Relationship Between the Electroglottographic Signal and Vocal Fold Contact Area

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Summary: Objective. Electroglottography (EGG) is a widely used noninvasive method that purports to measure changes in relative vocal fold contact area (VFCA) during phonation. Despite its broad application, the putative direct relation between the EGG waveform and VFCA has to date only been formally tested in a single study, suggesting an approximately linear relationship. However, in that study, flow-induced vocal fold (VF) vibration was not investigated. A rigorous empirical evaluation of EGG as a measure of VFCA under proper physiological conditions is therefore still needed.

Methods/design. Three red deer larynges were phonated in an excised hemilarynx preparation using a conducting glass plate. The time-varying contact between the VF and the glass plate was assessed by high-speed video recordings at 6000 fps, synchronized to the EGG signal.

Results. The average differences between the normalized [0, 1] VFCA and EGG waveforms for the three larynges were 0.180 (±0.156), 0.075 (±0.115), and 0.168 (±0.184) in the contacting phase and 0.159 (±0.112), −0.003 (±0.029), and 0.004 (±0.032) in the decontacting phase.

Discussions and conclusions. Overall, there was a better agreement between VFCA and the EGG waveform in the decontacting phase than in the contacting phase. Disagreements may be caused by nonuniform tissue conductance properties, electrode placement, and electroglottograph hardware circuitry. Pending further research, the EGG waveform may be a reasonable first approximation to change in medial contact area between the VFs during phonation. However, any quantitative and statistical data derived from EGG should be interpreted cautiously, allowing for potential deviations from true VFCA.

Key Words: Electroglottography–Vocal fold contact area–Excised hemilarynx–High-speed imaging.

INTRODUCTION

Electroglottography (EGG) is a noninvasive method to assess the vibratory behavior of the vocal folds (VFs) during voice production, introduced 6 decades ago by Fabre.[1] For acquiring the electroglottographic signal, two electrodes are placed at either side of the thyroid cartilage at the level of the VFs, and a low-amperage[2] frequency-modulated (0.3–5 MHz) current is passed between them. Variations in vocal fold contact area (VFCA) during the glottal cycle introduce variations in the electrical admittance across the larynx, resulting in variation in the current between the two electrodes. These variations of the electrical admittance are proportional to the resulting EGG waveform.[3–6]

Experimental research[7–15] suggests that there is a relation between kinematic events of the oscillating VFs and stereotypical landmarks in the EGG waveform (Figure 1). These findings were corroborated by modeling studies.[16–20]

Because of its low cost and noninvasive nature, electroglottography is an attractive alternative to direct (and thus more invasive) methods for observing VF vibration, such as videostrobolaryngoscopy,[21] videokymography,[22] or high-speed laryngeal videoendoscopy,[23–27] leading to an increasing number of publications using EGG as a primary data acquisition method in the recent past.[28–36] EGG-based studies are conducted under the assumption that the acquired EGG signal closely represents the relative VFCA during phonation. This is particularly crucial for quantitative methods analyzing the EGG waveform, for example, for calculating the EGG contact quotient[37,38] or the EGG contact index.[39]

Surprisingly, the putative direct relation between the EGG waveform and VFCA has, to the knowledge of the authors, to date only been formally investigated in a single study,[40] suggesting an approximately linear relationship between the change in VFCA and the EGG signal. This study investigated two canine hemilarynx specimens, using a mechanical arm to drive the VF against a conductive glass pane resulting in a sinusoidal signal at 10–30 Hz. Flow-induced VF vibration was not used. Furthermore, the study was conducted with videostroboscopy, that is, an aliasing technique that only provides an illusion of vibration, usually at a rate of 1 Hz, documented by 25 video frames per second. This suggests that, strictly speaking, a formal empirical evaluation of EGG as a measure of relative VFCA under more physiological conditions is lacking.

To address this issue, this study was concerned with the question whether the EGG waveform is a reliable physiological correlate of the relative VFCA during flow-induced sustained VF oscillation, using an excised hemilarynx setup, a conducting glass plate, and high-speed video (HSV) recording.

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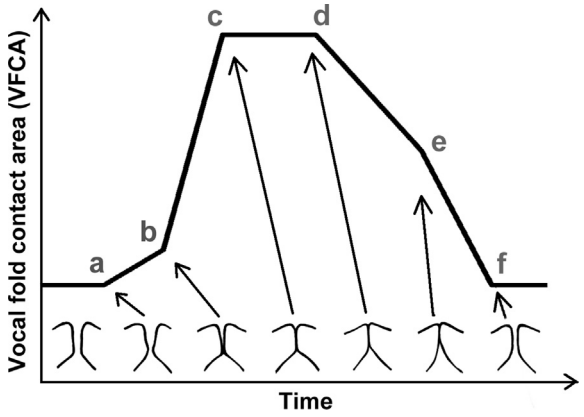

FIGURE 1. Landmarks in the EGG waveform according to Baken and Orlikoff[4] and Berke et al[20]: a—initial contact of the lower vocal fold (VF) margins; b—initial contact of the upper VF margins; c—maximum VF contact reached; d—decontacting phase initiated by separation of the lower VF margins; e—upper margins start to separate; and f—glottis is open, the contact area is minimal.

METHODS

Larynx specimens and experimental setup

The larynges investigated in this experiment came from three female red deer (*Cervus elaphus*) specimens. The choice of species was justified by results of a recently published study, suggesting that the EGG signal from a red deer larynx is comparable with that of humans and canines.[41] The deer were culled during an authorized third party hunt near Allentsteig, Lower Austria. The larynges were immediately harvested on site and were transported in ice boxes to the Department of Cognitive Biology, University of Vienna, where they were flash-frozen using liquid nitrogen[42] and then stored at −80°C for further use.

Each larynx was slowly thawed immediately before the experiment and cleaned (ie, the hyoid bone and epiglottis were removed as well as surplus extrinsic muscle tissue). For creating the hemilarynx, the left half of the thyroid cartilage, the left arytenoid cartilage, and a part of the cricoid cartilage were removed. This incision formed an L-shaped mortice allowing the larynx to be glued to a conductive glass plate (Figure 2) using dental cement (Kukident Super-Haftcreme complete; Reckitt Benckiser Deutschland GmbH, Mannheim, Germany). Another (nonconductive) glass plate was perpendicularly glued to the conductive glass plate, forming an L-shaped structure. To ensure good visibility of the VF from the top-view camera, the soft tissue above the VF (ie, the ventricular fold) was removed. The trachea was cut at the fourth tracheal ring, and the larynx was vertically mounted on an air supply tube as described in a previous publication[43] (Supplementary materials). The adduction of the VF was facilitated by use of a prong as described by Titze.[42]

The schematic of the experimental setup for obtaining the electroglottographic (EGG) signal is illustrated in Figure 2E. The EGG electrode attachment to the conductive glass plate and the hemilarynx, respectively, is shown in Figure 2A–D. The glass plate used in this experiment was covered with a layer of titanium-tin oxide, having a sheet resistance of 40 Ohms per square.

Self-sustained VF vibration was established by blowing warmed and humidified air through the hemiglottis. Subglottal pressure was varied via computer-controlled pressure sweeps in the range of 0–5 kPa (about 0–50 cm H_2O).

Data acquisition

The EGG signal was acquired with a Glottal Enterprises EG2-1000 electroglottograph (Glottal Enterprises, Syracuse, NY).

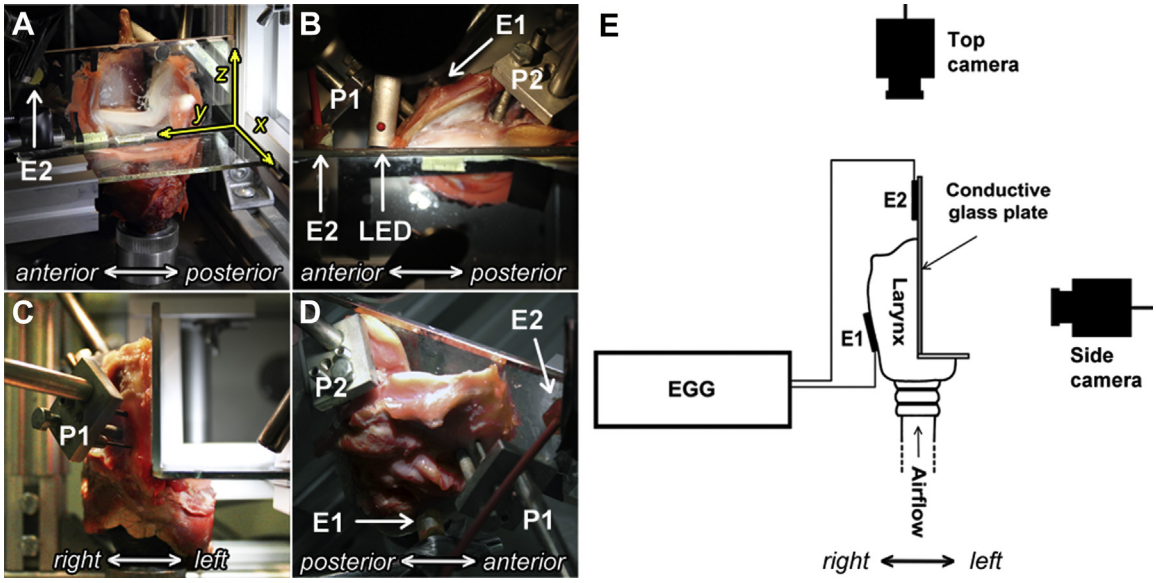

FIGURE 2. Hemilarynx setup with conductive glass plate used in this study: (**A**) side view through the glass. The orientation of the x, y, and z axis (eg, Equation 1) was adopted from Titze[42]; (**B**) top view; (**C**) anterior view; (**D**) anterolateral view (*right* side of hemilarynx attached to glass plate); and (**E**) schematic illustration of the experimental setup. E1—EGG electrode attached to muscles around the thyroid cartilage; E2—EGG electrode attached to the glass plate; LED—LED diode used for synchronization; P1—prong stabilizing the thyroid cartilage; P2—prong adducting VF.