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Summary: Electroglottography (EGG) is a method to monitor the vibrations of the vocal folds by measuring the varying impedance to a weak alternating current through the tissues of the neck. The paper is an attempt to give a state-of-the-art report of how electroglottography is used in the clinic. It is based on a search of the pertinent literature was well as on an inquiry to 17 well known specialists in the field. The EGG techniques are described and limitations to the method are pointed out. Attempts to document voice quality by EGG are recognized and computerized methods to obtain information about vibratory perturbations and/or the vibratory frequency of the vocal folds are described. The author's personal conclusion is that the EGG signal is especially well suited for measurements of the glottal vibratory period. In the clinic such measurements are useful for periodicity analysis, as a basis for recording intonation contours, and to establish the characteristics of the voice fundamental frequency. **Key Words:** Electroglottography—Electrolaryngography—Phonation—Voice quality—Voice pitch—Range of speaking voice—Voice therapy—Vocal biofeedback.

Electroglottography (EGG) (1) or electrolaryngography (2) is an entirely noninvasive, easy-to-handle method of monitoring laryngeal vibrations, impervious to ambient noise, and yielding seemingly straight-forward information about the vibratory behavior of the vocal folds during phonation. The instrumentation is easily available, either custom-built or as one of the at least three commercially available devices. No wonder, then, that the method has attracted great interest from many voice clinicians and that reports on clinical applications of EGG are abundant. On the other hand, EGG is far from being generally accepted in clinical work on voice disorders, and there is still intense work going on, aimed at the development and refinement of the EGG method to make it more suitable for clinical and research use.

Principally, EGG is a method to measure the resistance or, more precisely, the impedance to a weak alternating current through the tissues of the neck. These have moderately good conductive qualities, whereas air is an extremely poor conductor. Therefore, during the vibratory cycle of the vocal folds the impedance is increased when the glottis is opened. During the closure of the glottis, the electrical impedance drops as there is increased contact between the vocal folds. It is a common notion that the duty cycle of the electroglottogram represents the size of the area of contact between the vocal folds, a hypothesis that has been experimentally corroborated by Scherer et al. (3). For a detailed description of the EGG method and a thorough interpretation of the EGG waveform, the reader is referred to the articles by Baken (4) and Titze (5), respectively, immediately preceding the present paper at the 18th Symposium: Care of

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the professional voice, Philadelphia 1989. On the same occasion, a new EGG was presented by Rothenberg (6).

This state-of-the-art report is based on a computer search of the pertinent literature as well as on inquiry responses from 17 well-known specialists in the field (Baer, Chevrie-Muller, Childers, Dejonckere, Ferrero, Fourcin, Frøkjær-Jensen, Hacki, Hanson, Holmberg, Jentzsch, Lecluse, Pedersen, Reinsch, Schutte, Sopko, and Unger), whose valuable collaboration is hereby gratefully acknowledged. The present author's own experience of glottography dates back to 1961, starting with photoglottography under the guidance of Sonesson (7).

The report is not organized according to the different available EGG methods, as is rather common. Instead it will start from clinically used criteria of vocal function, and it will try to show how they can be documented by EGG. The criteria to be studied are register, quality, intonation, roughness, and pitch. The last two sections of the report will deal with the use of EGG in certain diagnoses and in therapy. But, first, there will be a short survey of the reported techniques for using the EGG signal, and some pitfalls and shortcomings of the method will be pointed out.

To fit into the given frame of time and space, the material has been condensed extremely, and, of necessity, the report will remain superficial on many issues. Therefore, the reader is strongly urged to consult the cited references for adequate information on points of special interest.

EGG TECHNIQUES

The information from EGG can be processed in many different ways. The generally used and most obvious method seems to be subjective visual evaluation of the wave shape (L_x) (8). To get objective data, durational and amplitude measurements can be carried out on different parts of the glottographic curve by aid of a ruler, with one commonly used measure being the time of glottal closure (or closed phase). As will be discussed under the heading of voice quality, these data often are parameterized by computing so-called quotients, like the open-quotient, i.e., the time of open glottis divided by the entire period time. The measuring and computing process may be computerized (9). Computers may also be used to differentiate the electroglottogram, with the resulting curves showing the velocity of change of the vocal fold contact area instead of only the amount (10–13). By plotting (the inverted) electroglottographic period time along a time axis, intonation curves (F_x) (8) can be obtained. Large cycle-by-cycle variations can already be seen in such curves, but they are more clearly demonstrated in scatterplots [C_x or digram distributions (8,14) or bihistograms (15,16)], where the period of one vibratory cycle is plotted against the next. The use of computerized statistics of period measurements is another way to handle electroglottographical data. In this way, measures of central tendency, like the mean, the median, or the mode, as well as measures of the range can be obtained. The result can be shown graphically, as the distribution of frequencies [or F_x histogram, according to Fourcin (8)]. Provided that aperiodic or extremely low frequencies are excluded from the computations, the mentioned statistics are reasonably representative of the mean pitch and range of the voice (17) [(F_x histogram of second and third order (8); truncated glottal frequency analysis (18)].

With growing insecurity as to the reliability of the EGG signal, a number of authors recommend that it be combined with other methods like videostroboscopy (19–23), photoglottography (24–28), inverse filtered flow glottography (29), xeroradiography (30), and phonetograms (31).

Recently, Titze et al. (32–34) have described an interesting method of treating EGG data alone or in combination with photoglottograms by matching them with simulated waveforms of a computer vibratory mode of the glottis. Their program is called glottal imaging by processing external signals (GLIMPES). It can generate a certain number of phonatory parameters, of which the so-called abduction quotient has been shown useful in describing voice quality along the sequence "breathy, normal, pressed."

LIMITATIONS OF THE EGG METHOD

The fact that it is usually very easy to obtain EGG curves may weaken awareness of the limitations of the method and of possible pitfalls when interpreting the results. The placement of the electrodes in front of the thyroid cartilage and the distance between them is rather critical (35), as is also the lowering of the skin-electrode electrical resistance by keeping the electrodes clean, lubricated with conductive paste, and firmly attached to the skin. Especially in female subjects, it may be impossible to obtain an EGG registration, most often because of abundant subcutaneous soft tissue (36–38). The generally smaller anatomical dimensions of the female larynx than the male may be another cause of insufficient EGG amplitudes. In this connection, one may recall that only ~1% of the total impedance through the neck is modulated by the glottal vibrations. Artifacts may be introduced into the signal by head movements or vertical shifts of the larynx (39,40). Compensating electric filtering and automatic gain control may also introduce distortion in the signal.

One cause of artifact, put forward for discussion by Smith (41), is that the glottographic signal could be acoustically dependent on the tissues acting as a kind of microphone. This possibility, however, seems to have been ruled out by a number of different experimental results, such as excitation of the vocal tract by an electrolarynx causing no EGG (1), phonation in helium causing no EGG changes in spite of drastical changes of the sound pressure waves (42), and the withdrawal of an electrically isolating polymer strip between the vocal folds, causing an increase of the amplitude (43). Besides, changes of mechanical contact between the vocal folds cause changes of glottal impedance even in the absence of phonation, as can be easily seen, e.g., in glottograms published by the present author (27).

To conclude this section, some caution against a too uncritical use of the EGG seems appropriate. An all-too-naive interpretation of EGG data may prove detrimental, especially in clinical applications. The user should always be aware that the electroglottogram does not represent vibrations of the vocal folds as such, but variations in the area of contact between them. And even this is only an approximation, as the cause of glottographically detected impedance changes still are not known in every detail, nor is the relevance of vocal fold contact area variations to the acoustic voice signal. There may be evidence for a reasonably good correlation between the vocal fold contact area changes and the electroglottograms in a number of publications, one of the most impressive being the detailed experiments with anesthetized dogs by the University of California at Los Angeles (UCLA) group (44). On the other hand, in this connection it seems impossible not to mention the latest evaluation by Childers (45, p. 21), an eminent authority on the physiological analysis of the electroglottogram, that it "remains a poorly understood tracking device, in its present form . . . not capable of contributing much to clinical diagnosis and treatment of voice disorders" (cf. also refs. 46–49).

EGG INVESTIGATION OF VOCAL REGISTERS

This is not the place for a detailed discussion of the controversial question of vocal registers. Suffice it to point out that the EGG waveform varies in a characteristic manner depending on the register. In this way, at least a qualitative documentation can be obtained that may be useful for voice therapists (14) as well as for singing teachers.

In vocal fry or pulse register, there can usually be seen double (so-called dichrotic) excitations and long closed phases (1,10,50). In chest or modal register, the electroglottograms normally show a somewhat rounded closed phase, whereas in falsetto or loft register, the closed phase typically is more pointed, due to the thinning of the vocal folds and to the very short or even insufficient closure of the glottis (22,23,51–53) (Fig. 1). This distinction can also be used to differentiate the falsetto from the operatic head register, even if the difference stands out more clearly in the photoglottogram (51). The ability of professional singers to egalize the transition between different registers without voice breaks or perturbations can be nicely shown in the electroglottogram (52). Finally, by parameterizing their EGG data, Dejonckere and Lebacq (54) have

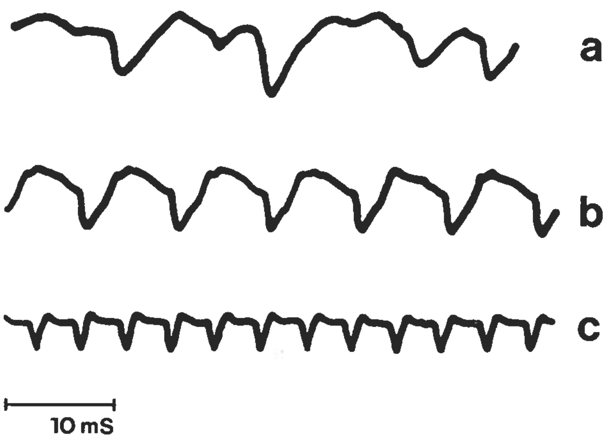

FIG. 1. EEG waveform at different registers. Tracings of electroglottograms from a normal male speaker. Increase of vocal fold contact (glottal closure) is indicated by downward deflection of the curves. (a) Pulse register with dichrotic wave configurations and aperiodicity. (b) Modal register, rounded closed phases. (c) Loft register, sharp closed phases.

shown the possibility of documenting the regular cyclic variations due to vibrato and trillo.

DOCUMENTATION OF VOICE QUALITY BY THE ELECTROGLOTTOGRAM

Ideas about voice quality differ tremendously, not to mention the Babylonian confusion prevailing in the terminology. However, there seems to exist widespread consent as to certain crude dimensions, such as amount of sonority or occurrence of harshness, and breathy (or leaky, hypofunctional) versus tense (or strained, hyperfunctional) mode of phonation. An objective quantification of such dimensions by analysis of the EGG waveform would certainly be helpful in clinical work, but this was reported not to be possible 20 years ago (55,56), and it still does not seem possible (19,25,39,57–61).

There are a number of reasons for the difficulties in correlating the EGG waveform with dimensions of voice quality. One of them is that the EGG primarily informs about events during the closed phase of the glottal period. Measures during the open phase important for the quality of voice, like the vibratory amplitude and the closing speed (62), cannot at all be depicted by EGG.

Based on EGG studies of more than 2,000 clinical phoniatric cases, Sopko (22,23) tried to give a qualitative description of typical EGG waveforms for different voice qualities. A rise of voice intensity typically caused an increase of the vibratory amplitude in the electroglottogram. In hyperfunctional dysphonia with strained quality of the voice, the EGG amplitudes were small and often irregular, with prolonged closed phases (cf. also ref. 63). Typically, for a strained or pressed quality of the voice an increase of the vocal intensity did not cause the EGG amplitudes to become larger. This was usually the case in hypofunctional, loose voice quality, where the EGG waveform was flat and sinosoidal at weak intensity. However, Sopko admits that in the evaluation of functional dysphonias the amplitude criterion cannot be used for comparisons between subjects because the EGG amplitude also depends on thickness of the soft tissues in the neck. To overcome this difficulty, Painter (64) normalized his EGG waveform so that the duration and amplitude became about equal before he classified phonations of a professional singer into 16 different EGG waveform types.

In the quantitative description of the EGG waveform, the relative duration of the closed phase has attracted great interest as it seems to grow when the voice changes from a leaky to a strained or pressed quality (Fig. 2). However, as pointed out by a number of authors (10,39,46,48,65), the peak of maximal vocal fold contact in the electroglottogram does not necessarily indicate complete glottal closure. Childers (45) even found certain breathy voices to have EGG waveforms similar to those found in voices with complete glottal closure. Besides, because of ambiguities in the definition of the moments of closure and opening in the EGG period, the duration of the closed phase may be difficult to measure. In a combined study of photoglottograms and electroglottograms, the present author managed to get acceptable measurements of the closed phase in only 60% of the observed electroglottograms (58).

Apart from discussions of whether the moment of glottal closure takes place at the peak of the EGG waveform (66) or just before (1,27,47), the greatest difficulty in measuring the EGG closed phase is caused by the gradual "peeling open" of the glottis, so that it often becomes impossible to make out any particular point in the continuous slope of the EGG curve as the exact moment of glottal opening and, thereby, the end of the closed phase. A number of authors have described an irregularity or knee in the EGG opening slope and have defined it as the moment of opening (1,19,27,28,65,66), but the knee is not to be found in every electroglottogram. Furthermore, irregularities of the wave slope may also represent artefacts caused by instantaneous ruptures of

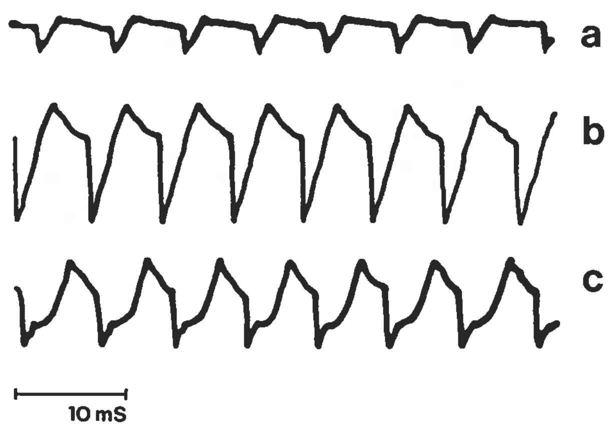

FIG. 2. Increasing EGG closed phase due to changes of the voice quality. Normal male speaker; vocal fold contact downwards. (a) leaky voice. (b) normal voice ("flow" quality). (c) strained or pressed voice.

mucous bridges or by polyps and nodules (1,10, 25,47,67).

With the increasing ease of access to computer capacity, electronic analysis of waveforms has become feasible even in the routine work of a voice clinic. In the beginning, the possibility of a differentiated EGG (DEGG) raised hopes for a more secure identification of the opening and closing moments in the curve (10,11). Closer theoretical and experimental analyses have shown, however, that measurements from the DEGG are not significantly more dependable than those from the straightforward EGG (48).

Computing the quotients between various segments of the waveform and the entire vibratory period has been a common method of creating parameters to be correlated with different qualities of the voice (68). In his monograph on EGG, Lecluse (69) found a closed quotient of 0.32 in chest register and of 0.12 for the falsetto. These data are in accord with the results of a photoglottographic study by the present author, where the open quotient was found to vary between 0.63 and 0.77 for low- and high-pitched voice, respectively, and between 0.83 and 0.70 for weak and strong intensity (7). An increase of the open quotient with rising pitch was found also in EGG data by Reinsch and Gobsch (70). In a study of laryngeal paralysis, Hanson et al. (25) found the open quotient to distinguish pathological phonation from normal, but not to be useful for the separation of different lesions. However, decrease in signal-to-noise ratio often made the EGG signal less useful than photoglottograms. The present author found that EGG measurements of the closed time could differ up to about 15% from photoglottographic measurements (71). This is within the same magnitude as the results of Childers et al. (45), who report that the open (and speed) quotients can be estimated from the EGG or DEGG with an average error of ~18%, with an increased risk of error in loud, high-pitched, and pathological voices. In the same paper, Childers et al. (45) describe an interesting criterion, the closing vocal fold interval, which decreases with increasing intensity of the voice, as was also shown by Sopko (22,23).

Trying to avoid the above-mentioned measuring errors, some authors have mathematically defined some kind of global quotients that can be easily assessed and averaged by computers but where the correlation with the vibratory events in the glottis remains somewhat questionable. One such sort of open quotient is the so-called beta (β) described by Frøkjær-Jensen (72). The glottal cycle is divided by a horizontal line into a negative and a positive part with equal areas, respectively. In the computations, the part of the line corresponding to the open phase of the electroglottogram is divided by the entire period, yielding the β. In clinical applications of this method, the β values tended to be lowered in hyperfunctional, strained voices, whereas they were increased in hypofunctional, loose-quality voices (72–74).

A somewhat different quotient, the surface (S) quotient has been described by Dejonckere (75,76). Here, the glottal cycle is divided by a line at equal distance from the peak and valley, and the S quotient is obtained by dividing the areas of the resulting "closed" part of the cycle with the "open" part. Studies of pathological voices have shown a statistically significant decrease of the S quotient compared to normal voices (75,76).

To conclude this section on the correlation between the quality of the voice and the EGG waveform, attention is drawn to the already mentioned abduction quotient in the GLIMPES program (32–34). Hopefully, this method of matching obtained glottograms with simulated glottal vibrations will make analyses of the EGG waveform more useful in the voice clinic. So far, in the present author's opinion, the EGG waveform is of interest mostly for qualitative illustrations. It should always be interpreted in the light of different simultaneous examinations of the vocal fold vibrations (Fig. 3), such as laryngeal stroboscopy, as it is perfectly possible to obtain normal electroglottograms from a pathological and even cancerous larynx (Fig. 4). It is also possible to get aberrant waveforms from a dys-

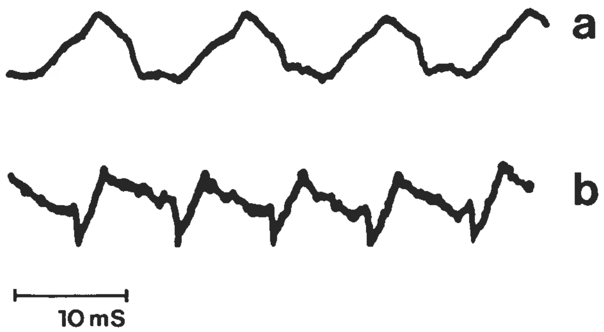

FIG. 3. Aberrant EGG waveforms due to laryngeal pathologies, diagnosed by video-stroboscopy. Vocal fold contact downwards. (a) Increased closed phases due to bilateral Reinke's oedema, female subject aged 65. (b) Shortened closed phases due to paresis of the left recurrent laryngeal nerve, male subject aged 55.

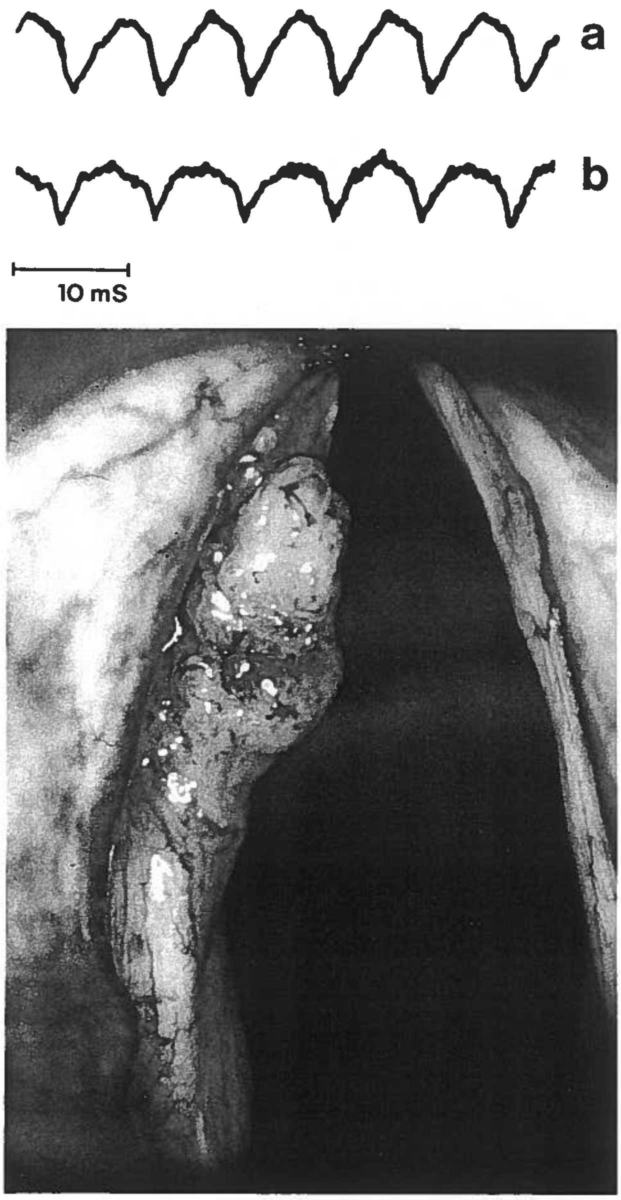

FIG. 4. EGG waveforms showing largely normal configurations in spite of laryngeal carcinoma. Male subject aged 68. Vocal fold contact downwards. (a) before surgery, (b) one week after taking the specimen, and (c) photograph of the microlaryngoscopy.

functioning but healthy vocal organ (cf. also refs. 46 and 57).

INTONATION CONTOUR: SHAPE AND SMOOTHNESS

Even if the analysis of single EGG waveforms still seems questionable, there is general consent that EGG is a very dependable method of measuring the glottal vibratory period. As will be shown in the following sections, such measurements can be used for different purposes, viz., to produce records of intonation contours, to register aperiodicities, and to calculate the mean and range of voice fundamental frequency.

The analysis of intonation contours is a common method in linguistic phonetics, and it may also be useful in teaching the correct "accent" of foreign languages. Also, in its clinical application, this method is used mostly as a teaching device, showing a visual display of the pitch level and intonation pattern of spoken utterances, which can be used as a visual feedback, e.g., in training the speech of deaf subjects.

An intonation curve based on EGG period measurements essentially consists of a string of instantaneous discrete values in contrast with the acoustic fundamental frequency (F_0) of the voice, which ordinarily is an average estimate based on a signal window. As pointed out by Fourcin (8,57,77), this has the advantage that the periodicity aspect of voice quality can also be displayed. Creaky voice and other irregular aspects of vibration show as a broken ragged trace in the intonation contour, whereas more periodic voice quality gives a smooth contour.

Aperiodic glottal vibrations typically occur in the beginning and end of utterances. Jentzsch, Sasama, and Unger (60,78,79) measured the time period between the start of phonation to achievement of steady periodic vibrations. In dysphonic patients, they found this settling time to decrease after voice therapy and to be increased in hypofunctional dysphonia. However, as shown by Kelman (80), the time required to achieve stable periodicity also depends on the vibratory frequency.

HARSH AND CREAKY VOICE

Aperiodic vibrations correspond to a harsh quality of voice. Instead of measuring the settling time until the vibrations are periodic, statistical perturbation measures represent a more direct way to quantify aperiodicities. Rambaud-Pistone (81) made a merely visual evaluation of morphological anomalies in the EGG waveforms, and counted, on average, 63% "pathological" waves in her group of 76 dysphonic patients, whereas the average was 36% in the normal controls (n = 30). A significant variability of EGG waveform data in pathological voices was found also by Hicks et al. (68), whereas the measurements from normal voices showed less dispersion (cf. also ref. 82). Measuring EGG period perturbations (jitter) by autocorrelation linear prediction was shown by Smith (83) to have a 76% discriminating power between pathological and normal voices. The discriminating power dropped to chance level (50%) when the same analysis was performed on sampled speech instead of electroglottograms (83). Furthermore, there has been shown a close relation ($rs = 0.73$) between perturbation analysis of EGG waves and the degree of hoarseness evaluated by auditory perception (37).

As already mentioned, EGG period perturbations can be depicted by the scattering of data points in intonation contours based on electroglottograms. Another method is to plot successive periods against each other in scatter-plots, sometimes called "digrams" (8) or "bihistograms" (16). This display can be extended to a distributional representation in three dimensions, where the occurrence rate or probability is shown by vertical excursions of the lines (2). In either of these displays, an increase of perturbations can be noted in the low frequency range when the voice quality is harsh or creaky.

Analyzing frequency distributions for the occurrence of low frequency vibrations has been reported to be an objective measure of hoarseness, a reduction of such vibrations signaling vocal improvement (59,84,85). By glottal frequency analysis (GFA) (18), a microprocessor-aided measurement of EGG periods, it is possible to quantify the occurrence of low-frequency periods. Recently, Aronsson et al. (86) showed a statistically significant correlation between such measurements and auditory perceptual evaluations of harshness and creakiness by expert listeners.

MEAN VOICE PITCH AND RANGE

Maybe the most obvious way to use measurements of laryngeal vibratory periods in the voice clinic is to get an estimate of vocal pitch. Probably it was Pawlowski and Mitrinowicz-Modrzejewska who in 1970 were the first to systematically use electroglottography to this end (87). However, even if the voice F_0 depends on the vibratory frequency of the vocal folds, measurements of the vibratory frequency do not always correspond well with experts' estimates of the voice pitch, which is a psychoacoustic entity. The reason is that low frequency and aperiodic vibrations seem to be perceived and described as changes of voice quality, not so much influencing the experience of pitch, which seems to be usually based on periodic sequences of phonation (57). As shown in Fig. 5, automatized calculations of the mean vibratory frequency typically give a lower result than estimations of mean pitch based on auditory perception.

For the measurements to represent the pitch correctly, vibrations representing "creaky" phonation first have to be eliminated. This can be accomplished in different ways. Chevrie-Muller (17) suggested discarding all measurements differing by more than one octave from the mean of the original distribution. Fourcin (8) introduced a periodicity criterion for the frequency histogram by incrementing each class of frequencies in the histogram only when two or three successive EGG periods corresponded to the range of that class, so-called histograms of second or third order.

In GFA (18), measurements falling outside the main distribution of vibratory frequencies are discarded once it has dropped under a certain level (cf. Fig. 5). The mean of the resulting "truncated" distribution has been shown to correlate very well ($r = 0.98$) with expert pitch estimations of more or less pathological voices. The GFA measurements differed from the pitch estimations by only 2.5% on average, the higher values pertaining to the estimations. On the other hand, Comot et al. (84) have shown the GFA values of mean frequency on the average to be 3.75% higher than corresponding measurements based on sonagrams.

A dependable method of measuring voice pitch is especially valuable in the voice clinic since it has

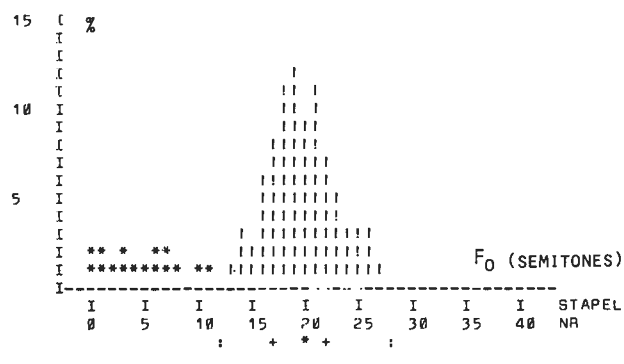

FIG. 5. The stars (*) and exclamation marks (!) show the percentage of occurrences in each class of semitones (from 59 Hz to 750 Hz) based on 1,700 measurements. The mean of this "raw" distribution is 175 Hz. After discarding measurements outside the main distribution (*), when this has dropped under a certain level, the resulting "truncated" distribution (!) shows a mean of 193 Hz. The pitch estimation for this voice by a group of trained listeners was 193.8 Hz.

been shown that correct pitch estimation is more difficult in pathological voices, lacking sonority, and at extreme levels and wide ranges as well as at plurimodal distributions of the speaking fundamental frequency (SFF). Besides, it is more difficult also when the sex of the listener differs from that of the speaker (18).

In a recent study, Krook (88) found that of the reported values of SFF in the literature >20% of the male voices and 70% of the female voices had been analyzed by aid of the GFA. The average SFF values for female voices reported in the literature are a mean of 211 Hz and a range of 5.4 semitones (±1 SD) for the female voices and a mean of 124 Hz and 5.8 semitones for the male voices.

These values cannot be taken as a general physiological norm as they are clearly language dependent. Swedish speakers were, for instance, found to use considerably lower speaking F_0 (188 Hz and 113 Hz, respectively), whereas Comot and Delaporte using the same GFA method found even higher SFF values in their French female speakers, viz., 222 Hz on average (84).

The larynx reacts as an endocrinological target organ during puberty. Pedersen et al. (89–91) showed measurements of the SFF to be useful as quantifiable secondary male sex characteristics, highly dependent of the serum levels of sex hormones. Apart from the dramatic lowering of the male SFF during the mutation, both sexes, but especially females, show an age-dependent, considerably smaller decrease of their SFF up to an age of ~60–70 years. Then there is a certain tendency for the SFF to rise again during senescence (84,87,92).

Besides depending on age and sex, the SFF is also influenced by the type and emotional character of the speech. Comparing the SFF when reading aloud to the pitch of free speech, most authors have reported a slightly raised SFF when reading, a finding that could not be replicated by the present author. Nor did a shift of the emotional character of the read text influence the SFF significantly. On the other hand, changes of the entire communicative situation or of the type of vocal activity were found to have obvious effects on the mean pitch and range of the voice (18). Provided such factors are kept under control by standardized repeatable methods of obtaining the speech sample (like reading aloud the same text), the mean SFF has been found to vary within subjects by only 2% on average between successive observations with a time interval of ~2 months (18).

Such a high degree of reproducibility provides a basis for using measurements of the SFF to monitor changes of laryngeal function in the voice clinic. The most conspicuous clinical findings are the lowering of the SFF in female subjects by either virilizing hormones or smoking, and the raised pitch in males due to puberphonia (mutational falsetto) (14,18,57,84). Voice therapy for phonasthenia (vocal fatigue) or functional dysphonia was found to cause a significant but only small lowering of the mean SFF in female patients as well as a slight widening of the range (18). Examining voice disorders due to organic lesions, the GFA has proven especially useful in the treatment of Reinke's oedema (polypoid degeneration), where the pathologically lowered SFF before and the return to normal levels after surgery and voice therapy could be easily documented (93). This usually also had a motivating effect on the patient to stop smoking and to engage in voice therapy.

Another way to use measurements of the SFF in the voice clinic is in a loading test of the voice, showing the capacity to endure vocal exertion. In patients with functional dysphonia, competing with 70 dB white noise caused a certain rise of the mean SFF both before and after voice therapy. After reading aloud against the noise for 15 and 30 min, there was an additional rise of the mean SFF by @15%, but only before therapy. When the white noise had ended, the mean SFF was still significantly raised before therapy. In the same situation after therapy, there was an immediate recovery of the mean SFF to almost the original level (18,94).

Measurements of the SFF range can be useful not only in the voice clinic but also when investigating patients with neurological and psychiatric disturbances (15,16).

APPLICATIONS OF EGG IN CERTAIN CLINICAL DIAGNOSES

Abberton (57) correctly pointed out that there is no unique relationship between a pathological electroglottogram and a given anatomical or physiological condition. Nevertheless, several authors have underlined the applicability of EGG in a number of special diagnoses.

Both in a computer model and in an in vivo EGG study of vocal fold polyps, Childers et al. (48,67) found that it was possible to differentiate soft, edematous lesions from fibrous ones. Dejonckere et al. (75) found their S quotient to be decreased in cases of vocal nodules. EGG has been successfully used by a number of authors to get an objective demonstration of laryngeal trauma in connection with endotracheal intubation (95–98) and cricothyroidotomy (99), as well as to measure the effect of antiinflammatory drugs to prevent intubation lesions (100). Studying the effect of laryngeal paralysis on the electroglottogram, Pedersen and Boberg (101) did not come up with conclusive results, whereas Hanson et al. (25) found the glottographic open quotient to distinguish paralytic phonation from normal, and combined photo- and EGG together with videostroboscopy to be useful also when investigating other types of neuromuscular voice impairment (26). Altered EGG waveforms and irregular vibrations have been found in spasmodic dysphonia (102) and stuttering (65,103,104). Regarding stuttering, the conclusion of Borden et al. (65) seems of interest; i.e., obvious temporal irregularities in the electroglottogram, such as abnormal voice onset time, repetitions and prolongations, can be explained by improper levels of activity rather than improper timing. EGG-based displays of intonation contours have been used in the analysis of voice disturbances due to hearing impairment (57). Another diagnostic application of EGG has been to map the pseudoglottis in the upper esophagus in esophageal speech, especially after tracheoesophageal shunt operations (1,105–107).

Variations of electrical impedance in the organism obviously can be caused by other phenomena than the vibrations of the larynx. For the phoniatrician and speech pathologist, an interesting application of the EGG is to monitor the movements of the soft palate as a preoperative examination before uvulopalatoplasty for severe snoring (108). Furthermore, recording low-frequency tissue impedance changes in the neck when swallowing is reported to have a potential for quantifying aberrant deglutition, e.g., in parkinsonian or dysphagic patients (109).

APPLICATION OF EGG IN CLINICAL THERAPY AND AS AN AID

As it seems, the EGG has been extensively used for therapy, especially in Great Britain, mostly for dysphonias and, lately, also in connection with cochlear implants.

Abberton (57) reported that displays both of the waveform and of EGG-based intonation contours (VOISCOPE) were useful in a pattern matching "biofeedback" therapy for dysphonias and distorted intonation, improving both perception and production by establishing auditory and kinesthetic awareness of the subject's own vocal patterns (cf. also refs. 14 and 105).

In children with profound hearing loss, a display of EGG-based intonation contours may help to avoid pathological speech patterns, especially high-pitched, monotonous, and creaky voice (110). Profoundly hearing-impaired subjects who are lipreaders may particularly benefit from displays of the F_0 because it is so rich in paralinguistic and prosodic information but entirely invisible (2).

An acoustic presentation of the intonation melody as a sinusoidal signal may be a more efficient hearing aid than an amplification of the entire speech signal (111). The same philosophy forms the basis for using only the F_0 signal for external electrocochlear stimulation (57,77,109,112–114).

However, in these two last mentioned applications, there seems to be a tendency to replace EGG by electronic pitch extraction from the acoustic speech signal (77,110).

CONCLUSIONS

A general conclusion on such a multifaceted topic as the many applications of EGG in the clinic obviously does not come easily, nor can it by any means be scientifically grounded. But here are the author's personal, very subjective evaluations, based on more than 15 years of almost daily use as a clinical method, be it in combination with photoglottography or stroboscopy, or as a tool to measure F_0 characteristics of the voice: (a) The interpretation of measurements of the individual EGG waveform, and parameters based on them, seem questionable, partly because the different phases of the period cannot be securely defined and also because we do not have sufficient knowledge about what they stand for physiologically and acoustically. (b) Valuable additional information may be obtained by monitoring the vocal fold vibrations, when the EGG is used in combination with other methods of investigating phonation such as videostroboscopy, photoglottography, and inverse filtered flow glottography. (c) Due to its paucity of overtones, the EGG signal is especially well suited for measurement of the glottal vibratory period. Such measurements are extremely useful in clinical work both for periodicity analysis, as a basis for recording intonation contours, and to establish the characteristics of the F_0 of the voice.

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