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Evaluation of the Electroglottographic signal variability by amplitude-speed combined analysis

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ABSTRACT

Background: Until now, it has been impossible to discriminate a pathology of the vocal folds and, in many instances, even to distinguish normal from pathological voices with an electroglottographic signal (EGG).
Objectives: To introduce a method for analyzing electroglottographic signals and for extracting features able to characterize phonation quantitatively.
Methods: The EGG signal recorded during a continuous vocal phonation is processed in order to obtain the first derivative, which is related to the velocity of movements and contact of the vocal folds. The average fundamental frequency is computed and its corresponding period is taken as the typical duration of the EGG cycle. After each glottal cycle has been identified, the EGG signal and its derivative are locally normalized in time. For each glottal cycle, the amplitude and related velocity signals are plotted in an X-Y graph thus forming a multi-layer display where each EGG cycle appears as a circular trace. This X-Y representation can be viewed as a polar graph: by increasing the angle from 0 to 360° with incremental steps corresponding to the time normalization re-sampling of the EGG cycle, mean value and variance are computed. The results are the curve of the amplitude-velocity mean cycle and the related variance curve. The shape of the mean loop is strictly associated with the relationships between amplitude-velocity changes and phonation phases. The surrounding area represents the variability of local vocal phenomena around the above mean curve. The phonation process can be characterized in more detail by computing couples of indices (mean and variance) as obtained by dividing the polar graph in 4 quadrants, roughly associated with the different phases of the glottal cycle. In our study we carried out the EGG analysis of 21 cases of normal voice and 21 cases of pathological voice, considering the variability based on the combined amplitude-velocity analysis.
Results: In normal subjects, the global variability indices (*VI*) (expression of Amplitude and Velocity variation) and the four *VI* of different physiological phases of glottal wave (VI_1, VI_2, VI_3 and VI_4), were definitely lower than in pathological subjects. Such difference was statistically significant ($p < 0.03$).
Conclusions: The above method for analyzing the EGG signal proved to be efficient to discriminate normal subjects from pathological ones. Additional trials with more subjects are needed to confirm this preliminary data and to evaluate possible differences between different pathologies.

1. Introduction

EGG is a non-invasive technique that studies the vibratory movements of the vocal folds indirectly by recording and measuring changes in electrical impedance between electrodes placed on the skin above the thyroid cartilage. These variations of electrical impedance occur at glottis level during phonation. Electrical

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impedance decreases as the area of vocal fold contact increases; EGG indirectly measures the extent of contact between the vocal folds [1–3]. In fact EGG has been used with stroboscopy to detect the glottal opening phase [4,5].

Since EGG is sensitive to changes in vocal fold contact area during phonation, it can be a valuable tool for both voice researchers and clinicians. Clinical observation and the application of various physical and mathematical models have been used to identify important EGG signal landmarks and to relate changes in signal morphology to specific aspects of laryngeal physiology and physiopathology [6,7].

From a clinical point of view, the advantages of Electroglottography are the following: the EGG cycle is repeated at each contact and its frequency is considered the most accurate indicator of the voice fundamental frequency (*F0*) [8–10]; still today, the EGG plot demonstrates the best indirect representation of the vocal fold vibration as a whole and particularly during its closing phase [8,10,11]. When used with high-speed imaging and acoustic analysis, EGG is able to highlight irregular vibratory patterns, demonstrating its clinical applicability to the analysis of pathological voice [12]. Hosokawa et al. have recently showed how EGG parameters related to the regularity of vocal fold vibration may be useful for the diagnosis of dysphonia and for the assessment of the efficacy of voice therapy [13]. Somanath and Mau confirmed that EGG parameters may serve as a marker for treatment response and found that they may provide a within-subject measure of vocal strain; adding EGG to multidimensional assessment may improve characterization of the voice disturbance [14]. Moreover, EGG is useful for the voices of singers in the study of diplophonia and vibrato (contemporary with spectrography) and for the training of singers (displaying the contact quotient associated with the trend of F0 in real-time). Finally, EGG examination is simple, not expensive and non-invasive [9,15–17].

Despite the above advantages, this procedure shows some limits: large variability among individuals prevents the definition of pathological and normal voice and the definition of the type of pathology. The EGG signal doesn't contain information either about glottal area during opening or the air flow that passes through or the side which is possibly affected by pathologies (left or right). The EGG waveforms are easily influenced by usual conditions of the glottis, such as mucus strands [8,18]. Moreover, the EGG cannot measure the amplitude of the mucosal wave or the anterior-posterior asymmetry, because it is a cumulative measurement of the vocal fold contact for all points that pass through the glottis. EGG would be useful in synchronous observations via laryngeal high-speed videoendoscopy (HSV) [19].

Actually, the EGG is a one-dimensional signal obtained from the complex three-dimensional motion of the vocal folds. The speed of such motion is strictly related to the contacting and decontacting phases of the vocal folds activity. The first mathematical derivative of the EGG waveform (DEGG) represents the speed of change of the EGG with time [8]. It is a common assumption that the maxima found in the DEGG signal always coincide with the moments of glottal closure and opening;thus the exact timing of glottal closure can be easily obtained from a single maximum in the DEGG signal [20,21]. In some subjects, multiple peaks for both the opening and the closing phase can be present, which can be caused by hopping behaviour of contact surface [22]. Besides, these peaks may be due to irregularities in the structure of the vocal folds that modify the EGG waveform [9,23], or to external artefacts, such as mucus strands [24]. Some recent findings suggest that DEGG peaks do not always coincide with the events of glottal closure and initial opening. Vocal fold contacting and decontacting do not occur at infinitesimally small instants of time, but extend over a certain interval (0.24–10.88%), particularly under the influence of anterior–posterior phase differences [21].

Anyway, the EGG and its first derivative are rich in useful information about the vocal folds activity, which is the result of the complex process of phonation at larynx level. Quantitative analysis of EGG could offer a valuable tool for evaluating the real behaviour of vocal folds in normal, pathological or unusual conditions, including the presence of mucus strands.

The measurement of the relative proportion of contact during a glottal vibratory cycle has allowed a quantitative evaluation of the EGG signal [25]. This parameter, known as "larynx closure quotient" [16] or "contact quotient" (CQEGG) [26], resulted useful both in clinical and in basic voice research [27]. Some authors reported a sudden decrease of the CQEGG, e.g. during the transition from chest/modal to falsetto register in singing [28,29]. Several authors demonstrated that CQEGG, being dependent on the type of the algorithm used to reveal the contacting and decontacting events, should be used with caution [30–33].

Irregularities in voiced speech are often observed as a consequence of vocal fold lesions, paralyses, and other pathological conditions. Many of these instabilities are related to the intrinsic nonlinearities in the vibrations of the vocal folds. Through the use of the EGG, various irregular vibratory patterns of the vocal folds have been observed in cases with voice disorders. These irregularities are thought to arise from the intrinsic nonlinearity of the vocal system and have been extensively examined by the theories of nonlinear dynamics [34]. Using the nonlinear dynamic methods, it was possible to quantitatively describe regular and irregular dynamics of the vocal folds, such as in asymmetric vocal folds and polyps [35,36]. Moreover, this approach was successfully employed to characterize different "vibratory states" of the vocal folds occurring at the transition between modal and falsetto voice [37].

In the present study, a new approach for the analysis of the electroglottographic signal is presented. The method is based on the EGG signal and its first derivative; it allows the extraction of quantitative indices about the EGG activity during contacting-decontacting phases of the vocal folds process during steady-state vocal tests. In our study, we carried out the EGG analysis of 21 cases of normal voice and 21 cases of pathological voice, considering the variability based on the combined amplitude-velocity analysis, in order to demonstrate any quantitative differences between pathological and normal subjects.

2. Materials and methods

For the evaluation of the method 42 subjects were enrolled, divided into 2 groups. The study group consisted of 21 patients (14 females, 7 men; mean age: 34.6 ± 3.4 SD) with voice quality disorders (disfunctional and/or organic dysphonia). The control group consisted of 21 subjects (15 females, 6 men; mean age: 35.2 ± 2.8 SD) with euphonic voice. All subjects were studied with laryngostroboscopy examination (KayPENTAX RLS 9100 Digital Strobo). Parametric analysis of their voice quality during phonation of the "a" vowel was performed using Multidimensional Voice Program (MDVP) (KayPENTAX CSL Model 4500). Laryngeal electroglottography examination (KAY Model 6103) was performed on all subjects while phonating the "a" vowel at a comfortable pitch and loudness. The voices of all the subjects, both pathological and normal, have been evaluated as type 1 or type 2 according to Titze's classification (1995) [38].

The registration of the EGG signal was performed four times for each subject during the same day (at 8 AM, 11 AM, 2 PM, 6 PM) on two different days. In this way we got 8 recordings of EGG signal for each subject, in order to calculate and subsequently examine within-subject and between-subject variability and the difference between different groups (normal vs pathological). In