Comparing Chalk With Cheese—The EGG Contact Quotient Is Only a Limited Surrogate of the Closed Quotient

*Christian T. Herbst, †Harm K. Schutte, *Daniel L. Bowling, and ‡Jan G. Svec, *Vienna, Austria, †Groningen, The Netherlands, and ‡Olomouc, Czech Republic

Summary: The electroglottographic (EGG) contact quotient (CQegg), an estimate of the relative duration of vocal fold contact per vibratory cycle, is the most commonly used quantitative analysis parameter in EGG. The purpose of this study is to quantify the CQegg's relation to the closed quotient, a measure more directly related to glottal width changes during vocal fold vibration and the respective sound generation events.

Thirteen singers (six females) phonated in four extreme phonation types while independently varying the degree of breathiness and vocal register. EGG recordings were complemented by simultaneous videokymographic (VKG) endoscopy, which allows for calculation of the VKG closed quotient (CQvkg). The CQegg was computed with five different algorithms, all used in previous research.

All CQegg algorithms produced CQegg values that clearly differed from the respective CQvkg, with standard deviations around 20% of cycle duration. The difference between CQvkg and CQegg was generally greater for phonations with lower CQvkg. The largest differences were found for low-quality EGG signals with a signal-to-noise ratio below 10 dB, typically stemming from phonations with incomplete glottal closure. Disregarding those low-quality signals, we found the best match between CQegg and CQvkg for a CQegg algorithm operating on the first derivative of the EGG signal.

These results show that the terms "closed quotient" and "contact quotient" should not be used interchangeably. They relate to different physiological phenomena. Phonations with incomplete glottal closure having an EGG signal-to-noise ratio below 10 dB are not suited for CQegg analysis.

Key Words: Electroglottography–EGG–Contact quotient–Closed quotient.

INTRODUCTION

The human singing voice is capable of producing a wide range of different vocal timbres. This is, among others, achieved by variation of the voice source quality at the laryngeal level. Both trained and untrained singers can influence glottal configuration by two independent means: (1) cartilaginous adduction (ie, adduction of the posterior glottis, controlled along the dimension of "breathy" to "pressed" via the lateral cricoarytenoid and the interarytenoid muscles) and (2) membranous medialization (ie, vertical bulging of the vocal fold via contraction of the thyroarytenoid muscle, induced by the choice of voice register).[1]

Assessment of glottal configuration is essential in (singing) voice research, pedagogy, and therapy. Although direct endoscopic observation produces the best insights, it is in many cases unpractical owing to its invasive nature. Often, electroglottography (EGG), pioneered by Fabre in 1957,[2] is used as a low-cost, noninvasive alternative. In EGG, a high-frequency, low-voltage current is passed between two electrodes placed on each side of the thyroid cartilage. Changes in vocal fold contact area (VFCA) during vocal fold vibration result in admittance variations, and the resulting EGG signal is proportional to the relative VFCA.[3,4]

The most commonly used quantitative analysis parameter derived from the EGG signal is the EGG contact quotient (CQ_{EGG}),[5] a concept originally introduced by Davies et al,[6] which was also referred to as EGG "duty cycle,"[7] "larynx closed quotient,"[8] "quasi-closed quotient,"[9] or "closed quotient."[10–12] In essence, the CQ_{EGG} is an estimation of the relative duration of vocal fold contact during one glottal cycle. To arrive at the CQ_{EGG}, one "contacting" (t_1) and one "de-contacting" event (t_2) is defined per glottal cycle (see Figure 1), and the duration of the "contact phase" (t_2–t_1) is divided by the period of the analyzed glottal cycle. The CQ_{EGG} is expressed in the range of 0–1, or as 0%–100% relative (time-normalized) cycle duration. It should be noted that EGG signal provides only information on changes in contact between the vocal folds; it cannot indicate whether there is full glottal closure. Therefore, the term "contact quotient" is more appropriate than the term "closed quotient" for the CQ_{EGG}.

In previous research, two different approaches have been applied to deriving the (de)contacting events t_1 and t_2: (1) a threshold-based method (see Figure 1A–C), where the (de)contacting events are determined by the moments when the locally normalized EGG waveform crosses a given threshold (typically set at 20%, 25%, or 35%);[5,7,13] or (2) a method operating on the first derivative of the EGG waveform (dEGG), where the (de)contacting events are constituted by positive peaks (for contacting) and negative peaks (for de-contacting) of the dEGG signal, corresponding to the moments of maximum increase or decrease of the relative VFCA (see Figure 1D).[14,15] Additionally, a hybrid method was proposed where the contacting event is con-

Accepted for publication November 8, 2016.

This research will be submitted to the Voice Foundation's 46th Annual Symposium: Care of the Professional Voice, from May 31 to June 4, 2017.

From the *Bioacoustics Laboratory, Department of Cognitive Biology, University of Vienna, Althanstrasse 14, 1090 Vienna, Austria; †Voice Research Lab Groningen, Wasaweg 9, 9723 JD Groningen, The Netherlands; and the ‡Voice Research Lab, Department of Biophysics, Faculty of Science, Palacký University Olomouc, 17. listopadu 12, 771 46 Olomouc, Czech Republic.

Address correspondence and reprint requests to Christian T. Herbst, Bioacoustics Laboratory, Department of Cognitive Biology, University of Vienna, Althanstrasse 14, 1090 Vienna, Austria. E-mail: herbst@ccrma.stanford.edu

Journal of Voice, Vol. 31, No. 4, pp. 401–409
0892-1997

http://dx.doi.org/10.1016/j.jvoice.2016.11.007

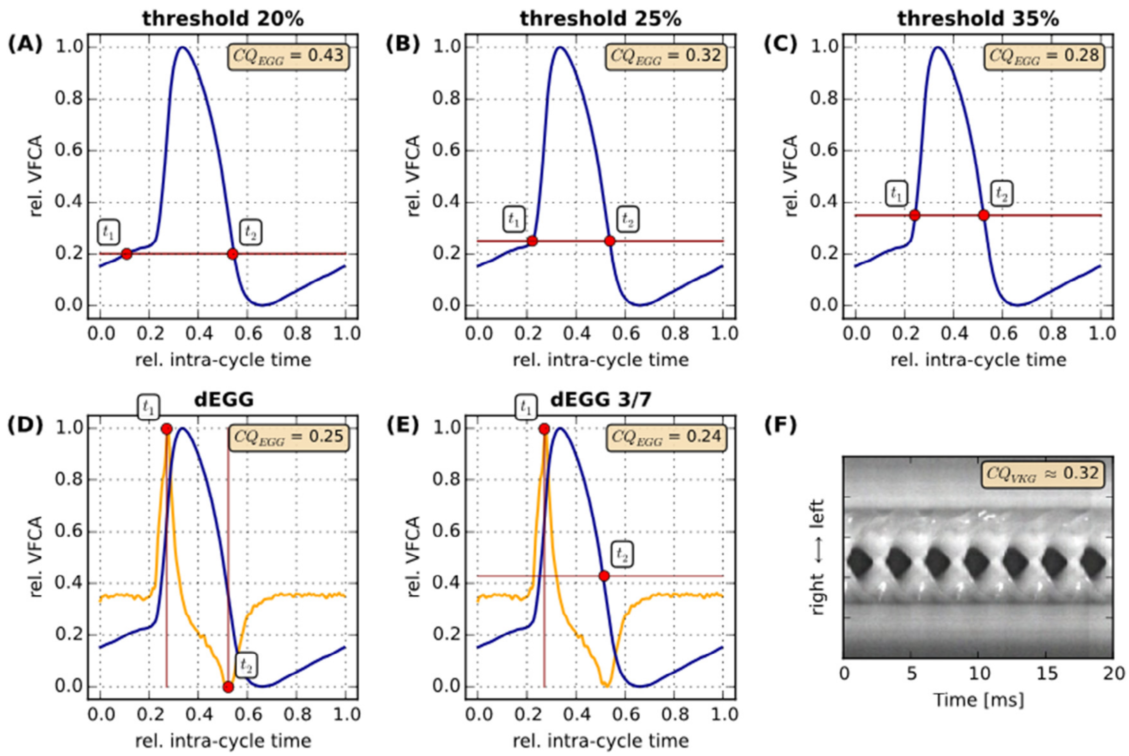

FIGURE 1. Overview of different methods to calculate the EGG contact quotient: (**A–C**) threshold-based methods; (**D**) dEGG-based method; (**E**) hybrid method (see text); and (**F**) videokymographic footage at the position of maximum vibration amplitude (perpendicular to the glottal axis), related to the shown EGG waveform.

stituted by the positive dEGG peak, and the de-contacting event is derived via a threshold set at ca. 0.43 (three-sevenths—see Figure 1E).[8] As can be clearly seen from Figure 1, different methods result in different CQ_{EGG} values,[13,14,16] with discrepancies up to 30% of the glottal cycle.[17] Apparently, the choice of the method for calculating the CQ_{EGG} is vital.

CQ_{EGG} measurements have been applied in many ways, including assessing registers in singing,[14,17–20] and discriminating "breathy," "normal," and "pressed" phonation.[16] These, and other studies,[14,21] appear to suggest that the CQ_{EGG} is a somewhat viable approximation of the actual closed quotient, if only to a certain degree. Indeed, there is mounting evidence suggesting that the discrepancy between CQ_{EGG} measurements and closed quotient measurements is systematic, as derived from either the glottal flow,[14,22] from videokymography,[17] or from laryngeal high-speed videoendoscopy.[19,20]

Accordingly, if these measurements are to be used properly, it is critical to establish expected discrepancy ranges between CQ_{EGG} and closed quotient measurements for phonation with different laryngeal configurations (ie, with different choices of posterior glottal adduction and membranous medialization or vocal registers). This issue is addressed here by analyzing EGG data from a previously used database of 13 singers phonating at known glottal configurations.[1] CQ_{EGG} measurements, as computed by five different CQ_{EGG} algorithms (see Figure 1), are related to the known videokymographically derived closed quotient.

Specifically, the following questions are addressed in this study:

(1) To what extent does the CQ_{EGG} deviate from the videokymographically derived closed quotient at different laryngeal configurations in singing?
(2) Which of the specified algorithms for calculating the CQ_{EGG} provides results closest to the respective closed quotients?
(3) Are there certain boundary conditions that need to be met for an EGG signal to be suitable for CQ_{EGG} calculation, or can CQ_{EGG} algorithms be indiscriminately applied to any EGG waveform?

METHODS

Participants and phonatory tasks

The data analyzed in this study consist of a unique database of four "extreme" singing types from 13 trained and untrained singers: aBducted falsetto (FaB), aDducted falsetto (FaD), aBducted chest (CaB), and aDducted chest (CaD). The participants' demographics, experimental protocols, and data acquisition methods are described in detail in a previous publication.[1]

All subjects were asked to sing target notes at their primary register transition (typically at or around pitch D4, fundamental frequency [f_0] ≈ 294 Hz). The target notes were reached by descending (in the case of falsetto register) and ascending scales (chest register), to guarantee phonation in the designated register. The singers were explicitly asked not to blend the registers. The choice of aBducted vs aDducted phonation was instigatedvia