is in agreement with the

findings of Celebi et al. (2013) and Barsities et al. (2013). Acoustically, the subtle changes related to the sub-glottal air pressure for voice production in individuals with obese BMI inferred to be stable during vowel phonation as similar individuals in the non-obese group by considering the same value of shimmer in both groups.

4. The present study found that the HNR for the obese group was 21.59 (±3.40) dB and in the non-obese group was 22.42 (±3.25) dB and the difference in HNR was not significant between the groups. The above findings are following the results of Barsities et al. (2013) and Celebi et al. (2013), where they reported no significant difference between obese and non-obese groups in the HNR parameter. The HNR found by Barsities et al. (2013) between the obese and non- obese groups is 26.30 (±3.2) dB and 24.56 (±3.1) dB. But Celebi et al. (2013) found lower HNR value in the obese group than in non- obese group with the values 24.1 (±3.6) dB and 24.9 (±3.6) dB, respectively. Both of these studies lacked the presence of significance. Harmonic-to-noise ratio measures the comparative level of additive noise in voice production. Additive noise originates during phonation from turbulent airflows produced at the glottis. Insufficient closing of vocal folds allows excessive airflow through the glottis, causing turbulence. The resulting noise from the friction mediated in a higher noise level in the spectrum. Noise in the signal can also be triggered by aperiodic vocal fold vibration. The ratio thus represents the superiority of harmonic (periodic) over noise (aperiodic) levels in the voice and is expressed in terms of dB (Ferrand, 2002). The findings of the present study support the results of Horii and Fuller (1990), where they reported

17 to 19 dB as the HNR in normo-phonic females. No significant difference in the obese and non-obese group on HNR indicates that the vocal fold vibration is stable and periodic in both the groups.

5. In Da Cunha et al. (2013) study, the noise component was a substantial difference between obese and non-obese groups. The NHR value obtained for the obese and non- obese groups in Solomon et al. (2011) study is 0.13 (±0.02), and 0.14 (±0.04), which was not significant and but they had observed interaction between NHR and BMI across the sessions (before the bariatric procedure or other abdominal procedure and repeated approximately two weeks, three months and six months post-surgery). Although the difference was absent preoperatively, the longitudinal analysis showed improved quality when overall body weight decreased. In the present study, the NHR was 0.00 in both groups. The obtained NHR value in both the group indicates that the vibration of vocal folds is more periodic. Thus, the result of the present study is in alignment with the reported findings of Solomon et al. (2011) and Da Cunha et al. (2013) studies where they reported no difference of NHR between obese and non-obese groups.
6. The SFF_0 obtained in the present study are 219 (± 26.98) Hz for individuals in the obese group and 224 (± 23.46) Hz for individuals in the non- obese group, which showed an insignificant difference. In the non- obese group, the SFF_0 is relatively greater than the obese group. The lowered SFF_0 in the obese group may be due to an increase of mass component in the phonatory system. In contrast, Barsities et al. (2013) found SFF_0 higher in the individuals of the obese group than the individuals of the non- obese group, which is observed to be insignificant between

the groups. The difference between the present study and Barsities et al. (2013) study on SFF_0, is that in their research SFF_0 was analyzed from a connected speech sample in German, while in the present research counting numbers from 1 to 10 was used in the Kannada language as the individuals had Kannada as their native or regional language. So, this raises the question of whether there is an effect of stimuli as well as a language over SFF_0.

From table 7, studies showed higher PFF_0 than SFF_0 except for Rohima's (1998) study. One possible explanation for the dissimilar findings would be the difference in the subject selection, instrumentation, and procedural variability among the studies. The outcome of the present study is in concordance with Rohima (1999), also from her work narration, or reading is found to be suitable for analysis of SFF_0 measure. Also, it is noted that the individuals were from the South India region; the language used for SFF_0 tasks is similar, which would be one of the reasons for similar findings. This directs the attention to establish and document F_0 differences between obese and non-obese individuals based on task specificity like phonation of vowels versus counting/reading/spontaneous speech.

Table 7

Comparison of PFF_0 and SFF_0 in Various Studies

Authors	Age Range	Tasks	Instrumentation	PFF_0 (in Hz)	SFF_0 (in Hz)	Remarks
Fitch (1990).	21-26 years	-Vowels /a/, /i/, /u/ and /ae/ -Reading -Monologue	Kay Electronics Visi Pitch Model 6087DS with an IBM PC Interface, Model 6098.	259 (± 30.1)	210 (± 18.6)	SFF_0 is lower than PFF_0.
Britto & Doyle (1990).	Mean age 23.6 (± 1.8) years	-Vowel /a/ -Reading -Monologue	Visi-Pitch Voice Analyzer (Model 6087-DS) (Kay Elemetrics, Pinebrook, NJ) and used a Visi-Pitch circuit interface (Model 6096).	218 (± 22.3)	199 (± 14.9)	SFF_0 is lower than PFF_0 *BMI was one of the variables, and it was normal.
Rohima (1998)	7-25 years	-Vowel /a/ -Reading -Narration	Vaghmi of Voice and Speech System (VSS)	218 (± 9.65)	263 (± 9.40)	Native Hindi speakers & (*).
				225 (± 8.53)	265 (± 7.37)	Native Kannada (*).
				263 (± 10.42)	236 (± 10.41)	English speaker with native Hindi& (*).
				277 (± 8.61)	231 (± 11.35)	English speaker with native Kannada & (*).
Macari et al. (2017)	6 – 35 years	-Vowel /A/ Prolongation -Counting 1 to 10 tasks	Visi-Pitch IV (Model 3300, KayPENTAX, Montvale, NJ)	229 (± 30.08)	196 (± 61.15)	SFF_0 is lower than PFF_0

Note. * SFF_0 is higher than PFF_0

7. In the aerodynamic measure, the performance of individuals in both groups showed a relatively similar result. The mean MPD of individuals in the obese and non-obese groups are 11.4 (± 2.19) seconds and 12.50 (± 2.55) seconds, suggesting that the individuals in group I (non- obese) have relatively higher MPD than group II (obese), but it did not show a significant difference. Barsities et al. (2013), in their study, on twenty- nine females between 17 to 31 years found the mean MPD of the participants in the non- obese group is 21.61 (±4.92) seconds, and the obese group is 17.83 (±3.23) seconds, but it did not show a significant difference. The present study findings of MPD support the results of Barsities et al. (2013), who reported poor MPD performance in obese females than non-obese females. Reduced MPD in obese females can be attributed to impaired pulmonary function where there is elevated adiposity around the ribs and abdomen regions. This increased accumulation of excessive fat around those areas would influence the glottal efficiency and thereby reduced MPD in obese females (group I).

   Also, Celebi et al. (2013) and Souza and Santos (2018) found a significant difference between groups; the mean MPD for the individuals in the non- obese group was higher than individuals in the obese group. The reason pointed by the authors for the considerable difference was the rise in difficulty in adjusting the aerodynamic and myoelastic forces of the larynx due to elevated adiposity around the structures of respiratory mechanism and thereby affecting its function, which is necessary for good vocal production (Da Cunha et al., 2011).The result of the current study varied in terms of significance compared to the reviews, as mentioned above.

Correlation between BMI and Acoustic Voice Parameters

In the present study, there was no correlation found between the acoustic parameters (except Ji, SFF, and MPD) and BMI. But, jitter (Ji) was moderately correlated, Speaking Fundamental Frequency (SFF_0) had a strong- negative correlation, and MPD showed weak- negative correlation with BMI. In addition to this, these correlations showed the absence of a significant difference. The results of the present study are in accord with Solomon et al. (2011) results, where they found the lack of correlation between acoustic parameters and BMI. Authors of the latter study found an interaction of the only one acoustic measure, noise component, noticed in longitudinal analysis with groups. They reported that the NHR parameter reduced as per the reduction in the overall body weight.

The absence of correlation of major acoustic parameters in the present study may be due to the fewer individuals in the obese group. Also, the insignificant, weak relationship of acoustic measures with BMI can be due to the individuals' age factor (very young females). The prevalence of obesity is more common among middle-aged women, particularly in the upper age limit, where the accumulation of fat deposition in the pulmonary, laryngeal, and articulatory system would be remarkably present than in very young females (Chowdhary et al., 2018). The other reason could be the acoustic parameters chosen in the present study, which would not be sensitive enough to detect and document the underlying influence of obese related issues on voice feature differences between individuals with and without obesity.

Hence, the present study accepts the null hypotheses proposed, such as

- There is no significant difference in acoustic parameters and body mass index (BMI) between groups
- There is no correlation between acoustic parameters and body mass index

Therefore, the results of the present study conclude that the body mass index does not alter the voice quality and other measures (MPD) in young females (22 to 35 years of age) .

Chapter VI

Summary and Conclusions

Obesity is one of many health issues that are raising serious concern, since the last 30 years in underdeveloped and developing nations, where the obesity rate has risen by 40% (Engin, 2017). The prevalence of obesity is high in females than in males (Aslan et al., 2019; Ogden et al., 2015 and Parimalavalli and Kowsalya, 2015). Also, the obesity rate in females residing in urban areas is higher than the females in rural areas (Chowdhary et al., 2018) due to low physical activity and excessive intake of high-energy food; this leads to the deposition of excessive fat in the abdominal, laryngeal and supralaryngeal regions which alters the production of voice at the level of power, source, and filter (Source Filter Theory, Fant, 1960)

Da Cunha et al. (2011) reported altered jitter, shimmer, vocal instability, hoarseness, whispering, and strangulation towards the end of the voice production are the noticeable characteristics of individuals with obesity. Takaki et al. (2016) found a direct correlation between BMI and third formant frequency (F_3), even though the significance is low. Souza and Santos (2018) found a significant difference in fundamental frequency (F_0) and Maximum Phonation Duration (MPT) between participants with underweight, overweight, and obese BMI and participants with healthy and obese BMI. However, Solomon et al. (2011) study did not show substantial differences in perceptual, acoustic, or aerodynamic measures between the non- obese and obese groups' baseline results but noticeable auditory-perceptual (especially strain) and noise measure difference across sessions in longitudinal analysis. There was no consensus or unison finding among researches to explain the effect of body weight on voice. Further, there is a dearth of literature on the effect of obesity on the voice in the Indian population. In this context, the present study attempted to study the relationship between obesity and voice.

The present study aimed to compare the acoustic characteristics between individuals with normal and obese BMI and to find the relationship between BMI and acoustic parameters, especially in females, because the physiology of vocal changes, obesity, and their prevalence is high in females. Participants were selected from the City of Mysuru and its nearby locality. Individuals with adequate communication skills and negative/no history of vocal complaints, dysphonia or other laryngeal pathology, smoking, alcohol consumption, structural deformities, upper and lower respiratory infection, GERD, medication for hormonal imbalance, PMS and third-trimester gestational period at the time of recording was selected for the participation.

Totally fifty- one healthy non- dysphonic individuals participated in the study between the ages range of 22-35 years. Each participant's height was measured using a flexible measuring tape (in centimeter unit and converted to meter unit). Weight was measured using a digital personal weighing machine (in Kilogram unit) for the human body with participants maintaining their position with feet barefoot and parallel, back and head straight in Frankfurt horizontal plane in the mid-line of weighing machine. The BMI was calculated using the "Weight (kg)/ Height (m^2)" formula of Groff and Gropper (2009). Based on "The Revised Consensus of BMI guidelines for Indians (Misra et al., 2011), participants were grouped. The participants with BMI between 18.5 to 22.9 kg/m^2 assigned to Group I (non-obese group) and those with a BMI $\geq$ of 25 kg/m^2 assigned to Group II (obese group). Examiner used Olympus Multi-Track Linear PCM recorder LS-

100 (Olympus Imaging Corp. designed by Olympus in Tokyo) to record each participant's phonation of vowel /a/ and counting tasks by placing the device 10cm away from the mouth. The samples were analyzed using Praat software (v. 5.3.56) {(Boersma et al., 2013), [Amsterdam, Netherlands]}to extract the raw data of acoustic measures such as Phonation Fundamental Frequency (PFF0), Jitter (Ji), Shimmer (Shi), Noise to Harmonic Ratio (NHR), Harmonic to Noise Ratio (HNR), Speaking Fundamental Frequency (SFF0) and Maximum Phonation Duration (MPD). Statistical analysis was done using SPSS software. Results of the Shapiro - Wilk test of Normality showed normal and skewed distribution. Hence One Way ANOVA parametric test and Mann-Witney U and Spearman's Correlation non- parametric tests were done accordingly. The results of the present study revealed several points of interest.

The obese group had relatively higher age and high BMI value than non-obese group implying that the obese features might emerge in the later stage of young-middle age rather than at a very young adolescent or early adulthood period due to less physical activity, more screen time, reduced daily activities, and excessive intake of high energy food.

The acoustic measures Phonation Fundamental Frequency (PFF_0) and Jitter (Ji) were relatively higher in group II than group I. Shimmer (Shi), Harmonic-to-Noise Ratio (HNR), and Maximum Phonation Duration (MPD) were relatively lower in the obese group than the non- obese group. Also, the Noise-to-Harmonic ratio (NHR) was similar in both groups. These findings did not show a significant difference between the groups. Present study findings support the findings of Celebi et al. (2013) and Barsities et al.

(2013), where they found no difference between acoustic voice measures between obese and non-obese participants.

There was no correlation found between the acoustic parameters (except jitter, speaking fundamental frequency and maximum phonation duration) and Body Mass Index. But, jitter was moderately correlated, speaking fundamental frequency had a strong- negative correlation, and maximum phonation duration showed weak- negative correlation with Body Mass Index parameter without any significance.

The above findings are insignificant, mostly due to the BMI and age of the participant. The BMI found in this study was not sufficient to cause modification in the acoustic characteristics in young- middle age females. The prevalence of obesity is common in middle-aged females, particularly at the upper age limit, where an accumulation of fat deposition in the pulmonary, laryngeal, and articulatory system would be remarkably present than in very young females (Chowdhary et al., 2018). The other explanation may be the acoustic parameters chosen in the current analysis, which would not be sufficiently sensitive to detect and record the underlying effect of obese related issues on differences in voice features between obese and non-obese individuals.

Hence, from the findings of the above study, the proposed null hypothesis "there is no difference on acoustic and MPD measures of voice between obese and non-obese," and “there is no correlation between acoustic and MPD parameters of voice and body mass index in obese and non-obese individuals" are accepted.

Clinical Implications

1. The present study augments the knowledge and understanding of voice clinician about the relationship between Body Mass Index (BMI) and acoustic voice measures in healthy young adult females where the present study revealed no influence on BMI on certain acoustic parameters of voice.
2. This study found differences in fundamental frequency between speaking and phonation tasks. Studies in this direction also highlight differences that exist in phonation versus speaking tasks. Hence, in the routine clinical evaluation of voice, the fundamental frequency needs to be profiled by considering both the tasks, speaking as well as phonation.
3. The results of the present study help the clinician in counseling procedure to create awareness among females about the effect of obesity on the voice at different age groups. The presence of a few subtle differences between the obese and non-obese individuals in acoustic characteristics of voice and MPD measures needs to be addressed. Additionally, the study results can be used in counseling about the impact of weight loss on voice.

Limitations of the present study

1. In the present study, the number of participants was lesser, and groups were heterogeneous as they were not age-matched.
2. The present study did not employ visual examination of the larynx using imaging procedure and auditory- perceptual evaluation of voice, which would have given more insight into the current findings.

3. The present study did not control the time of recording the voice/speech sample on a day; as per the participants and examiner's convenient and available time, it was recorded.

Future Directions

1. Future research focusing on comparing and documenting voice features in different groups like underweight, normal, overweight, and obese individuals to understand the impact of body size on voice needed.
2. The present study focused on female participants. Studies on the effect of body mass index on the voice in males are warranted. Studies focusing on BMI across age groups, namely young adulthood, middle age, and older age on voice, needed further.
3. Other acoustic parameters, including multi-parametric indices like Dysphonia Severity Index (DSI), Acoustic Voice Quality Index (AVQI), and cepstral measures, can be considered.

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Appendix

Informed consent letter

Title: "Body Mass Index (BMI) and Acoustic voice parameters in Indian females: A correlation study

Guide: Dr.R.Rajasudhakar**,** Reader in Speech Sciences**,** Department of Speech-Language Sciences, AIISH, Mysuru.

Student: Ms. Sashirekha N (Register No: 18SLP032), II MSc (Speech Language Pathology), AIISH, Mysuru.

Description of the study: The aim of the study is to determine the effect of BMI on acoustic voice parameters and to determine the relationship between BMI and acoustic voice parameters in young female adults. The participants will be involved in recording the voice using laptop and microphone. The approximate time taken will be around 5 to 10 minutes per individual. This data will be helpful to find the effect of BMI on voice and to create awareness about the effect of obesity on voice. The data confidentiality will be maintained for the collected data.

Informed consent (Consent for participation)

I have been informed about the aims, objectives and the procedure of the study. The possible risks- benefits of my participation as human subject in the study clearly understood by me. I understand that I have a right to refuse participation or withdraw my consent at any time without adversely affecting my ward's treatment at AIISH. I will have to give more time for assessments by the investigating team and that these assessments any not result in any benefits to me.

I, ____, the undersigned, give my consent for being participant of this investigation/ study / program.

(AGREE/ DISAGREE)

Signature of the participant:

Date: