Original Article

Effects of hearing loss on vocal fold vibrations: an electroglottographic analysis

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Abstract. Pre-lingually hearing impaired persons have abnormal pattern of vocal fold vibration and electroglottography has been used to qualitatively describe these anomalies. However quantitative parameterization using the contact quotient and contact index lacks in literature and necessitates the present study. Three groups of moderately severe, severe and profound pre-lingual hearing impaired children were subjected to Electroglottographic analysis by vowel prolongation and the derived contact quotient and contact index data were compared with that of a control group. Results demonstrated statistically significant deviancies of contact quotient and contact index with increasing hearing loss. It was concluded that improper acoustic feedback in hearing impaired leads to a vibratory cycle with a longer than normal and more symmetrical closed phase leading to a breathy, creaky, falsetto voice with little adduction, which increases with increasing hearing loss. The study highlighted the importance of contact quotient and contact index in both evaluative and therapeutic domains.

Key words: Electroglottography, hearing loss, contact quotient, contact index

1. 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 (1), and the vocal folds are the main structures. A single vibratory cycle of the vocal folds is generally studied to understand the biomechanical behaviors and their perceptual correlates. High speed stroboscopic pictures (2) 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 & the closing phase. The events during vocal fold vibratory cycle, the corresponding biomechanical and aerodynamic changes, the modes of vocal fold displacement and phase differences, the changes of mucosal layer movements has all been investigated using electroglottography (3,4).

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Received: 18.05.2011
Accepted: 02.12.2012

The underlying physiology, 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 to produce vocal ligament- mucus membrane coupling in different types of phonations (5, 6).

Electroglottogram (EGG) provides both qualitative (3,7) and quantitative (8,9,10) data regarding patterns of vocal folds vibrations. Different parameters exist in describing the EGG waveform (3,11,12), like the open quotient, speed quotient and vocal fold contact area. However, the measurement of open quotient requires the precise estimation of opening instant which is doubtful due to mucus bridging effect, and often vocal fold opening may be gradual without any knee in the EGG waveform (13). On contrary, the closure instant was more readily distinguishable; thus, Contact Quotient (CQ) has been proposed as a better alternative (9). Thus, contact quotient and contact index have better clinical applicability and adequately high predictability in identifying deviancies in vocal folds vibrations. Among the factors affecting vocal fold vibratory patterns, no significant age effect has been reported between the adult and pediatric populations (14); but there is a significant gender effect on EGG measures (15), although nonexistent for prepuberscent children (16).

It has been observed that persons with substantial amount of hearing loss have a voice quality markedly deviated from the normal which can be attributed to anomalous vocal fold vibratory behavior as a result of disrupted auditory feedback (17,18,19). The vocal fold vibratory patterns show a predominant hypoconstriction which is due to shorter closed phase of the vibratory cycle (20,21). Such vibratory patterns results in a larger open phase in one vibratory cycle and deviation from a more asymmetric open phase towards a more symmetric one. Contradictory findings have been reported (11) which shows greater than normal open quotient in adult hearing impaired females with no such differences in hearing impaired adult males. Higgins, Carney and Schulte (21) found that in adult hearing impaired, those with profound loss had at least one parameter of vocal fold physiology outside normal range. Higgins, Mc Cleary, Ide-Helvie and Carney (22) examined the nature of deviancy of speech/voice physiology in persons with hearing loss ranging from moderate to severe and found that such deviancies occurred to a limited extent in children with severe hearing loss. It may be hypothesized thus, that increased amount of auditory disturbances would cause increased disturbance in auditory feedback loop leading to an increasingly deviant vocal fold vibratory pattern.

Information regarding objective quantification of vocal fold vibratory behavior in congenitally hearing impaired persons are lacking in literature. The use of EGG for such purpose is even less. The more recent parameterizations of EGG, which are thought to better reflect the vocal folds vibratory patterns, have not been studied in the context of hearing impairment. Ambiguity and contradictions exist among available literature, which stem from the variations in EGG analysis, data extraction and parameterization techniques, effects of uncontrolled extraneous variables like degree of hearing loss, gender, period of amplification received and presence of concomitant laryngeal pathologies. Moreover, although it is hypothesized that severity of the vocal fold anomalies would increase with increasing degree of hearing loss, empirical evidence supporting this notion, and its reflection on the EGG parameters does not exist. All these points necessitate further study on the subject.

The present study aims to provide objectively quantifiable data regarding effects of hearing impairment incurred since birth & also the effects of degree of such hearing loss on certain aspects of vocal fold vibratory behavior, i.e., only those parameters which are most likely to be affected and have been shown to have a direct relation with the nature of physiological changes in hearing impaired (Contact Quotient and Contact Index). The study also tries to provide statistical quantification to inter-group variability, if any, of each of the above parameters, observed between different degrees of hearing impairment and between normal hearing persons, so that a generalization might be drawn regarding the expected values of the vocal fold vibratory parameters in different degrees of hearing loss.

Based on the inferences drawn from the literature, and keeping regard of the general aims of the study as discussed above, the following research questions were hypothesized:

Significant effect of hearing loss on parameters of vocal fold contact phase (Contact Quotient), vocal fold contact symmetry (Contact Index) would be demonstrated, i.e., statistically significant differences would be expected to exist between each hearing loss groups and the control group of normal hearing children, for the two parameters.

It was further hypothesized that the degree of difference would increase with increasing hearing loss, that is to say, the profound loss group would have the most difference with the normal group, and the moderately severe loss group the least.

2. Materials and methods

One factor that was considered during subject selection is the amount and period of auditory feedback (in form of amplification) available to the child, which has been documented to have a positive effect. Thus, only pre lingual hearing impaired children with moderately severe to profound hearing losses were considered as participants for the study. None of the participants had prior history of using amplification system or of undergoing auditory training, to exclude the positive effects of auditory feedback. Since literature predicts a strong gender effect on EGG parameters, only per pubertal children were taken up for the study. The pre pubertal age was taken as 10 years for girls and 12 yrs for boys as according to the criteria laid by authors (23).All the participants had a

Table 1. Participants details

Group	Hearing sensitivity (according to PTA)	No. of Participants	Age range
Group A	Normal hearing	30	5-10 yrs
Group B	Moderately severe hearing loss	15	5-10 yrs
Group C	Severe hearing loss	15	5-10 yrs
Group D	Profound hearing loss	15	5-10 yrs

normal cognitive and motor development and cooperated during EGG . None of the participants had history of any pathology affecting the laryngeal system including inflammatory conditions, hormonal imbalances, congenital deformities.

For the assessment of vocal parameters, EG-PC3 electroglottograph system of the DR. SPEECH software, Tiger DRS Inc and Vocal Assessment for Windows, Version-4.30; 1998, Tiger DRS, Inc. was employed for the procedure.

The subjects were made to wear the external neck electrodes after adequate skin preparation and were instructed to vocalize /a/. 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.), which is then demodulated and stored in a Windows PC. This average EGG waveform is then preconditioned (FFT band pass filtering with a 55 to 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 was also obtained from the averaged waveform. The crest factor (peak value / root mean square (rms) value computed for the whole period) characterizes the peakedness of the Lx pulse. After the amplitude and duration normalization (i.e data is shrinked to the 0.1 interval) of the average pulse has been accomplished, the irregularities of the rising flanks were compared within the differentiated EGG signal by means of a surface comparison of the dips and the entire area. The data was statistically analyzed. Measures of central tendency (arithmetic mean) & dispersion (standard deviation) was performed for each EGG parameter in each group. One-way analysis of variance (ANOVA) test for each parameter, with both between-group and within-group variability analyzed at 95% level of significance. For each ANOVA table, a post-hoc "Dunnett C" analysis of multiple comparisons was done. All statistical analysis was performed using the Software Package for Social Sciences (SPSS) version10.0 computer software.

3. Results and Discussions

Authors (9,10), in their study stated that, the relative values of Contact quotient CQ are taken to be of more importance for practical purposes rather than absolute values. The control group had the greatest mean contact quotient values (71.841). The mean (±s.d) contact quotient values of moderately severe, severe, profound groups were 69.34 %(±5.43), 59.46 %(±12.82), and 52.17 %(±13.74) respectively which indicates progressively decreasing mean values with increasing variability. ANOVA revealed at least one inequality of means amongst the four groups, calculated at 5% level of significance ($F = 0.161 > F_{0.05}(3, 71) = 0.922$). Dunnett C post hoc analysis for multiple comparisons for contact quotient revealed significant differences (5%) between the means of normal hearing and severe loss group, and also between normal hearing and profound loss group. The mean of the profound group also differed significantly from the mean value of the moderately severe group. No significant difference existed between the normal and the moderately severe group. There was no significant difference between the moderately severe and severe group also.

Thus, it is found that the contact quotient is abnormally small in the hearing impaired population, the degree of which increased with increasing hearing loss. As discussed before, contact quotient reflects the movement and status

Table 2. Means and standard deviations of the 4 subject group across 6 parameters

Parameters → Groups ↓		CQ	CI
Normal	M	71.84	-0.52
	S.D	5.60	0.24
Moderately severe	M	69.34	-0.48
	S.D	5.43	0.22
Severe	M	59.46	-0.34
	S.D	12.87	0.19
Profound	M	52.17	-0.31
	S.D	13.74	0.21

of the vocal folds during phonation, or as (24) puts it, a measure of the 'relative vocal fold abduction'. The contact quotient measure is related to the degree of vocal fold approximation during phonation, that is, to relative compression in the horizontal plane, and, may provide an objective yardstick of phonatory hypo- or hyperfunction at a given vocal intensity. Thus, a low contact quotient indicates a relatively longer open phase of the glottal cycle, leading to a voice quality of breathy or falsetto with little adduction. Apparently contradictory findings were presented (21), but many other investigators have found evidence of increased glottal aperture and phonatory air flow for some individuals with pre- and postlingual profound hearing loss (11,25-27). Findings consistent with the present one was demonstrated by Metz, Whitehead and Whitehead (27) and Mahshie & Oster (11) who attributed this to anomaly in precise laryngeal control. Similar trends were exhibited by authors (28) who support the view that breathiness is caused by an increase in the open phase of the glottal vibration cycle (29, 30).

Table 3. Mean, Standard deviations and Level of significance of CI

	Mean	Standard Deviation	Level of significance
Normal	-0.52	0.23	0.009
Moderately Severe	-0.47	0.21	
Severe	-0.33	0.19	
Profound	-0.31	0.20	

* The mean difference is significant at the .05 level

Another striking aspect of the contact quotient is large intra-group variability in the severe and profound loss groups, as evidenced by the large standard deviations, which suggest that the vocal fold anomalies of hearing impaired children may differ widely: from hypo- to hyper-constriction. It explains the fact that perceptual descriptions of voice of hearing impaired varies so greatly in literature, for example, as given by (31): breathiness, hypernasality, hyponasality, too high pitch (sometimes falsetto), monotonous pitch, loudness misuse (too high or too low), slow rate, monotony in rhythm & rate, hard glottal attacks, & differences such as harshness & a hollow, non resonant quality.

Table 4. Mean, Standard deviations and Level of significance of CQ

	Mean	Standard Deviation	Level of significance
Normal	71.84	5.60	0.00
Moderately Severe	69.33	5.43	
Severe	59.45	12.81	
Profound	52.17	13.74	

* The mean difference is significant at the .05 level

Contact Index (CI) was also evaluated in all the groups. The mean (±s.d) contact index for normal, moderately severe, severe and profound groups are -0.52(±0.24), -0.48(±0.22), -0.37 (±0.19), -0.31 (±0.20). In the case of contact index, the mean normal value corresponds well to that found by (11) in his group of normal adults (-0.52 ± 0.08). However, the mean values for moderately severe, severe and profound hearing loss children differs markedly from the normal values and the means are progressively reduced with increasing hearing loss suggesting greater symmetry of the vocal fold vibratory cycle than their normal hearing peers. ANOVA revealed at least one inequality of means amongst the four groups, calculated at 5% level of significance (F= 0.161> F0.05 (3, 71) = 0.922). Dunnett C post hoc analysis for multiple comparisons for contact index also shows significant differences (at 5% level) between the normal and profound hearing impaired group and between normal and severe hearing impaired group. Although differences exist between the normal hearing and moderately severe loss groups and between each of the hearing loss groups, there were not statistically significant at 5% level, probably due to large within group variability.

Contact Index reflects the symmetry of the contact phase, is thought to reflect vocal fold tonus and to be particularly sensitive to mucosal dynamics within the vertical plane (6,24). In the present data, the contact index of the hearing impaired groups, especially profound group has significantly greater contact index than the normal control indicating a wider CCP (contact-closing phase). More the contact index is symmetrical; with a correspondingly wider CCP, the less is the duration of vocal fold contact, and hence more breathy will be the perceived voice quality (32, 33). Moreover, a wider contact closing phase (CCP) compared to contact-opening phase (COP) is generally associated with a falsetto register: more the comparative difference between the two, more will be the perceived falsetto quality (4,34,35). In fact, more symmetrical EGG shape has been associated with the "whistle" or "flageolate" register (36) which is often the perceived voice quality of the hearing impaired (20,22). Reduced vocal fold mobility and efficiency has also been demonstrated by (11) with the comparable parameters of speed quotient and abduction quotient.(21) also found inappropriate stiffening of the vocal cords and a consequent reduction of vibratory amplitude, which is in agreement with the present findings.

Moreover, the present study demonstrates a greater effect on vocal fold vibrations with increasing hearing impairment which strongly correlates with findings of (21). Further, this study further validates the certain hypotheses regarding vocal abnormalities in the hearing impaired. (37) stated that voice quality & poorly controlled pitch & intonation of the hearing-impaired speakers could be attributed to their inability to control their laryngeal performances due to lack of proper auditory feedback. This hypothesis has been specifically addressed and empirically tested in post lingual hearing impaired by (19). Further support is provided by (17, 18). Evidence in support has been provided by the study of (18) with cochlear implant users, which demonstrated that even short periods of auditory deprivation can effect speech and voice production. If this statement holds true, then it can be further assumed that greater auditory deprivation will lead to greater degree of vocal deviancy. The present finding supports this assumption.

Foremost is the lack of monitoring of the vocal sound pressure level (SPL) while recording the phonations of the subjects. The parameters of contact quotient and contact index are related to intensity of the phonation and it has been shown that contact quotient decreases with increasing vocal intensity while contact index increases from mild to moderate vocal intensity (9). Technical constraints in recording and calculating the root mean square (rms) intensity precluded the use of statistical covariance in the present study to control the said extraneous variable. In the study as much control as could be achieved was attempted by instructing the subjects to phonate at their comfortable loudness level.

Further, (10) has cautioned about artifacts introduced due to ill-defined closing-opening instances, tongue or vertical laryngeal movements, and mucus strands, as well as the variable results elicited by different algorithms used, while measuring the contact quotient. Recent literature recommends using EGG and imaging techniques like the videostroboscopy or the videokymography simultaneously and superimposing the EGG waveform over the images for a better representation of the vocal fold vibratory patterns.

4. Conclusion

The present study opens up the necessity of several corresponding studies. Adequate supportive studies for most of the present findings are few in literature. Replicable studies have to be undertaken for the validation and generalization of the present findings. The use of a simultaneous EGG and laryngeal imaging (videostroboscopy or videokymography or high-speed-laryngeal-imaging) technique in such studies would give further validation to the present finding, as well as solve most of the procedural limitations mentioned above. Future studies should also employ the method of statistically controlling the effect of vocal intensity as mentioned above.

It is hoped that the present study will provide some insight into the vocal fold vibratory behavior in absence of auditory feedback and demonstrate clearly the utility of certain objective, quantifiable parameters in predicting the voice quality of the hearing impaired using an easy method like EGG. The clinical utility of the study is that the data could be utilized in voice assessment of the hearing impaired as well as in planning therapeutic intervention to improve voice quality of the hearing impaired (38).

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