Electroglottographic Parameterization of the Effects of Gender, Vowel and Phonatory Registers on Vocal Fold Vibratory Patterns: An Indian Perspective

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Abstract In-depth study on laryngeal biomechanics and vocal fold vibratory patterns reveal that a single vibratory cycle can be divided into two major phases, the closed and open phase, which is subdivided into opening and closing phases. Studies reveal that the relative time course of abduction and adduction, which in turn is dependent on the relative relaxing and tensing of the vocal fold cover and body, to be the determining factor in production of a particular vocal register like the modal (or chest), falsetto, glottal fry registers. Studies further point out Electroglottography to be particularly suitable for the study of vocal vibratory patterns during register changes. However, to date, there has been limited study on quantitative parameterization of EGG wave form in vocal fry register. Moreover, contradictory findings abound in literature regarding effects of gender and vowel types on vocal vibratory patterns, especially during phonation at different registers. The present study endeavors to find out the effects of vowel and gender differences on the vocal fold vibratory patterns in different registers and how these would be reflected in standard EGG parameters of Contact Quotient (CQ) and Contact Index (CI), taking into consideration the Indian sociolinguistic context. Electroglottographic recordings of 10 young adults (5 males and 5 females) were taken while the subjects phonated the three vowels /a/, /i/, /u/ each in two vocal registers, modal and vocal fry. Obtained raw EGG were further normalized

using the Derived EGG algorithm and the CQ and CI values were derived. Obtained data were subject to statistical analysis using the 3-way ANOVA with gender, vowel and vocal register as the three variables. Post-hoc Dunnett C multiple comparison analysis were also performed. Results reveal that CQ values are significantly higher in vocal fry than modal phonation for both males and females, indicating a relatively hyperconstricted vocal system during vocal fry. The males have significantly greater CQ values than females both at modal and vocal fry phonations which indicate that the males are predisposed to greater vocal fold constriction. Females demonstrated no significant increase in CI values in vocal fry state; and in some cases actually decrease in the CI values which suggest an inherently distinct vocal fold physiological adjustment from that in males. No vowel effects were found in any conditions. Perturbation values (CQP and CIP) are significantly more in vocal fry register than in modal register, and the increase was more in case of females than males. The findings give strong evidence to certain hypotheses in literature regarding effects of vowel, gender and phonatory register on vocal fold vibratory patterns.

Keywords Electroglottograph · Contact quotient · Gender · Modal register · Vocal fry

Introduction

The larynx, by virtue of its diverse anatomical and physiological capacity for sound generation, has often been regarded as a microcosm of the entire vocal tract [15], and the vocal folds are the main structures of the larynx. The relationship between the functional anatomy and biomechanical properties of the vocal folds has been described in

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the cover-body theory of phonation [12, 5]. A single vibratory cycle of the vocal folds is generally studied to understand the biomechanical behaviors and their perceptual correlates. High speed stroboscopic pictures [20] reveal that the entire glottal cycle may be divided into two major phases: the closed phase & the open phase. The open phase is further divided into the opening phase and the closing phase. In-depth research on the subject by Hirano [11], gave 12 most important parameters reflecting VF vibratory behavior, which includes: (1) Glottal width (2) Glottal area (3) Opening, closing, open and closed phase. (4) Open quotient, speed quotient and speed index Amplitude, (5) Regularity or periodicity of successive vibrations, (6) Symmetry of bilateral VFs. The events during vocal fold vibratory cycle, the corresponding biomechanical and aerodynamic changes, the modes of vocal fold displacement and phase differences (lateral, horizontal and vertical), the changes of mucosal layer movements has all been investigated using various methods including electroglottography [3, 14]. The underlying physiology, and biomechanical principles of vocal fold oscillations has been studied, both empirically, and using computer models by Cooper et al. [5], Hirano [11], Titze and Talkin [19]. They highlight the effects of external forces of gravitation, aerodynamics, and internal tissue strain on the vocal fold movement patterns and how these forces are controlled by precisely coordinated contractions of the Cricothyroid, Lateral Cricoarytenoid, Posterior Cricoarytenoid and Interarytenoid muscles (mediated by the direct control of the upper and lower motor neurons and the central executive functions of the central nervous system) to produce vocal ligament- mucus membrane coupling in different types of phonations like soft phonation at low fundamental frequency, loud phonation at middle fundamental frequency, modal registers, loft registers etc. The mode of vocal fold vibrations in different voice registers has been discussed by Brodnitz [1], Zemlin [22], and more recently by Roubeau [17], Henrich et al. [7], and Gendrot et al. [6]. According to video kymographic data of Svec et al. [18], the closure of vocal folds is untypically short for chest vibratory pattern, and the vocal folds exhibit a “ripple” during register transitions. The physiological explanations regarding registers and their transitions has been given by Titze and Talkin [19], emphasizing on the relative time course of abduction and adduction, which in turn is dependent on the relative relaxing and tensing of the vocal fold cover and body, to be the determining factor in production of a particular register. Electroglottography has been found to be highly suitable for the study of the vocal fold vibratory patterns in register changes especially in conjuncture with imaging techniques. Gendrot et al. [6] investigated the different vibratory patterns that can be involved in glottal fry by high speed cinematography and

compared them with the EGG signal. Based on the notion of the use of different laryngeal mechanisms [7, 17], among which laryngeal mechanisms Chest and falsetto are the most frequently used and studied in speech and singing, the authors investigated the glottal vibratory movement simultaneously with EGG, and high-speed cinematography. The findings corroborated a known fact that the glottal area function in glottal fry, if produced with vocal effort, is characterized by short pulses, which can be single, double or triple within a fundamental period [21, 4]. Physiologically, the thyroarytenoid muscles tend to shorten, subsequently thickening the anterior-posterior dimension of the vocal folds, and allowing the anterior part of the vocal ligaments to vibrate [13]. To date, there has been limited study on quantitative parameterization of EGG wave form in vocal fry. Exception is that of Childers and Lee [4] who found greater skewness in vibratory cycle during vocal fry, using the speed quotient (SQ) parameter. Similarly, Chen et al. [2] found an increased SQ and frequent dicrotic vibratory patterns during vocal fry (Table 1, 2).

Due consideration must be given to the effect of gender and different vowels on vibratory patterns. In case of EGG, the effects of gender and vowel were studied by Chen et al. [2], using SQ and confirmed that gender differences in vocal fold contact behavior exist both during modal and vocal fry register. No vowel effects on vocal fold contact behavior as inferred using the SQ measure were found for either modal or vocal fry registers. Further evidence in this regard comes from the study of Higgins and Saxman [9]. They found that aged women exhibit a smaller EGG duty cycle (OQ) during vowel prolongation and lower F0 during syllable repetition than young women, whereas aged men have a significantly greater EGG duty cycle during vowel prolongation and syllable repetition than young men. A significant gender effect was found for in the condition of high loudness, with males displaying smaller EGG duty cycles than females. Lastly, the superiority of CQ and CI over SQ and OQ has been proved by Orlikoff [16] and Herbst [8].

Need of the study

Thus, contradictory findings abound in literature regarding gender and vowel effects on vocal fold vibrations in different vocal registers. The EGG parameters of CQ and CI have rarely been used for such purposes. Moreover, socio-linguistic variations must be taken into account for a study on vowel effect, but such studies are virtually nonexistent in the Indian context.

Aims

Firstly, the present study aims to find out the exact nature of vocal fold vibrations in males and females during

Table 1 Means (standard deviations): CQ

	Vocal fry			Modal		
	/a/ Mean (s.d.)	/i/ Mean (s.d.)	/u/ Mean (s.d.)	/a/ Mean (s.d.)	/i/ Mean (s.d.)	/u/ Mean (s.d.)
Male	70.321 (0.3889)	70.145 (1.1243)	70.292 (0.2758)	65.1796 (0.46669)	65.2668 (1.131371)	65.2472 (0.035355)
Female	67.8368 (1.916259)	67.6088 (3.676955)	67.6188 (2.969848)	60.1216 (0.304056)	60.624 (0.66468)	60.284 (0.141421)

Table 2 Mean (standard deviation): CI

	Vocal fry			Modal		
	/a/ Mean (s.d.)	/i/ Mean (s.d.)	/u/ Mean (s.d.)	/a/ Mean (s.d.)	/i/ Mean (s.d.)	/u/ Mean (s.d.)
Male	−0.7668 (0.3889)	−0.766 (1.1243)	−0.7684 (0.2758)	−0.5384 (0)	−0.5412 (0.035355)	−0.54 (0.028284)
Female	−0.4672 (0.042426)	−0.468 (0.049873)	−0.4674 (0.045106)	−0.494 (0.04142)	−0.4944 (0.035355)	−0.4928 (0.049497)

phonation of different vowels in different vocal registers. Keeping the extraneous variables well-controlled, and using the EGG parameters of CQ and CI, the present study endeavors to find out which one of the contradictory hypotheses and findings it replicates in this regard. Secondly, since vowel effect might differ in terms of sociolinguistic background, the present study for the first time tries to extract the findings in the Indian context.

Methodology

1) Subjects

Males	Females	Age range m	Age range f	Mean age m	Mean age f
25	25	19–30	19–26	21.04	21.2

2) Subject Selection Criteria

- Young adults with no developmental delay.
- No h/o metabolic/hormonal disturbances like hypo/hyperthyroidism, pituitary gland dysfunction, sex-hormone disturbances etc.
- No h/o any laryngeal pathology like nodules, muscle tension dysphonia etc.
- Bilaterally having normal hearing sensitivity.
- Scores within normal limits on the Buffalo III Voice Screening Profile.

3) Instrumentation

- EG-PC3 electroglottograph system of the DR. SPEECH software, Tiger DRS Inc. Vocal

Assessment for Windows, Version-4.30; 1998, Tiger DRS, Inc.

- Recording and playback settings: (a) Device—SBLive, (b) Sampling rate—44100 Hz, (c) Recording time—3,000 s, (d) Wave volume—1
- Real-time recording and analysis parameter settings: (a) Audio wave—digital, (b) EGG contact area—up, (c) Fundamental frequency range—200–550 Hz (child), (d) Low pass filter for F0 extraction—33, (e) Voicing sensitivity—medium, (f) Intensity range—low limit 10 dB high limit 90 dB.

4) Method

- Subject eligibility as given above is ascertained.
- Parameters for EGG are set in the DR.SPEECH program.
- The skin of the neck is prepared by rubbing with a skin prep gel.
- The electrodes, mounted on a Velcro strip, are smeared with an electrode conductance gel and then put on the neck tightly, so that the two electrodes lie overhanging the thyroid lamina.
- Appropriate EGG gain settings done.
- Patient asked to phonate /a/, /i/, /u/ and the time is noted.
- Obtained graph and the parameter values are analyzed.
- Data recording and extraction:
- The percentage of amplitude modulation of the received signal in the sensing electrode reflects the percentage change in tissue impedance in the current's path (ibid.). The received signal is then demodulated and stored in a Windows PC. This average EGG waveform is then preconditioned

(FFT band pass filtering with a 55–4000 Hz band), and recordings of ca. 0.3 s were used for further analysis. The maximum of the differentiated EGG signal marked the start of a period, and the pulses were superimposed (using the start of the period as a reference point) to obtain an averaged, typical pulse. During averaging, the shape (defined as the minimum of the squared amplitude differences within a period) was extracted. The description of the shape is also obtained from the averaged waveform. The crest factor (peak value/r.m.s value computed for the whole period) characterizes the peakedness of the Lx pulse. After the amplitude and duration normalization (i.e. data is shrunk to the 0.1 interval) of the average pulse has been accomplished, the irregularities of the rising flanks are compared within the differentiated EGG signal by means of a surface comparison of the dips and the entire area.

5) Statistics

3-way ANOVA with gender, register and vowel type as three variables. Dunnett C post hoc multiple comparisons were also done.

Results and Discussions

The statistical analysis reveals that significant differences ($P > 0.005$) exist for CQ and CI values between modal and vocal fry phonations. CQ values are considerably higher in vocal fry phonation than modal phonation for both males and females, ($F = 0.161 > F_{0.05}(3, 71) = 0.922$), indicating a relatively hyperconstricted vocal system with relatively greater compression of the vocal folds in the horizontal plane during vocal fry. However, the males were found to have significantly greater CQ values than females both at modal and vocal fry phonations which indicate that the males are predisposed to greater vocal fold constriction, as reflected in a longer closed phase than the females, a finding which is well explained by the current theories and observations on laryngeal biomechanics. However, the findings slightly contrast those of Chen et al. [2], who found comparatively less increase of SQ values than females in vocal fry. However, comparison between the present and previous studies is difficult due to parametric differences. No significant differences whatsoever were found between the three vowels at any of the phonatory conditions, either for males or for females, which is at par with the conclusions of Chen et al. [2] and contrasts that of Higgins et al. [10]. Similar findings emerged in case of contact index for males with a large increase in the CI values which almost neared zero in some cases, and in

conjunction with corresponding CQ values indicates a greater contact-closing phase. The finding clearly indicates the underlying contractile state of the cover-body system and the decoupling of the mucosal wave in vocal fry phonation. Somewhat different findings were observed in the females, with no significant increase in CI values in vocal fry state; and in some cases actually decrease in the CI values. Correlating this with increased CQ values, it indicates a large increase in the contact-opening phase and unchanged contact-closing phase which suggests a vocal fold physiological adjustment in females which is inherently distinct from that in the males. Similar studies on CI are nonexistent in literature. However, findings on airflow rates [2] suggest similar inferences. These findings are also supported by the studies of Orlikoff [16] and Henrich et al. [7]. Here also, no vowel effects were found. Perturbation values (contact quotient perturbation: CQP and contact index perturbation: CIP) demonstrated significant increase in vocal fry register from that in modal register, and the increase was more in case of females than males. These findings again can be evidenced in favor of certain hypotheses regarding vocal fold functional anatomy and biomechanical adjustments.

Conclusions and Future Directions

The current study gives a clear and objective idea about the effects of vowel, gender and phonatory register on vocal fold vibratory patterns and the intricate relationship between these variables in determining vocal fold vibratory behavior. The findings give strong correspondence to certain hypotheses in literature regarding this matter and refute the other hypotheses. Applicability of the study could be considered in two domains: firstly in understanding, evaluating and treating certain voice disorders and, secondly for efficient vocal adjustments during singing, especially where greater amount of glissando production is necessary. Although not much in use in western operatic singing, vocal fry register has important role in Indian singing.

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