LARYNGEAL AERODYNAMIC MEASURES IN NORMAL ADULTS

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Abstract

Laryngeal aerodynamic analysis measures respiratory and laryngeal functions reflecting the coordinative nature of voice production. The present study primarily aimed at establishing the normative data for four laryngeal aerodynamic parameters viz. Estimated Sub- Glottic Pressure (ESGP), Mean Air Flow Rate (MAFR), Laryngeal Airway Resistance (LAR), and Laryngeal Airway Conductance (LAC) in adult Indian population. A second purpose was to examine the effect of age and gender on these measures. Eighty five participants including 54 males and 31 females in the age range of 18-40 years, with no known problems in voice were considered for the study. Aeroview from Glottal Enterprises was used to record and analyze the data. The participants were instructed to produce CV syllable train "papapapa" into the circumvented mask at comfortable loudness and pitch. Thus recorded stimuli were analyzed to obtain all four parameters (mentioned earlier). Mean and standard deviation for the all the parameters were calculated separately for both the groups of males and females. Box plots were drawn and 8 outliers were removed manually from the main data. Two way MANOVA (performed on remaining data) revealed significant main effects of age for the parameters ESGP and LAC. No significant main effects of gender were observed for the any of the laryngeal aerodynamic parameters studied. The data obtained from this study can be used as normative for laryngeal aerodynamic analysis in the adult population in the age range of 18–40 years.

Keywords: *Estimated Sub-Glottic Pressure, Laryngeal Airway Resistance, Normative data.*

Voice production involves the coordinated interactions of the respiratory, phonatory and resonatory subsystems. It is an aerodynamic process in which the laryngeal modulations of respiratory airflow create the acoustic waves that are subsequently modified by vocal tract resonances. The acoustic analysis of voice provides information on the source and filter characteristics. The Static respiratory analysis provides information on the respiratory volumes. However, these measures represent the individual phonatory and respiratory subsystems and might not reflect the coordinative interactions of these systems in voice production. Therefore, a combined measurement that captures the relations among/relationship between respiratory and laryngeal functions is essential to reflect the coordinated nature of these systems in voice production.

Laryngeal aerodynamic measures such as maximum phonation duration, S/Z ratio, mean air flow rate (MAFR), estimated sub-glottal pressure (ESGP), laryngeal airway resistance (LAR), laryngeal airway conductance (LAC), phonatory power, vocal efficiency, phonation threshold pressure, etc provide information's about efficiency of the glottis valve during phonation (Grillo, Perta & Smith, 2009). The laryngeal aerodynamic measure such as MAFR and ESGP has been studied extensively to investigate the relationship between these measures and phonatory processes (Hill man, Holmberg, Perkell, Walsh & Vaughan, 1989; Iwata, Von Leden & Williams, 1972; Netsell, Lotz & Shaughnessy, 1984). MAFR is the volume of air flow across the vocal folds during phonation in one second. It is generally measured in liters or milliliters per second (l/s or ml/s). Subglottic pressure is the amount of pressure required to generate and sustain the oscillation of the vocal cords during voice production. It is often measured in centimeters of water (cm H_2O). Laryngeal airway resistance (LAR) is the ratio of estimated subglottal pressure to mean air flow rate (Smitheran & Hixon, 1981) and reflects the resistance offered by the vocal folds to airflow at glottic level. Laryngeal airway conductance (LAC) is the ratio of mean air flow rate to the estimated subglottal pressure. It is the converse of LAR and reflects the conductance for airflow at the level of glottis. Both LAR and LAC are the derived parameters.

Very few studies have focused on establishing normative data of adults in the age range of 18-40 years for laryngeal aerodynamic parameters ESGP, MAFR, LAR, and LAC. Stathopoulos and Sapienza (1993) investigated the simultaneous function of the laryngeal and respiratory systems during changes in three vocal intensity levels (soft, comfortable, loud) during the repetition of syllable /pa/. Ten males and ten females in the age range of 20- 30 years served

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as subjects. The laryngeal parameters such as maximum flow declination rate (MFDR), LAR, open quotient (OQ), tracheal pressure, translaryngeal flow were measured using Pneumota chometer Model MS 100 A-2. The laryngeal results revealed significant increase in MFDR and LAR and significant decrease in OQ during changes in three vocal intensity levels. A statistical gender effect was found for MFDR and OQ parameters. Male subjects had higher MFDR than female subjects and female had higher OQ values than males at each intensity level. The LAR increased in both male and female group consistently as vocal intensity increased. The authors concluded that examination of simultaneous laryngeal and respiratory system provides broad description of interactive patterns used during speech production.

Goozee, Murdoch, Theodoros, and Thompson (1998) obtained the respiratory measures of 56 male and 53 female normal adults in the age group of 20 to 80 years. They analyzed aerodynamic parameters such as ESGP, LAR, phonatory airflow, phonatory SPL, phonatory power and phonatory efficiency using Aerophone II Model 6800. The results indicated high inter-subject variability for the parameters: - phonatory airflow, LAR, phonatory power and phonatory efficiency, whereas the phonatory SPL and ESGP were reported to be most consistent. Further, among the parameters investigated, significant age and gender effects were reported only for MAFR. The 20-30 year-old subjects produced significantly lower MAFR values than the 31-40 and 41-50 year old subjects. The females had significantly higher MAFR values than males. These results are attributed to the male or female subjects making laryngeal and respiratory behavioral adjustments, differences in methodology and instrument employed and the subject group tested. The parameters ESGP, LAR, phonatory power, phonatory efficiency and phonatory SPL (during running speech vowel /i/ and / u/) were found to be independent of age and gender.

Hiss, Treole, and Stuart (2001) measured peak intraoral air pressure (P_0) in sixty adult participants in the age range of 20 to 83 years. The subjects were divided into three age groups (20-39, 40-59, & 60-83), comprising of 10 males and 10 females in each age group. Aerophone II Model 6800 was used for analysis of P_0 during voiceless stop plosive /p/ productions in repeated CV combinations. Repeated trials of measurement of P_0 resulted in negligible mean difference between trials. Further P_0 was also not found to be varying as a function of age or gender ($p > 0.05$). Based on these findings, the authors concluded that P_0 was a stable measure within a short sampling session.

Weinrich, Salz, and Hughes (2005) assessed 33 boys and 37 girls between the age range 6 - 10.11 years. The Pneumotachometer Model MS 100 A-2 was used to obtain aerodynamic measures such as Open quotient (OQ), Speed quotient (SQ), Maximum Flow Declination Rate (MFDR), Sub-Glottal Pressure (ESGP). These parameters were examined as a function of vocal frequency (low, comfort, & high). The results did not reveal age or gender effect for any of the aerodynamic measures studied. However, they observed a trend of decrease in ESGP with age and slightly higher ESGP values for female children than for male children across all the frequencies.

In a recent study Zraick, Olinde, and Shotts (2012) evaluated 68 male 89 female normal adults in the age range of 20-86 years. Further, the subjects were subdivided into three age groups including 18-39 years, 40-59 years and 60-80 years. The Phonatory Aerodynamic System Model 6600 was used to analyze 41 aerodynamic measures. The results revealed statistically significant main effect of age on measures for peak expiratory airflow, expiratory volume, mean SPL, SPL range and Mean F_0. A statistically significant main effect of gender was found for mean F_0. Based on the findings, authors opined that one must account for age and gender variables during laryngeal aerodynamic analysis as changes related to these variables were found for some measures.

The laryngeal aerodynamic parameters have been found to be useful in discriminating normal from dysphonic voices. Some of these parameters such as ESGP, LAR were robust and aid in diagnosing conditions such as vocal hyperfunction or muscle tension dysphonia. Despite these merits, there have been very few attempts made to establish normative database for these parameters. Although few studies established the normative data, the sample size used was small and scattered over a vast age range. The normative data reported by the earlier studies for the laryngeal aerodynamic parameters ESGP, MAFR, LAR, and LAC for subjects in the age range of 18-40 years is summarized in the table 1.

Table 1: *Normative values (Mean and Standard deviation) for ESGP, MAFR, LAR and LAC*

Laryngeal aero-dynamic measures		Stathopoulos et al., (1993)	Goozee et al., (1998)		Hiss et al., (2001)	Zraick et al., (2012)
		Pneumotachometer Model (MS 100 A-2)	Aerophone II Model 6800		Aerophone II Model 6800	Phonatory Aerodynamic System Model 6600
		20-30yrs	**20-30yrs**	**30-40yrs**	**20-39 yrs**	**18-39 yrs**
ESGP (cm H2O)	M	-	9.34 (± 1.87)	6.56 (± 2.08)	-	6.65 (±1.98)
	F	-	6.73 (± 1.47)	7.9 (±1.33)	5.55-6.79	5.4 (± 1.37)
MAFR (L/s)	M	-	0.52 (±0.27)	0.38 (±0.29)	-	0.38 (±0.34)
	F	-	0.39 (±0.25)	0.5 (±0.19)	-	0.16 (±0.08)
LAR (cm H2O/ L/s)	M	50.43* (±23.37)	30.58 (±35.0)	48.1 (±57.84)	-	79.44 (±120.0)
	F	40.62* (±13.67)	26.4 (±20.53)	18.26 (±8.23)	-	68.20 (±53.08)
LAC (L/s/cm H2O)	M	-	-	-	-	-
	F	-	-	-	-	-

- Not studied, * included values obtained at comfortable intensity level only

Further, all the above mentioned data was reported on the western population. However, literature reveals that the aerodynamic measures vary across geographical and ethnic groups. For instance Miller and Daniloff (1993) opined that aerodynamic parameters such as MAFR are influenced by a number of anatomical features and physiological events, such as the driving pressure arising from the respiratory system, the constriction, size and timing of movements of the vocal cords, together with the size, shape and biomechanical properties of the vocal tract as a whole. Also, Rajeev (1995) reported that the maximum phonation time (MPT), which is an aerodynamic parameter is found to be less in the Indian population compared to western norms.

Hence, it is essential to establish the normative data for laryngeal aerodynamic parameters in the Indian population. Also, earlier studies had reported that some of the laryngeal parameters were influenced by age and gender of the participants. However, other studies had contradicted these results and said that the same laryngeal aerodynamic parameter was influenced by either age or gender, making this issue unresolved. For example, Goozee et al. (1998) reported that the MAFR values was affected by both age and gender, whereas Zraick et al. (2012) reported that the MAFR values was affected by only age. Therefore, the present study established normative data for the laryngeal aerodynamic parameters: Estimated Sub- Glottic Pressure, Mean Air Flow Rate, Laryngeal Airway Resistance, and Laryngeal Airway Conductance (LAC) in adult population in the age range of 18 to 40 years and investigated the effect of age and gender on the laryngeal aerodynamic measures.

Method

Participants: Eighty five participants (fifty four males & thirty one females), in the age range of 18-40 years divided into two groups of 18-25 years and 26-40 years, participated in the study. The participants selected were with no history of upper respiratory tract infection, speech or voice problems, laryngeal injury or surgery, neurological condition. The participants with voice or respiratory related problems and active laryngeal or pharyngeal infections were not included in the study.

Instrumentation: The Aeroview 1.4.4 version (Glottal Enterprises Inc, USA) was used to collect aerodynamic data from each participant. The Aeroview is a computer-based system that measures the MAFR and ESGP pressure during vowel production. The derived parameters such as LAR (ESGP/MAFR) and LAC (MAFR/ESGP) using an automated factory-optimized algorithm are also displayed. Other measures of voice such as the Sound Pressure Level (SPL) and the Fundamental Frequency (F_0) of the measured vowel segment phonation and the Phonatory Threshold Pressure (PTP) can also be obtained.

Instrument calibration: Before recording, the transducers for measuring airflow and air pressure were calibrated on daily basis as per the guidelines provided by Glottal Enterprises.

Recording: The participants were seated comfortably and the procedure was explained clearly. The participants were instructed to hold the mask firmly against the face so that nose and mouth were covered with the intraoral tube placed between the lips and above the tongue. The examiner confirmed the correct placement of the transducer or ensured that the mask is firmly fitted. The participants were then 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 rate and style of production was demonstrated by the examiner and two practice runs were given before the actual recording. Following practice, the actual recordings were made. The recording with syllable production rate between 2.0 to 3.5 per second (recommended by manufacturer) and with appropriate pressure peak morphology was considered for the further analysis. Typical pressure peak and airflow wave morphology are shown in figure 1.

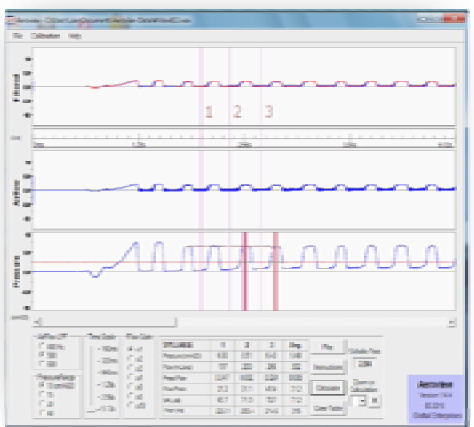

Figure 1: *Typical morphology of appropriate pressure peak and airflow wave*

Analysis: The recorded waveform was analyzed by placing the cursors on flat portions of two adjacent pressure peaks. The application software analyzes the waveform and provides the values of Estimated Sub-Glottic Pressure (cmH_2O), Mean Air Flow Rate (ml/sec), Laryngeal Airway Resistance (cmH_2O/ml/sec), Laryngeal Airway Conductance (ml/sec/cmH_2O) values. On obtaining three peak to peak measurements, the software automatically provides their average value. In order to facilitate comparison of MAFR values with earlier studies, MAFR which is obtained in ml/sec was converted manually to Liters/sec. Accordingly, derived parameters such as LAR and LAC obtained values were converted to (cmH_2O/L/sec) and (L/sec/cmH_2O) respectively.

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 the all the parameters were calculated separately for both 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 (2 levels) and gender (2 levels) served as the independent variables, and the parameters measured (ESGP, MAFR, LAR, LAC) served as the dependent variables.

Results

zUsing the obtained data from 85 participants, box plots were drawn using SPSS 18.0 considering all the four laryngeal aerodynamic parameters. The possible outliers were identified from the box plots and were removed manually from the main data. Following the outlier removal, further statistical procedures were performed on a total of remaining 77 participants (47 males & 30 females).

Normative value for laryngeal aerodynamic parameters: The mean and standard deviation of ESGP (Figure 2a) in 18-25 years males was 4.62 cm H_2O (±1.20) and in 26- 40 years males was 5.48 cm H_2O (±0.94) and in 18-25 years females was 4.98 cm H_2O (±1.63) and 26- 40 years females was 5.93 cm H_2O (±1.53). The mean and standard deviation values of MAFR (Figure 2b) in 18-25 years males was 0.25 L/s (±0.14) and in 26-40 years males was 0.26 L/s (±0.13) and in 18-25 years females was 0.26 L/s (±0.16) and 26- 40 years females was 0.24 L/s (±0.10). The males between the age range of 18-25 years and 26-40 years obtained an average LAR value (Figure 2c) of 22.56 cmH_2O/L/s (±11.92) and 26.53 cmH_2O/L/s (±15.00) while in females it was 24.21 cmH_2O/L/s (±15.14) and 28.63 cmH_2O/L/s (±16.04) respectively. In general, ESGP and LAR values increase in both groups across age. The average LAC values (Figure 2d) in males between the age range of 18-25 years was 0.05 L/s/cmH_2O (±0.03) and 26-40 years was 0.04 L/s/cmH_2O (±0.22) and in females between the age range of 18-25 years was 0.06 L/s/cm H_2O (±0.04) and 26-40 years was 0.04 L/s/cmH_2O (±0.02).

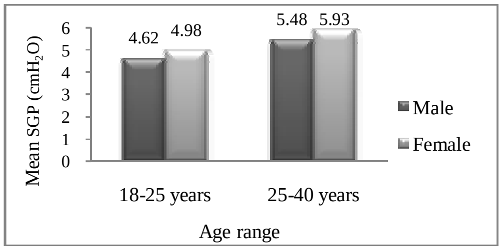

Figure 2 (a): *Mean values of ESGP (cmH_2O)*

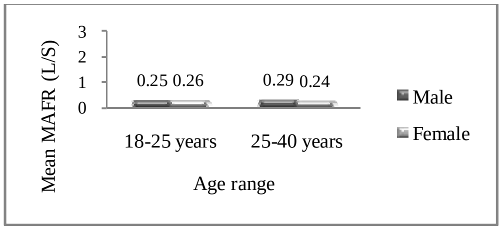

Figure 2 (b): *Mean values of MAFR (L/S)*

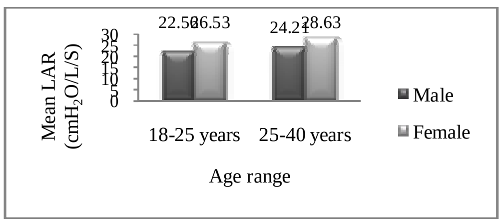

Figure 2 (c): *Mean values of LAR (cmH_2O/L/S)*

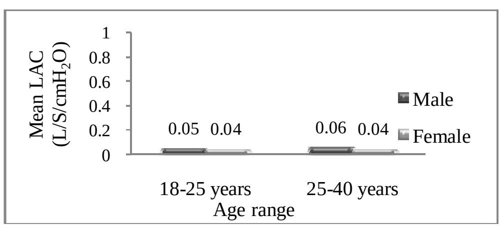

Figure 2 (d): *Mean values of LAC (L/S/ cmH_2O)*

a) **Effect of age and gender on Laryngeal Aerodynamic parameters:** The two way MANOVA (Table 2) did not reveal significant main effects for gender across all the LA parameters except the ESGP which was found to be significant at $p < 0.05$ level. A main effect of age was observed for the ESGP and LAC parameter. The ESGP values were shown to be higher in both male and female older age group and LAC values were higher only in male older age group. MANOVA did not reveal interaction effects of independent variables age and gender. Since, there was no significant gender effect across all four laryngeal aerodynamic measures, mean for each of the laryngeal aerodynamic measures was calculated using formula-Total score of all subjects/total number of subjects. Thereby, range (min-max) and SD was also calculated. The 95 % confidence intervals for each of the laryngeal aerodynamic parameter are shown in table 3.

Table 2: *Two- way MANOVA interaction effects*

Type of effect	Laryngeal aerodynamic measures	*p* values
Age effect	ESGP(cm H_20)	0.004*
	MAFR(L/s)	0.649
	LAR (cm H_20/ L/s)	0.217
	LAC (L/s/ cm H_20)	0.052*
Gender effect	ESGP(cm H_20)	0.186
	MAFR(L/s)	0.767
	LAR (cm H_20/ L/s)	0.579
	LAC(L/s/ cm H_20)	0.890
Age*Gender effect	ESGP(cm H_20)	0.881
	MAFR(L/s)	0.366
	LAR (cm H_20/ L/s)	0.947
	LAC (L/s/ cm H_20)	0.380

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

Table 3: *95 % level of confidence interval across subjects for the laryngeal aerodynamic measures*

Laryngeal Aerodynamic measures	Age range	95 % Confidence interval formula for Mean		
		Mean	Lower Bound	Upper Bound
ESGP (cm H_20)	18-25 years	4.74	4.30	5.19
	26-40 years	5.68	5.27	6.08
MAFR (L/s)	18-25 years	0.26	0.21	0.31
	26-40 years	0.25	0.21	0.29
LAR (cm H_20/ L/s)	18-25 years	0.23	18.87	27.37
	26-40 years	0.27	22.49	32.40
LAC(L/s/ cm H_20)	18-25 years	0.05	0.04	0.06
	26-40 years	0.04	0.03	0.05

Discussion

This first aim of the study was aimed to establish normative data for the for four laryngeal aerodynamic parameters Estimated Sub-Glottic Pressure, Mean Airflow rate, Laryngeal Airway Resistance and Laryngeal.

Airway Conductance in adult population in the age range of 18 to 40 years. Because, Sharma and Goodwin (2006) reported that the lung function undergo a developmental phase and maturation phase during the first two decades of life and achieve maximal lung function will be achieved by 20 years of age in female and 25 years of age in males. The ESGP and MAFR values obtained from the present study vary from the earlier studies by Gooze et al. (1998), Hiss et al. (2001), and Zraick et al. (2012). This can be attributed to the variation in the age group and number of participants considered. The study by Gooze et al. (1998) considered 20-30 years and 30-40 years including 5 male and 5 female in each group, whereas Hiss et al. (2001) considered 20-39 years including 10 male and 10 female and Zraick et al. (2012) considered 18-39 years including 32 male and 47 female.

The LAR values obtained from the present study is different from the earlier normative studies by Stathopoulos et al. (1993), Gooze et al. (1998) and Zraick et al. (2012). This can be attributed to the variation in different instruments used, stimuli as well as the recording protocol. The present study used Aeroview instrument for laryngeal aerodynamic analysis and 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. But Stathopoulos et al. (1993) used Pneumotachometer Model (MS 100 A-2) and the subjects were asked to produce and utterance of a syllable train consisting of seven repetitions of /pa/ at three intensity levels (soft, comfortable and loud) into the circumferentially vented wire screen pneumotachograph mask which consists of both air pressure and airflow transducer. Gooze et al. (1998) used Aerophone II Model 6800 and subjects were asked to repeat the consonant vowel sequence, /ipipipi/ for several seconds into mask of the transducer module until recording was done, whereas Zraick et al. (2012) used Phonatory Aerodynamic System (PAS) and subject were instructed to repeat the voiced vowel /a/ and the voiceless stop plosive /p/ nine times in vowel or consonant format (i.e.,/apapapapapapapa/, placing equal stress on each syllable into the hand-held module consisting of both air pressure and airflow transducer. The derived parameter LAC has not been explored in previous studies and the current study provides normative data for the same. The reliability of using LAC measure as an effective tool to quantify laryngeal aerodynamic changes has to be further established using a larger sample size and its correlation with other laryngeal aerodynamic measures.

The second aim of the study was to investigate the effect of age and gender on laryngeal aerodynamic measures. Table 2 indicates statistically significant main effect of age on the parameter ESGP. The ESGP value was observed to be increasing with age, i.e., the higher ESGP values were observed for the 26-40 years than 18-25 years age group. The difference observed across the age may be attributed to age-related anatomical and physiological changes in the respiratory and laryngeal system. Mittman, Edelman and Norris (1965) reported reduction in chest wall compliance in adults compared to young adults. Also, Sharma and Goodwin (2006) reported that lung function remains steady with very minimal change from age 20 to 35 years and starts declining thereafter. In general, Kahane (1987) has reported that age related changes in anatomy have the ability to affect the laryngeal valve airstream mechanism that takes place during phonation and thereby ESGP measure. The results of the present study are inconsistent with earlier findings reported by Goozee et al. (1998); Hiss et al. (2001) and Zraick et al. (2012) who did not find age effect on ESGP. From the Table 1, it is also evident that there is no statistically significant main effect of gender for the parameter ESGP. This finding is consistent with the previous reports from Goozee et al., (1998), Hiss et al, (2001), Ketelslagers, De Bodt, and Wuyts and Heyning (2007) and Zraick et al. (2012), who also reported that ESGP was least affected across the subjects among all the parameters of laryngeal aerodynamics.

The MAFR parameter was not affected by the age and gender of the participants ($p>0.05$) (Table 2). This result is supported by the findings of Hiss et al. (2001), who did not find effect of age and gender on MAFR. Stathopoulos and Sapienza (1993) also did not find significant gender differences and opined that phonatory airflow represents the effects of both laryngeal valving and vocal tract function. Based on this, they proposed that factors such as supraglottal resistance may have affected the airflow values that they obtained. However, Goozee et al. (1998) reported that the MAFR was affected by both age and gender, whereas Zraick et al. (2012) reported that the MAFR was affected by only age. This may be attributed to that fact that these studies considered a wider range of age groups including geriatric population. However, the present study considered participants in the age range of 18-40 years only.

The LAR parameter was not affected by the age and gender of the participants ($p > 0.05$) (Table 2). Laryngeal airway resistance cannot be measured directly, but rather is calculated as the ratio of estimated subglottal pressure to phonatory flow rate (Smitheran & Hixon, 1981). As no significant gender effects were found for the MAFR and ESGP parameters in the present study, the finding that the male and female subjects also exhibited similar laryngeal airway resistances was not unexpected. These findings are in consistent with the previous reports from Goozee et al., (1998) and Zraick et al., (2012). The LAC parameter (Table 2) is not found to be affected by gender of the participants. But, age was found to have a statistically significant effect on this parameter at $p< 0.05$ level (Table 2). However, the reliability of the same has to be further established using a larger sample size and its correlation with other laryngeal aerodynamic measures.

Conclusions

The present study aimed to establish normative database for adults in some of the laryngeal aerodynamic parameters across in the age range of 18-40 years. The ESGP and MAFR findings were inconsistent with earlier studies due difference in age group and number of participants in that sub-age group (Gooze, et al. 1998, Hiss, et al. 2001, Zraick, et al. 2012). The LAR and LAC findings were also inconsistent with earlier studies because of different instruments used, stimuli as well as the recording protocol (Stathopoulos, et al. 1993, Gooze, et al. 1998, Zraick, et al. 2012).The age related changes were found for some laryngeal aerodynamic measures such as ESGP and LAC. In addition, all the laryngeal aerodynamic measures were found to be independent of the effect of gender. The normative data established in the present study (Appendix 1) can be used clinically in the assessment of voice disorders and for research purposes. Further research into the development of Indian normative data and effects of age and gender on laryngeal aerodynamic measures across ages including pediatric and geriatric population is required. Since there is a dearth of clinical data regarding the laryngeal aerodynamic analysis in individuals with various disorders, further studies in these lines is warranted.

References

Al-Malki, K. H. (2005). Aerodynamic Analysis of Vocal Fold Polyps. *Saudi Journal of Oto-Rhino-Laryngology Head and Neck Surgery, 7 (1)*, 5-9.

Baken, R. J. (1987), *Clinical Measurement of Speech and Voice*. Boston, MA: College-Hill Press.

Bard, M.C., Slavit, D. H., Mc CaVrey, T.V., & Lipton, R. J. (1992). Noninvasive technique for estimating subglottic pressure and laryngeal efficiency. *Annals of Otology Rhinology and Laryngology,* 101, 578-582.

Goozee, J. V., Murdoch, B. E., Theodoros, D. J., & Thompson, E. C. (1998). The effects of age and gender on laryngeal aerodynamics. *International Journal of Language and Communication Disorders*, 33, 221-238.

Grillo, E. U., Perta, K., & Smith. L. (2009). Laryngeal resistance distinguished pressed, normal, and breathy voice in vocally untrained females. *Logopedics Phoiatrica Vocology,* 34 (1), 43-48.

Grillo, E. U., & Verdolini, K. (2008). Evidence for distinguishing pressed, normal, resonant, and breathy voice qualities by laryngeal resistance and vocal efficiency in vocally trained subjects. *Journal of Voice,* 22, /546-552.

Hertegrad, S., GauYn, J., & Lindestad, P. A. (1995). A comparison of subglottal and intraoral pressure measurements during phonation. *Journal of Voice,* 9, 149-155.

Hillman, R, E., Holmberg, E. B., Perkell, J, S., Walsh, M., & Vaughan, C. (1989). Objective assessment of vocal hyperfunction: an experimental framework and initial results. *Journal of Speech and Hearing Research,* 32, 373–392.

Hiss, S. G., Treole, K., & Stuart, A. (2001). Effect of age, gender, and repeated measures on intraoral air pressure in normal adults. *Journal of Voice,* 15, 159-164.

Hoit, J. D., & Hixon, T. J. (1987). Age and speech breathing. *Journal of Speech Hearing Research,* 1987, 30, 351–366.

Iwata. S., Von Leden. H. & Williams. D. (1972). Airflow measurement during phonation. *Journal of Communication Disorders,* 5, 67-79.

Kahane, J. C. (1987). Connective tissue changes in the larynx and their effects on voice. *Journal of Voice,* 1, 27–30.

Ketelslagers, K., De Boldt, M. S., Wuyts, F. L., & Van de Heyning, P. (2007). Relevance of subglottic pressure in normal and dysphonic subjects. *European Archives of Oto-Rhino Laryngology,* 264, 519-523.

Klich, R.J., & Sabo, W. J. (1988). Intraoral pressure differences in various degrees of breathiness. *Folia Phoniatrica,* 40, 265-269.

Löfqvist, A., Carlborg, B., & Kitzing, P. (1982). Initial validation of an indirect measure of subglottic pressure during vowels. *Journal of Acoustic Society America,* 72, 633-635.

Miller, C. J. and Daniloff, R. (1993). Airflow measurements: theory and utility of findings. *Journal of Voice,* 7, 38–46.

Mittman, C., Edelman N. H., & Norris, A. H. (1965). Relationship between chest wall and pulmonary compliance with age. *Journal of Applied Physiology,* 20, 1211-1216.

Netsell, R., Lotz, W., & Shaughnessy, A. L. (1984). Laryngeal aerodynamics associated with selected voice disorders. *American Journal of Otolaryngology*, 5, 397-403.

Rajeev, P. (1995). *A normative data on aerodynamic parameters in normal adults*. Unpublished Master's dissertation, University of Mysore, Mysore.

Sharma, G., & Goodwin, J. (2006). Effect of aging on respiratory system physiology and immunology. *Clinical Interventions in Aging,* 1(3), 253-260.

Smitheran, J. R., & Hixon, T. (1981). A clinical method for estimating laryngeal airway resistance during vowel production. *Journal of Speech Hearing Disorders,* 46, 138-146.

Sperry, E. E., & Klitch, R. J. (1992). Speech breathing in senescent and younger women during oral reading. *Speech Hearing Research*, 35, 1246–1255.

Stathopoulos, E. T., & Sapienza, C. (1993). Respiratory and laryngeal function of women and men during vocal intensity variation. *Journal of Speech and Hearing Research,* 36, 64–75.

Weinrich, B., Salz, B., & Hughes, M. (2005). Aerodynamic measures: Normative data for children ages 6:0 to 10:11 years. *Journal of Voice*, 19, 326–339.

Yiu, E. M., Yuen, Y. M., Whitehill, T., & Winkworth, A. (2004). Reliability and applicability of aerodynamic measures in dysphonia assessment. *Clinical Linguistics and Phonetics,* 18, 463-478.

Zheng, Y. Q., Zhang, B. R., Su, W. Y., Gong, J., Yuan, M. Q., Ding, Y.L., & Rao, S. Q. (2012). Laryngeal aerodynamic analysis in assisting with the diagnosis of muscle tension dysphonia. Journal of Voice, 26 (2), 177-181.

Zraick, R.I., Smith-Olinde, L., & Shotts, L. L. (2012). Adult Normative Data for the KayPENTAX Phonatory Aerodynamic System Model 6600. *Journal of Voice,* 26 (2), 164-176.

Appendix-1

Mean, SD and range for laryngeal aerodynamic measures ESGP, MAFR, LAR, and LAC.

Laryngeal aerodynamic measures	Age range (n=38) (18-25 years)		Age range (n=39) (26-40 years)	
	Mean (±SD)	Range	Mean(±SD)	Range
ESGP (cm H_2O)	4.74 (±1.35)	2.89-9.13	5.68(±1.23)	4.00-9.04
MAFR* (L/s)	0.26(±0.14)	0.02-0.63	0.25(±0.12)	0.71-0.52
LAR* (cm H_2O/ L/s)	23.12(±12.93)	6.99-56.86	27.44(±15.29)	11.03-69.15
LAC (L/s/ cm H_2O)	0.05(±0.03)	0.00-0.14	0.04(±0.02)	0.01-0.09

*No age effect ($p<0.05$)

** Gender was not found have significant effect on these parameters at $p<0.05$ significance level, hence the presented normative is independent of gender.