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ON THE USE OF ELECTROGLOTTOGRAPHY FOR CHARACTERISATION OF THE LARYNGEAL MECHANISMS

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ABSTRACT

In order to produce a wide range of pitches, the human vocal production is characterized by the use of four distinct laryngeal configurations. The evidence of such division is given by noticeable transitions in the audio signal, the electroglottographic signal and its derivative, during the production of a glissando. So as to avoid the confusion linked to the notion of register in singing and to bring out the difference between change in the glottis configuration (laryngeal mechanism) and adjustment of the vocal tract (resonance register), the following terminology is proposed: mechanism 0 ("vocal fry"), mechanism I ("modal" or "chest" register), mechanism II ("falsetto" for male voice and "head" register for female voice) and mechanism III ("whistle" register). A shape description of the electroglottographic signal (EGG) and its derivative (DEGG) is provided in the case of the four laryngeal mechanisms and the strong correlation between electroglottography-based open quotient measurements and laryngeal mechanisms is illustrated. The possibilities and limitations of using the electroglottography in order to detect a given laryngeal mechanism are discussed.

1. INTRODUCTION

From the lowest tone (about 60 Hz) to the highest one (around 1500 Hz), the production of a glissando can sometimes be clearly divided into four distinctive parts, as illustrated in Figure 1. The evidence of such division is given by the noticeable jumps in fundamental frequency which can be detected at the transitions from one part to another, suggesting that these phenomenons would be related to some adjustments in the vocal folds' vibratory movement. For clarity, these four distinctive parts will be called: "mechanism 0 (m0)", "mechanism I (mI)", "mechanism II (mII)" and "mechanism III (mIII)". A rationale will be formulated later in this article to explain this terminology.

In order to define these mechanisms and understand more about them, the electroglottography (EGG) is chosen as a very simple and non-invasive method for indirect exploration of the vocal folds' vibratory process. In which way can electroglottography help for characterisation and identification of these mechanisms ? What is the relation between these observations and the notion of vocal register ?

To answer these questions, the conclusions resulted from recent and more ancient research studies are brought up. We refer to two major studies for which audio and EGG signals were recorded simultaneously :

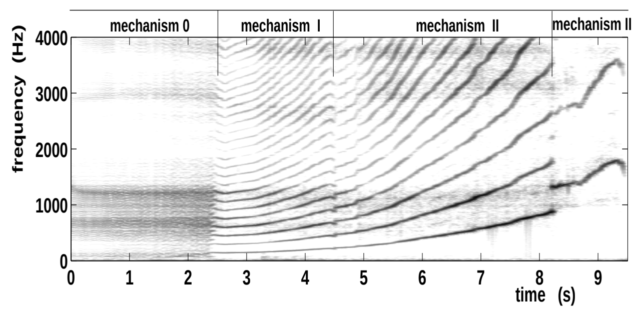

Figure 1: *Illustration of the four laryngeal mechanisms on an ascending glissando sung by a soprano.*

- **study S1** (Roubeau *et al.* [1, 2, 3, 4], 1993) :
  19 subjects, male and female, trained and untrained singers, participated in this study, which purpose was to explore the voice registers. The subjects were asked to produce ascending and descending glissandos, and sustained vowels with a noticeable register transition.

- **study S2** (Henrich *et al.* [5, 6], 2001) :
  A corpus of sung items designed for the purpose of open quotient measurements was recorded by 18 classically trained singers (7 baritones, 2 tenors, 3 counter-tenors, 3 mezzo-sopranos and 3 sopranos). The subjects were asked to sing a few sentences, sustained vowels, crescendos, decrescendos and glissandos.

The most significant outcomes of these experiments will be summed up here and illustrated on a few typical examples, with a view to shed light on the notion of vocal register. In the first part, we will define the laryngeal mechanisms on the basis of observations made on the EGG signal and its derivative (DEGG) at the instants of transition. In the second part, the four laryngeal mechanisms will be described within a glottal period. The notion of register will be discuss with regard to these observations. We will finally conlude in discussing whether an EGG signal and its derivative could be a relevant indicator of the laryngeal mechanism.

2. THE LARYNGEAL MECHANISMS

2.1. The contribution of electroglottography

Electroglottography, which was invented by Fabre in 1956 [7], is nowadays a widespread technique that enables the investigation of vocal folds contact area in phonation, in an easy and non-invasive way (for a detailed review, see Childers & Krishnamurthy [8], Colton & Conture [9], Orlikoff [10]). Two electrodes are placed on the neck of the subject, and they generate a high-frequency modulated current which admittance varies with the vibratory movements of the glottis : it increases as the glottis closes. In comparing this signal with other means of exploration, it has been shown that the EGG signal is related to the vocal folds contact area : the larger the contact surface, the larger the measured admittance.

A few studies have shown that the EGG shape over a glottal period is dependent on the vocal registers, i.e. ”chest” versus ”falsetto” register (Lecluse & Brocaar [11], Kitzing [12]). The EGG glottal period is more asymmetric in chest than in falsetto register, with a more rapid closure phase and a gradual opening phase. These differences reflect the differences observed on a glottal flow period (Childers & Lee [13]) and can be explained in terms of vertical glottal contact behavior by the use of a mathematical model of vocal folds contact area (Titze [14]).

Nevertheless, the observation of an EGG glottal period seems not sufficient enough to characterize a voice production in terms of vocal register. Indeed, in studying in detail the EGG shape in the case of 19 subjects (study S1), Roubeau [3] observed a large amount of variation across subjects and within a given subject. In order to understand more about the stable phases of a given vocal production, we shall first look at the transition phenomenons which could occur during this production and which may convey much information about the production before and after the transition phase.

2.2. Illustration of the transition phenomenons

Two typical examples have been chosen to illustrate the observations of transition phenomenons : an ascending-descending glissando produced by a baritone singer (see Figure 2) and a descending-ascending glissando produced by a soprano (see Figure 3).

As illustrated in Figure 2, the transition between mechanism 0 and mechanism I is clearly visible on the sound spectrum. The change of voice quality is audible and it is thus easy to determine whether a given voice production is done in mechanism 0 or not. The transition is easily detectable on the EGG signal and its derivative, as illustrated on the bottom panel in Figure 2.

The transition between mechanism I and mechanism II is illustrated in both Figure 2 and Figure 3. It goes with an abrupt amplitude modification in the EGG and DEGG signals. This transition may go with a characteristic jump in frequency (Roubeau *et al.* [1, 3], Svec *et al.* [15], Miller [16]) but the EGG and DEGG amplitude change does not depend on this frequency jump : as illustrated on the sound spectrogram in Figure 2, the transition mI $\rightarrow$ mII goes with a jump in frequency and the transition mII $\rightarrow$ mI is smooth. It must be emphasized that the frequency region of the jump do not vary much and is not dependent on the sexe or the tessitura of the singer. In both examples, it takes place around 250 - 300 Hz.

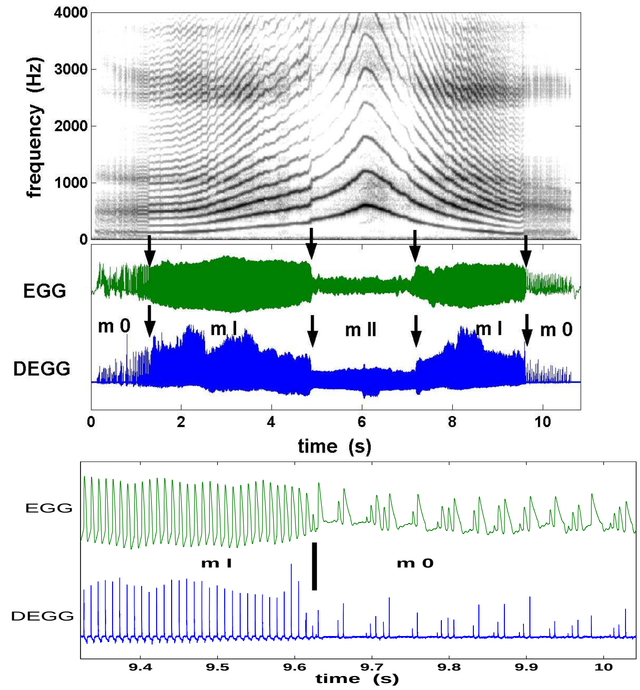

Figure 2: *Ascending-descending glissando produced by a baritone singer, which can be divided into 5 parts : m0 - mI - mII - mI - m0. The bottom panel presents a zoom on the last transition (mI - m0). (example extracted from study S2)*

The transition between mechanism II and mechanism III is illustrated in Figure 3. Similar to transition mI $\leftrightarrow$ mII, the transition mIII $\rightarrow$ mII is very sudden and it goes with a great amplitude change in the EGG and DEGG signals. This example illustrates also a peculiar behavior. The transition mII $\rightarrow$ mIII goes with a jump in fundamental frequency, but the great amplitude change occurs 200 ms before the transition. In this case, one can not rely on the EGG or DEGG global amplitude change to detect the transition. The change of shape from one period to another should be taken into account, as we will see in part 3.

To summarize, during a transition from one mechanism to another, we observe a change in the amplitude of the EGG and DEGG signals. It can go with a characteristic jump in fundamental frequency, but it occurs also when the transition is produced smoothly. It must be emphasized that the amplitude change is a characteristic of the transition phenomenon and it does not give any information which would be reliable for mechanism detection during the stable part. Indeed, similar signal amplitude can be observed in the different mechanisms, as illustrated in Figures 2 and 3.

2.3. Definition of the laryngeal mechanisms

As the EGG signal is related to the vocal folds contact area, an abrupt amplitude change in the EGG and DEGG signals provide clear evidence that the transition phases go with great modification in the vocal folds vibratory process (Hirano [17]). On the basis of these transition phenomenons, we define the laryngeal mechanisms, which correspond to different physiological, mechanical

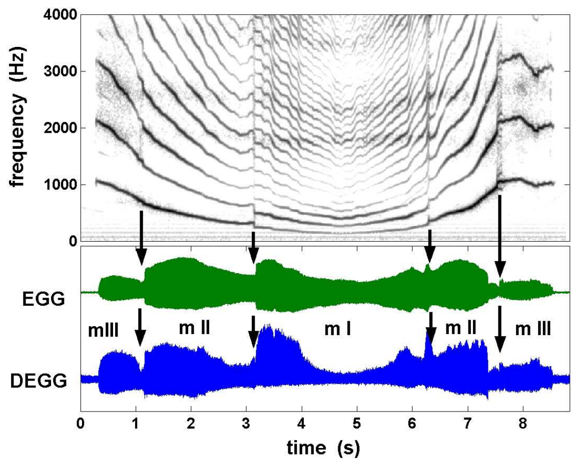

Figure 3: *Descending-ascending glissando produced by a soprano singer, which can be divided into 5 parts : mIII - mII - mI - mII - mIII. (example extracted from study S1)*

and vibratory glottal behaviors.

The laryngeal mechanisms can be related to the physiological knowledge that we have of the glottal vibratory process and to the notion of vocal register, a notion which is widespread in the literature but rather confused and badly defined. As matters stand, the notion of register combines the acoustical phenomenons which are related to the laryngeal configuration and its vibratory properties, and the acoustical phenomenons which depend only on the resonance properties of the vocal tract. So as to avoid this confusion and to bring out the difference between change in the glottis configuration (laryngeal mechanism) and adjustment of the vocal tract (resonance register), we have chosen to use the term *laryngeal mechanism* instead of *register*, and to number them.

3. ELECTROGLOTTOGRAPHIC DESCRIPTION OF A GLOTTAL CYCLE

In the previous section, we have based the definition of the laryngeal mechanisms on the noticeable transitions which can be found on an EGG or DEGG signal. We will now provide an electroglottographic description of the glottal cycle within a given laryngeal mechanism and relate this terminology to our knowledge of the laryngeal physiology and vocal registers.

3.1. Laryngeal mechanism 0

Laryngeal mechanism 0 corresponds to the so-called "vocal fry", "pulse" or "strohbass" register (Hollien [18]). It is the way to produce the lowest tones. It is much used in speech, especially by male voice. It is hardly used in western operatic singing.

A few EGG and DEGG periods are shown on the bottom panel in Figure 2. In this mechanism, the vocal folds are short, very thick and slack (Hollien [18]). The vibratory process is characterized by a very long closed phase, with respect to the fundamental period.

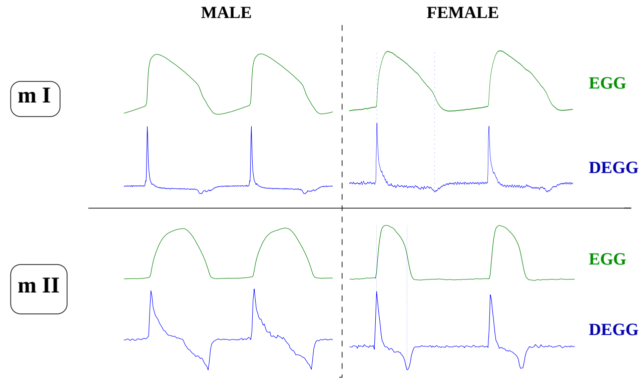

Figure 4: *Typical examples of EGG and DEGG glottal periods in mechanism I and II, in the case of male and female singers.*

3.2. Laryngeal mechanisms I and II

Laryngeal mechanism I corresponds to the so-called "chest" or "modal" register for male and female and male "head" register. Laryngeal mechanism II corresponds to the "falsetto" or "loft" male register, and to the "head" female register. Both mechanisms are commonly used in speech and singing.

Typical electroglottographic signals are shown in Figure 4. In mechanism I, the vocal folds are thick and they vibrate over their whole length with a vertical phase difference, whereas in mechanism II, the mass and vibratory length is reduced (Vennard [19]) and there is no vertical phase difference. The EGG shape is thus more asymmetric in mI than in mII. The DEGG present a strong glottal closure peak and a weak glottal opening peak in mI, whereas both peaks could present similar amplitude in mII.

3.3. Laryngeal mechanism III

Laryngeal mechanism III corresponds to the so-called "whistle", "flageolet" or "flute" register (Miller & Schutte [20]). It is used to produce the highest tones and is hardly used in speech and singing.

In this mechanism, the vocal folds are thin, very tensed and the vibratory amplitude is much reduced as compared to mechanism II. The aperture between the vocal folds is very thin, and there could be no contact between the vocal folds. Either there is no EGG signal, or the EGG glottal period is very symmetric in shape.

3.4. Open quotient

The observations made about the difference in shape of EGG signal between mI and mII can be quantified in measuring the open quotient (O_q), defined as the ratio between glottal open time and fundamental period. The measurements conducted on a singing database (study S2) confirm that the open quotient is dependent on the laryngeal mechanism used during the vocal production : open quotient values are usually lower in mechanism I than in mechanism II, as illustrated in Figure 5. Thus, the open quotient can be seen as a good indicator of the laryngeal mechanism within a given voice production. Yet, one should not rely solely on the values of open quotient to determine which laryngeal mechanism is used, as there is a degree of overlap between the O_q ranges corresponding to laryngeal mechanisms I and II. Listening to the corresponding sound samples can provide additional information and help to characterize a given vocal production. Nevertheless, the ear can sometimes be tricked by the vocal technique of the singer. For this reason, a combination of both analysis, listening and measuring of open quotient and other acoustical and EGG parameters, is usually required to find out which laryngeal mechanism is being used.

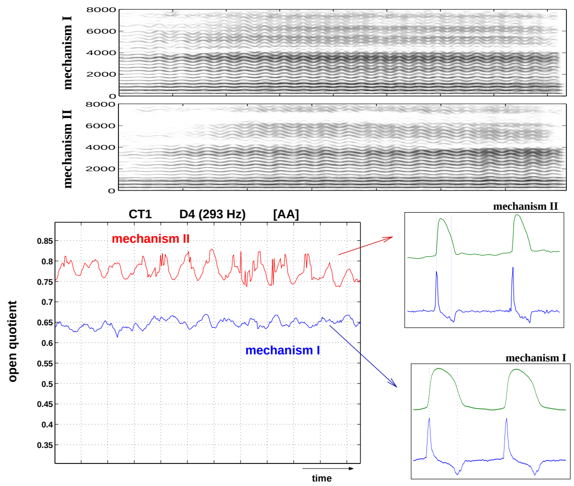

Figure 5: *Measurement of open quotient in the case of vowel [a] sung by a counter-tenor (study S2) on the same pitch (D4) in mechanism I and II (bottom left panel). The corresponding EGG and DEGG signals have also been plotted (upper and lower bottom right panels). The spectrograms of the two sound samples are shown on the two top panels.*

4. CONCLUSION

In this article, we have pointed out that the human male and female vocal production is characterized by the use of four laryngeal mechanisms. The evidence of such division is given by the abrupt amplitude change which can be observed on the EGG and DEGG signals during a transition. These laryngeal mechanisms are similar for male and female. They correspond to different glottal configurations and different vibratory process, which are not fully understood yet.

The electroglottography can be used as a reliable indicator of a laryngeal mechanism. In some cases, the EGG and DEGG features are typical of a given laryngeal mechanism and we can easily conclude. In other cases, the distinction remains unclear. It is then necessary to explore the vocal production within a transition phenomenon to assess the validity of a laryngeal mechanism estimation. An abrupt change in the EGG and DEGG signals gives a clear clue to a laryngeal change.

Such a characterization of the laryngeal mechanisms should help to clarify the notion of vocal register. It lays the foundation for further investigation on resonance registers, like the ”middle” voice.

5. REFERENCES

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