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Published in:
Folia phoniat

1974

Folia phoniat. *26:* 138–149 (1974)

A Photoglottographical Study of the Female Vocal Folds during Phonation

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Introduction

The photoglottographical method for studying the vibratory movements of the vocal folds was introduced in 1959 by SONESSON [1960]. Briefly, the method is as follows (fig. 1): light from a lamp placed against the neck just below the larynx suffuses the subglottic space and transilluminates the glottis. A curved perspex rod is introduced into the mouth and throat. The rod transmits the light from the glottis to a multiplier phototube connected to a cathode-ray oscilloscope. During vibration of the vocal folds, the glottis is alternately opened and closed, the passage of light through the glottis being interrupted intermittently. In this way, a curve corresponding to the vibrations of the vocal folds is obtained on the oscilloscope screen.

The vibratory pattern of the male vocal folds has been studied in detail by LUCHSINGER [1954], MOORE and VON LEDEN [1958], TIMCKE *et al.* [1958], SONESSON [1960] and others. To the knowledge of the authors of this paper no systematic studies of the vibratory pattern of the vocal folds in the female have as yet been published. Because of the higher fundamental frequency of the female voice and its different quality compared to the male voice a closer study of the vibratory pattern of the female vocal folds as recorded by the photoglottographical method was thought to be of interest.

In this study the normal vibratory pattern at different pitch and at different loudness of the voice was recorded and analyzed. Special attention was focused on the vibratory movements at the beginning and ending of phonation.

Received: December 31, 1971; accepted: January 14, 1972.

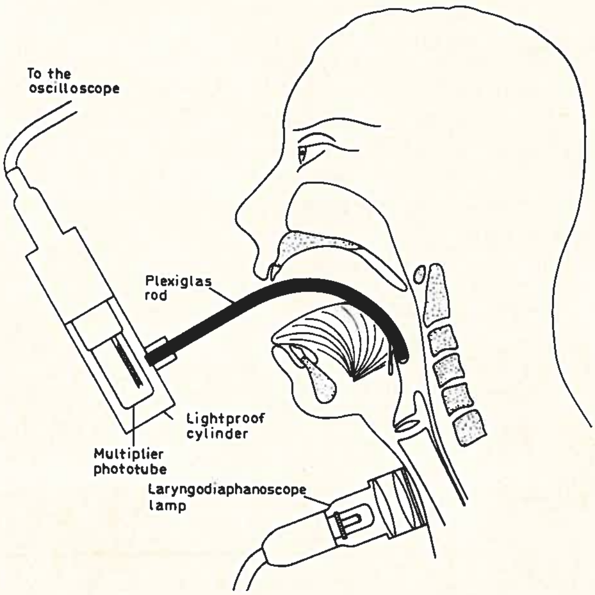


Fig. 1. The photoglottographical method. Light from a laryngodiaphanoscope lamp is shining through the tissues of the neck illuminating the subglottic space. In its passage through the glottis the lightbeam is interrupted intermittently corresponding to the movements of the vocal folds, and is then by a perspex rod transmitted to a multiplier phototube connected to a cathode-ray oscilloscope. On the oscilloscope screen a curve, the glottogram, is obtained corresponding to the vibrations of the vocal folds.

Method

Twenty female subjects, aged 20–30, with normal voice function and without any clinical vocal disturbances were included in the study.

The photoglottograph described by SONESSON [1960] was used for recording the vibratory movements of the vocal folds. In front of the oscilloscope screen was mounted a film camera (Paillard, 16 mm) by means of which the glottographic curves could be registered during several seconds. The speed of the camera was 8 frames/sec.

The camera was started by a magnetic releaser. Each time a frame was forwarded in the camera an impulse from its synchronizing contact triggered the oscilloscope to start the trace on the cathod-ray screen. The camera exposure time was $^1/_{20}$ sec and the writing speed of the oscilloscope sweep was 2 mm/msec. This means that about 15 vibratory cycles could be recorded on each frame, the number of cycles varying with fundamental frequency. The deflexion sensitivity of the oscilloscope beam was 20 mV/cm.

A dynamic microphone was connected to a tape recorder (Telefunken Type M24), whose starting was synchronized with the starting of the film camera. By means of the tape recordings, the relative voice intensity could be determined. For this purpose an intensity meter (type KTH-T-I-112)[1] was used.

For convenient measuring the film was enlarged 2½ times, and from the measurements obtained the cycle duration and the different quotients were calculated. The quotients were obtained from the measurements of the open period (O wave), the closure period (C interval) and – within the open period – the opening phase (CO phase), and the closing phase (OC phase), respectively (fig. 2).

The following quotients were calculated:

$$\text{the open quotient (Oq)} = \frac{\text{open period (O)}}{\text{vibratory cycle (O+C)}};$$

$$\text{the speed quotient (Sq)} = \frac{\text{opening phase (CO)}}{\text{closing phase (OC)}}.$$

In the present study, a third quotient was introduced, called the *rate quotient*

$$\text{(Rq)} = \frac{\text{closure period (C)} + \text{opening phase (CO)}}{\text{closing phase (OC)}}.$$

The experiments were planned as follows:

The starting and the ceasing of the vibratory movements were recorded by switching on the glottograph a few seconds before the subjects began to vocalize a sustained tone (the vowel [ae]) with the pitch and loudness of the voice corresponding to normal speech level. The recording was stopped a few seconds after the subjects had finished to voice.

Variation in tone intensity. The subjects were instructed to sound the vowel [ae], first

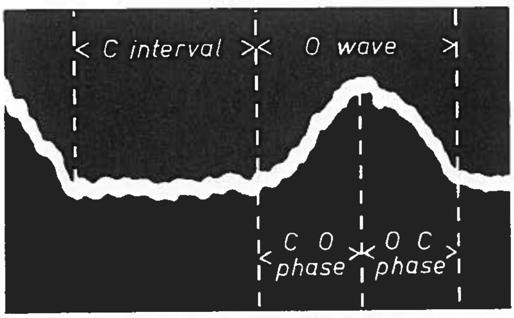


Fig. 2. The normal glottogram.

[1] We are grateful to Prof. B. MALMBERG, Head of the Department of Phonetics, University of Lund, for putting the equipment at our disposal.

in fortissimo, then diminuendo. They were asked to hold the frequency constant, corresponding to that of normal speech.

Variation in tone frequency. The subjects were instructed to phonate the vowel [ae] in glissando, starting at low tone frequency, trying to keep the tone intensity unchanged.

Results

General Characteristics of the Glottograms

The mean values of the measurements made on the glottograms are given in tables I and II.

At the loudness and pitch level corresponding to that of normal speech (about 220 Hz), the glottograms consisted of regular curves with alternating O waves and C intervals (fig. 2). For rather long periods of time the cycles showed a remarkably constant regularity. In some cases, however, the C interval dropped out and the O wave was directly followed by the next O wave, the periodicity of the cycles being maintained. As a rule, the transition from the OC phase to the C interval was abrupt, whereas the transition from the C interval to the CO phase tended to be less abrupt.

The O waves could be either sharp or smooth in form. In addition, the curves usually sloped to the right or to the left, depending on the unequal length of the CO and OC phases, respectively.

Table I. The mean length of time for the different parts of the normal vibratory cycle of the female vocal folds

Vibratory cycle	4.6 msec[1]
O wave	3.0 msec
CO phase	1.6 msec
OC phase	1.4 msec
C interval	1.6 msec

[1] Corresponding to 220 Hz.

Table II. The quotients calculated from the normal vibratory cycle of the female vocal folds

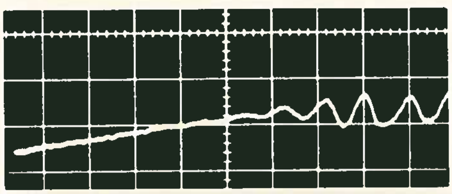
Open quotient	0.65
Speed quotient	1.14
Rate quotient	2.3

At normal speech level (220 Hz), the length of the vibratory cycle averaged 4.6 msec. The open quotient averaged 0.65, which means that the glottis was closed during one third of the vibratory cycle. The speed quotient averaged 1.14, which means that during phonation, the vocal folds closed somewhat faster than they opened.

The rate quotient averaged 2.3 implying that the closing time (OC phase) was about one third of the vibratory cycle.

Start of Vibration

At start of phonation the glottographic curve usually showed an OC phase initially, which means that the vocal folds started their vibration with a closing movement. Generally, the length of the cycles was constant from the very first beginning of glottogram. Thus, a steady pitch was achieved from the start of phonation. The amplitude, however, was not constant but increased successively and did not reach steady level until about 7 cycles had elapsed. (fig. 3). Sometimes, complete approximation of the vocal folds took place *before* the vibratory movements had started, which, in the tape recording, could be heard as a glottal stop (fig. 4). In such cases, the glottographic trace was horizontal at the start of phonation, indicating that the vocal folds started their movement from the closed position.



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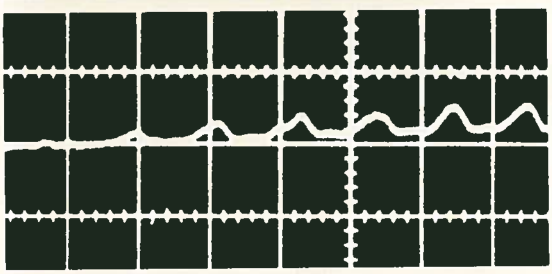

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Fig. 3. Start of phonation. Normal pattern.
Fig. 4. Start of phonation with initial glottal stop.

Ceasing of Vibration

At the end of phonation, the C intervals in the glottograms usually shortened gradually and finally disappeared, while the curves showed a decreasing amplitude (fig. 5). The length of the glottographic cycles was generally unchanged during the whole recording, although in some cases there was a tendency for the final cycles to be lengthened. The last cycle contained a complete O wave, indicating that the vibration ended with a final approaching movement of the vocal folds. The changes in the glottogram connected with the ceasing of vibration occurred in the last 6–10 cycles. At the end of phonation the O waves sometimes tended to slope to the left, indicating that the closing movement of the vocal folds was relatively slower than the opening movement.

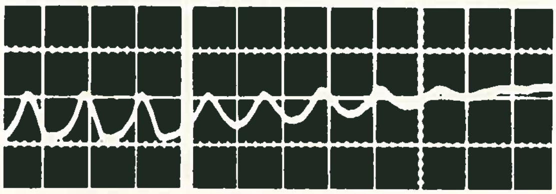

Fig. 5. End of phonation. The figure is composed of two glottograms taken at a time difference of $^1/_8$ sec.

Variation of Pitch (table III)

At the pitch corresponding to 175 Hz, the shape of the glottograms was similar to those recorded at 225 Hz. The open quotient, however, tended to be smaller, the average amounting to 0.50. In glottograms recorded at high pitch (corresponding to 500 Hz) no C intervals could be identified and, therefore, the recording resembled a sinus curve. At high pitch the amplitude was smaller than that observed at low pitch (fig. 6).

Table III. The quotients at changes in pitch

Pitch	Open quotient	Speed quotient	Rate quotient
Low	0.63	1.1	2.3
High	0.77	1.1	1.7

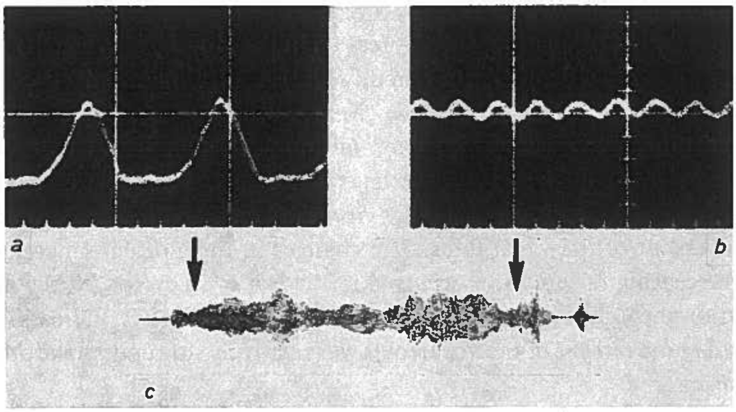

Fig. 6. Rising pitch. *a* Glottograms at low pitch; *b* glottograms at high pitch; *c* intensity of tone. From the glottograms it appears that the vibratory frequency is increased about three times, whereas the intensity of tone is kept almost unchanged, as can be seen in the intensity recording *c*.

At rising pitch, the C intervals were relatively more shortened than the O waves. Thus, the open quotient increased with rising pitch and this relationship could be verified statistically. The disappearance of the C intervals occurred at a pitch level, being different for different subjects. For instance, in some cases the C interval disappeared already at a pitch corresponding to 225 Hz, whereas in other cases it did not disappear until at 330 Hz. At repeated recordings, from one and the same subject the frequency at which the C interval disappeared varied from time to time.

At increasing pitch the CO phase and OC phase were both shortened to the same extent, the speed quotient remaining unchanged. At rising pitch, the rate quotient was decreased, a phenomenon which was statistically highly significant.

Variation of Tone Intensity (table IV)

At decrease of the tone intensity, the curve amplitudes in the glottograms were reduced and the O waves tended to slope to the left.

The C intervals observed in the glottograms at high tone intensity, were shortened or disappeared completely at weak tone intensity and the O waves changed from a peaked to a more rounded shape (fig. 7). Lowering tone in-

Table IV. The quotients at changes in tone intensity

Intensity of tone	Open quotient	Speed quotient	Rate quotient
Weak	0.83	1.1	1.5
Strong	0.70	1.1	2.1

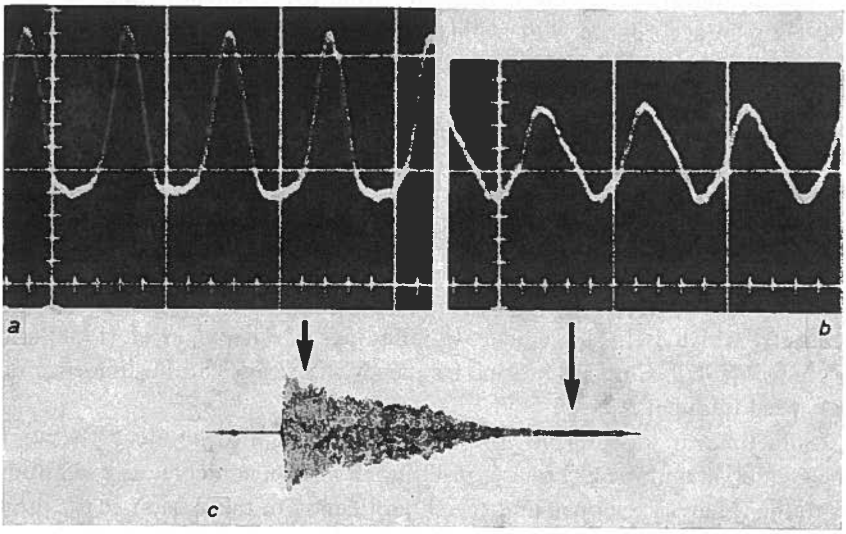

Fig. 7. Lowering of tone intensity. *a* Glottograms at high intensity; *b* glottograms at low intensity; *c* intensity of tone. At low intensity the length of the OC phase is relatively increased, signifying a slower closing movement of the glottal folds in relation to the opening movement (CO phase). During lowering of tone intensity the C intervals disappear.

tensity usually resulted in an increase of the open quotient, a relationship which was of probable statistical significance. With increasing intensity of tone the O waves sometimes sloped to the right which resulted in an increase of the speed quotient (fig. 7). Furthermore, with increasing tone intensity there was a statistically verified increase of the rate quotient.

Discussion

The open quotient (on average 0.65) found in the present study at normal female speech level, was in accordance with the figure, obtained from male subjects at normal speech level [SONESSON, 1960].

In the majority of the subjects the open quotient increased with rising pitch. This is in agreement with the findings of LUCHSINGER and PFISTER [1959] and SONESSON [1960]. At 225 Hz more than 60% of the subjects showed an incomplete closure of the glottis (Oq = 1.0), but in the rest this did not happen until the frequency reached 300 Hz.

The disappearance of the C interval within the frequency range of 200–300 Hz is in accordance with results from similar studies on male subjects [SONESSON, 1960]. As the female vocal folds are relatively delicate they may grow even thinner and vibrate edge to edge already at moderate extension [HOLLIEN, 1962]. This results in but momentary closing of the glottis, or no closure at all, a pattern of vibration described by LUCHSINGER [1949] in his study of the falsetto voice. For this reason, at rising pitch the disappearance of the C interval may occur relatively earlier in the female glottogram than in recordings obtained from male subjects.

The speed quotient averaged 1.14, usually increasing with rising tone intensity, which is in agreement with findings of TIMCKE *et al.* [1958] and SONESSON [1960]. Changes in tone frequency, however, had no influence on the speed quotient.

Sometimes it was difficult to establish a well-defined boundary between the C interval and the CO phase, resulting in a lessened degree of exactitude as to the values of the open and speed quotients. For this reason, in the present study, a new quotient was introduced – the rate quotient – being based on easily distinguishable measuring points in the glottogram. The two points chosen were the summit of the O wave and the point marking the boundary between the OC phase and the C interval, respectively. Furthermore, as the latter point represents the instant of approximation of the vocal folds, i.e. the closing moment of the glottis, this point may be of special interest from the aerodynamic standpoint, as the excitation of the *sound waves* is presumed to occur at the closing moment of the vibratory cycle [LINDQVIST, 1963].

It is known that during the closure period there is a vertical movement in the vocal folds propagating from the lower edges upwards [FARNSWORTH, 1940; SMITH, 1954; SONESSON, 1960]. This means that the opening movement starts already during the closure interval and is not completed until the glottis is maximally opened. In this way, the rate quotient gives the relationship between the time for the *entire* opening movement, which starts immediately after the closure of the glottis and the time for the closing movement, represented by the OC phase in the glottogram.

In the present study the rate quotient was 2.3 at normal pitch. At rising pitch, the rate quotient was reduced, due to a shortening of the vibratory cycle, being most pronounced for the C interval. At high-tone intensity instead the rate quotient was increased, the main reason for this being an increase in the length of the C interval.

The onset of vibration was characterized by a closing movement of the vocal folds. This is in agreement with the findings of MOORE and VON LEDEN [1958]. The sudden fall of the air pressure taking place in the glottis according to the law of Bernoulli is the most reasonable cause for this initial closing movement. At start of phonation the vibrations became regular after 6–10 vibratory cycles, corresponding to about 0.05 sec. This figure agrees with that given by MOORE and von LEDEN [1958].

At the end of phonation there was a successive diminishing of the speed quotient, indicating a relatively slower closing than opening movement of the vocal folds. This observation confirms similar findings of MOORE and VON LEDEN [1958]. However, a fall in vibratory frequency at the end of phonation as reported by these authors could be seen in only few cases. In most of the glottograms, the length of the vibratory cycles remained unchanged, and only the amplitudes became reduced successively in the very last cycles.

During continuous phonation, the consecutive vibratory cycles in the glottogram were found to be of identical appearance, which means, that the vocal folds were vibrating very regularly. This agrees with results of SONESSON [1960], MOORE *et al.* [1958], and WENDAHL [1963].

The photoglottographic method made it possible to record in detail the different phases of consecutive vibratory cycles. Further, our method was very timesaving as the glottograms could be obtained directly on the oscilloscope screen without laborious frame-by-frame measuring as in high-speed filming.

In functional voice disturbances and other kinds of laryngeal dysfunction, occasional pathological cycles may alternate with normal vibratory cycles, as described by DUNKER and SCHLOSSHAUER [1961], VON LEDEN *et al.* [1961], SONESSON [1962], and WENDAHL *et al.* [1963]. For the purpose of picking up isolated pathological vibratory cycles the continuous recording during relatively long periods of phonation by means of photoglottography could be a very useful method.

Summary

By the photoglottographical method the vibratory pattern of the female vocal folds was studied in twenty healthy young females during normal phonation. The *open* and *speed quotients* were calculated from the glottograms. A new quotient, called the *rate quotient*, was introduced.

During phonation at the pitch corresponding to 220 Hz and medium intensity of tone in female subjects the open quotient was in the mean 0.65 and the speed quotient 1.14. The *rate quotient*, i.e. the time ratio for the entire opening movement and the closing movement of the vocal folds, was in the mean 2.3. *The open quotient* was increased at increasing pitch and at decreasing tone intensity. *The speed quotient* tended to increase at increasing intensity of tone, this tendency, however, not being statistically significant. The speed quotient was not influenced by changes in the pitch. *The rate quotient* was increased at increasing intensity of tone and at decreasing pitch (cf open quotient). The *start of vibration* was characterized by an initial closing movement of the vocal folds. The vibratory pattern became regular after 6–10 cycles. At the *end of vibration* there was a successive diminution and disappearance of the closure intervals in the vibratory cycles, the length of which remained unchanged throughout the final vibrations. At the end of phonation the speed quotient tended to decrease.

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