WHAT DOES THE LARYNGOGRAPH MEASURE?

D. Miller(1), S. Nevard(2), R. Brun(2) and A.J. Fourcin(2)

(1) Laryngograph Ltd (2) University College London

ABSTRACT

A review of the literature reveals, in the case where the electrodes are placed on the wings of the thyroid cartilage, that this question has been investigated and broadly answered on several levels: electrically, physiologically and acoustically. We note results obtained from the Laryngograph at a new site: the nose. We focus on the boundaries of the Laryngographs use in order to highlight areas of possible improvement to the Laryngograph. We try to focus on questions of acoustic/phonetic (and to a lesser extent clinical) relevance.

1. ELECTRICALLY

The Laryngograph was originally developed as a means to accurately and non-invasively measure and display, in real time, the fundamental frequency of voicing, the acoustic correlate of intonation. Developed on the basis of an impedance measuring technique pioneered by Fabre its rather different electrical characteristics were shaped by this application.

The Laryngograph is an admittance variation sensor. It is self adjusting and is capable of displaying very small variations of admittance at frequencies between 10Hz to 20kHz. The phase response is linear from approximately 50Hz to 20kHz. Low frequency phase distortion can be corrected in subsequent processing. Versions are available with a phase and frequency response down to d.c.. Admittance variations can be caused by resistive and reactive effects and the relative importance of each depends on what is between the electrodes e.g. simply holding the electrodes in air and shaking them will give a "waveform" but here the very high resistive path between the electrodes will ensure the capacitative effect dominates; when the electrodes have a relatively low conductive path between them (such as on the neck) the resistive component will dominate. The current laryngograph is not designed to distinguish resistive and capacitative effects, nor is it able to make absolute measurements.

2. PHYSIOLOGICALLY

When applied to the body our question can only be answered in relation to a knowledge of what is physically, physiologically and where applicable, phonetically possible between the electrodes at a specific site. Some possible artifacts which have been suggested are: tissue contact, vibration, tissue compression, muscular contraction, electrode/skin contact variation.

2.1 PLACEMENT EITHER SIDE OF THE LARYNX AT THE LEVEL OF THE VOCAL FOLDS.

2.1.1 Direct evidence that vocal fold contact variation modulates the electrical conductance across the larynx was found in a study of the transglottal impedance prior to the development of the Laryngograph: there was greater conductance across the larynx in a static closed glottal state than when the folds were apart (contrary to Fabres observations). The percentage change was increased when a three terminal (guard ring) electrode system was used to reduce the effect of skin conduction.

The most conclusive evidence that the Laryngograph measures vocal fold contact area variation is provided in an experiment by Gilbert [6]. A 5mm wide insulating polyethylene strip was slowly withdrawn from between the vibrating vocal folds during phonation; the simultaneously recorded Laryngograph output waveform (Lx) increased as the area of obstruction to vocal fold contact decreased, the speech waveform remained relatively constant throughout. This experiment effectively eliminates all other variables except those which relate to the nature and area of vocal fold contact variation, for a steady state vowel in normal conditions, it falsifies Smith's [10] claim that tissue compression consequent on the acoustic pressure wave and the relative tenseness of the contracted musculature are the sole causes of Lx; these factors obviously can produce waveforms but all explanations must be site specific.

2.1.2. Correlations between the laryngographic waveform and direct observation of the detail of vocal fold contact cycle have been made.

Viewing down on the vocal folds: Fourcin, Donovan and Roach using a cine camera and stroboscope synchronised to the Lx waveform; Childers [2] using synchronised ultra high speed laryngeal films and Laryngograph waveforms.

Viewing the vocal folds from the front Noscoe et. al.[7] used X-flash imaging with a specially developed high voltage x-ray technique.

The results of these analyses broadly confirm the schematisation made by Fourcin [5] and, in a slightly different way, by Rothenberg [8]. Childers [2] cautions that the model's features tend to be inferred from research observations rather than from a compilation of statistical data extracted from experimental measurements, but their own work reaches the same broad conclusion.

Computer simulations of the vocal fold area contact (VFCA) variation have produced waveforms similar to Lx, and enable the effect of various features of vocal fold action to be modelled independently Titze [11], Childers [2].

2.2. ELECTRODES ACROSS THE BRIDGE OF THE NOSE

If the electrodes are placed either side of the bridge of the nose a larynx-periodic waveform can be observed which varies in amplitude during phonation according to the degree of nasalisation [1]. We currently have no direct evidence of the physiological cause of this waveform. It would be reasonable to suggest the amplitude is modulated by the opening of the velum, and that the coupling of the nasal cavities causes them to respond and change their geometry.

3. ACOUSTIC CORRELATIONS OF LX

Correlations have been made with the inverse filtered flow waveform by Fourcin and by Rothenberg. These confirm an approximately antiphase relationship between Lx and the glottal flow waveform. Acoustically the abrupt cessation of the airflow is of primary significance and this is clearly correlated with the rapid closure of the vocal folds evident in the Lx waveform.

4. BOUNDARIES OF LX APPLICATION

Vocal fold vibration is a complex three dimensional wavelike motion in response to which the laryngograph can only give an integrated two dimensional representation of the varying effects of the nature and area of vocal fold contact. This sets the limits to any physiological and acoustic interpretation of the Lx waveform although for some analyses its simplicity is a positive advantage. In addition the vocal fold element has to be extracted from other gross physiological movements such as of the larynx as a whole.

For its original purpose of providing an accurate means to measure and display the fundamental frequency (Fx) of voiced speech on a period by period basis the Laryngograph has become a reference. The limitations of Lx as the basis for a measure of Fx and voicing appear in cases where an oscillatory volume velocity flow is observable but Lx is not. This can occur in laryngeal co-articulation (e.g. [ehe]) where the vocal folds adduct to such an extent that they no longer actually contact although they still produce an oscillatory airstream.

It is generally agreed that closure is one of the most clearly defined events in the Lx waveform [5][8], although it must be emphasised that an Lx peak does not necessarily denote full closure along the length of the vocal folds. A "chink" may remain in breathy voice.
There is interest in the measurement of vocal fold closed phase (or some related ratio to open phase, or related duty cycle): for closed phase formant analysis; in the study of the structured variability of voiced excitation (for analysis and synthesis of more natural speech [4]; in the related study of relative vocal fold abduction [9]; in the study of voice quality and pathology (Fourcin 1990); and in the study of vocal efficiency in trained singers (Howard.D 1990).

The problem here is the definition of vocal fold opening. By its nature this is a less well defined event: typically the vocal folds peel apart from the bottom up and then split along the upper edge. Correlations have been made with the "knee" which is sometimes apparent in the opening edge of the waveform and the breaking of the mucus bridge on the upper edge of the folds and with the onset of airflow. This is the justification for one of the practical measures that have been applied to the measurement of opening [4]; (1) the maximum rate of change on the opening edge. Other measures chosen are: (2) when the voltage on the opening edge reaches the same level as existed when the closure point was chosen; (3) the point where the opening edge falls to some fixed percentage of the peak voltage or (4) some average level [9]. Given the indeterminacy of this feature, decisions are necessarily pragmatic. Generally a percentage fall from a peak value is more reliable on the opening edge than the differential.

In pathology all problems are likely to be compounded. Fourcin [5] suggests five key features of the Lx waveform, useful when using Lx as an analytical tool in the physical interpretation of aspects of voice: Uniformity of peaks = uniform output; Sharply defined Lx contact = good excitation of vocal tract; long closure duration = well defined formants; regular, sharply defined contact periodicity = well defined pitch; progressive change in sharply defined period lengths = smoothly changing pitch.

Childers [2] appears to be investigating more of a "template" approach. The use of computer simulation is obviously attractive here. Colton and Conture [3] warn of the dangers of interpreting pathological data on the basis of a model of normal vocal fold vibration. All waveform interpretation must be based on a knowledge of the phonetically structured variability which is a property of normal speech.

5. CURRENT WORK

Our original intention, prompted by the nasal results and a desire to quantify effects at the larynx, was to review what the Laryngograph was measuring by making some comparisons of its sensitivity to factors which can affect the impedance between the electrodes at various sites on the body. This could be seen as a quantitative version of Smiths experiments. It is evident that the following factors need to be taken into account:

1. All explanations must be site specific.
2. Gilberts experiment and the X-flash observations show the overwhelming effect of vocal fold contact.
3. Further consideration of the problems of using signals in the existing Laryngograph circuit to measure absolute or even relative impedance would make intersite comparisons difficult.

We have therefore decided to concentrate on the neck and nose.

At the neck the main limitation to Laryngographic measurement is that in some cases the signal to noise ratio is poor. We are conducting a series of measurements relating the output of the Laryngograph on the neck to absolute impedance measures on a range of subjects in order to determine the correlations between larynx size, the effects of varying amounts of subcutaneous fat and the effects of different current levels.

Measures on the nose can similarly be made to clarify the result here.

Results of these and related studies will be presented at the conference.

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