F0 lowering, creaky voice, and glottal stop: Jan Gauffin's account of how the larynx works in speech

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Abstract

F0 lowering, creaky voice, Danish stød and glottal stops may at first seem like a group of only vaguely related phenomena. However, a theory proposed by Jan Gauffin (JG) almost forty years ago puts them on a continuum of supralaryngeal constriction. The purpose of the present remarks is to briefly review JG:s work and to summarize evidence from current research that tends to reinforce many of his observations and lend strong support to his view of how the larynx is used in speech. In a companion paper at this conference, Tomas Riad presents a historical and dialectal account of relationships among low tones, creak and stød in Swedish and Danish that suggests that the development of these phenomena may derive from a common phonetic mechanism. JG:s supralaryngeal constriction dimension with F0 lowering ⇔ creak ⇔ glottal stop appears like a plausible candidate for such a mechanism.

How is F0 lowered?

In his handbook chapter on "Investigating the physiology of laryngeal structures" Hirose (1997:134) states: "Although the mechanism of pitch elevation seems quite clear, the mechanism of pitch lowering is not so straightforward. The contribution of the extrinsic laryngeal muscles such as sternohyoid is assumed to be significant, but their activity often appears to be a response to, rather than the cause of, a change in conditions. The activity does not occur prior to the physical effects of pitch change."

Honda (1995) presents a detailed review of the mechanisms of F0 control mentioning several studies of the role of the extrinsic laryngeal muscles motivated by the fact that F0 lowering is often accompanied by larynx lowering. However his conclusion comes close to that of Hirose.

At the end of the sixties Jan Gauffin began his experimental work on laryngeal mechanisms. As we return to his work today we will see that, not only did he acknowledge the incompleteness of our understanding of F0 lowering, he also tried to do something about it.

Jan Gauffin's account

JG collaborated with Osamu Fujimura at RILP at the University of Tokyo. There he had an opportunity to make films of the vocal folds using fiber optics. His data came mostly from Swedish subjects. He examined laryngeal behavior during glottal stops and with particular attention to the control of voice quality. Swedish word accents provided an opportunity to investigate the laryngeal correlates of F0 changes (Lindqvist-Gauffin 1969, 1972).

Analyzing the laryngoscopic images JG became convinced that laryngeal behavior in speech involves anatomical structures not only at the glottal level but also above it. He became particularly interested in the mechanism known as the '*aryepiglottic sphincter*'. The evidence strongly suggested that this supraglottal structure plays a significant role in speech, both in articulation and in phonation. [Strictly speaking the 'ary-epiglottic sphincter' is not a circular muscle system. It invokes several muscular components whose joint action can functionally be said to be 'sphincter-like'.]

In the literature on comparative anatomy JG discovered the use of the larynx in protecting the lungs and the lower airways and its key roles in respiration and phonation (Negus 1949). The throat forms a three-tiered structure with valves at three levels (Pressman 1954): The aryepiglottic folds, ventricular folds and the true vocal folds. JG found that protective closure is brought about by invoking the "*aryepiglottic muscles, oblique arytenoid muscles, and the thyroepiglottic muscles. The closure occurs above the glottis and is made between the tubercle of the epiglottis, the cuneiform cartilages, and the arytenoid cartilages*".

An overall picture started to emerge both from established facts and from data that he gathered himself. He concluded that the traditional view of the function of the larynx in speech needed modification. The information conveyed by the fiberoptic data told him that in speech the larynx appears to be constricted in two ways: at the vocal folds and at the aryepiglottic folds. He hypothesized that the two levels "*are independent at a motor command level and that different combinations of them may be used as phonatory types of laryngeal articulations in different languages*". Figure 1 presents JG's 2-dimensional model applied to selected phonation types.

In the sixties the standard description of phonation types was the one proposed by Ladefoged (1967) which placed nine distinct phonation types along a single dimension.

In JG's account a third dimension was also envisioned with the vocalis muscles operating for pitch control in a manner independent of glottal abduction and laryngealization.

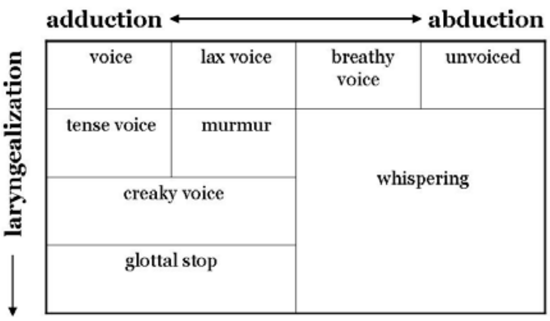

Figure 1. 2-D account of selected phonation types (Lindqvist-Gauffin 1972). Activity of the vocalis muscles adds a third dimension for pitch control which is independent of adduction/abduction and laryngealization.

JG's proposal was novel in several respects:

(i) There is more going on than mere adjustments of vocal folds along a single adduction-abduction continuum: The supralaryngeal (aryepiglottic sphincter) structures are involved in both phonatory and articulatory speech gestures;

(ii) These supralaryngeal movements create a dimension of 'laryngeal constriction'. They play a key role in the production of the phonation types of the languages of the world.

(iii) Fiberoptic observations show that laryngealization is used to lower the fundamental frequency.

(iv) The glottal stop, creaky voice and F0 lowering differ in terms of degree of laryngeal constriction.

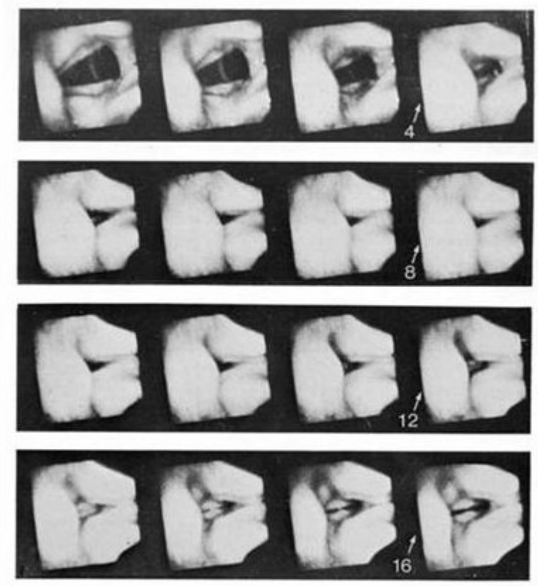

Figure 2. Sequence of images of laryngeal movements from deep inspiration to the beginning of phonation. Time runs in a zig-zag manner from top to bottom of the figure. Phonation begins at the lower right of the matrix. It is preceded by a glottal stop which is seen to involve a supraglottal constriction.

Not only does the aryepiglottic sphincter mechanism reduce the inlet of the larynx. It also participates in decreasing the distance between arytenoids and the tubercle of the epiglottis thus shortening and thickening the vocal folds. When combined with adducted vocal folds this action results in lower and irregular glottal vibrations in other words, in lower F0 and in creaky voice.

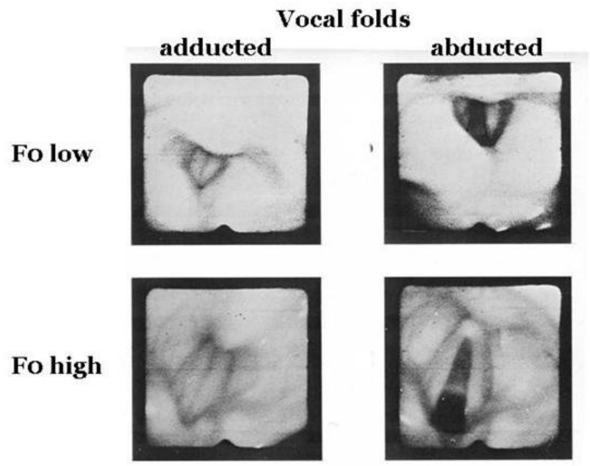

Figure 3. Laryngeal states during the production high and low fundamental frequencies and with the vocal folds adducted and abducted. It is evident that the low pitch is associated with greater constriction at the aryepiglottic level in both cases.

Evaluating the theory

The account summarized above was developed in various reports from the late sixties and early seventies. In the tutorial chapter by Hirose (1997) cited in the introduction, supraglottal constrictions are but briefly mentioned in connection with whispering, glottal stop and the production of the Danish stød. In Honda (1995) it is not mentioned at all.

In 2001 Ladefoged contributed to an update on the world's phonation types (Gordon & Ladefoged 2001) without considering the facts and interpretations presented by JG. In fact the authors' conclusion is compatible with Ladefoged's earlier one-dimensional proposal from 1967: "*Phonation differences can be classified along a continuum ranging from voiceless, through breathy voiced, to regular, modal voicing, and then on through creaky voice to glottal closure*……".

JG did not continue to pursue his research on laryngeal mechanisms. He got involved in other projects without ever publishing enough in refereed journals to make his theory more widely known in the speech community. There is clearly an important moral here for both senior and junior members of our field.

The question also arises: Was JG simply wrong? No, recent findings indicate that his work is still relevant and in no way obsolete.

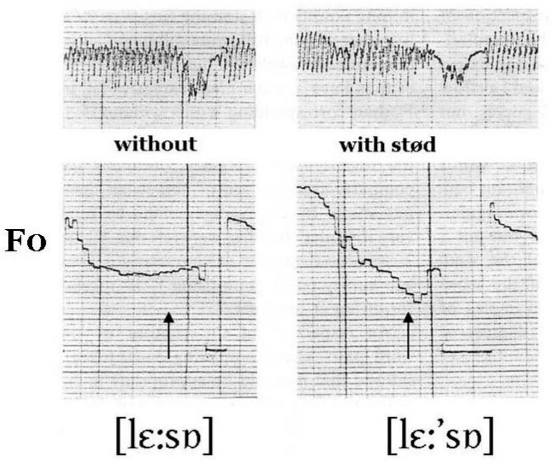

Figure 4. Effect of stød on F0 contour. Minimal pair of Danish words. Adapted from Fischer-Jørgensen's (1989). Speaker JR

One of the predictions of the theory is that the occurrence of creaky voice ought to be associated with a low F0. Monsen and Engebretson (1977) asked five male and five female adults to produce an elongated schwa vowel using normal, soft, loud, falsetto and creaky voice. As predicted every subject showed a consistently lower F0 for the creaky voice (75 Hz for male, 100 Hz for female subjects).

Another expectation is that the Danish stød should induce a rapid lowering of the F0 contour. Figure 4 taken from Fischer-Jørgensen's (1989) article illustrates a minmal pair that conforms to that prediction.

The best way of assessing the merit of JG's work is to compare it with at the phonetic research done during the last decade by John Esling with colleagues and students at the University of Victoria in Canada. Their experimental observations will undoubtedly change and expand our understanding of the role played by the pharynx and the larynx in speech. Evidently the physiological systems for protective closure, swallowing and respiration are re-used in articulation and phonation to an extent that is not yet acknowledged in current standard phonetic frameworks ((Esling 1996, 2005, Esling & Harris 2005, Moisik 2008, Moisik & Esling 2007, Edmondson & Esling 2006)). For further refs see http://www.uvic.ca/ling/research/phonetics .

In a recent thesis by Moisik (2008), an analysis was performed of anatomical landmarks in laryngoscopic images. To obtain a measure of the activity of the aryepiglottic sphincter mechanism Moisik used an area bounded by the aryepiglottic folds and epiglottic tubercle (red region (solid outline) top of Figure 5). His question was: How does it vary across various phonatory conditions? The two diagrams in the lower half of the figure provide the answer.

Along the ordinate scales: the size of the observed area (in percent relative to maximum value). The phonation types and articulations along the x-axes have been grouped into two sets: Left: conditions producing large areas thus indicating little or no activity in the aryepiglottic sphincter; Right: a set with small area values indicating strong degrees of aryepiglottic constriction. JG's observations appear to match these results closely.

Conclusions

JG hypothesized that "*laryngealization in combination with low vocalis activity is used as a mechanism for producing a low pitch voice*" and that the proposed relationships between "*low tone, laryngealization and glottal stop may give a better understanding of dialectal variations and historical changes in languages using low tone*".

Current evidence lends strong support to his view of how the larynx works in speech. His observations and analyses still appear worthy of being further explored and tested. In particular with regard to F0 control. JG would have enjoyed Riad (2009).

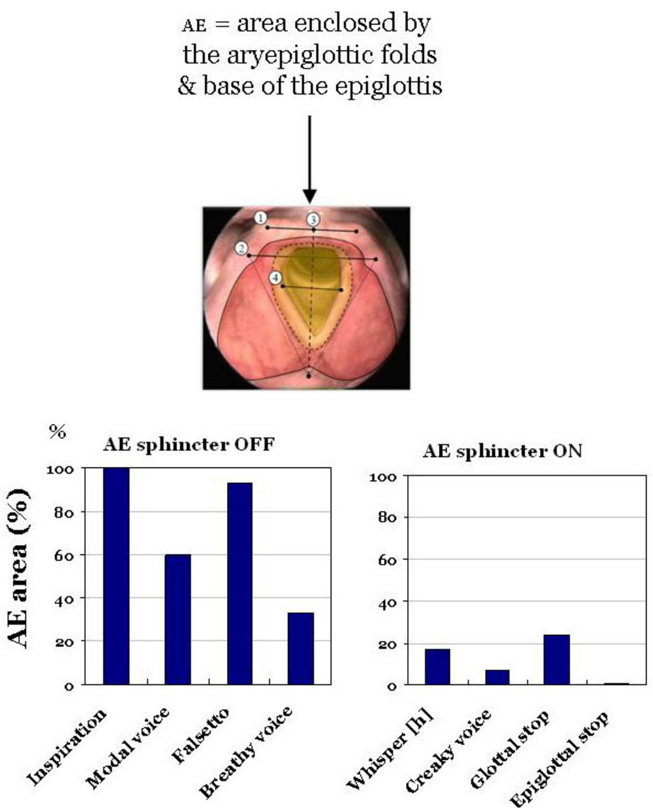

Figure 5. *Top:* Anatomical landmarks in laryngoscopic image. Note area bounded by the aryepiglottic folds and epiglottic tubercle (red region (solid outline). *Bottom part:* Scales along y-axes: Size of the observed area (in percent relative to maximum value). *Left:* conditions with large areas indicating little activity in the aryepiglottic sphincter; *Right:* Small area values indicating stronger of aryepiglottic constriction. Data source: Moisik (2008).

Acknowledgements

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