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Photo- and Electroglottographical Recording of the Laryngeal Vibratory Pattern during Different Registers

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Voice physiologists and speech pathologists usually recognize two kinds of registers, i.e. the chest register and the falsetto. Whether this is the most suitable terminology and whether the low-pitched vocal fry and the high-pitched laryngeal whistle or different other kinds of voice quality should be included into the conceptual scheme of physiological registers still remains open to discussion [*Hollien,* 1974 for an extensive survey]. Many teachers of singing also seem to use the concept of head register, but since the 17th century there are at least two different traditions, one teaching three registers, chest, head *and* falsetto, and the other recognizing only two, chest, head *or* falsetto [*Large* et al., 1972]. According to *Luchsinger* [1949], the male head voice can be divided into three different qualities: (1) the natural falsetto voice (German: Fistelstimme), (2) the artistic falsetto or false soprano (German: Falsett) and (3) the loud full-tone head voice of trained opera singers or operatic head register (German: Vollton der Kopfstimme).

Especially at comparable pitch, as in the natural falsetto compared to the operatic head register, the differences in voice quality between registers might not always be easy to identify perceptually [*McGlone and Brown,* 1969], and the need for objective criteria for the identification of voice registers is widely recognized. The purpose of the present paper is to illustrate, how register-dependent changes in the laryngeal vibratory pattern can be objectively recorded by means of combined photo- and electroglottographical registration.

Procedure

The method for combined photo- and electroglottographical registration of glottal vibrations during phonation has been described in some detail elsewhere [*Kitzing,* 1977]. Briefly, in photoglottography continuous light shining through the neck tissues into the subglottal space is recorded with a light-sensitive transistor placed in the pharynx above the glottis by means of a thin catheter via the nose. Variations in glottal area during phonation will modulate the light through the glottis which can be recorded as a curve, the photoglottogram. In electrical glottography the variations in impedance to a weak high-frequency alternating electrical current through the neck tissues are recorded. Even if the changes in impedance in relation to the vibrations of the vocal folds are not completely understood, there is good evidence that at least the vibratory period and the moment of glottal closure can be unequivocally registered by the method [*Le Cluse,* 1977; *Fourcin,* 1975].

The instruments used were the Photoglottograph LG 900 and the Electroglottograph EG 830 from F.-J. Electronics AS, Copenhagen. The signals from the glottographs as well as that from a high-quality microphone were stored on an FM tape recorder (Lyrec TR 86). The glottographic and microphone curves were produced by means of an ink recorder (Mingograph 800) playing back the tape at 1/64 of the recording speed to enhance the temporal resolution of the equipment.

Registrations were made from 2 middle-aged male subjects without known pathology of the larynx, one of them with a normal but untrained voice, the other one being an experienced professional tenor singer of high reputation. The nonsinger produced tones of continuously rising and falling pitch, thereby passing from chest register to falsetto and back to chest register. The tenor singer was told to sing a musical scale with very loose attacks (soft start of phonation) sounding almost as a continuous phonation, and to equalize his registers to an operatic head register at the top of his range. Told to sing the same scale in a 'naive' way without equalizing the registers he did not manage to change his voice quality very much. Therefore, the operatic head register could not be compared to the falsetto in the same subject.

To control the influence of the catheter in the nasal airways on the tenor's voice quality, a recording was made without the catheter in place. Compared to the earlier registrations, the electroglottographic recordings were practically identical (not shown) and there was no conspicuous alteration of the voice quality. The vowel [e:] was used for all vocalizations, as this affords the best articulatory condition for photoglottographic recordings.

Table I. Glottographic parameters at different registers

	Pitch	F_o, Hz	OQ	SQ
Untrained singer				
Chest register (C)	d	141	0.61	1.00
Falsetto (F)	c′	260	1.00	0.79
Voice break C/F	g/d′	191/302	0.74/0.84	1.15/0.55
Voice break F/C	h/d	241/148	1.00/0.51	0.87/0.91
Trained tenor				
Chest register (C)	f	179	0.62	0.83
'Equalized' register	c′	258	0.60	1.14
Op. head register (H_1)	e′	328	0.49	1.50
Op. head register (H_2)	g′	392	0.52	1.67

F_o = Fundamental frequency; OQ = open quotient; SQ = speed quotient; Op. = operatic.

Results and Discussion

Typical registrations are shown in a series of figures (fig. 1–8). In each graph the curves represent from top to bottom (1) the time mark (1/64 s), (2) the photoglottogram, (3) the electroglottogram, and (4) the microphone signal. In both kinds of glottograms, the peaks of the curves indicate an opening of the glottis.

Figure 1 is a typical registration of the untrained singer's chest register. In the photoglottogram there is a distinct closed segment, which compares well with the time of decreased impedance in the electroglottogram and has a duration of about 40% of the entire vibratory period (open quotient, i.e. the open time divided by the entire period, = 0.61, table I). The time from onset of opening to maximal opening, or the opening time of the glottis, is about the same as the closing time (speed quotient, i.e. the opening time divided by the closing time, = 1.00). The configuration of the microphone signal with two distinct peaks in each period indicates the existence of several harmonics.

Compared to the chest register, the natural falsetto (fig. 2) is acoustically characterized by a higher pitch and a scarcity of higher partials, as can be gathered from the sinusoidal configuration of the microphone signal. In the electroglottogram, there is a short decrease of impedance during each period,

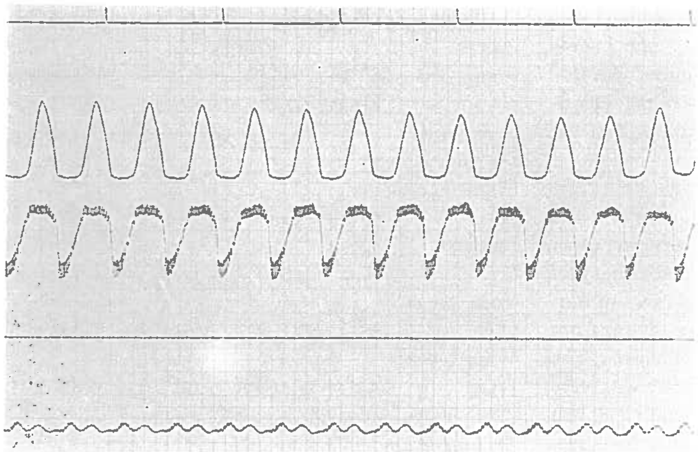

Fig. 1. Untrained singer, chest register. From top to bottom: Time mark (1/64 s), photoglottogram electroglottogram, microphone signal. Upward direction in the glottograms indicates opening of the glottis.

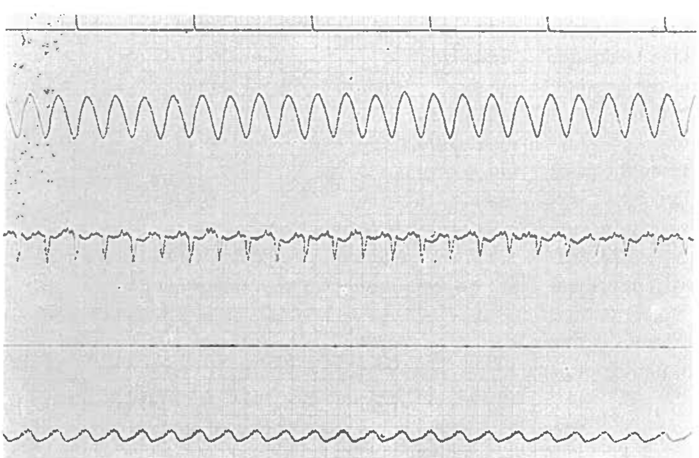

Fig. 2. Untrained singer. Natural falsetto register.

probably representing a small momentary contact between the vocal folds. On the other hand, in this registration there appears no closed segment in the photoglottogram (open quotient = 1.00). The closing time of the glottis is somewhat longer than its opening time (speed quotient < 1.00), probably because of a reduction in the muscle tone of the laryngeal adductors, which compares with the finding of lowered adductor EMG activity in the 'light' register reported by *Hirano* et al. [1970].

Figure 3 is a typical registration of a voice break from chest register to natural falsetto (C/F break). Immediately before the break, the duration of the closed period is somewhat reduced, which might be interpreted as an anticipation of the reduced closure in falsetto, even if in this registration the closed period does not disappear entirely in the falsetto as in figure 2. There is, moreover, a shortening of the closing time resulting in an increased speed quotient before the voice break, but an instantaneous change to an

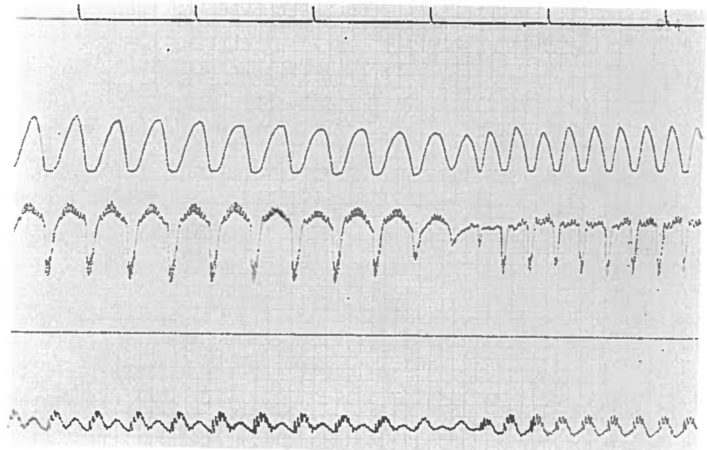

Fig. 3. Untrained singer. Voice break from chest to falsetto register.

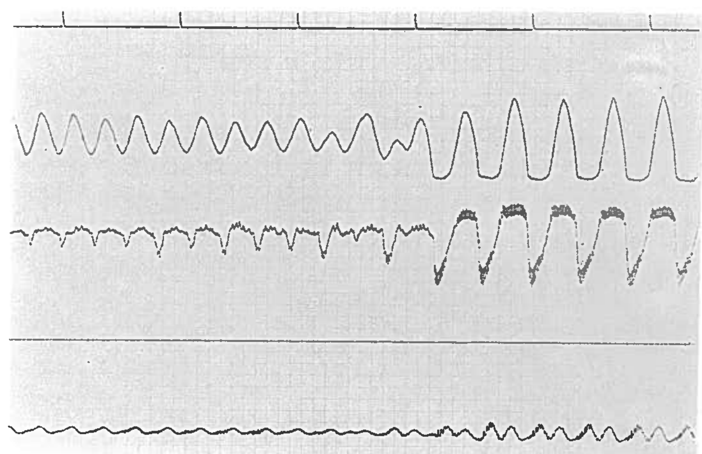

Fig. 4. Untrained singer. Voice break from falsetto to chest register.

increased closing time and thereby a reduced speed quotient after the break.

In addition to the reduction of the period time and of the vibratory amplitude, the increase of the speed quotient shortly before the C/F voice break and its instantaneous decrease after the break seem to be the most characteristic features in the photoglottogram of the falsetto. They might be understood as signs of increasing adductor muscular tension at rising pitch in the chest register and an instantaneous reduction of such tension at the time of the break to the falsetto. This reduction of tension in the falsetto is in accordance with the above-mentioned EMG findings [*Hirano* et al., 1970] and also with the subjective sensation in the throat at the break reported by several singers [*Luchsinger,* 1949].

In the voice break from natural falsetto to chest register (F/C break, fig. 4) no conspicuous change of the speed quotient is found. On

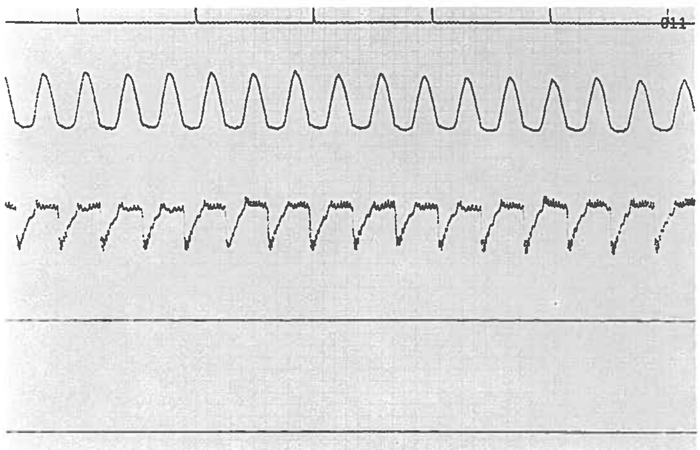

Fig. 5. Trained singer. Chest register.

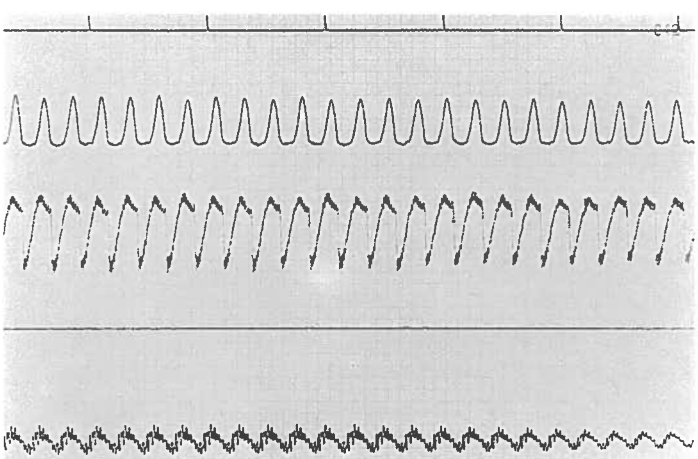

Fig. 6. Trained singer. 'Equalized' register.

the other hand, the occurrence of long closed segments in the periods immediately after the break is reflected in a marked reduction of the open quotient. The increased closed segments most probably are accomplished by the mucosal ridge on the vertical edge of the vocal folds being propagated in an upward direction by the aerodynamic forces (glottal wave), when the folds start vibrating in their entirety again in the chest register.

The untrained singer's C/F voice breaks generally started at g (191 Hz) and comprised a jump of seven semitones up to d′ (302 Hz). The F/C jump usually was even greater, namely 9 semitones from h to d (241 Hz to 148 Hz).

The trained tenor singer did not produce any voice breaks in his singing on rising and falling pitch. Figure 5 shows a representative registration of his lower range, bearing the

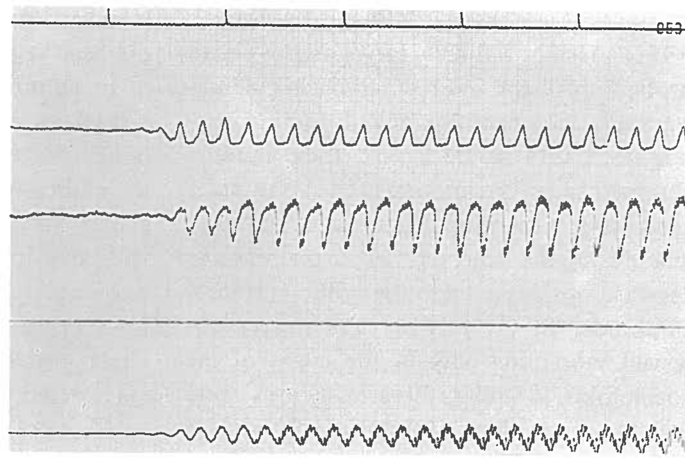

Fig. 7. Trained singer. Operatic head register (H_1).

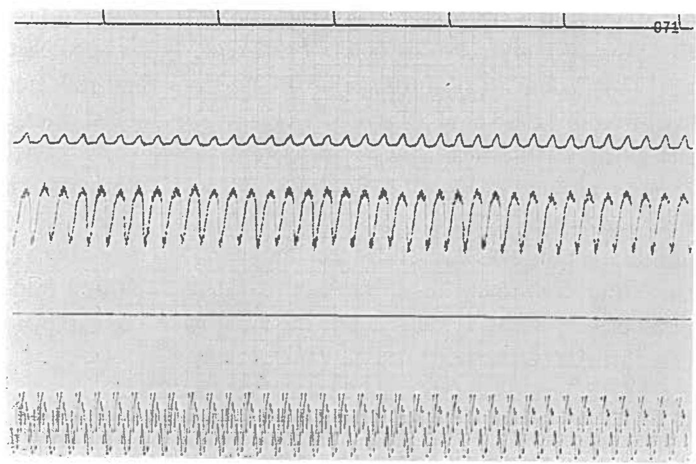

Fig. 8. Trained singer. Operatic head register (H_2).

characteristics of a chest register already discussed above. However, from c′ (258 Hz) upwards (fig. 6) [the point of C/H voice break for tenors given by *Luchsinger,* 1949, and *Seidner and Wendler,* 1978], one finds a continuous increase of the speed quotient as well as a slight decrease of the open quotient.

From figure 7 it appears that the singer at a still higher pitch (e′, 328 Hz) had adopted a new laryngeal vibratory pattern with small amplitudes of the vibrations, long closed segments (open quotient about 0.5), and shortened closing times reflected in a continuous increase of the speed quotient (table I). These features are most prominent at the highest pitch (g′, 392 Hz) recorded in this experiment (fig. 8). Here, there is a marked reduction of the vibratory amplitude in the photoglottogram.

The appearance of these glottograms at high pitch from a trained singer compares well with descriptions of the operatic head register by *Luchsinger* [1949] and *Large* et al. [1972]. Using indirect laryngoscopy with stroboscopic light, indirect laryngeal cinematographic photography and frontal tomographic X-rays of the larynx, these authors observed an approximation of the ventricular folds and a narrowing of the entire laryngeal tube during the head register, explaining the decrease of the photoglottographic vibratory amplitude. In the falsetto, *Luchsinger* observed vibrations only in the edges of the vocal folds, whereas these structures were seen to vibrate along their entire width in the head register. However, *Luchsinger* reports a constant glottal opening throughout the entire vibratory period even in the head register. This is not in accordance with the description of *Large* et al. of a firmer closure of the glottis in the head register nor with the present photoglottographic findings. Probably, *Luchsinger's* impression of permanent glottal opening was caused by too long exposure times for the tomographic X-rays. *Large* et al. [1972] report a lowering of the air flow rate through the larynx caused by the narrowing of the laryngeal tube and the firmer closure of the glottis during the head register. These findings correspond to the reduction of the vibratory amplitude and the decrease of the open quotient in the present photoglottographic registrations of the operatic head register.

Acoustic analyses reported by the earlier cited authors [*Luchsinger,* 1949; *Large* et al., 1972] showed the head register to be characterized by greater energy in the higher partials than the falsetto. From a theoretical study of the voice source spectrum, *Fant* [1979] showed the amount of energy in the partials to be directly related to the closing velocity of the glottis. This compares well with the reduced closing time or continuously increasing speed quotient in the glottograms from the head register shown above.

In summary, the glottographic registrations from this pilot study show the existence of a laryngeal vibratory pattern distinct from the earlier well-known chest and falsetto registers. Its glottographic characteristics agree with descriptions of the qualities of the operatic head register and may be listed as follows: (1) continuous development out of the chest register without any voice break; (2) lowered amplitude of vibrations; (3) distinct closed phase in the vibratory cycle, reflected in a slight reduction of the open quotient, and (4) reduced closing time, caused by an increased closing velocity of the glottis and reflected in a continuous increase of the speed quotient.

To conclude, the method of combined glottographic registrations seems to be well suited for objective recordings or register-dependent changes in the laryngeal vibratory pattern and reasonably useful for forthcoming expansions of this pilot study.

Résumé

Les voix chantées d'un professionnel (ténor) et d'un amateur ont été enregistrées à l'aide d'une méthode combinant la photoglottographie et l'électroglottographie. Chez le professionnel, on a pu observer un mode caractéristique de vibration glottique qui correspond au «registre de tête» des chanteurs d'opéra. Ce mode, ainsi que les différences entre les deux voix, sont discutés en détail.

Zusammenfassung

Mit Hilfe der kombinierten photo- und elektroglottographischen Methode wurde das Schwingungsmuster der Stimmlippen beim Auf- und Abwärtssingen registriert. Eine normale Männerstimme ergab

zwei Schwingungsmuster in Übereinstimmung mit Brust- und Falsettregister, abgegrenzt durch deutliches Umkippen der Stimme, während die Registrierungen von einer Tenorstimme eine kontinuierliche Veränderung des Schwingungsmusters ohne Umkippen der Stimme aufwiesen. Das Glottogramm der Tenorstimme in hohen Lagen stand in Einklang mit Beschreibungen des als Vollton der Kopfstimme bezeichneten Registers.

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