An Examination of the Relationship Between Electroglottographic Contact Quotient, Electroglottographic Decontacting Phase Profile, and Acoustical Spectral Moments

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Summary: Objectives. To date, only a few studies have examined the possible relationship between electroglottographic (EGG) data and spectral characteristics of the voice. This study examined the possible association between EGG signal data (contact quotient [CQ] and decontacting phase profile) and spectral moments of the acoustic signal (spectral mean, spectral standard deviation (SD), spectral skewness, and spectral kurtosis). Furthermore, the possible effects of gender on these measurements were analyzed.

Methods. Sustained vowel /ɑ/ productions were obtained from 48 normophonic individuals (24 adult males and 24 adult females). The central 1-second portions of the acoustic vowel samples were analyzed for spectral moments, and the EGG signal was analyzed for CQ (CQ_{EGG}), fundamental frequency (F_0), and decontacting phase profile.

Results. Across all subjects, the spectral characteristics of the voice (in particular, spectral SD, skewness, and kurtosis) are significantly related to changes in the relative duration of vocal fold contact (as measured via CQ_{EGG}). In addition, significant effects of the profile of the EGG decontacting phase (ie, concave down/"knee" vs concave up/"no knee") on spectral SD were also observed, as well as a strong trend for decontacting phase profile to influence the spectral mean.

Discussion. Although the degree of vocal fold contact and differences in decontacting phase profile may have an influence on the spectral characteristics of the acoustic voice signal, the strength of correlations between CQ_{EGG} values and measures of spectral moments only accounted for approximately 13–16% of the variation in spectral distribution characteristics. These results stress the importance of the transformative role of the supraglottal vocal tract in producing an acoustic output that maintains some of the characteristics of the glottal source, but which modifies the source characteristics in ways not completely accounted for by single parameters such as CQ_{EGG} or EGG profile.

Key Words: Electroglottography–Spectral moments–Contact quotient.

INTRODUCTION

When analyzing vocal fold movement during phonation, adult males and females have been described as exhibiting physiological differences throughout the glottal cycle.[1] During the contact phase of vibration, men have been reported to approximate more complete glottal closure than women,[2,3] corresponding to a greater relative duration of vocal fold closure in men versus women.[3,4] In contrast to observations for adult male speakers, multiple researchers have noted that a majority of adult females produce comfortable pitch and loudness phonation with incomplete vocal fold closure (posterior glottal gap) during modal register phonation,[5–8] resulting in a relative increase in the duration of the open phase and a possible tendency for a subtle breathy voice quality in some women. In addition, adult females have been described as having less abrupt contacting and decontacting behavior than adult males.[9]

One method for objectively analyzing vocal fold contact during the phonatory cycle is electroglottography (EGG).[10,11] EGG is a noninvasive method of measuring vocal fold contact during voice production[4] that provides a physiological correlate of vocal fold vibration.[12] To obtain the EGG signal, two electrodes are placed on either side of the neck at the level of the vocal folds, and a small high-frequency current is passed between the electrodes.[4] When the current is transmitted during vocal fold vibration, the EGG signal varies in response to the fluctuations in electrical impedance that are induced by changes in the contact area of the vocal folds.[13] The resulting EGG waveform can be analyzed for contact quotient (CQ_{EGG}—the relative duration of vocal fold contact during the phonatory cycle[14]). In addition, modeling studies have shown that a description of the quality of vocal fold contact during the contacting and decontacting phases may be made from the EGG waveform.[15,16]

Previous research has described key characteristics of adult male versus female EGG waveforms. As expected, men have been observed to produce greater CQ_{EGGs} than women[3,17] although this observation may depend on the method used for computation of the CQ_{EGG}.[18] In addition, description of the EGG waveform profile has indicated that many adult male EGG waveforms are characterized as having a concave-down profile or knee in the decontacting phase[1,2,19] that corresponds to a bulging or skirting motion of the vocal fold(s) in the vertical dimension,[1] resulting in a tendency for increased vocal fold contact per glottal cycle.[2] Although the knee tends to occur in the majority of adult male EGG waveforms, the presence of a decontacting knee has also been reported in a smaller percentage of adult female EGG waveforms at habitual speaking pitch/

Accepted for publication October 23, 2014.

Portions of this manuscript were presented at the 43rd Annual Symposium: Care of the Professional Voice, Philadelphia, PA. May 29, 2014.

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Journal of Voice, Vol. 29, No. 5, pp. 519-529
0892-1997/$36.00

http://dx.doi.org/10.1016/j.jvoice.2014.10.016

frequency levels[17,20,21] (eg, Awan and Awan[17] recently reported that the knee was present in 76% of the males and 36% of the females that they studied).

In humans, most of the acoustic energy is generated by the cessation of the transglottal airflow.[22] The relative duration of the closed phase during a glottal cycle has a direct influence on the shape of the glottal airflow pulse and hence the generation of stronger high-frequency partials in the radiated sound source spectrum.[23,24] Therefore, it may be expected that differences in the relative duration and the quality or type of vocal fold contact during the glottal cycle (as discussed in the aforementioned literature review regarding adult male vs female EGG waveforms) will have an effect on the spectral characteristics of the acoustic voice signal. Holmberg et al[25] examined the relationships between aerodynamic, acoustic, and EGG measures of voice in consonant-vowel syllable and vowel production. Results showed weak but significant negative relationships between EGG adduction quotient and harmonic-to-harmonic (H1-H2) and harmonic-to-formant (H1-F1 and H1-F3) amplitude differences, whereas weak positive correlations were observed between H1-F3 noise and F1-F3 noise. These authors hypothesized that gradual closing movements of a somewhat abducted membranous portion of the vocal folds would result in relatively sinusoidal glottal waveforms and small adduction quotients and that the corresponding acoustic spectrum would be characterized by a first harmonic with relatively high amplitude, a steep overall spectral slope, and an attenuated F1 peak amplitude (because of a relatively wide F1 bandwidth). However, it was reported that strong relationships (r's > 0.70) between EGG adduction quotients and the aforementioned spectral characteristics were observed in $\leq$35% of the subjects. Winkler et al[26] examined the effect of aging on EGG, acoustic, and perceptual analyses of the voice. Results indicated a characteristic spectral distribution in the /ɑ/ vowel of male voices. Long-term average spectra (LTAS) of the male voices perceived as old had relatively little harmonic energy between 2 and 4 kHz, whereas younger male voices showed distinct spectral harmonics up to 4 kHz. The spectral characteristics for the young males coincided with EGG waveforms that showed a steep increase of vocal fold contact in the closing and a more extended opening phase with the instant of glottal opening clearly visible in the EGG signal as a knee. In contrast, the EGG waveforms for the older males were nearly sinusoidal with reduced steepness of the increasing signal slope. Bestebreurtje and Schutte[27] examined EGG and spectral characteristics of the belting singing style in a single subject study. Results indicated that the loud bright sound of the belting style is achieved by enhanced higher harmonics in the acoustic spectrum and a corresponding raising of the CQ_{EGG} above 52% (the authors speculated that this was an apparent threshold value for belting).

In addition to the examination of isolated spectral harmonic amplitudes, one of the methods that may be used to summarize the spectral characteristics of the acoustic voice signal is by examining the spectral moments of the LTAS.[28] In the computation of spectral moments, the spectral values are treated as a random probability distribution, with the first spectral moment being the *spectral mean* (a measure of the spectrum's central tendency in hertz; the center of gravity); the second spectral moment the standard deviation (SD; a measure linked with the variance around first moment); the third spectral moment being skewness (a dimensionless measure reflecting the average symmetry of the spectral distribution; positive skewness coincides with a higher concentration of energy in the lower spectral regions and negative vice versa); and the fourth spectral moment being kurtosis (a dimensionless measure of the shape of the spectrum, with positive values representative of a compact spectrum and energy concentrated within a very small frequency range versus low or negative values indicative of a flattened spectrum; may be interpreted via peakedness (width of the peak), as well as tail weight (heavy vs light tails), and the presence of infrequent extreme deviations).[29–33] Spectral moments analyses have had various applications to speech/voice analysis and have been used to assess the impact of vocal effort on voice characteristics[31]; to distinguish between typical versus disordered voice subjects during continuous speech[34]; to evaluate the impact of unilateral vocal fold paralysis on pre versus post-therapy voice characteristics[35]; to provide a voice treatment outcomes measure[36]; to aid in the differential diagnosis of adductor spasmodic dysphonia versus muscle tension dysphonia patients[37]; to discriminate between hypokinetic dysarthric and neurologically normal subjects[38]; and to assess the effects of cochlear implant on speech characteristics.[39]

Investigation of the possible relationships between physiological measures of voice (such as EGG) and the acoustic output of the speech/voice mechanism is valuable in our attempts to gain a deeper understanding of normal voice production.[25] Because acoustic measures are readily available, low cost, noninvasive, and familiar to researchers and clinicians alike, they are probably the most frequently used "objective" measures of voice. Research that can establish the relationship(s) between acoustic and physiological measures of voice are important in demonstrating the validity of these methods. Because EGG is a noninvasive (and hence easily obtained) physiological correlate of vocal fold vibration, it is important to relate acoustic measures (spectral or time based) to data from the EGG waveform and thus possibly gain a better understanding of the causal relationship between the quality of vocal fold vibration and the resulting sound output. Spectral-based measures (such as spectral moments) are of particular interest because (1) they have been reported to be effective in documenting voice types that are problematic for traditional perturbation measures (eg, strained voice) and (2) (although not the focus of this study) they have been shown to be applicable to the analysis of continuous speech samples. Therefore, the purpose of this study was to examine the possible association between EGG characteristics (including CQ_{EGG} and EGG profile) and spectral characteristics referred to as spectral moments from corresponding acoustic voice signals. In addition, possible gender differences in EGG and spectral characteristics of the voice were also investigated.

METHODOLOGY

The Bloomsburg University of Pennsylvania Institutional Review Board approved the methodology used in this study.