AERODYNAMIC MEASURES IN CHILDREN

IN THE AGE RANGE OF 8 TO 12 YEARS

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CERTIFICATE

This is to certify that this dissertation entitled "**Aerodynamic measures in children in the age range of 8 to 12 years**" is the bonafide work submitted in fulfillment for the degree of Master of Science (Speech-Language Pathology) of the student Registration No: 11SLP003. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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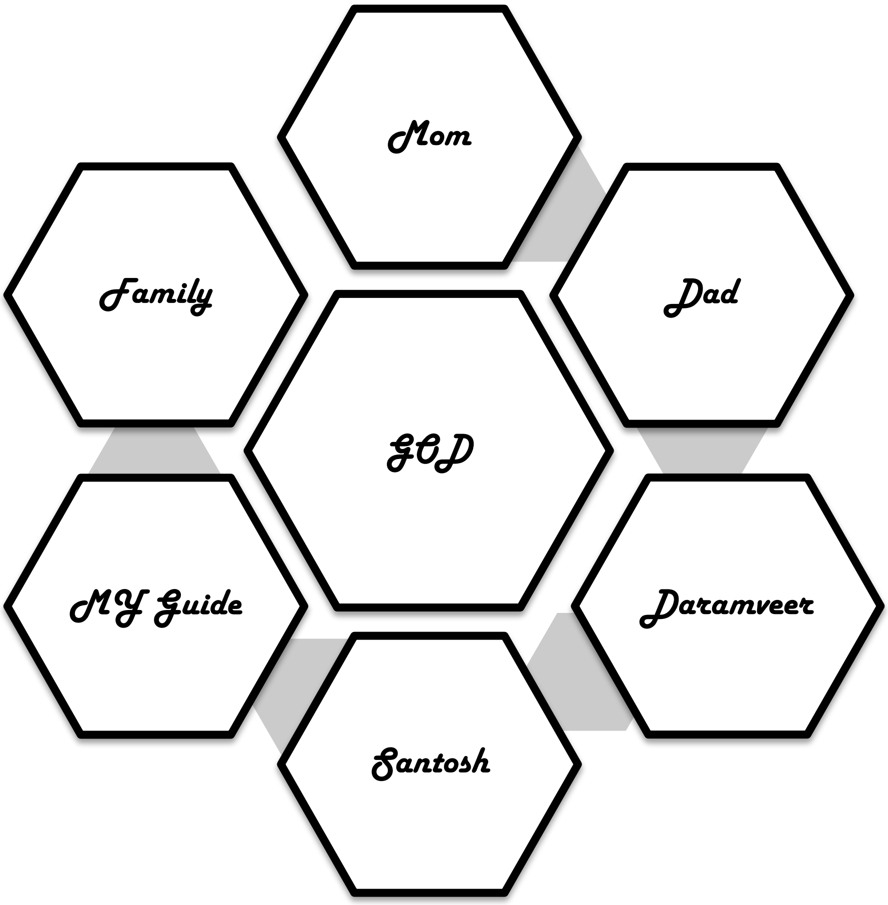
Specially Dedicated To



Life is Beautiful, if you know how to live!!!

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CHAPTER - I

Introduction

Voice is defined as the "laryngeal modulation of the pulmonary air stream, which is further modified by the configuration of the vocal tract" (Bracket, 1971).

Voice is produced by the coordinated interactions of respiratory, phonatory, and resonatory subsystems. It is an aerodynamic process in which the respiratory airflow is modified by laryngeal modulations to create the acoustic waves. These waves are amplified and filtered subsequently by vocal tract resonance.

Voice can be assessed under perceptual, acoustic, aerodynamic, vocal imaging and voice related quality of life domains. The perceptual evaluation can be done through different rating scales like GRABS or CAPE V and Voice Handicap Index (VHI) in which the severity is qualitatively measured. The acoustic analysis of voice provides information on the frequency, intensity, perturbation, and noise related measures. The vocal fold vibratory characteristics observed through video laryngoscopy/stroboscopy provides information on structure of vocal folds and their function during voice production.

Aerodynamic analysis assesses the interaction of both respiratory and laryngeal functions (Grillo, Perta and Smith, 2009) and provides information related to the valving efficiency of the glottis during phonation. Aerodynamic analysis of voice includes static measures of respiration and dynamic measures of laryngeal valving. The static measures help in understanding the volumes of air that can be inhaled / exhaled in a breath and maximum capacities of an individual's respiratory system. The dynamic measures provide information about the efficiency of laryngeal valving in converting the expiratory airstream to acoustic energy. Dynamic measures that aid in assessing efficiency of laryngeal valving comprise majorly of the measures of pressure variations at the level of glottis and airflow through the glottis during phonation. These measures include maximum phonation duration, s/z ratio, estimated subglottic pressure, mean airflow rate, laryngeal airway resistance, laryngeal airway conductance, phonation threshold pressure, and vocal efficiency.

Mean airflow rate is the volume of air flow across the vocal folds during phonation in one second. It is generally measured in litres or millilitres per second (L/s or ml/s). Estimated subglottal pressure is aerodynamic parameter proposed by (Hirano, 1981). It is the amount of pressure exerted on the vocal folds during adduction which is measured in cm H_2O. Phonation threshold pressure is the minimal pressure required to set the vocal folds into vibration (Titze, 1994).

Laryngeal airway resistance is the ratio of estimated subglottal pressure to mean air flow rate (Smitheran and Hixon, 1981) and reflects the resistance offered by the vocal folds to airflow at glottis level. It serves in estimating the valving efficiency and aid in deciding whether the glottic closure is too tight (hyperfunctional) or too loose (hypofunctional) or normal (Hoit and Hixon, 1992; Melton, Hoit, and Hixon, 1989). These parameters play an important role in diagnosis and management of voice disorders.

Need for the study

Few studies have been initiated in Indian context to explore the normative data of aerodynamic parameters. Rashmi (1985) investigated the acoustic and aerodynamic aspects of speech in 220 children age ranging from 4 to 15 years. The aerodynamic parameters which she considered were maximum phonation duration

(MPD) and s/z ratio, and MPD ranged from 4.08 seconds to 12.48 seconds and s/z ratio of 0.69-0.99 in children of 4-15 years. Venugopal, Sudhakar, and Savithri (2005) studied MPD and s/z ratio in 80 Dravidian normal children in the age range of 5-13 years. The results indicated that increase in MPD was statistically significant upto the age of 8 years for all the three vowels in both boys and girls; in general, boys had longer MPD compared to girls.

Recently Weinrich et al. (2005) studied aerodynamic measures in 75 children from 6 to 11 years. The parameters considered were speed quotient, open quotient, subglottic pressure, and maximum flow declination rate. The results revealed variations across the age and gender in some of the parameters.

These studies provided insight into different aspects of aerodynamic parameters in children and adults. However, considering the ethnic, racial variations and instrumental variations these results cannot be applied directly to Indian children. Although similar attempts have been made in the Indian context, the parameters these studies considered were limited. In view of the clinical and research applications of aerodynamic parameters and the dearth of studies in the Indian context, the present study was taken up with the aim of developing normative database for typically developing children in the age range of 8-12 years and to investigate the effect of age and gender on these parameters.

Aim of the Study

The present study was aimed at establishing normative data for aerodynamic parameters estimated subglottic pressure, mean airflow rate, and laryngeal airway resistance in typically developing children in the age range of 8-12 years.

Objectives of the Study

1. To investigate the reliability of the aerodynamic parameters ESGP, MAFR, and LAR.
2. To establish normative data for aerodynamic parameters ESGP, MAFR, and LAR in typically developing children in the age range of 8-12 years.
3. To investigate the effect of age on aerodynamic parameters ESGP, MAFR, and LAR.
4. To investigate the effect of gender on aerodynamic parameters ESGP, MAFR, and LAR.

CHAPTER - II

Review of Literature

Voice is produced by the coordinated interactions of respiratory, phonatory, and resonatory subsystems. It is an aerodynamic process in which the respiratory airflow is modified by laryngeal modulations to create the acoustic waves. These waves are amplified and filtered subsequently by vocal tract resonance. Balance across the respiratory, phonatory, and resonatory subsystems is essential for an economical or optimum vocal output. A disturbance at any of these subsystems may lead to compensatory changes at other subsystem and results in voice problem. Therefore, for voice evaluation to be complete, it should involve the assessment of functioning of each of these subsystems of voice production. A comprehensive evaluation of voice involves assessment under perceptual, acoustic, aerodynamic, vocal imaging and voice related quality of life domains.

Perceptual assessment is the core foundation for voice evaluation and for treatment outcomes in both surgical and behavioural intervention of voice disorders. It involves describing the voice solely through listening by an experienced clinician. It can be performed in either formal or informal ways. Informal assessment takes place through the conversation between the clinician and client. During this the clinician engages the client in spontaneous conversation to conduct a brief history of the problem and gather information about the voice difficulty with reference to medical, lifestyle, different situations and trauma. Formal evaluation involves the use of standardized protocols and is performed systematically using standardized procedures.

Some of the standard protocols used for perceptual evaluation of voice include GRBAS (Hirano, 1981), Consensus Auditory-Perceptual Evaluation of Voice (ASHA, 2002), Buffalo Rating Voice Profile (Webb, Carding, Deary, MacKenzie, Steen, and Wilson, 2004). GRBAS is a rating scale used extensively for the research and clinical purpose. It is an acronym where G stands for Grade, R for Roughness, B for Breathiness, A for Asthenia, and S for Strain. Each perceptual entity is rated on a 4-point scale where 0 = normal, 1= mild, 2= moderate, and 3=severe. Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) is another clinical as well as research tool used to evaluate and document auditory perceptual judgments of voice quality. Whereas GRBAS is a rating scale, CAPE-V is a visual analog scale and therefore offers "more sensitivity to small differences within and among individuals than the GRBAS scale".

The perceptual features of voice quality are also likely to have greater shared reality among a wide range of listeners including clinicians, clients, employers and other associates of those clients. Therefore, perceptual evaluation is often considered as a gold standard in voice assessment. However, the very limitation of the perceptual evaluation is its subjective nature. It is affected by the factors such as the experience of the clinician, stimulus used for elicitation. Hence, the perceptual evaluation has to be substantiated by the objective measurements of voice.

Acoustic analysis of voice provides information regarding the stability or variability of the vocal fold movement through perturbation measures of amplitude and frequency. It also yields information about harmonic and noise components of the voice, thus help in understanding the presence of turbulence at the level of vocal folds. However, the correlation of acoustic measures with perceptual evaluation is found to be only at moderate level (Dejonckere, Remacle, Fresnel-Elbaz, Woisard, Crevier Buchman, and Millet, 1996; Wolfe, Fitch, and Martin, 1997). Further, acoustic analysis can only analyze the periodic or quasi-periodic voices and is not suitable for analyzing strongly aperiodic acoustic signal. The perturbation values that are less than five are reported to be reliable (Titze and Liang, 1993).

Vocal imaging techniques such as videolaryngoscopy, high- speed digital videoendoscopy, videolaryngostroboscopy, or videokymography are used for the visualizing the glottic and supraglottic structures of larynx. The vocal fold vibratory characteristics observed through these imaging techniques are useful in understanding the etiology of the voice disorder and in documenting the therapeutic/surgical outcomes. Each of these imaging techniques provides information about different physiological aspects of vocal function that is complementary to each other.

It is essential to know the patient's perspective of their voice problem as it helps understanding the functional impact and emotional repercussions of dysphonia on his/her quality of life. Several self-assessment instruments such as Voice Handicap Index (Jacobson, Johnson, Grywalski, Silbergleit, Jacobson, Benninger, and Newman, 1997), Voice-Related Quality of Life measure (Hogikyan and Sethuraman, 1999), are developed for assessing quality of life specific to dysphonia.

Aerodynamic analysis of voice is based on the fact that voice production is essentially an aerodynamic phenomenon, whereby the glottis transforms aerodynamic power into acoustic power. For phonation to take place, both a suitable quantity of air and a suitable air pressure are needed. The aerodynamic forces working at the glottis are responsible for the creation of the sustained vibratory system of the vocal folds. Aerodynamic analysis provides information about the respiratory support and laryngeal valving characteristics which in turn facilitates understanding vocal physiology in normal as well as disordered voices.

Aerodynamic analysis of voice includes static measures of respiration and dynamic measures of laryngeal valving. The static measures help in understanding the volumes of air that can be inhaled / exhaled in a breath and maximum capacities of an individual's respiratory system. The dynamic measures provide information about the efficiency of laryngeal valving in converting the expiratory airstream to acoustic energy.

Static measures that aid in measuring the respiratory support include lung volume and capacity measurements. Lung volumes are single, non-overlapping values, whereas lung capacities include two or more lung volumes. Lung volume refers to the amount of air in the lungs at a given time which is used for various purposes, including speech (Solomon and Charron, 1998). It is measured either in liters (l), millilitres (ml), cubic centimetres (cc or cm^3) or percentage of vital capacity. The parameters of lung volume include tidal volume, inspiratory reserve volume, expiratory reserve volume, and residual volume.

Tidal volume refers to the volume of air breathe in and out during a cycle of respiration. It varies, depending on age, build, and degree of physical activity. Inspiratory reserve volume refers to the amount of air that can be inhaled above the tidal volume; it can be used by speakers to obtain more air for a particularly loud utterance. Expiratory reserve volume is the amount of air that can be exhaled below tidal volume. Residual Volume is the amount of air that remains in the lungs even after a maximum exhalation.

Vital Capacity is the combination of tidal volume, inspiratory reserve volume, and expiratory reserve volume. It is the maximum amount of air that a person can exhale after having inhaled as deeply as possible. Functional residual capacity is the amount of air remaining in the lungs and airways at resting expiratory level, that is, at the end of a normal quiet exhalation. Total lung capacity refers to the total amount of air that the lungs are capable of holding, including tidal volume, inspiratory reserve volume, expiratory reserve volume and residual volume.

Dynamic measures that aid in assessing efficiency of laryngeal valving comprise majorly of the measures of pressure variations at the level of glottis and airflow or volume velocity through the glottis during phonation. These measures also provide information about the respiratory-phonatory control and the economy of expiratory air usage during phonation. These measures include maximum phonation duration (MPD), s/z ratio, estimated subglottic pressure, mean airflow rate, laryngeal airway resistance, laryngeal airway conductance, phonation threshold pressure, and vocal efficiency.

Maximum Phonation Duration (MPD) is the maximum time an individual can sustain phonation of a vowel in a single breath. Factors such as vital capacity, age, gender, height, and health of the individual influence the value of MPD. According to Prater and Swift (1984), MPD as a parameter reflects the efficiency of glottal closure during phonation and the efficiency of respiratory system to maintain sustained subglottic pressure during phonation. It is measured for three basic vowels /a/, /i/ and /u/.

Although a large part of the evaluation of vocal function is based on the clinician's subjective impressions, the measurement of MPD of sustained vowels is one of the objective measures that can be done. The major assumption in measuring maximum phonation duration is that the normal laryngeal mechanism uses the available air supply effectively when sustaining phonation. Most subnormal or disordered laryngeal mechanisms use the air supply ineffectively, thus producing a shorter than expected maximum phonation duration (Tait, Michel and Carpenter, 1980).

Boone (1977) introduced the s/z ratio as a means of expanding the information derived from MPD and as a method by which respiratory inefficiencies could be distinguished from those of a laryngeal nature. Here the participants are asked to take deep breath and sustain the unvoiced sss and voiced zzz to the maximum duration possible. Following this the ratio of s and z durations will be calculated. Interpretation of this ratio is based on the assumption that an individual with adequate laryngeal valving will be able to sustain a voiced phoneme (/z/) and an unvoiced phoneme (/s/) approximately for the same duration.

Only s/z ratio ≥1.0 is of clinical significance. Since the underlying assumption of this task is that the duration of /s/ should always be equal or greater than /z/, the ratios substantially < 1.0 do not make clinical sense. However, the actual norms often provide s/z ratio slightly less than 1.0, which may be due to the fact that an efficient phonatory mechanism results in voiced durations slightly longer than voiceless durations. Further, if the ratio is substantially <1.0, it may also indicate that the patient did not carry out the task maximally for the /s/ production. Both the MPD and s/z ratio can be measured by noting the phonation duration in seconds using a stop watch.

Glottal Airflow and Related Measures

Airflow modulated by the vocal folds during voicing (glottal airflow) can be estimated by inverse filtering the oral airflow. Rothenberg's circumferentially vented mask can be used to obtain the oral airflow waveform. Inverse filtering of this oral airflow waveform will result in estimated glottal airflow waveform. Holmberg, Hillman, and Perkell (1988), Stathopoulos and Sapienza (1997) reported several measures of glottal airflow that are obtained by analyzing the glottal airflow waveform obtained through inverse filtering. These include mean airflow rate / average airflow, airflow open quotient, maximum flow declination rate, peak glottal airflow, alternating glottal airflow, and minimum glottal airflow.

Mean airflow rate (MAFR) is the volume of airflow across the vocal folds during phonation in one second. It is generally measured in liters or millilitres per second (L/s or ml/s). The laryngeal air flow during sustained vowel production range from 0.040 – 0.320 L/s in males and 0.050 to 0.220 L/s in females with the average data reported as 0.119 L/s and 0.115 L/s, respectively (Bless, Glaze, Biever–Lowry, Campos, and Peppard, 1993). Mean air flow signal provides a general impression of laryngeal physiology but does not give the detail about the flow modulated at the level of the glottis. When extracted from a voicing signal that is other than a sustained vowel prolongation, it not only estimates glottal air flow but also the air flow that is modulated by other articulators within the oral, nasal, and pharyngeal cavities.

Bielamowicz, Berke, and Gerratt (1995) exemplified the use of MAFR as an outcome measure in individuals who underwent medialization procedures. They found a significant decrease in airflow from pre to post surgery. Kimura, Nito, Sakakibara, Tayama, and Nimi (2008) used mean air flow rate as an indicator to document pre and post collagen injection of the vocal folds.

Airflow open quotient is a measure that provides information about the length of time the glottis is open relative to the duration of the entire cycle of vocal fold vibration. It helps in defining the degree of glottal adduction from a pressed to a breathy voice (Sundberg, 2008). Scherer (1991) provided an excellent overview of the relationship between the glottal airflow signal and the mechanics of phonation, and introduced a parameter called maximum flow declination rate (MFDR). MFDR is measured as the maximum negative peak from the first derivative of the glottal airflow waveform. It can be used to define hypo and hyperfunctional glottal configurations.

Peak glottal air flow is a parameter that relates to the maximum glottal area during vocal fold vibration. This airflow parameter can be influenced and reduced in conditions that restrict the lateral displacement vocal folds such as pressed voice. Minimum glottal air flow is the amount of airflow through the glottis during the closed phase of vocal fold vibration. The parameter helps in documenting the hypophonic component of voice disorders that involve glottal incompetence. Fisher, Scherer, Guo and Owen (1999) reported the use of this measure for tracking the glottal incompetence following botulinum toxin injection in individuals with spasmodic dysphonia.

In summary, the glottal airflow can be measured indirectly by inverse filtering the airflow waveform obtained from pneumotachograph. The glottal airflow measurements such as mean airflow rate, airflow open quotient, peak glottal airflow and minimum glottal airflow vary depending on the type of phonation and aid in identifying the phonation type. For example, in a breathy type of phonation, there will be higher open quotient, peak glottal airflow, whereas in a pressed voice these measures will be reduced due to dominant closed phase.

Subglottic Pressure and Related Measures

Subglottic pressure is the pressure required to initiate and maintain the vocal fold vibrations during phonation. It is measured in cm H_2O. It can be measured through direct or indirect methods. The direct method involves placing a pressure transducer via the cricothyroid membrane by puncture between the vocal folds. Although this method of measurement provides accurate values of subglottic pressure, considering the discomfort involved in procedure, it is clinically not a feasible method.

Smitheran and Hixon (1981) developed a non-invasive or indirect method of measuring subglottic pressure known as "The airway interrupted method". In this method, the participants were asked to phonate the syllable /pi/ in one stretch of several repetitions. During production of vowel /i/, the vocal folds are vibrating and the lips are open, hence the intra-oral pressure is equal to atmospheric pressure. During the production of unvoiced phoneme /p/, the lips are closed, the vocal cords are open, and subglottic pressure and intra oral pressures are equal (figure 1). The intra oral pressure can be measured by an oral pressure sensor. Therefore, the subglottic pressure can estimated from the measured intra oral pressure which is relatively non-invasive and comfortable to the participant being tested. The pressure thus measured is called as estimated subglottic pressure (ESGP).

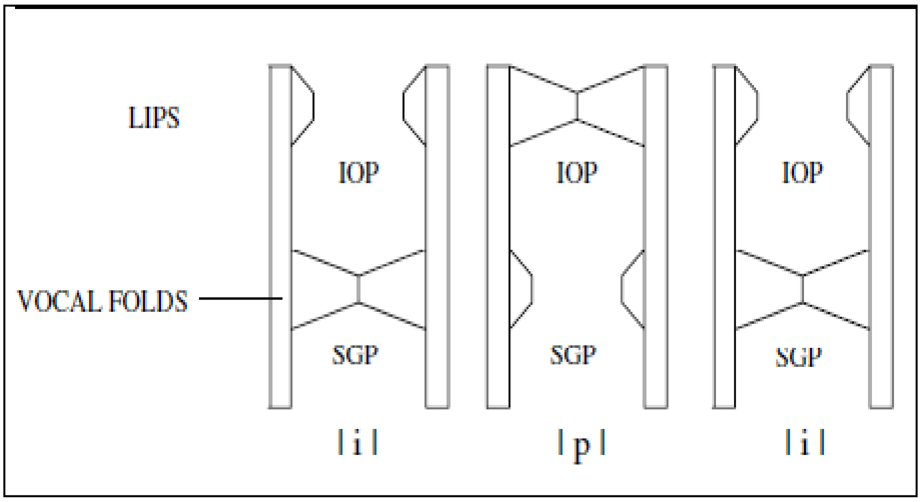

Figure 1. The principle of subglottic pressure (SGP) from an intra-oral pressure (IOP) (Source: Ketelslagers, Bodt, Wuyts, and Heyning, 2007).

Lofqvist (1982) demonstrated that this indirect technique closely estimates subglottic pressure. Also Hertegrad, GauYn, and Lindestad (1995), and Bard, Slavit, McCaVrey, and Lipton (1992) found a significant correlation between the indirectly measured subglottic pressure in the oral cavity and subglottic pressure obtained directly by translaryngeal puncture. The airway-interrupted method has already been used in the assessment of dysphonia.

The intra oral pressure is an accurate estimate of subglottic pressure only under the following assumptions. The oral plosive constriction creates a momentary airtight seal, which provides a continuous opening from the lungs to the lips. The vocal folds are open so that the oral pressure produced in the plosive production is analogous with the respiratory effort that would be available as driving pressure to set the vocal folds into oscillations (Netsell, 1969). An oral tube is placed between the closed lips and connected to a pressure transducer the oral catheter must be placed carefully in the mouth sealed by lips and not occluded by the tongue. The length, diameter and angle of the tube can influence the pressure measurement (Baken, 1987). The peak intra oral pressure recorded during the plosive production is considered to be equal to the subglottic pressure.

Phonation threshold pressure (PTP) is defined as the minimum amount of pressure required to set the vocal folds into vibration (Titze, 1994). PTP is dependent upon the biomechanical properties of larynx such as vocal fold thickness, tissue dampening coefficient, pre-phonatory glottal width and mucosal wave velocity which reflects the physiological state of larynx. Viscosity and stiffness affect the mucosal wave velocity and dampening co efficient, which in turn influences the PTP. PTP is measured indirectly by the similar technique (i.e. airflow interruption method) used for obtaining ESGP. However, the procedure is different in terms of task used for measuring PTP. For obtaining PTP, the individual is asked to produce syllable train /pa/ at softest intensity possible or at an intensity level that is just above the whisper. PTP is found to be a parameter that is sensitive to slight changes in vocal function such as vocal loading (Solomon and DiMattia, 2000), vocal hydration (Roy, Tanner, Gray, Blomgren, and Fisher, 2003).

In summary, the subglottic pressure can be estimated indirectly and noninvasively using airflow interruption method. This method involves the use of a polyethylene tube placed between the lips for measuring intraoral pressure, from which the value of SGP is extrapolated. The related measures such as phonation threshold pressure vocal efficiency are used frequently for clinical and research purposes.

Laryngeal Airway Resistance

Laryngeal airway resistance (LAR) is the ratio of estimated subglottal pressure to mean air flow rate (Smitheran and Hixon, 1981) and reflects the resistance offered by the vocal folds to airflow at glottic level. It serves in estimating the valving efficiency, and to verify whether the voice is too tight (hyperfunctional) or too loose (hypofunctional) or normal (Hoit and Hixon, 1992; Melton, Hoit and Hixon 1989).

LAR is a derived parameter and its value depends on the independent values and variations in ESGP and MAFR. In normal adults the value of LAR was found to be 50.43 cm H_2O/L/s in males and 40.62 cm H_2O/L/s in females (Stathopoulos et al., 1993). Goozee et al. (1998) reported 30.58 cm H_2O/L/s in males and 26.4cm H_2O/L/s in females in the age range of 20-30 years. In young Indian adults, the LAR values were found to be 22.56 cm H_2O/L/s in males and 26.53 cm H_2O/L/s in females in the age range of 18-25 years (Gopikishore, Pushpavathi and Sheela, 2012). Further, females were found to have higher LAR values than the males (Netsell et al., 1991; Goozee et al. 1998; and Gopikishore et al., 2012).

Although LAR is a derived parameter, it reflects the actual function of the larynx and is reported to be a useful parameter in differentiating normal and pathological voices. Holmberg (1980) attempted to verify the variations of LAR in young adults during the production of normal, breathy and pressed phonation types. She reported higher LAR values for pressed phonation and lower LAR values for breathy phonation. She opined that the LAR would vary either by the aerodynamic events or by physiological changes of the laryngeal mechanism or by both.

Grillo and Verdolini (2008) investigated the efficacy of laryngeal airway resistance in distinguishing pressed, normal, resonant, and breathy voice qualities in vocally trained subjects. The authors concluded that laryngeal resistance was efficient in distinguishing the pressed from normal and breathy voice qualities. In a similar study by Grillo, Perta and Smith (2009), reported that laryngeal airway resistance was found to be successful in distinguishing the pressed, normal, and breathy voice qualities in vocally untrained females.

Factors Affecting Aerodynamic Measures of Voice

Considering the fact that aerodynamic parameters ESGP, MAFR and LAR are combined measures that reflect efficiency of respiratory and phonatory systems, these parameters are influenced by several factors that affect these systems. The factors such as vital capacity, decreased lung pressure; vocal fold tension, viscosity; frequency and intensity of phonation are known to influence the aerodynamic measures of voice. According to Stathopoulos and Sapienza (2010) age, cognitive ability issues, cooperation, physical ability, phonation patterns, mask seal, and laryngeal surgeries may influence the aerodynamic measures of voice.

Aerodynamic parameters vary as a function of age. Hirano, Kurita, and Nakashima, (1981) and Tang and Stathopoulos, (1995) stated that the children's smaller size limits glottal area and vocal fold vibrational amplitude and thereby it affects the aerodynamics to acoustic energy conversion. Stathopoulos and Sapienza (1997) studied aerodynamic features of voice production in children between 4 and 14 years of age and compared them to adults to determine aerodynamic functions of their developing structure. The results revealed many functional differences between children and adults, the authors attributed these variations to the developmental anatomy of the larynx. Based on the results, authors concluded that the laryngeal size for females and children is more similar than that of females and males.

Anatomic degenerations with age influence on the mechanical function of the larynx and affect the aerodynamic aspects of voice. Kahane (1987) opined that the age related changes have potential to influence the laryngeal valving of airstream during phonation. Sapienza and Dutka (1996) studied 60 women (20 to 70 years) and found no significant group differences, but they found increased glottal air flow produced during speech for 70 years old group. These results suggest that aerodynamic measures document the air flow which accompanies the aging process.

Studies reported that aerodynamic measures vary based on the gender of the participant being tested (Netsell et al., 1994; Weinrich et al., 2005; and Gopikishore et al., 2012). The studies documented differences in the values of estimated subglottic pressure, amplitude-based flow parameters such as mean, peak and alternating flow and maximum flow declination rate in men and women. Titze (1989) reported the distinctions in glottal area and vibratory pattern differences documented between men and women. Klatt and Klatt (1990) related this to the perception that the female voice is weaker and breathy compared to the male voice.

Studies Related to Normative Data for Aerodynamic Measures

Studies have been attempted to document the normative data for these parameters. However, these studies did not aim at developing normative data for all the aerodynamic parameters. Rashmi (1985) focused on developing normative data for phonation duration and s/z ratio in 220 children in the age range between 4-15 years, while Venugopal, Sudhakar and Savithri (2005) studied maximum phonation duration (MPD) and s/z ratio in 80 Dravidian normal children in the age range of 5-13 years. In the western context, Stathopoulos and Sapienza (1993) studied respiratory and laryngeal measures in twenty 4-year-olds, twenty 8-year-olds, and twenty adults. Weinrich, Salz, and Hughes (2005) studied aerodynamic measures in 75 children between the ages 6 and 10.11 years.

Rashmi (1985) investigated the acoustic aspects of speech in 220 children age ranging from 4 to 15 years. The age range was further divided into 11 subgroups with one year interval. Each age group consisted of 10 subjects including 5 girls and 5 boys. The sustained phonation duration was measured using vowel /a/, /i/, /u/ and phonemes /s/ and /z/ were tape recorded, played back and analyzed using stopwatch. The other acoustic parameters such as fundamental frequency, fluctuation in frequency, intensity frequency, intensity range, rise fall time using pitch analyser were considered. The results revealed no statistical significant of age as well as gender difference for both MPD and S/Z ratio. The MPD ranged from 4.08 seconds to 12.48 seconds and S/Z ratio of 0.69-0.99 in children of 4-15 years. Also, she found no significant difference in aerodynamic and acoustic parameter with increasing in age and between genders.

Holmberg, Hillman, and Perkell (1988, 1989) studied on glottal airflow and transglottal pressures in 25 males in the age range of 17 to 30 years and 20 females in the age range of 18 to 36 years. The participants were non-smokers and they were not professional in speaking, singing, or voice training. The results revealed an estimated subglottal pressure ranged from 5 to 10 cm H_2O and mean airflow rate 0.07 to 0.20 L/s. The authors attributed that the average airflow measures were significantly higher for males than for females within all loudness conditions.

Stathopoulos and Sapienza (1993) studied respiratory and laryngeal measures in both children and adults. Participants included twenty 4-year-olds, twenty 8-year-olds, and twenty adults. All participants were healthy, American-English speaking, had normal hearing, with no professional voice, speech, or singing training. Results indicated that there was a significant increase in estimated subglottal pressure between loudness conditions for the children, but only from soft to loud for the adults. Also, significantly higher tracheal pressure was noted in comfortable and loud measures for children than for adults. Possible explanations for this finding point to the difference in vocal tract size and surface area between the two groups. Measures in children indicated that there was no significant difference between airflow values in boys and girls. Results further indicated that a significant difference existed between the airflow measures of men and women. Men were noted to have significantly higher airflow measures.

Jotinder Preet Sandhu (1994) did a study to establish normative data in adult group of 30 males and 30 females in the age range between 17 to 24 years for aerodynamic parameters using Aerophone II. The parameters which were considered for the study were maximum peak flow and vital capacity on sustained phonation, minimum, maximum and average sound pressure level, dynamic range, volume of air used during phonation mean flow rate and quotient of phonation. The results revealed no significant difference between males and females in vital capacity, peak flow, most comfortable phonation and vocal efficiency.

Rajeev (1995) conducted a study to establish normative data for aerodynamic parameters in adults in the age range of 15 to 25 years and to understand the effect of gender on aerodynamic measures. The aerodynamic parameters peak airflow during phonation, vital capacity, maximum sustained phonation, and vocal efficiency were measured in 60 normal adults using Aerophone II instrument. Results of the study revealed that mean value of maximum peak flow for males was 5.91 l/s and mean value of maximum volume was 3.75cc. Females had mean value of maximum peak flow as 4.08 l/s and mean value of maximum volume was 3.03 cc. Also it was found that there was a significant difference seen between males and females when peak air flow was considered. Males had higher aerodynamic values for vital capacity, peak flow, volume, MPT, MAF rate, mean SPL, peak air pressure and mean power. The author found no significant difference between males and females in terms of vocal efficiency but it was observed that the values obtained by males were towards higher side as compared to females. Further, the vocal resistance was found to be higher in females than males.

Venugopal, Sudhakar, and Savithri (2005) studied maximum phonation duration (MPD) and s/z ratio in 80 Dravidian normal children in the age range of 5-13 years. The participants were further subdivided into 8 age groups including 5-5.11, 6-6.11, 7-7.11, 8-8.11, 9-9.11, 10-10.11, 11-11.11, and 12-12.11 years with each age group consisted of 5 girls and 5 boys. The children were instructed to sustain vowels

/a/, /i/, /u/ and fricatives /s/ and /z/ as long as possible. The MPD and s/z ratio was measured using a stop watch. The results indicated that increase in MPD was statistically significant upto the age of 8 years for all the three vowels in both boys and girls. In general boys had longer MPD compared to girls. However, significant difference between genders was observed in the age range 5-5.11 for vowel /u/, 7-7.11 and 10-10.11 for all the three vowels (/a/, /i/, /u/), and 11-12.11 for vowel /a/. Among the vowels, /i/ was found to have maximum MPD in both genders. They attributed this to the greater extent for velopharyngeal closure required for /i/ vowel. The s/z ratio ranged from 0.49 to 0.83. The significant age difference was observed only between 5 and 6 years.

Weinrich, Salz, and Hughes (2005) evaluated aerodynamic measures in 75 children between the ages 6 and 10.11 years. The children were further divided into 5 subgroups such as 6-6.11 (2 males and 3 females), 7-7.11 (13 males and 3 females), 8-8.11 (6 males and 12 females), 9-9.11 (7 males and 12 females), and 10-10.11 (10 males and 7 females). The Pneumotachometer model MS 100 A-2 was used to obtain aerodynamic measures such as Open quotient, Speed quotient, Maximum flow declination rate, subglottal pressure. The subjects were asked to sustain vowel /a/ at low, comfort and high pitches for a minimum of 5 seconds and 5-7 repetitions of /pa/ at low, comfort and high pitches. The results did not reveal age or gender effect for any of the aerodynamic measures. However, they observed a trend of decrease in ESGP with age for all frequency levels. They observed slightly higher ESGP values for female children than for male children across all the frequencies.

In a recent study, Gopikishore, Pushpavathi, and Sheela (2012) obtained aerodynamic measures in 85 adults including 54 males and 31 females in the age range of 18 to 40 years. The participants were divided further into two age groups of

18-25 years and 26-40 years. ESGP, MAFR, and LAR were measured using Aeroview 1.4.4 version. The results revealed no statistically significant effect of gender on any of these aerodynamic measures. The age related changes were found for the ESGP and LAR, where older adult group showed more values than the younger adult group. MAFR and LAR were found to be higher in females than males. However, the ESGP values were found to be independent of participant's age at $p<0.05$ level of significance. A significant age effect was seen in ESGP and LAC parameters which were more for the older adult group. The ESGP is increasing with the increase in age. The authors stated that the difference in the parameters may be due to the age-related anatomical and physiological changes in the respiratory and laryngeal system.

Studies Related to Application of Aerodynamic Measures in Clinical Population

Iwata, Leden and Wilfiams (1972) compared the aerodynamic measures obtained from 181 individuals with laryngeal pathologies. They reported that the MAFR demonstrated by speakers with vocal hypofunction was statistically significantly higher than that of speakers with vocal hyperfunction. Netsell et al (1984) compared the aerodynamic measures obtained from 18 individuals with laryngeal abnormalities with those obtained from 30 normal adults. They reported that individuals with breathy voices demonstrated insufficient adduction of vocal folds, normal ESGP and high MAFR. The individuals with strained voices showed hyper adduction of vocal folds, increased ESGP and low MAFR.

Klich and Sabo (1988) examined ESGP of 10 individuals with breathy voices. They reported that ESGP decreased as breathiness of voice increased. Yiu, Yuen, Whitehill and Winkworth (2004) used the Aerophone II to collect data from 56 females native speakers of Cantonese (28 normal and 28 dysphonic). Seven measures related to the parameters of ESGP and MAFR were investigated. The results indicated that these parameters can be used to predict non-dysphonic versus dysphonic voices.

Salaj Bathanagar (1994) studied aerodynamics of voice of hearing impaired by comparing with aerodynamic features of normal healthy adults. The parameters considered were peak air flow during phonation, vital capacity, Maximum phonation duration, vocal efficiency. In 80 subjects, further the participants were divided into 40 normal typical subjects of 20 males and 20 females with the mean age group of 24.2 years and 40 hearing impaired population, with the mean age group of 22.4 years. The results revealed in maximum peak flow normal subjects showed higher peak flow values than hearing impaired and males had higher peak flow than females. In peak flow volume normal hearing subjects showed higher value than hearing impaired in vital capacity, maximum phonation duration vocal efficiency and in compared to normal females, males had higher values.

Hartl, Hans, Vaissiere, and Brasnu (2003) studied objective measures of breathiness with unilateral vocal fold paralysis in adult males. Both normal and clinical participants were asked to prolong /a/, and to read phonetically balanced sentence. The grade of dysphonia, roughness, breathiness, asthenia, and strain of the participants were perceptually analyzed by Speech-language pathologists and Otolaryngologists. Acoustic and aerodynamic measures of voice were obtained. The results revealed that there is a significant difference between the unilateral vocal fold paralysis participants and the control participants. To successfully differentiate the unilateral vocal fold paralysis from the control participants 10 of the 14 objective measures were used. The authors concluded that objective measures are effective and reliable to distinguish the individuals with vocal pathology from those with normal vocal quality.

Holmberg, Doyle, Perkell, Hammarberg, and Hillman (2003) did a study on 10 males in the age range from 19 to 35 years who had bilateral vocal nodules. Aerodynamic and acoustic measures were carried out for all the individuals with vocal fold nodules. The authors concluded that compare to acoustic measures, aerodynamic measures indicated the existence of vocal pathologies more effectively. Thus, they attributed that aerodynamic measures is a reliable tool for the voice evaluation to detect the presence of vocal pathologies.

Al-Malki, (2005) compared aerodynamic analysis of 31 adult individuals with vocal fold polyps on either or both vocal folds with age and gender matched control group. Aerophone II (Model 6800, Kay Elemetrics Corp., Lincoln Park, NJ, USA) was used to obtain vital capacity, maximum phonation time, phonation quotient, mean airflow rate, subglottic pressure, glottal aerodynamic input power, glottal efficiency, and laryngeal airway resistance. Results revealed that vocal fold polyps caused statistically highly significant increase in phonation quotient, mean airflow rate, subglottic pressure, and glottal aerodynamic input power. They also caused statistically highly significant decrease in maximum phonation time and laryngeal airway resistance. There were no statistically significant differences in vital capacity or glottal efficiency. The authors concluded that aerodynamic analysis of voice is one of the essential tools in the assessment of vocal fold polyps.

The laryngeal aerodynamic parameters have been found to be a useful tool in discriminating normal vocal function from pathologic ones. The importance of these measures in the assessment and treatment of individuals with voice disorders is increasingly being recognized (Baken, 1987). Grillo and Verdolini (2008) investigated the efficacy of laryngeal aerodynamic parameters laryngeal resistance and vocal efficiency in distinguishing pressed, normal, resonant, and breathy voice qualities in vocally trained subjects. The authors concluded that, out of the two parameters the laryngeal resistance was efficient in distinguishing the pressed from normal and breathy voice qualities. In a similar study by Grillo, Perta and Smith (2009), laryngeal resistance was found to be successful in distinguishing the pressed, normal, and breathy voice qualities in vocally untrained females.

Zheng, Zhang, Su, Gong, Yuan, Ding, and Rao, (2012) studied the role of laryngeal aerodynamic analysis in the diagnosis of muscle tension dysphonia (MTD). Aerodynamic parameters, including estimated subglottal pressure level, laryngeal airway resistance, mean airflow rate, and maximum phonation time, were analyzed for 26 MTD participants and 27 normal adults. Receiver operating characteristics (ROC) analysis and multivariate logistic regression were used to verify sensitivity of each of these parameters in participants with MTD. Results indicated that male participants with MTD had higher ESGP, LAR, and reduced MAFR, and MPT compared to controls. In female participants ESGP is the only parameter that differed significantly between control and clinical participants. Further, multivariate logistic regression established a credible model (with ESGP and MPT as the predictors) for classifying MTD, with a 92.5% percentage correct. The authors concluded that the aerodynamic parameters could provide additional information and aid in the diagnosis of MTD.

The above studies provided insight into different aspects of aerodynamic parameters in children and adults. However, considering the ethnic, racial variations and instrumental variations these results cannot be applied directly to Indian children. In view of the clinical and research applications of aerodynamic parameters and the dearth of studies in the Indian context, the present study is taken up with the aim of developing normative database for typically developing children in the age range of 8-12 years.

CHAPTER - III

Method

The aim of the present study was to establish normative data for aerodynamic parameters estimated subglottic pressure (ESGP), Mean airflow rate (MAFR), and laryngeal airway resistance (LAR) in typically developing children between 8 and 12 years of age and to investigate the effect of age and gender on these parameters.

Participants

Eighty three typically developing children in the age range of 8 to 12 years were considered for the study. The children were made into four groups with one year age interval (8-9, 9-10, 10-11, and 11-12) with upper limit excluded from the class interval. Each age group consisted of a minimum of 20 with 10 males and 10 females (table 1).

Table 1.

Distribution of participants by age and gender.

Age	Males	Females	Total
8 – 9	10	10	20
9 – 10	10	11	21
10 – 11	11	11	22
11 – 12	10	10	20
Total	41	42	83

Inclusion criteria: All the participants were randomly selected from the schools of Mysore city. The participants were interviewed and perceptually judged about the status of their voice by qualified SLP. Based on the informal interview and information from class teacher, the participants fulfilling the following criteria were included in the study.

- Participants who were identified with perceptually normal voice by a qualified Speech language pathologist.
- Participants without active laryngeal or pharyngeal infections on the day of study.
- Participants with normal oral cavity structures and lip seal (to facilitate in building of intra oral pressure and holding the intra oral tube firmly).
- Participants without orofacial anomalies such as cleft palate or submucous cleft.
- Participants without sensory motor issues such as hearing loss, paresis/paralysis of oral structures.

Instrumentation

The Aeroview 1.4.4 version (Glottal Enterprises Inc, Syracuse, NY) was used to measure ESGP, MAFR, and LAR. The Aeroview is a computer-based portable system consists of a circumferentially vented (CV) pneumotachograph mask coupled to PT-25B air pressure transducer and PT-2E wideband model air flow transducer (figure 2). Low pass filtering for airflow was set at 500 Hz as per the manufacturers recommended. Window length of 5.12 seconds, which is the maximum limit, was selected for recording.

Figure 2. Pneumotachograph mask with PT-2E wideband airflow transducer and PT-25B pressure transducer.

Procedure

All the measurements were obtained in a distraction free room with minimal noise level. Airflow and air pressure transducers of Aeroview were calibrated daily as per the instructions provided by the manufacturer. The pneumotachograph mask was wiped with Dettol solution and the intra oral tubes were rinsed thoroughly with running water and kept in Dettol solution for 5 minutes at starting of the day and following each testing. The participants were seated straight, comfortably and complete procedure was explained. The participants were instructed to hold the mask firmly against the face to completely cover the nose and mouth (figure 3). It was ensured that the intraoral tube was placed between the lips and above the tongue. Further, the oral end of the tube was kept slightly elevated so that the opening of the tube is not blocked by the tongue.

Figure 3. A view of a child performing aerodynamic measurements.

The participants were instructed to produce the repetitions of CV syllable /pa/ 6-7 times into the circumvented mask at a comfortable pitch, loudness. The rate and style of production was demonstrated by the examiner and two practice trials were given before the actual recording. Following practice, the actual recordings were taken. The recordings with syllable production rate between 2.5 to 4 per second and flat pressure peak morphology (figure 4) were considered for the further analysis. Recordings with significantly higher syllable rates of more than 4.0 or lower syllable rates of less than 2.50 are suitable for extrapolating subglottic pressure. The higher rates may yield pressure pulses in which the sub glottal and oral pressures have not equalized or yield a vowel that does not have a quasi-steady-state segment that can be measured. If the rate is lower than 2.5/s, the participant would not be able to maintain constant subglottic pressure over the syllable and may use different subglottic pressure for each syllable.

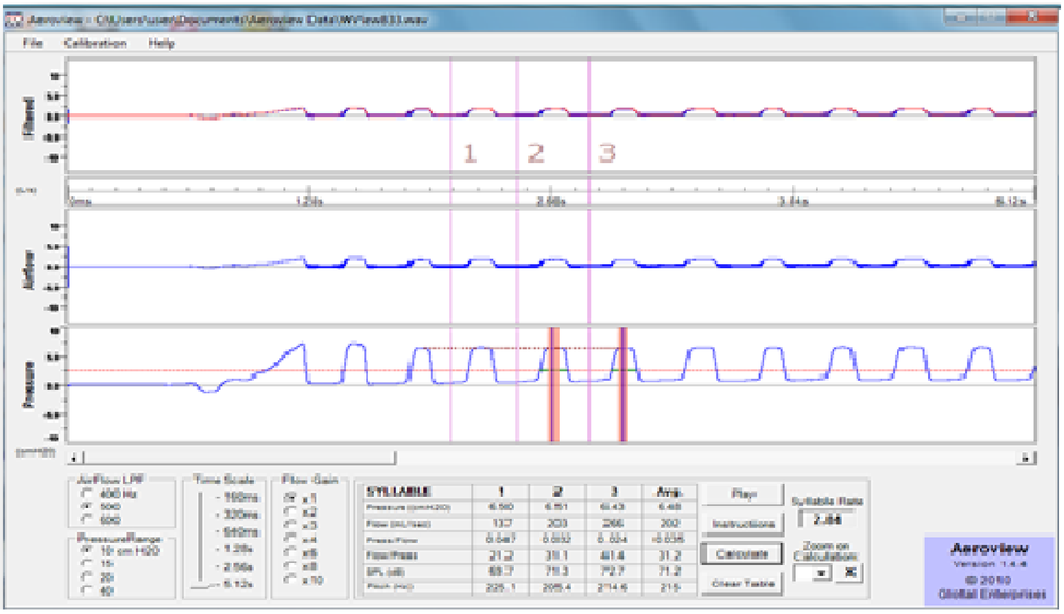

Figure 4. Typical morphology of appropriate pressure peak and airflow wave.

The recording was repeated twice or thrice when required, so as to obtain appropriate recordings (figure 4). The recorded waveform was analyzed by placing the cursors on flat portions of the two adjacent pressure peaks. The Aeroview software analyses the waveform and provides the values of ESGP (cm H_2O), MAFR (ml/s), and LAR (cm H_2O/ml/s) values. Three peak to peak measures were obtained and their average was considered for further analysis. The MAFR and LAR measures were manually converted to liters per second (L/s) in order facilitate comparison with the earlier studies. 10% of the recorded data was analyzed by the same speech language pathologist after a gap of 1 week so as to measure intra tester reliability, and by two other qualified speech language pathologists in order to measure inter tester reliability.

Statistical Analysis

Statistical Package for Social Sciences (SPSS) version 18.0 was used to perform all the statistical analysis. Descriptive statistical measures mean and standard deviation for all the parameters were calculated separately for all the age groups and across the gender. Two way multivariate analysis of variance (MANOVA) was conducted to verify the main effects of independent variables on the dependent variables. Age (4 levels) and gender (2 levels) served as the independent variables, and the parameters measured (ESGP, MAFR, and LAR) served as the dependent variables.

CHAPTER - IV

Results and Discussion

The present study was conducted with the aim of establishing normative data for aerodynamic measures estimated subglottic pressure (ESGP), mean airflow rate (MAFR) and laryngeal airway resistance (LAR) in typically developing children. To achieve this, data was obtained from 83 participants of 41 males and 42 females in the age range of 8-12 years. Further, these participants were divided under four age groups with one year age interval. It was ensured that each age group should have approximately equal number of participants. It was observed during the data collection that participants across all the ages followed the instructions and performed consistently. Some of the participants achieved extreme scores, influencing the mean value. In order to regulate this, box plots were drawn using SPSS 18.0 considering the three aerodynamic parameters. The possible outliers were identified from the box plots and were removed manually from the main data. Following this, further statistical analysis was performed on a total of remaining 74 participants (38 males and 36 females).

The results of the study will be presented and discussed under the following headings

- Reliability of the aerodynamic parameters ESGP, MAFR, and LAR.
- Normative data for ESGP, MAFR, and LAR in children.
- Effect of age on ESGP, MAFR, and LAR.
- Effect of gender on ESGP, MAFR, and LAR.

Reliability of the Aerodynamic Parameters ESGP, MAFR, and LAR

To verify the reliability of measured aerodynamic parameters, 10% of the samples were randomly selected and reanalysed by the same examiner and by two other qualified speech language pathologists. Intra judge and inter judge reliability tests were performed on this obtained data.

Intra judge reliability: For intra judge reliability, Cronbach's alpha was used and it revealed 0.91, 0.99, and 0.96 as the reliability coefficients for the parameters ESGP, MAFR, and LAR respectively (table 2). The high Cronbach's alpha value (> 0.90) indicates that these aerodynamic parameters have good intra judge reliability.

Table 2.

Cronbach's Alpha for inter and intra judge reliability

Parameter	Cronbach's Alpha Coefficient	
	Intra judge reliability	**Inter judge reliability**
Estimated subglottic pressure	0.91	0.99
Mean airflow rate	0.99	0.99
Laryngeal airway resistance	0.95	0.99

Inter judge reliability: For inter judge reliability, Cronbach's alpha was used and it revealed 0.99 value as the reliability of coefficients for the three measured aerodynamic parameters ESGP, MAFR, and LAR (table 2). The high Cronbach's alpha value (> 0.90) indicates that these aerodynamic parameters have good inter judge reliability.

Normative Data for ESGP, MAFR, and LAR in Children

Estimated subglottic pressure: The mean and standard deviation of the estimated subglottic pressure (ESGP) is given in the table 3. In general the ESGP values decreases as the age increases. From the table-3, it is evident that the ESGP in males is lowest in the age range of 8-9 years at 6.16 cm H_2O, whereas it is highest in the age range of 10-11 years at 6.79 cm H_2O. In females, consistent trend was not observed, ESGP was lowest in the age range of 11-12 years with 5.85 cm H_2O and it is highest in the age range of 9-10 years with 7.11 cm H_2O. The overall value of ESGP is more for males with 6.48 (±1.57) cm H_2O as compared to females with 6.30 (±1.37) cm H_2O.

The ESGP values obtained in the present study are in consistency with the results obtained by (Keilmann and Bader, 1995). These authors investigated the estimated subglottic pressure in children between 4-15 years and reported that the value of ESGP ranged from 6-10 cm H_2O in younger children. In the present study, this value ranged from 4.03 - 9.96 cm H_2O in males and 4.18 - 9.48 cm H_2O in females. However, the slightly lower ESGP values in the present study may be due to the use of low vowel /a/ versus use of high vowel /i/ by Keilmann and Bader (1995), in the context of /pa/ for measuring ESGP.

This explanation is supported by the earlier studies which reported higher ESGP values with vowel /i/ than /a/ (Netsell et al. 1991, Higgins, Netsell, and Schulte, 1998). Netsell et al. (1991) attributed this to the use of tenser vocal folds during the production of high vowels, which requires greater pressure to set these vocal folds into vibration. Higgins et al. (1998) attributed the use of higher ESGP for /p/ in the context of /i/ than /a/ to the tenser vocal tracts in the /i/ context, resulting in greater impedance. Hence the lower value of ESGP is due to the vowel /a/.

Table 3.

Mean and Standard deviation of ESGP (cm H_2O) across age and gender.

Age (yrs)	**Gender**			
	Male		**Female**	
	Mean (±SD)	**Range**	**Mean (±SD)**	**Range**
8 – 9	6.16 (1.60)	4.13 – 9.44	6.56 (1.72)	4.35 – 9.48
9 – 10	6.35 (1.55)	4.03 – 8.32	7.11 (1.30)	4.85 – 8.54
10 – 11	6.79 (1.27)	4.93 - 8.90	5.89 (1.04)	4.26 – 7.48
11 – 12	6.61 (2.08)	4.51 - 9.96	5.85 (1.16)	4.18 – 7.36
Overall	6.48 (1.57)	4.03 – 9.96	6.30 (1.37)	4.18 – 9.48

Participants in the present study obtained an ESGP value slightly lower than reported by Weinrich et al. (2005). These authors investigated the ESGP in children from 6 to 11 years using Pneumotachometer facemask coupled to a wide band pressure transducer (model MS 100 A-2, Glottal Enterprises, Syracuse, NY) and obtained the value of 8.72 cm H_2O to 9.86 cm H_2O. The difference in ESGP of the present study values from the Weinrich et al. (2005) study may be due to the age range, different instrument and ethnic and racial variations of the participants considered for the study. Their study included children from 6 years of age onwards.

Therefore, the higher subglottic pressures from these younger children might have influenced the overall ESGP value. Further, the present study was done on the Dravidian children, whereas, the Weinrich et al. (2005) study was done on western children. Literature reveals that the vital capacity (Bhattacharya, 1963; Kamat, Tyagi and Rashid, 1982) and average Indian height (Marshall, 1981) were less for Indians compared to western population. These physical variations would have led to the difference in ESGP value in the present study.

Mean airflow rate: The mean and standard deviation of Mean air flow rate (MAFR) is given in the table. 4. Table 4 reveals that the males in the age range of 8–9 years obtained lowest MAFR i.e. 0.218 L/s and those in the age range of 10–11 years obtained highest MAFR value of 0.273 L/s. In females, the MAFR value is lowest in the age range of 9–10 years with 0.149 L/s and highest in females in the age range of 8–9 years at 0.223 L/s. There is no specific trend or pattern of increase or decrease in MAFR observed with respect to age and gender. However, the total value of MAFR is more for males with 0.250 (± 0.100) L/s as compared to females with 0.196 (± 0.106) L/s.

Table 4.

Mean and Standard deviation of MAFR (L/s) across age and gender.

Age (yrs)	**Gender**			
	Male		**Female**	
	Mean (± SD)	**Range**	**Mean (± SD)**	**Range**
8 – 9	0.218 (0.102)	0.132 - 0.471	0.223 (.131)	0.109 - 0.495
9 – 10	0.264 (0.117)	0.083 - 0.442	0.149 (.078)	0.105 - 0.326
10 – 11	0.273 (0.116)	0.093 - 0.479	0.206 (.131)	0.107 - 0.515
11 – 12	0.244 (0.047)	0.173 - 0.294	0.192 (.065)	0.109 - 0.344
Overall	0.250 (0.100)	0.083 - 0.479	0.196 (.106)	0.105 - 0.515

The overall MAFR value obtained in the present study is 0.250 L/s in males and 0.196 L/s for females. In males MAFR value increased from the age of 8–9 years to 10-11 years, but decreased from 10-11 years to 11-12 years. These values are lesser when compared to that of those reported in the literature (Netsell et al. 1994; and Stathopoulos and Sapienza, 1997). Netsell et al. (1994) reported the MAFR values to be 0.111 L/s in males and 0.09 L/s in females using syllable train /pa/ as stimuli and at a syllable rate of 3.0/s. This finding may be the result of physical variations in the average height (Marshall, 1981), vital capacity (Bhattacharya, 1963; Kamat, Tyagi and Rashid, 1982) of the Indian children. Marshall (1981) reported that the average Indian height is 10 cm less than those of western population, which indicates the possibility of variation in vocal tract size. This factor may lead to the variations in the MAFR value across the studies.

Laryngeal airway resistance: The mean and standard deviation of Laryngeal airway resistance (LAR) is given in the table. 5. The below table 5 depicts that the males in the age range of 11-12 years acquired lowest LAR value of 27.50 cm H_2O/L/s, whereas the highest value for males is at 31.95 cm H_2O/L/s for the age range of 8-9 years. In females, the LAR with the age range of 11-12 years acquired lowest value at 34.04 cm H_2O/L/s, whereas females with the age range of 9-10 years has highest LAR value of 55.97 cm H_2O/L/s. The total value of LAR is more for females with 39.46 (±18.77) cm H_2O/L/s as compared to males with 29.65 (±13.18) cm H_2O/L/s.

Table 5.

Mean and Standard deviation of LAR (cm H_2O/L/s) across age and gender.

Age (yrs)	**Gender**			
	Male		**Female**	
	Mean (± SD)	**Range**	**Mean (± SD)**	**Range**
8 – 9	31.95 (12.16)	12.86 – 46.36	37.38 (19.84)	11.15 – 70.18
9 – 10	27.58 (11.78)	18.50 – 56.12	55.97 (20.97)	20.27 – 77.38
10 – 11	30.82 (18.32)	13.69 – 75.16	35.59 (15.38)	11.45 – 57.66
11 – 12	27.50 (8.37)	15.34 – 41.82	34.04 (15.15)	13.60 – 67.33
Overall	29.65 (13.18)	12.86 – 75.16	39.46 (18.77)	11.15 – 77.38

In the present study, overall laryngeal airway resistance values for males are 29.65 cm H_2O/L/s and for females it is 39.46 cm H_2O/L/s. These values are much lesser than those reported in the earlier studies (Netsell et al., 1994 and Stathopoulos and Sapienza, 1997). The participants in the present study obtained higher MAFR values and a relatively equal ESGP values when compared to the western studies. This can be the reason for lower LAR values, as the LAR is a derived parameter that is based on the independent values of ESGP and MAFR.

The LAR values obtained in the present study was higher than those reported by Gopikishore et al. (2012) in adults, thus maintaining the trend of decrease in LAR with participant's age. Gopikishore et al. (2012) reported the LAR value in adults in the age range of 18-25 years as 22.56 cm H_2O/L/s and 26.53 cm H_2O/L/s in males and females respectively. In the present study, these values in children are on a lower side at 29.65 cm H_2O/ L/s in males and 39.46 cm H_2O/ L/s in females. Further, the finding that females obtained higher LAR values than males is also is in consistency with several studies in the literature (Shaughnessy, Lotz, and Netsell, 1981; Holmberg et al., 1988; Netsell et al., 1991; Wilson and Leeper, 1992; Holmes, Leeper, and Nicholson, 1994; Netsell et al., 1994; Goozee et al., 1998; and Gopikishore et al., 2012).

It can be observed that, although the LAR values of the present study vary with those reported in literature, but the trends with respect to the age and gender are well maintained. Hence, it may be concluded that the absolute values of LAR in Indians will be different from those of western population. Nevertheless, the relative trends in LAR are true with respect to the age and gender.

Effect of age on ESGP, MAFR, and LAR

To analyze the effect of age on ESGP, MAFR and LAR, Two way MANOVA was used. The result of Two way MANOVA did not reveal significant main effect of age for any of the measured laryngeal aerodynamic parameters ESGP [F (3, 66) = 0.347, $p>0.05$], MAFR [F (3, 66) = 0.310, $p>0.05$], or LAR [F (3, 66) = 1.365 $p>0.05$] (table 6). The finding that ESGP is not influenced by the age of the participant is in consistency with the earlier study by Weinrich et al. (2005). This study also reported that ESGP did not vary significantly in children as a function of age.

In the present study, although the participant's age did not influence the ESGP significantly, some interesting trends are observed with increasing age (figure 5). In males the value of ESGP increased till the age of 10-11 years and declined in the age group of 11-12 years. In females, the ESGP values increased from 8-10 years of age and then onwards shown a decline with increasing age. These findings are in coherence with several of the earlier studies by Netsell, Lotz, Peters, Schulte, 1994; Keilmann and Badder 1995; Stathopoulos and Sapienza, 1997; and Weinrich et al. 2005. The decline in of ESGP values in both males and females in the age range of 11-12 years is also in coherence with the study by Hoit and Hixon (1987) who reported that children acquire adult like values in acoustic and articulatory kinematics of speech by 10 to 12 years of age.

Table 6.

Two-way MANOVA interaction effects.

Type of effect	Parameter	*p* value
Age	ESGP (cm H_2O)	.791
	MAFR (L/S)	.818
	LAR (cm H_2O/L/S)	.261
Gender	ESGP (cm H_2O)	.720
	MAFR (L/S)	.024*
	LAR (cm H_2O/L/S)	.004*
Age * Gender	ESGP (cm H_2O)	.257
	MAFR (L/S)	.400
	LAR (cm H_2O/L/S)	.119

*parameters found to be significant at $p<0.05$

Stathopoulos and Sapienza (1997) attributed this decreasing trend in ESGP to the anatomical differences in the upper and lower airway that affect the acoustic output of the vocal tract. Muller and Brown (1980) opined that the increased airway resistance in children may in turn lead to substantial increase in their tracheal pressures. This may also be explained by the fact that the vocal fold structure in children matures by their adulthood. For instance, the layered structure of the vocal folds, stability in the vocalis muscle improves as a function of age. These anatomical and physiological changes may improve the vocal functioning in children as they grow older, which makes their voice more economical and allow them to phonate using lesser subglottic air pressures.

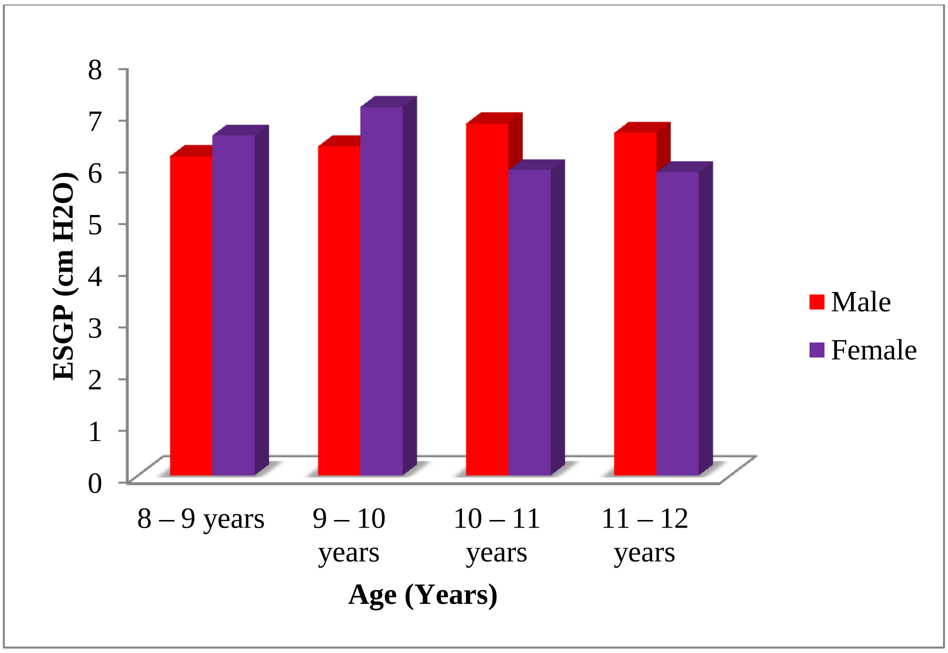

Figure 5. Mean ESGP (cm H_2O) across the age and gender.

Similar to the ESGP, the MAFR values also are not observed to be influenced by participant's age (figure 6). Also there are no specific trends observed in the MAFR value with respect to participant's age. These findings are in consistency with the study by Stathopoulos and Sapienza, (1997) who reported that translaryngeal airflow did not change as a function of age or gender. Ordinarily MAFR is not affected by the size of the vocal folds and is affected only by the degree of vocal fold closure and tracheal pressure. Since the present study considered children with perceptually normal voice, a consistent MAFR value is expected across the age groups.

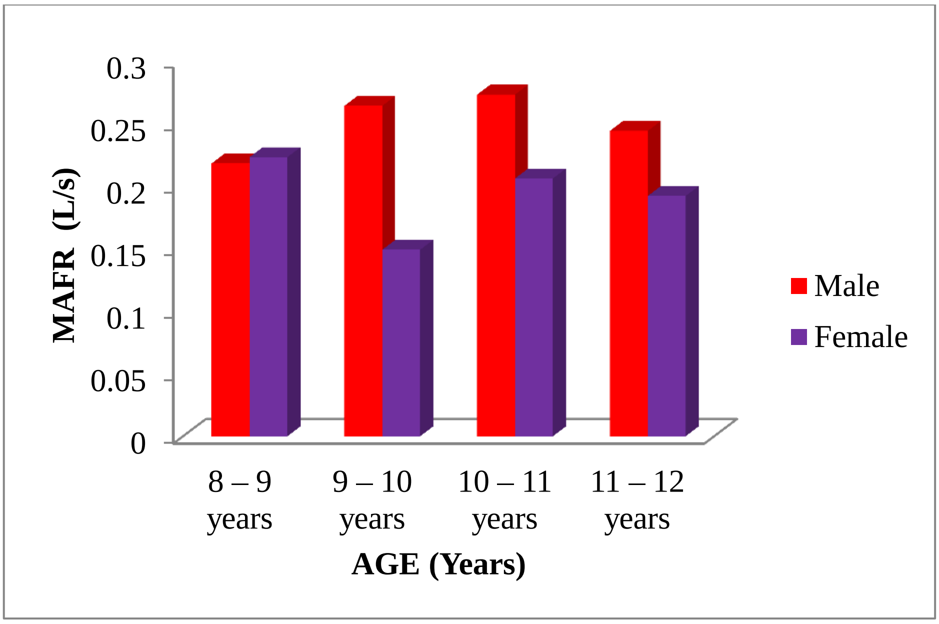

Figure 6. Mean MAFR (L/s) across the age and gender.

In the present study the Laryngeal airway resistance did not vary as a function of age. LAR is a derived parameter that is based on the values of ESGP and MAFR. The individual values of ESGP and MAFR did not vary significantly with age in the present study, which may be the reason for consistent LAR values across the age groups. Further, an interesting trend of decrease in LAR value with age is observed in females (figure 7).This is an expected finding as in the present study the ESGP decreased with age and MAFR remained relatively constant.

This finding is in agreement with the previous study (Stathopoulos and Sapienza, 1997). These authors found that children uses higher LAR, which starts decreasing from 6 years of age and achieves adult like LAR values by the age of 14. In the present study, the decrease in LAR values is observed from 10 years of age. This can be attributed to the difference in ethnic and racial variations of the children being studied. Although the same trend in LAR values is not evident in male participants of the present study, their LAR values reduced from 31.95 cm H_2O/L/s at 8-9 years to 27.50 cm H_2O/L/s at 11-12 years of age.

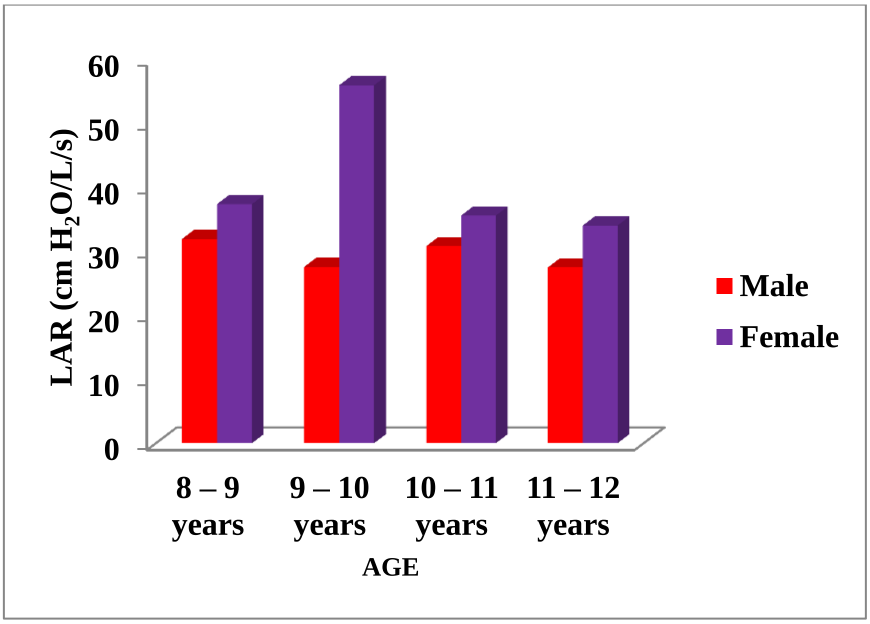

Figure 7. Mean LAR (cm H_2O/L/s) across the age and gender.

Effect of gender on ESGP, MAFR, and LAR

Gender is found to have a different influence on each of the measured aerodynamic parameters ESGP, MAFR, and LAR. Two way MANOVA revealed significant main effect of gender for the MAFR [F (1, 66) = 5.305, $p<0.05$], and LAR [F (1, 66) = 8.962, $p<0.05$]. However, it did not reveal a significant main effect of gender for ESGP [F (1, 66) = 0.130, $p>0.05$].

The finding that ESGP is not influenced by the gender of the participant is in consistency with several of the earlier studies done in children (Stathopoulos and Sapienza, 1993; Netsell et al. 1994; and Weinrich et al. 2005) and in adults (Holmes et al. 1994; Goozee et al. 1998; Ketelslagers et al. 2007; and Gopikishore et al. 2012). These authors had hypothesized that males and females maintain same range of ESGP by balancing the elastic recoil and muscular forces of the respiratory system.

Weinrich et al. (2005) did not find any significant difference in ESGP of males and females till 14 years of age. The data in the present study also did not reveal a statistically significant effect of gender till 12 years of age. From these findings, it can be explained that subglottic pressure may not vary across the gender at least until puberty. Netsell et al. (1994) attributed to the comparable airway size and recoil systems of the respiratory system in male and female children of similar age.

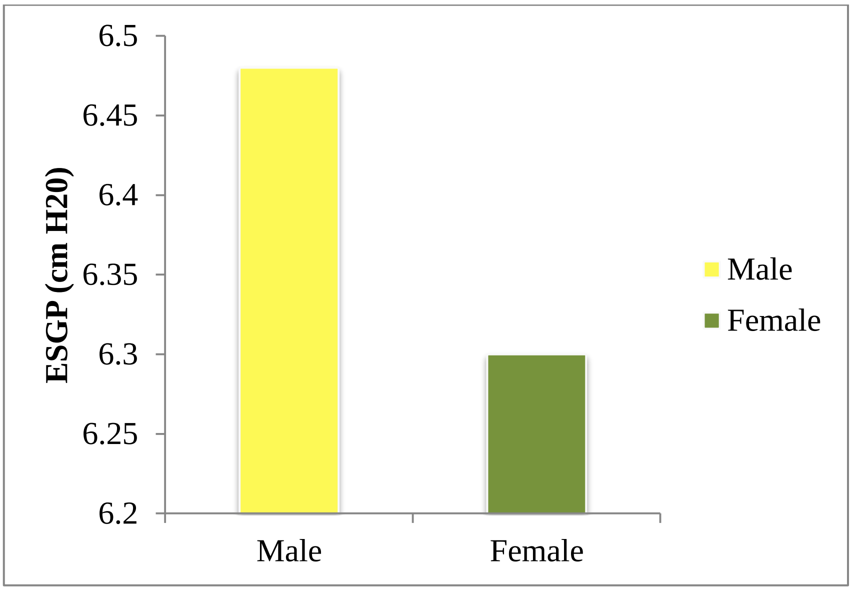

Figure 8. Mean of ESGP (cm H_2O) across the gender.

Further, in the present study, the observed overall ESGP measures are slightly lower in females (6.30 cm H_2O) than for males (6.48 cm H_2O). Similar findings were also reported by Netsell et al. (1994) and Weinrich et al. (2005). Netsell et al. (1994) also reported that the male participants used slightly higher pressures than the female participants (7.9 versus 7.3 cm H_20). This may be attributed to the difference in lung volumes and capacities in male and female children.

Male participants showed greater MAFR values compared to females. This supports the findings of (Shaughnessy *et al*. 1981, Stathopoulos and Weismer 1985, Holmberg *et al*. 1988, Higgins and Saxman 1991, Wilson and Leeper 1992, Holmes *et* *al*. 1994). The authors hypothesized that the anatomical and physiological differences were responsible for higher flow rates produced by the male participants. When compared to MAFR value in normal Indian adults (Gopikishore et al. 2012), children acquired lower values in both males and females. However, these findings are in contrary to those reported by Stathopoulos and Sapienza (1997), who reported that MAFR values were more for females compared to males.

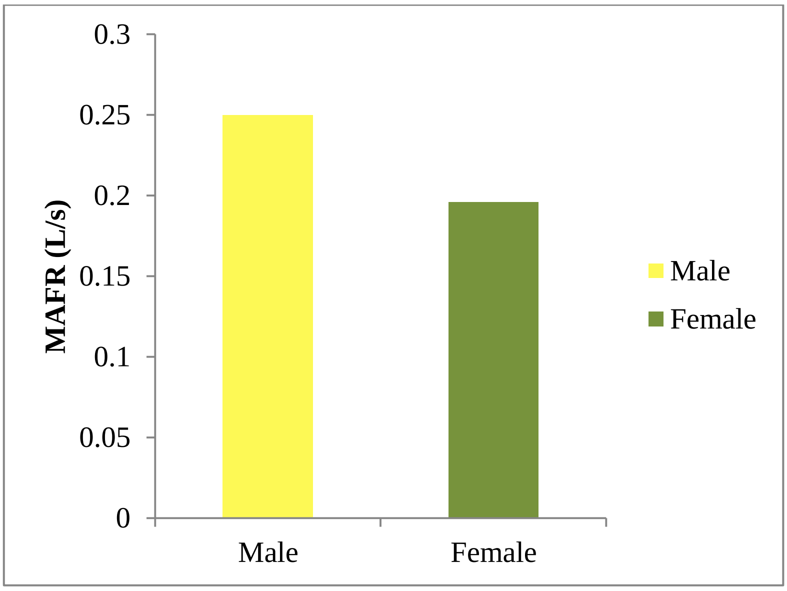

Figure 9. Mean of MAFR (L/s) across the gender.

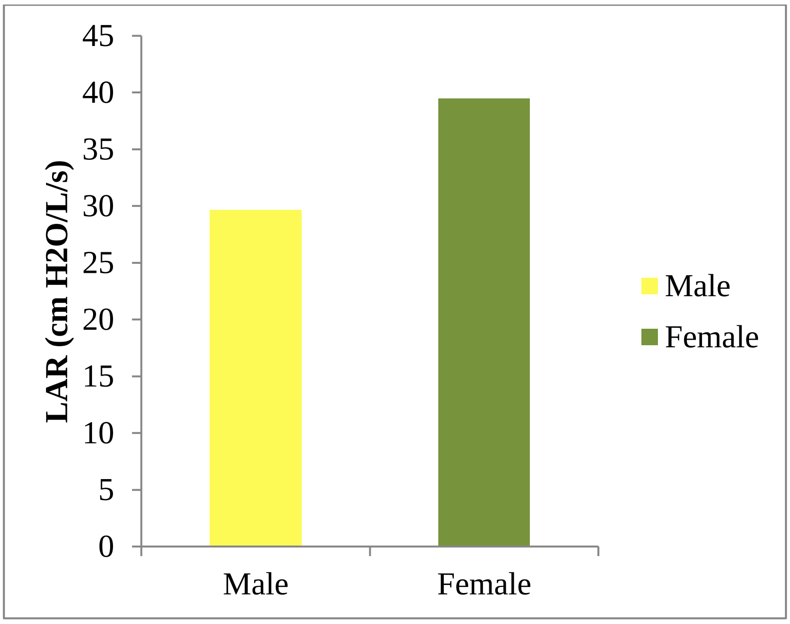

Figure 10. Mean of LAR (cm H_2OL/s) across the gender.

The LAR values obtained in the present study were more for females in comparison to males. This supports the findings reported in the literature (Netsell et al. 1994, Holmberg et al., 1988; Wilson and Leeper, 1992; Holmes, Leeper, and Nicholson, 1994; Goozee et al., 1998; and Gopikishore et al., 2012). These authors also reported that females exhibit significantly higher laryngeal airway resistance values than males. These findings are in contrary to those reported by Stathopoulos and Sapienza (1997). They reported higher LAR values for males compared to females. The authors attributed this variation in MAFR and LAR values to the variations in the instruments used and to the anatomical and physiological variations between males and females.

CHAPTER - V

Summary and Conclusion

Voice is the vital source for the efficient communication through which words are uttered. Voice is the tone which is generated by the vibration of larynx further gets amplified and modified as it passes through the vocal tract. The current study was conducted to establish normative database for aerodynamic parameters of estimated subglottic pressure (ESGP), mean airflow rate (MAFR) and laryngeal airway resistance (LAR) in typically developing children in the age range of 8–12 years. The study was also aimed to explore the effect of age and gender on these three parameters.

The instrument used in this study was Aeroview1.4.4 version (Glottal Enterprises Inc, USA) and the parameters which were considered are ESGP, MAFR and LAR. A total of 74 children including 38 males and 36 females participated in the study. The subjects were instructed to produce the repetitions of CV syllable /pa/ 6-7 times into the circumvented mask at a comfortable pitch and loudness to obtain six to seven stable peaks of intraoral pressure. The mean values were extracted for these parameters across the age groups. Two way MANOVA were used to verify the statistical significance of the effect of age and gender of the obtained aerodynamic parameters.

The parameters considered for developing normative data were ESGP, MAFR and LAR. ESGP in males is lowest in the age range of 8-9 years at 6.16 cm H_2O, whereas it is highest in the age range of 10-11 years at 6.79 cm H_2O. In females, ESGP was lowest in the age range of 11-12 years with 5.85 cm H_2O and it is highest in the age range of 9-10 years with 7.11 cm H_2O. The overall value of ESGP is more for males with 6.48 (±1.57) cm H_2O as compared to females with 6.30 (±1.37) cm H_2O.

The ESGP values obtained in the present study are in consistency with those reported in the literature (Keilmann and Bader, 1995). In the present study, this value ranged from 4.03 - 9.96 cm H_2O in males and 4.18 - 9.48 cm H_2O in females. However, the slightly lower ESGP values in the present study may be due to the use of low vowel /a/ versus use of high vowel /i/ by Keilmann and Bader (1995), in the context of /pa/ for measuring ESGP. This explanation is supported by the earlier studies which reported higher ESGP values with vowel /i/ than /a/ (Netsell et al. 1991, Higgins, Netsell, and Schulte, 1998). Netsell et al. (1991) attributed this to the use of tenser vocal folds during the production of high vowels, which requires greater pressure to set these vocal folds into vibration.

The results of Mean airflow rate reveals that the males in the age range of 8–9 years obtained lowest MAFR i.e. 0.218 L/s and those in the age range of 10–11 years obtained highest MAFR value of 0.273 L/s. In females, the MAFR value is lowest in the age range of 9-10 years with 0.149 L/s and highest in females in the age range of 8–9 years at 0.223 L/s. There was no specific trend or pattern of increase or decrease in MAFR observed with respect to age and gender. However, the total value of MAFR is more for males with 0.250 (± 0.100) L/s as compared to females with 0.196 (± 0.106) L/s.

The average MAFR obtained in the present study is 0.250 L/s in males and 0.196 L/s for females. These values are lesser when compared to that of those reported in the literature (Netsell et al. 1994; and Stathopoulos and Sapienza, 1997). Netsell et al. (1994) reported the MAFR values to be 0.111 L/s in males and 0.09 L/s in females using syllable train /pa/ as stimuli and at a syllable rate of 3.0/s. This finding may be the result of physical variations in the average height (Marshall, 1981), vital capacity (Bhattacharya, 1963; Kamat, Tyagi and Rashid, 1982) of the Indian children.

Laryngeal airway resistance of the males in the age range of 11- 12 years acquired lowest LAR value of 27.50 cm H_2O/L/s, whereas the highest value for males is at 31.95 cm H_2O/L/s for the age range of 8 – 9 years. In females, the LAR with the age range of 11- 12 years acquired lowest value at 34.04 cm H_2O/L/s, whereas females with the age range of 9 – 10 years has highest LAR value of 55.97 cm H_2O/ L/s.

The overall value of LAR is more for females with 39.46 (±18.77) cm H_2O/L/s as compared to males with 29.65 (±13.18) cm H_2O/L/s. These values are much lesser than those reported in the earlier studies (Netsell et al., 1994 and Stathopoulos and Sapienza, 1997). The participants in the present study obtained higher MAFR values and a relatively equal ESGP values when compared to the western studies. Considering this, it is not surprising to find lower laryngeal resistance values, as the LAR is a derived parameter that is based on the independent values of ESGP and MAFR.

The LAR values in children in the present study are on a lower side at 29.65 cm H_2O/L/s in males and 39.46 cm H_2O/L/s in females. Further, the finding that females obtained higher LAR values than males is also is in consistency with several studies in the literature (Netsell et al., 1994; Goozee et al., 1998; and Gopikishore et al., 2012). It can be observed that, although the LAR values of the present study vary with those reported in literature, the trends with respect to the age and gender are well maintained. Hence it may be concluded that the absolute values of LAR in Indians will be different from those of western population. Nevertheless, the relative trends in LAR are true with respect to the age and gender.

Two way MANOVA was used to study the effect of age on ESGP, MAFR and LAR and the results did not reveal significant main effect of age for any of the measured laryngeal aerodynamic parameters ESGP [F (3, 66) = 0.347, $p>0.05$], MAFR [F (3, 66) = 0.310, $p>0.05$], or LAR [F (3, 66) = 1.365 $p>0.05$] . The finding that ESGP is not influenced by the age of the participant is in consistency with the earlier study by Weinrich et al. (2005). This study also reported that ESGP did not vary significantly in children as a function of age. In the present study, although the participant's age did not influence the ESGP significantly, some interesting trends are observed with increasing age. In males the value of ESGP increased till the age of 10-11 years and declined in the age group of 11-12 years.

In females, the ESGP values increased from 8-10 years of age and then onwards shown a decline with increasing age. These findings are coherence with several of the earlier studies (Stathopoulos and Sapienza, 1997; and Weinrich et al. 2005). The decline in of ESGP values in both males and females in the age range of 11-12 years is also in coherence with the study by Hoit and Hixon (1987) who reported that children acquire adult like values in acoustic and articulatory kinematics of speech by 10 to 12 years of age.

Stathopoulos and Sapienza (1997) attributed this decreasing trend in ESGP to the anatomical differences in the upper and lower airway that affect the acoustic output of the vocal tract. These anatomical and physiological changes may improve the vocal functioning in children as they grow older, which makes their voice more economical and allow them to phonate using lesser subglottic air pressures.

Similar to the ESGP, the MAFR values also not observed to be influenced by participant's age. Also there are no specific trends observed in the MAFR value with respect to participant's age. These findings are in consistency with the study by Stathopoulos and Sapienza, (1997) who reported that translaryngeal airflow did not change as a function of age or gender. Ordinarily MAFR is not affected by the size of the vocal folds and is affected only by the degree of vocal fold closure and tracheal pressure. Since the present study considered children with perceptually normal voices, a consistent MAFR value is expected across the age groups.

In the present study the Laryngeal airway resistance did not vary as a function of age. This LAR is a derived parameter that is based on the values of ESGP and MAFR. The individual values of ESGP and MAFR did not vary significantly with age in the present study, which may be the reason for consistent LAR values across the age groups. Further, an interesting trend of decrease in LAR value with age is observed in females. This is an expected finding as in the present study the ESGP decreased with age and MAFR remained relatively constant.

This finding is in agreement with the previous study (Stathopoulos and Sapienza, 1997). These authors found that children uses higher LAR, which starts decreasing from 6 years of age and achieves adult like LAR values by the age of 14. In the present study, the decrease in LAR values is observed from 10 years of age. This can be attributed to the difference in ethnic and racial variations of the children being studied. Although the same trend in LAR values is not evident in male participants of the present study, their LAR values reduced from 31.95 cm H_2O/L/s at 8-9 years to 27.50 cm H_2O/L/s at 11-12 years of age.

The study was also aimed to explore the effect of gender on ESGP, MAFR, and LAR. Gender is found to have a different influence on each of the measured aerodynamic parameters ESGP, MAFR, and LAR. Two way MANOVA revealed significant main effect of gender for the MAFR [F (1, 66) = 5.305, $p<0.05$], and LAR [F (1, 66) = 8.962, $p<0.05$]. However, it did not reveal a significant main effect of gender for ESGP [F (1, 66) = 0.130, $p>0.05$].

The finding that ESGP is not influenced by the gender of the participants is in consistency with several of the earlier studies done in children (Netsell et al. 1994; Weinrich et al. 2005) and in adults (Holmes et al. 1994; Goozee et al. 1998; Ketelslagers et al. 2007; and Gopikishore et al. 2012). These authors had hypothesized that males and females maintain same range of ESGP by balancing the elastic recoil and muscular forces of the respiratory system. Weinrich et al. (2005) did not find any significant difference in ESGP of males and females till 14 years of age. The data in the present study also did not reveal a statistically significant effect of gender till 12 years of age. From these findings, it can be explained that subglottic pressure may not vary across the gender at least until puberty. Netsell et al. (1994) attributed this finding to the comparable airway size and recoil systems of the respiratory system in male and female children of similar age.

Further, in the present study, the observed overall ESGP measures are slightly lower in females (6.30 cm H_2O) than for males (6.48 cm H_2O). Similar findings were also reported by Netsell et al. (1994) and Weinrich et al. (2005). Netsell et al. (1994) also reported that the male participants used slightly higher pressures than the female participants (7.9 versus 7.3 cm H_20). This may be due to the difference in lung volumes and capacities in male and female children.

Male participants showed greater MAFR values compared to females. This finding is supported (Wilson and Leeper, 1992 and Holmes et al. 1994). The authors hypothesized that the anatomical and physiological differences were responsible for higher flow rates produced by the male participants. When compared to MAFR value in normal Indian adults (Gopikishore et al. 2012), children acquired lower values in both males and females.

The LAR values obtained in the present study were more for females in comparison to males. This finding was supported by the studies reported in the literature in children (Netsell et al., 1994) and in adults (Goozee et al., 1998; and Gopikishore et al., 2012). These authors also reported that females exhibit significantly higher laryngeal airway resistance values than males.

The aerodynamic parameters ESGP, MAFR, and LAR are found to be useful as diagnostic indicator. Hence developing normative data across age and languages is essential. Based on the results of the present study, the normative data obtained for the children in the age range of 8-12 years is as follows (table 7).

Table 7.

Normative data for aerodynamic measures ESGP, MAFR, and LAR in children in the age range of 8-12 years.

Aerodynamic parameter	**Male**	**Female**
ESGP (cm H_2O)*	6.48	6.30
MAFR (L/s)	0.250	0.196
LAR (cm H_2O/L/s)	29.65	39.46

*No significant gender effect $p > 0.5$

Note: There is no significant effect of age on the measured aerodynamic parameters; hence the values from the table 7 will be applicable from children between 8 and 12 years.

Limitations of the study

- The present study considered only 74 children in total, therefore further studies may be conducted by considering large number of participants under each age group and gender.
- The present study was carried out on limited age range of children, which do not aid in understanding the developmental trends comprehensively.

Implications of the study

- ➢ The results of the present study will provide normative data for aerodynamic parameters ESGP, MAFR, and LAR in typically developing children in the age range of 8 to 12 years.
- ➢ Data obtained from this study can be used clinically as reference for assessing children with voice disorders and for the research purposes.
- ➢ The results of the study will facilitate understanding the effects of age and gender on aerodynamic parameters ESGP, MAFR, and LAR.

Future Directions

- Longitudinal studies with wider age range including infants, children, and adults will aid in understanding the developmental trends in aerodynamics comprehensively. Hence this may be considered in future studies.
- Since there is a dearth of clinical data regarding the aerodynamic analysis in individuals with various disorders, further studies in these lines is warranted.

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