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Electroglottography is a method to monitor vocal fold movements by studying their effect on a weak electrical current through the soft tissues of the neck. As it is easy to handle and entirely non-invasive, the method has attracted increasing interest and is now in common use in voice clinics as well as in phonetic laboratories.

Based on earlier studies of the effects of pulsatile variations of the bloodstream on the impedance of body tissues, so called impedance plethysmography, it was Fabre who in 1957 was the first to report on percutaneously measurable electric phenomena depending on the vibratory movements of the vocal folds during phonation. He called his new method high frequency glottography.[27] Nowadays the term glottography denotes all physiological – as opposed to optic, acoustic, or auditively perceptual – methods to study vocal fold vibrations. In addition to electroglottography, photoglottography, ultrasonoglottography and inverse-filtered flow glottography can be mentioned.[51]

In *photoglottography*, the varying amounts of light from an outside source shining through the glottis during phonation are detected by a photosensitive device.[5,55,87] The photoglottogram corresponds on the whole to the variable area of the glottis (projected area function), but artifacts, like light shining through thin parts of the mucosa even if the glottis is closed and the difficulty to calibrate the curve amplitudes, diminish the reliability of the results. Besides, the method is rather invasive, as it is necessary to place either the light source or the light sensor in the throat immediately above the glottis, so photoglottography has not become generally accepted.

Ultrasonoglottography[38,44] is another method which, though promising initially, has almost entirely been abandoned. The method is completely non-invasive. It is the only type of glottography to sense the movements of each vocal fold and thereby well suited to diagnose one-sided lesions, but the complicated and varying configurations of the vocal fold medial edges during phonation scatter the ultrasonic echoes too much to yield consistent results. In addition, progressing calcification of the thyroid cartilages prevents their penetration by ultrasound.

In inverse-filtered *flow glottography*,[42,75] the airflow through the mouth is measured by a pneumotachograph placed in a mask. The signal is inverse-filtered to eliminate the influence of the vocal tract resonators. Even if not entirely identical, the resulting flow glottogram (FLOGG) is very similar to the glottal area function and it is possible to calibrate and measure essential parts of single curves, such as the baseline and the amplitude. The mask may be somewhat cumbersome but it is not an obstacle to prevent simultaneous registrations of, e.g. oral pressure or a microphone signal. Furthermore, it has been possible to correlate special features of the FLOGG curve to spectral analysis of the voice signal,[28,32,33] thereby bridging the gap between physiologic and acoustic aspects of voice.

Electroglottography makes use of the electrical conductivity of the body tissues. Two metal electrodes, the size of about 1 cm^2, are placed on the skin on each side of the neck in the thyroid region at the level of the glottis. With the neck tissues functioning as a mass conductor with a certain impedance, an electric current can pass between the electrodes and, depending on the construction of the instrument used (constant voltage or constant current), the amount of current or the impedance through the tissues is measured. Obviously, the current has to be weak so as not to cause tissue damage or to provoke muscle contractions or nerve impulses. Typically, electroglottographs use currents of 20 mA or less, yielding a voltage across the neck of about 0.5 V. Actually, the current is not perceptible to the subject as it is high frequency (0.3–5 MHz) alternating, which also reduces signal loss at the electrode skin boundary.

The impedance of the tissues depends on their chemical quality. Adipose tissue as in obese persons, for instance, has a rather high impedance, whereas the impedance of muscle tissue and body fluids such as blood, mucus and saliva is low. Other factors that may influence the amount of current between the electrodes are the position and shape of intrinsic organs in the neck, and the moisture of the skin. The electrical signal may therefore be influenced by muscle contractions when swallowing or by respiratory and articulatory movements of the larynx, but also by changes in electrode placement. As these signal changes usually are of little interest, glottographs are equipped with high pass filters and often also with an automatic gain control (AGC) to stabilize the amplitude of the most interesting part of the signal.[6] This is the impedance variation caused by the vibratory movements of the vocal folds. As the impedance of air is almost infinitely high, even the small variations in the glottal air gap during phonation will to some extent influence the total neck impedance. By demodulation and amplification, these impedance variations can be isolated as a separate signal, the electroglottogram. However, it should always be clear that the electroglottogram only represents a small fragment (about 1%) of the entire tissue impedance between the electrodes, the necessary high amplification causing a risk for spurious signals and artifacts.

As the electric current cannot be focused directly to the vocal folds, most of it will pass through the tissues around the airway whether the glottis is open or closed. This is the reason why a number of researchers refrain from naming the signal an electro*glottogram*. Fourcin[29] has instead suggested the term electro*laryngogram*, as it represents the status of the entire larynx as a unit. Unfortunately, this terminology may be ambiguous, as laryngography also means radiologic examination of the larynx by the aid of a contrast medium.[8,57]

Those in favour of 'laryngography' usually let the upper part of the resulting curve represent the part of the cycle when the amount of current passing through the tissues is at its largest, consistent with the engineering usage to let the duty cycle be portrayed by an upwards deflection. This means that the upper parts of the curve indicate a closure of the glottis. On the other hand, many voice physiologists, used to graphs from high-speed films or photo- and flow-glottographic curves, where the upwards deflection indicates an open glottis, prefer to have the glottogram oriented in the same way with the maximum current during glottal closure being shown as a downwards deflection. Practically, this is a minor problem, as many instruments have a switch for inversion of curves, but when studying electroglottograms, their orientation should always first be made clear.

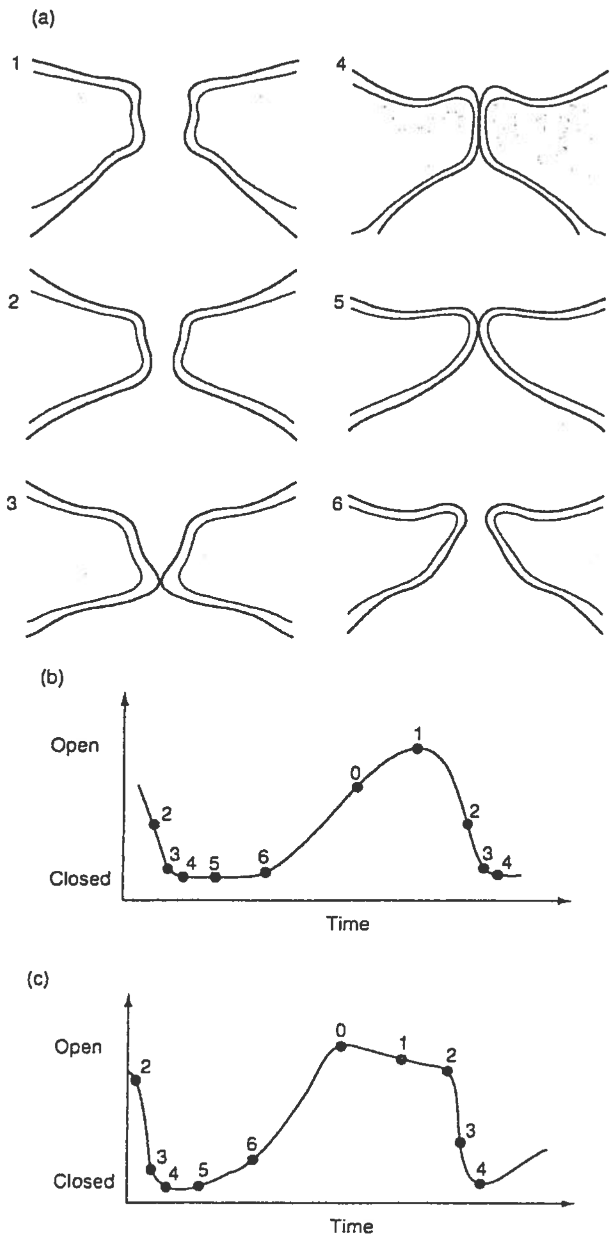

Figure 11.1 *(a) Schema of frontal sections through the glottis illustrating different moments of a vibratory cycle: 0, point of largest impedance (only shown in Fig 1b and 1c); 1, maximal open (point of largest amplitude); 2, closing; 3, closed; 4, maximum contact; 5, closed (but different from 3); 6, opening. (b) Location of these moments in the glottal area function represented by a flow glottographic (FLOGG) curve. (c) The same moments in the contact area function represented by an electroglottographic (EGG) curve.*

The electroglottographic curve

Electroglottograms are often described in terms of open and closed phases of the wave or opening and closing segments of the open phase, relating to the varying area of the glottis as depicted by high-speed movies, stroboscopy and also by photo- and inverse-filtered flow glottography. This strive is understandable as theoretical models of phonation often imply the phonatory area function of the glottis and its influence on the acoustic signal and thereby on voice quality. It is acceptable, however, only as a very coarse approximation, as the impedance of the laryngeal tissues is not related to the area of the glottis. As is nowadays generally agreed, the impedance variations detected in the electroglottogram are rather caused by variations of the contact area between the two vocal folds. In fact, during the part of the vibratory cycle, when there is no contact between the vocal folds (positions 0–2 in Fig 11.1), the electroglottogram is not sensitive to variations of the glottal area. Impedance is at a maximum, whether the air gap between the vocal folds is large or small, and it is not possible to define the acoustically important moment of the greatest glottal opening (point 1 in Fig 11.1) from an electroglottogram. Changes of the wave shape during the period when presumably there is no contact between the vocal folds can be explained as caused by electrical filters in the electroglottograph. Furthermore, it is notoriously difficult to make out the moment when the glottal opening starts (point 6 in Fig 11.1), which makes attempts to calculate the open time related to the entire period (the so-called open quotient) problematic.

Because of the risk of confounding the contact-area-depending impedance with variations of the glottal area, Fourcin[30] has avoided the qualification 'glottal' and coined the term Lx for the EGG wave. Orlikoff,[69] too, recommends a clear terminological distinction between the *vibratory* cycle, defined by contact phenomena, and the *glottal* cycle, representing the changes of the glottal area. In accordance with this, a 'contact phase' and a 'minimal contact phase' should be distinguished in the electroglottogram, and it should be acknowledged that these are not synonymous with the traditional closed and open phases of the glottal area function. The incorrect terminology is so common, however, that it will be impossible to avoid altogether in the discussion below.

When comparing the glottal area function with that of the contact area (Fig 11.1b vs 11.1c), it can be seen that the former shows the changes in greatest detail while the glottis is open, whereas the latter shows the greatest resolution of changes while the glottis is closed. The moments of opening and closing of the glottis as well as the instant of maximum opening and the glottal amplitude have been shown to correlate well with the resulting acoustic signal and thereby to voice quality.[32,33] This information can be obtained directly from the glottal area function but not from a curve representing the varying contact area between the vocal folds. Despite considerable research, the immediate relevance of the vocal fold contact ('depth of closure'[5]) to phonation remains to be shown. On the other hand, as the electroglottogram is so easily obtained it has become very popular and a great number of reports show that useful information about normal as well as pathologic phonation can be inferred from it.[6,7,15,16,18,20,30,53,69,71,78]

Qualitative appraisal of the EGG waveform

Though the exact physiological relevance of the electroglottogram remains to be shown, the shape of the EGG waves in many ways parallels different modes of phonation so well that a common application is to use the electroglottogram just qualitatively as a graphical illustration of different aspects of phonation.[64] This is shown in Figs 11.2–11.6, the interpretation of which is eased by combining the electroglottograms with inverse-filtered flow glottograms.

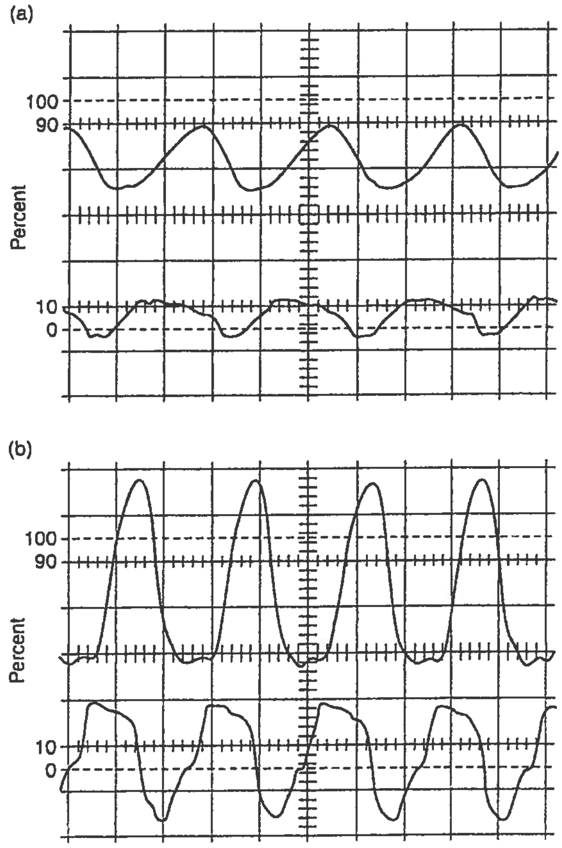

Figure 11.2 *Simultaneous flow glottagram and electroglottogram of a normal male voice at (a) low intensity, 139 Hz, and (b) high intensity, 156 Hz. Upper trace: FLOGG. Signal delayed because of distance between glottis and mouth opening. Lower trace: EGG with maximum impedance (glottal opening) shown upwards. Note the small hump in the rising part of the EGG at high intensity (see text).*

Intensity (Fig 11.2)

The registrations of increased intensity certainly show an increased EGG amplitude, as might be expected and which is common,[88] but one should keep in mind that there is no clear relationship between the amplitude of the acoustic wave and that of the EGG. Furthermore, the EGG amplitude may be influenced by the position of the larynx relative to the electrodes, e.g. by vertical movements of the larynx when singing an upwards glissando or by changes of posture. What might be less conspicuous when just looking at the curves is the increased time of vocal fold contact ('closed phase') relative to the entire period when intensity is increased. Quantitative studies have shown that this effect is consistent.[26,37,67] The small hump in the rising ('opening') part of the curve at high intensity is incidental and could be caused by a small strand of mucus forming an additional electrical path beside the contacting vocal fold edges.

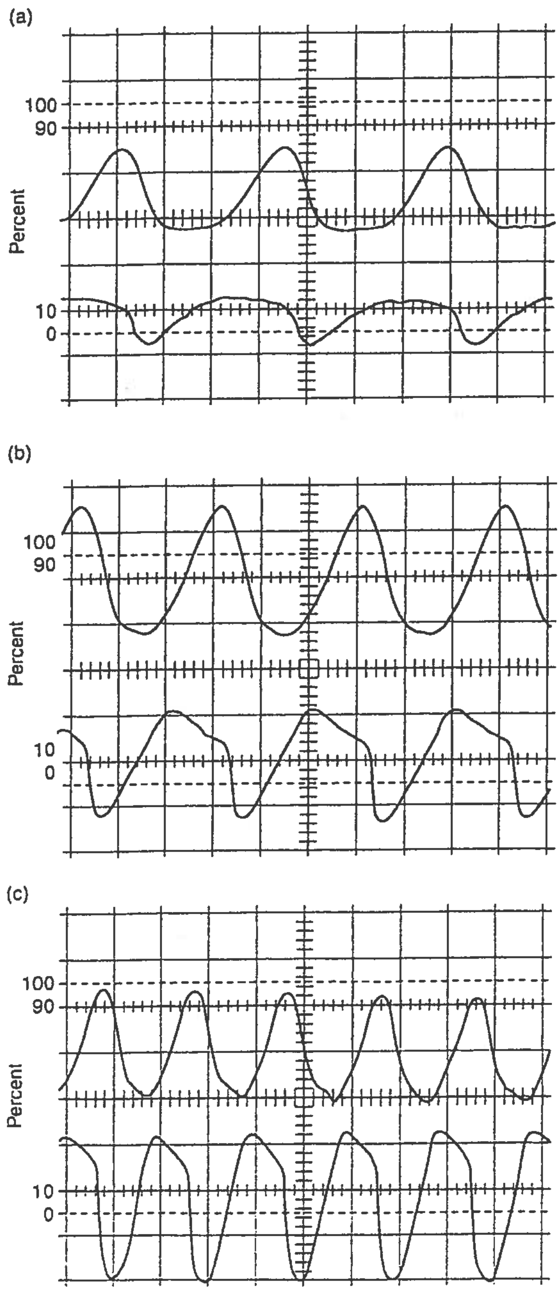

Figure 11.3 *Simultaneous flow glottogram and electroglottogram of a normal male voice at different fundamental frequencies: (a) 100 Hz, (b) 128 Hz, (c) 200 Hz.*

Fundamental frequency (Fig 11.3)

The fundamental frequency of the acoustic signal matches exactly the vibratory period of the electroglottogram.[93] As the EGG wave shape with its just one maximum per period is far less complicated than the acoustic wave, pitch extraction from the electroglottogram is more straightforward than that from the acoustic signal. Actually, simple and accurate measurements of the voice fundamental frequency is one of the most important applications of the electroglottographic method (see below).

Quality (Fig 11.4)

One important aspect of voice quality is described by the continuum leaky–flow–strained. This is well reflected in the electroglottogram by the increasing contact time ('closed phase') relative to the entire period. However, especially in the example from the strained voice, it becomes evident that the time of contact by no means agrees with the closure time of the flow glottogram; nor can one be sure that the dip of minimum contact in the electroglottogram represents a complete closure of the glottis. As was shown by Orlikoff,[69] it is actually perfectly possible to produce an entirely normal electroglottogram even if – because of a laryngeal paresis – a large part of the glottis remains continuously open during the entire vibratory cycle.

Registers and perturbations (Figs 11.5, 11.6)

Vocal register relates to both fundamental frequency and voice quality. Apart from the obvious differences in period length, the shape of the electroglottogram varies in a characteristic manner. In chest or modal register, it typically shows a somewhat rounded contact ('closed') phase, whereas in falsetto or loft register, this part of the wave is usually more pointed, due to the thinning of the vocal folds and the very short closure of the glottis. By aid of glottography, it is possible to differentiate between falsetto and operatic head register.[49,82,94] Furthermore, the ability of professional singers to equalize the transition between different registers without voice breaks can be

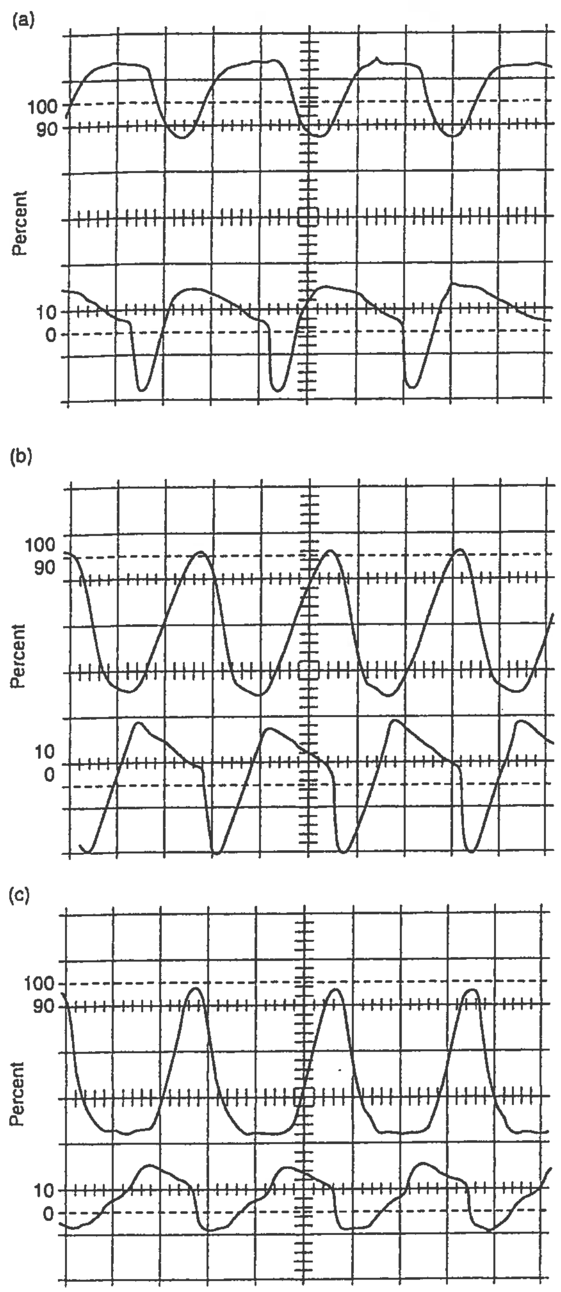

Figure 11.4 *Simultaneous flow glottogram and electroglottogram of a normal male voice at (a) leaky, (b) flow, and (c) strained voice quality.*

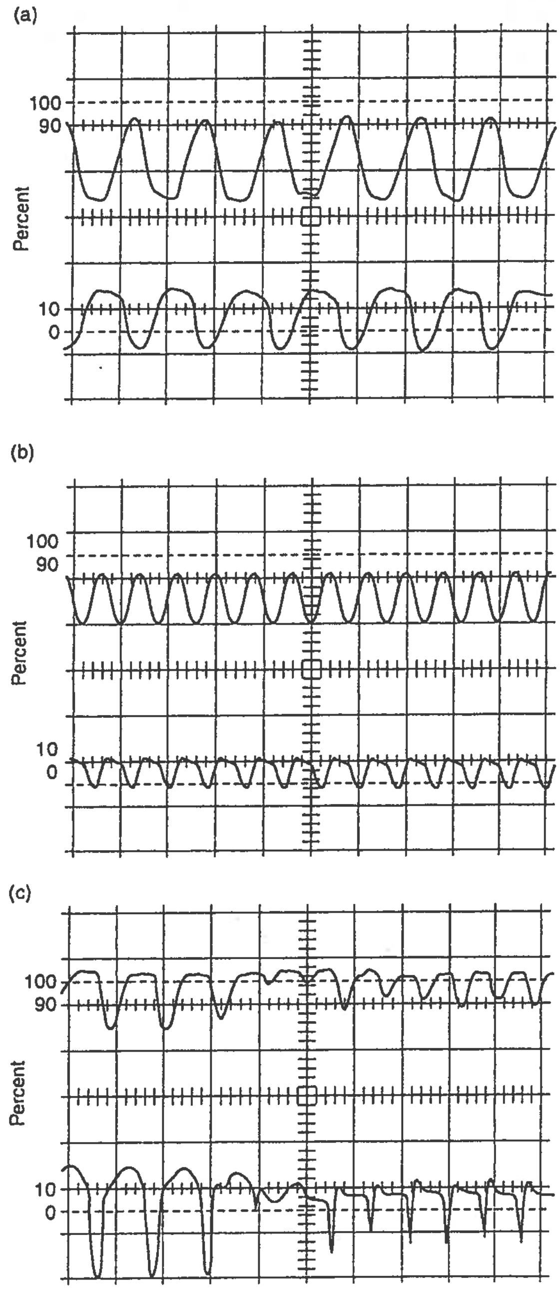

Figure 11.5 *Simultaneous flow glottogram and electroglottogram of a normal male voice at different registers: (a) chest register, (b) head register, and (c) voice break from chest to head register.*

easily shown.[79] It is also possible to document regular cyclic variations of phonation due to vibrato and trillo.[25]

Irregularities of vibration stand out especially well in the electroglottogram. This is illustrated by the example of a voice break (Fig 11.5c), where the wave shape in the very moment of register shift is similar to glottograms of creaky voices (pulse register, not illustrated here as such).

Vibratory irregularities (perturbations) are common at the start of phonation. This is illustrated in the examples of soft and hard glottal attack (Fig 11.6). At the hard

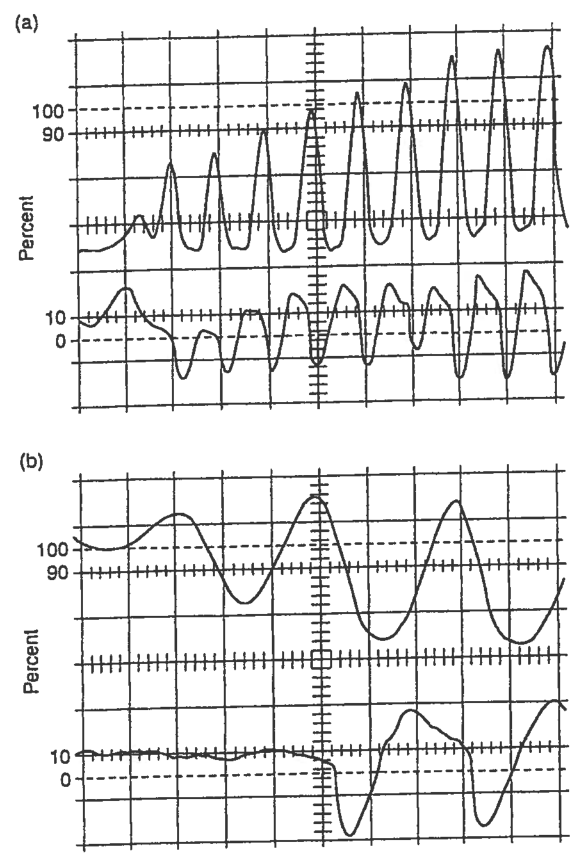

Figure 11.6 *Simultaneous flow glottogram and electroglottogram of a normal male voice at (a) hard vocal attack, and (b) at soft attack. For explanation see text.*

attack, it takes seven periods before the vibrations become regular, and they appear in the EGG from the very start of phonation. In the example of soft attack (recorded with a different time scale), by comparison with the flow glottogram it can be seen that the electroglottogram does not register the first two waves. Even if there are (acoustically relevant) vibrations of the vocal folds, these cannot be seen in the electroglottogram if the folds do not make contact.

Irregularities of the electroglottogram should be interpreted cautiously. Even if conspicuous, their cause may be very trivial, like a strand of mucus between the vocal folds. On the other hand, there may occur sequences of largely normal electroglottograms even in cases of full-blown vocal fold cancer.[53]

Quantifying EGG findings

Period-to-period irregularities or so-called perturbations of the period time and amplitude of the acoustic voice signal have been generally regarded as an important correlate to rough or harsh voice quality and hence as a sign of laryngeal pathology. They are called jitter and shimmer, respectively. A very simple way of quantifying the occurrence of waveform irregularities is by just counting their number and relating it to the total of inspected waves. Electroglottograms have been treated in this way and even with this crude method it has been possible to distinguish dysphonic voices from normal ones.[74]

Automatic measurements of period perturbations (jitter) have been shown to have 76% discriminating power between pathologic and normal voices whereas the discriminating power dropped to chance level (50%) when the same analysis was applied on microphone signals of sampled speech instead of electroglottograms.[86] To get a more secure period detection, some researchers transform the electroglottogram to its first derivative.[17,39,85] However, small irregularities and artifacts in the original signal may cause spurious spikes in the differentiated glottogram, so the derivation hardly means any advantage.[16] One way to control for common measurement errors in jitter extraction is to compare pitch period information obtained simultaneously from the acoustic and the EGG signal.[80]

It is possible to carry out EGG measurements even on children down to an age of about 7 years.[61,97] In children with velopharyngeal incompetence due to (surgically treated) cleft palate or after earlier adenotonsillectomy, EGG-based measurements of jitter were found to be positively correlated with ratings of perceived nasality, whereas shimmer was correlated to hoarseness.[97]

Besides measuring of jitter, EGG period perturbations may be depicted by the scattering of data points in EGG-based intonation contours. A somewhat similar method is to plot successive periods against each other in scatter-plots, which have been called 'digrams' or 'bihistograms'.[29,35] In such displays, most perturbations can be seen to occur in the lower frequency range, where the voice may sound creaky or harsh. Another measure of hoarseness is to analyze frequency distributions for the occurrence of low-frequency periods, and a reduction of the number of such low-frequency vibrations has been reported to signal perceived vocal improvement after therapy.[3,21,66,96]

EGG- and microphone-based measurements of frequency and jitter are comparable as both depend on the period length. The same does not hold for amplitude and shimmer, as there is no simple relation between the vocal fold contact area and the amplitude of the lip-radiated voice signal. However, there is some evidence that EGG amplitude perturbations may be a more sensitive gauge of perceived vocal disorder than acoustic measures of shimmer.[45,70] For normal phonation, EGG amplitude perturbation of about 0.2 dB appears typical, which is roughly half the normal acoustic amplitude perturbation (shimmer).[45,61]

A frequently used method of quantifying EGG findings is by computing quotients between various time segments of the wave or between such segments and the entire period, thus creating parameters to be correlated with different qualities of the voice. EGG data compare with photoglottographic measurements, indicating that the relative closure time tends to decrease with rising pitch, i.e. decreased time of vocal fold contact relative to the entire period (closed quotient) or increased open quotient, and to increase with growing intensity.[26,37,55,58,67] From this later correlation it can be inferred that the closed quotient also correlates with subglottal pressure, a fact that does not always seem to be recognized by researchers who uncritically use this quotient as a measure of vocal hyperfunction (pressed phonation).[91] An increase of the open quotient has been shown to distinguish pathologic from normal phonation but not to be useful for separating different lesions. However, when measuring pathologic voices, the described EGG parameters often become less dependable because of decreased signal-to-noise ratio. The magnitude of the method error has been shown to be approximately 15–18 % in such cases.[18,50]

Errors when metrically measuring single-period segments can be avoided by mathematical treatment of the entire curve, which has become feasible with increased computer capacity. The resulting global quotients, which thus represent an average across a number of periods, are obviously not directly related to individual glottal vibratory events, and their relevance has to be shown by statistical matching with various types of phonation. One such quotient is the so-called surface quotient. The EGG wave is divided by a line at equal distance from its maximum and minimum, and the S-quotient is computed by dividing the area of the resulting 'closed' part of the cycle with the area of the 'open part'. The S-quotient has been shown to increase with raised vocal intensity and to be decreased in pathologic voices.[23,24]

Another 'global' quotient is the quasi-open quotient, QOQ, also called β (beta) by some researchers. It is computed by dividing the EGG cycle by a zero line, so that the area of the part above the line (corresponding to high impedance) equals that under the line. The time corresponding to the part with the highest impedance ('open' part) is divided by the entire period. With this method a tendency has also been shown towards increased relative glottal closure when intensity was raised[36,37] as well as in hyperfunctional, strained voice quality, whereas the contrary was true for hypofunctional, 'loose' quality voices.[31]

Methods as described above to 'globally' define certain parts of the EGG curve to be used for computing quotients have been called criterion-level methods by Rothenberg and Mahshie.[78] With these methods, quotients can be defined by determining either the area or the amplitude of the waveform above or below a certain criterion level. The above-mentioned methods used 50% levels of distance or area, respectively. Using a 25% distance criterion for the EGG duty cycle, a 'contact quotient' ('closed quotient') was found to vary directly with vocal SPL.[67] A similar criterion level dependent variable is the EGG 30% open quotient. In a study comprising also stroboscopy and flow glottography, this quotient was shown to differ between various states of adduction (voice strain), though the variable seemed to be dependent also on F_0.[42]

EGG and measurements of fundamental frequency

Vocal pitch is one of the most important criteria when describing voice quality. It is a psychological entity, and its physical equivalent is fundamental frequency, F_0. The fundamental frequency of speech or speaking fundamental frequency, SFF, is of great interest in the voice clinic and also in phonetic research. Unfortunately, analysis of the SFF from the acoustic (microphone) signal is all but trivial, one reason for this being the fact that the acoustic voice spectrum may be entirely void of energy in the frequency region of the fundamental, and another that the signal may be so rich in strong overtones that these are wrongly taken for the fundamental by the analyzing device, so-called octave error.[43] These difficulties may be overcome by complex circuitry or computer algorithms, but many researchers prefer to use electroglottography for F_0 tracking because of its obvious advantages: it is almost as non-invasive as a microphone, it is not sensible to ambient noise and the EGG waveshape is so uncomplicated that it takes only simple zero-crossing to extract the period time or – by its inversion – the vocal vibratory frequency.

By definition, this is identical to the fundamental frequency of the acoustic signal. However, the EGG frequency at least of pathologic voices cannot without qualification be directly taken as a measure of SFF or rather the speaking voice pitch. When estimating the pitch level of speech, listeners tend in fact to neglect aperiodic and low frequency parts of the signal. These are perceived rather as signals of a certain quality, such as creakiness or harshness, and as pointed out above, they may as such be used as an objective measure of hoarseness.[1] Automated calculations of the EGG vibratory frequency consequently give lower results than estimations of mean pitch by auditory perception. For the measurements to correspond correctly to the perceived pitch, low-frequency period measurements of creaky phonation have to be eliminated. This has been accomplished in different ways, e.g. by discarding all measurements differing from the mean of the original distribution by more than an octave.[14] Another method is to introduce a periodicity criterion by accepting measurements only when two or three consecutive EGG periods, respectively, correspond to the same class range, forming so-called histograms of second or third order.[29]

The Glottal Frequency Analyzer (GFA) is a special device for measuring the mean speaking fundamental frequency, and its range and distribution in classes of semitones. Here frequency measurements at the extremes of the main distribution are discarded, once the distribution has dropped below a certain level (Fig 11.7). The results have been shown to correlate well (r = 0.98) with the pitch

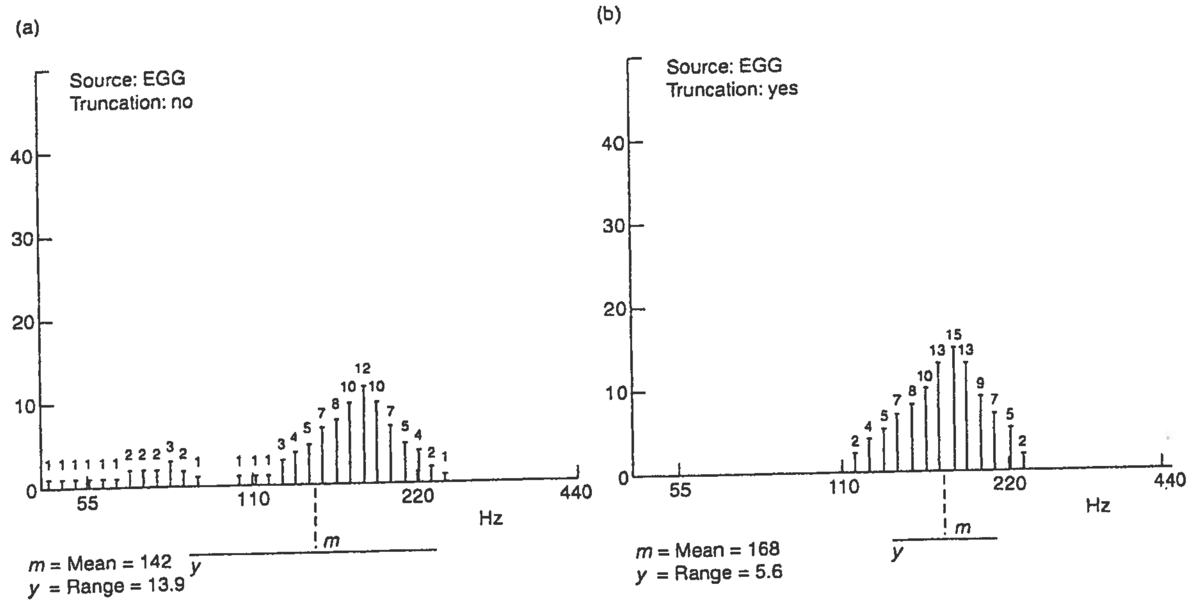

Figure 11.7 (a) EGG-based measurement of 1000 glottal vibratory periods by aid of the Glottal Frequency Analyzer (GFA). Distribution by classes of semitones is shown as percentage of entire sample. Female subject, Reinke's edema. Mean 142 Hz, mode 175 Hz, range 13.9 semitones. Note occurrence of low-pitched vibrations below 100 Hz. (b) Same analysis as in (a) after discarding the low-frequency measurements. Mean 168 Hz, range 5.6 semitones. Estimated speaking pitch by trained listeners: 170 Hz.

estimates of expert listeners, even if the analysis was made on pathologic voices. The pitch was on an average estimated to be only slightly (2.5%) higher than the GFA measurements, while SFF measurements by sonograms have been shown to give almost 4% lower results than those of the GFA.[21,47]

The mode of the distribution does not seem to be ideally suited as a central tendency measure of SFF because even normal voices often show asymmetric or bimodal distributions. In these cases as well as in pathologic voices in general, estimation of pitch by just listening (and comparing to a given pitch from a tuning fork, or the like) is rather difficult. Therefore, the access to a dependable method of measuring voice pitch is especially helpful in the voice clinic. Average SFF for female voices reported in the literature is 211 Hz, and the range (± 1 SD) is 5.4 semitones on average. The correspondent values for male voices are 124 Hz and 5.8 semitones. However, these values are not generally applicable as they are clearly language dependent. Swedish speakers, for instance, use much lower SFF (180 Hz and 113 Hz, respectively), while a group of French female speakers, studied by the aid of the same GFA method, speak at even higher average pitch (222 Hz).[21,47,56]

In studies of puberty, EGG-based measurements of the SFF have shown to be useful as quantifiable secondary male sex characteristics, highly correlating with serum levels of the sex hormones.[72,73] Besides depending on age and sex, the SFF is also dependent on the emotional character of the speech and the general situation, where the speech takes place. Provided such factors are kept under control when obtaining the speech sample, the mean SFF is strikingly stable and has been found to vary between successive observations of the same subjects at a time interval of about 2 months by only 2%.[47]

Considering such a high reproducibility, EGG-based measurements of SFF changes become highly relevant for the work in a voice clinic. The most conspicuous findings are the lowered SFF in female subjects either by virilizing hormones or by smoking, and the elevated pitch in males due to puberphonia (mutational falsetto).[12] As to organic voice disorders, GFA has proven especially useful as a means of monitoring the treatment of Reinke's edema, as the changes from pathologically lowered SFF to normal after surgery and voice therapy can be distinctly documented.[52]

Clinical applications of electroglottography

Electroglottography has found numerous clinical applications even if no single anatomic or physiologic condition can be diagnosed by EGG only.[95] It has been used especially for the assessment of laryngeal function in connection with interventions such as thyroplasties,[85] endotracheal intubation[59,60] and cricothyroidotomy,[34] as well as to study the effect of anti-inflammatory drugs after such interventions.[63] Computerized electroglottography in combination with sonography has been used for voice evaluation of myomucosal shunts after total laryngectomy.[10] Another application is to monitor laryngeal function in different types of neuromuscular impairments[92] and in laryngeal paralysis,[40] when the acoustic analysis alone cannot tell if compensatory contact between the vocal folds is made and where the very inability to obtain an EGG signal may be a pertinent clinical finding.[69] Spasmodic dysphonia and stuttering have been studied with the findings of altered EGG waveforms and perturbations.[9,13,22] Intonation contours based on electroglottograms have been used to analyze dysphonia due to hearing impairment as well as for a pattern matching biofeedback therapy of these patients.[1] EGG feedback has also proven to be useful in clinical voice therapy.[11]

By not using the high pass filter of the glottograph, slow changes of tissue impedance in the neck may be assessed. In this way it is possible to monitor the movements of the soft palate, for example before uvulo-palatoplasty for severe snoring[19] or the vertical movements of the larynx, e.g. when swallowing.[62,81,90] Swallowing movements can be monitored particularly well by the aid of a special multichannel electroglottograph including two electrodes on each side of the neck. This arrangement also simplifies optimal electrode placement.[77]

For clinical applications many authors prefer to use electroglottography in combination with other methods to investigate vocal function like videostroboscopy,[2,46,83,84,88,89] where the EGG signal also can be used to trigger the stroboscope. Other such combinations are with photoglottography,[40,41,48,54,65] and inverse-filtered flow glottography.[42,76]

Conclusions

Because electroglottograms are so very easy to come by, the risk is great that they are used incautiously. It should always be remembered, that 'the EGG is not the voice',[69] and that it represents changes of contact between the vocal folds and not of the varying area of the glottis.

Among the drawbacks of electroglottography may be mentioned technical difficulties to get a signal if the neck impedance is increased by subcutaneous adipose tissue or by scarring, e.g. after thyroid surgery. Similar difficulties occur when the vibration-induced impedance variations are reduced either due to diminished vibratory amplitudes (laryngeal paresis) or to small dimensions of the vocal folds as in small female subjects, in whom the obtuse angle between the thyroid plates may cause additional difficulties by impeding optimal electrode placement.

Correct electrode placement, both vertically and horizontally, is in any case critical to obtain a good EGG signal, and the best position should be tried out by monitoring the signal amplitude on an oscilloscope. The subject should not wear a metal necklace as this may function as an electric conductor interfering with the impedance between the electrodes. The same effect may be caused by moist and greasy skin, which may have to be dried with alcohol to get an acceptable signal. At small EGG amplitudes, the content of overtones in the acoustic signal tends to be reduced. This is an ideal situation to track the period time with just a contact microphone, which can be used in these cases as a complementary signal source.[4]

Automatic gain control and electric filters cause distortions of the EGG wave shape. The user should be aware of these effects, and especially seek information as to the cutoff frequency of the high pass filter in her/his instrument.

It should also be acknowledged that apart from the exact and dependable measure of the glottal period, no single feature of the EGG curve can be unequivocally correlated to the dimensions or movements of the vibrating glottis, which makes the computation of different suggested quotients as parameters of vocal function rather questionable. Not even glottal closure can be inferred from the electroglottogram with certainty, as a negative excursion of the curve signals just a minimum of impedance which may occur even when the glottis stays partly open during the entire vibratory cycle. Finally, small irregularities of the wave, like 'knees' and 'bumps', may be caused simply by unimportant mucous strands whereas the wave may show normal configuration even in serious conditions, such as cancer (see also reference 20).

As to the advantages of electroglottography, the fact that the signal is so easy to access is without doubt one of the best reasons for the vast popularity this method enjoys. It is almost as non-invasive as a microphone, but contrary to the acoustic signal it is entirely immune to ambient noise and to interference from the varying resonances of the vocal tract and articulation.[68] Contrary to the acoustic signal, it represents a perfect base for vibratory period measurements,[93] thereby easing fundamental frequency tracking, to be used as intonation curves or as objective measures of the mean pitch of speech. Again contrary to the microphone signal, the configuration of the EGG wave varies in accordance with different qualities of phonation, such as the increased relative contact time in loud and pressed phonation, the vibratory irregularities in rough voice, and the typical differences in wave shape relating to chest and falsetto register. Though exact correspondence between the EGG wave shape and the glottal area function and thereby the acoustic qualities of the voice remains to be established, the described changes of the EGG wave are evident enough to serve as a general illustration of what is going on in the larynx at different modes of phonation, and in this way the method may serve as a kind of biofeedback in the voice clinic.

Finally, the method can be expected to be rewarding also in future voice research, as the significance of vocal fold contact variations to phonation remains a widely open and challenging question.

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