A descriptive model of laryngeal articulation in speech

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I. SPEECH PRODUCTION

A. A DESCRIPTIVE MODEL OF LARYNGEAL ARTICULATION IN SPEECH

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Abstract

In a previous paper(1) we have suggested a two-dimensional model of laryngeal articulation for production of phonatory types used in different languages. A mechanism for controlling downward pitch inflections was also discussed. The model was based on observations made with fiber optics inserted through the nasal passage(2). The philosophy of the model was that laryngeal speech mechanisms are closely related to more basic, phylogenetically old, laryngeal mechanisms associated with breathing, phonation, and protection. Essentially the same ideas are used in the present paper to describe more explicitly the function of the larynx in terms of a hypothetical model.

Introduction

The laryngeal muscles are organized in functional groups. Each muscle acts in one or more of these groups. An independent control of a single muscle is a difficult task, although not impossible, but can be regarded as a less natural activity. In order to develop such activities it is necessary to have an accurate control of the result of the action by means of, for instance, acoustic feedback. However, in speech communication a very precise control of the acoustic signal is neither possible nor necessary. Perception makes use of the redundancy inherent in speech which allows great variability in the signal. Coarticulation effects are therefore generally not compensated for(3) and thus the speech apparatus is free within limits to produce the speech in the most natural way. In the search for these natural articulatory gestures which it may be reasonable to look for among those which are innately organized, or the basic laryngeal gestures, the phylogensis of the larynx may give valuable information. Unfortunately there are divergent opinions about the nature of the basic laryngeal functions. We therefore start our discussion with some aspects of the evolution of the human larynx. The conclusions made in this paper are primarily based on our own observations with fiberoptics, but facts found in the literature are also considered(4).
Basic laryngeal functions

An important function of the larynx is to work as a sphincter. Phylogenetically this sphincter exhibits two functions, one related to air-trapping and one to protection of the subglottic system. We will argue here that in the human larynx these two functions make use of the same laryngeal mechanism. The air-trapping inlet and outlet valves have been the true and false vocal folds, respectively. Air-trapping, which has some influence on the pectoral girdle function in, for instance, the apes when swinging from a branch\(^5\) is not important for human beings. Instead the true vocal folds have been specialized for phonation and the retrogression of the false vocal folds has made these structures less efficient as a valve for air-trapping. Effective air-trapping in the human larynx is in our opinion always supplemented by the mechanism of the protective closure. This closure is at a level above the glottis and is made between the tubercle of the epiglottis, the cuneiform cartilages, and the arytenoid cartilages\(^6\).

In Fig. I-A-1 a sequence of frames from a film registration of this type of laryngeal closure is shown. Our experimental observations indicate that breath-holding is often performed with the respiratory muscles and not by closing the larynx, but sometimes, as e.g. if the intrathoracic pressure is raised, as when someone coughs, this protective closure is used.

The larynx is also active during respiration\(^7\). This activity is found in the muscles that adduct and abduct the glottis. The adducted state of the glottis is used for phonation. Evolutionary evidence indicates that phonation is not exclusively connected with speech (see ref. 5). Consequently it seems reasonable to conclude that the adducted state of the glottis, the "voicing position", is a basic and language independent laryngeal function.

From the discussion given above we can identify three basic laryngeal functions related to breathing, phonation, and protection. The corresponding postures or positioning of the larynx are the breathing position, the voicing position, and the protective closure\(^8\). Innately organized muscle groups are used for movements intermediate and superimposed on these postures. The movement from the open position (breathing position) to the voicing position is called glottal adduction and the movement from the voicing position to the open position is called glottal abduction. The muscles
Fig. I-A-1. A sequence of frames from a fiberoptic film registration showing a laryngeal closure. This closure is performed between the arytenoid cartilages, the cuneiform cartilages, and the tubercle of the epiglottis (Lindqvist, 1969).
used for these movements are posterior crico-arytenoids which abduct the vocal folds, and the inter-arytenoid muscle which adducts the vocal folds. EMG-measurements indicate that probably no other muscle activities are necessary for these movements\(^{9}\) although it is traditional to attribute an adducting function to several intrinsic laryngeal muscles. The observed movements of the arytenoids are a rocking or rotatory movement around the cylindrical joint on the cricoid cartilage in a dorso-lateral direction.

Movements from either the open or the voicing position to the protective closure are made by inhibiting the crico-thyroid muscles and by activating all sphincter muscles of the larynx including the ary-epiglottic sphincters. The ary-epiglottic sphincters are here defined as the ary-epiglottic, the oblique arytenoid, the thyro-epiglottic, and the external thyro-arytenoid muscles\(^{10}\). In our opinion the ary-epiglottic sphincters are of primary importance. The movements of the arytenoids from voicing position to closed position take place in a forward tilting direction towards the tubercle of the epiglottis\(^{11}\). The tubercle of the epiglottis is at the same time pulled dorsally, by a rotation of the thyroid cartilage about its joint, and approaches the arytenoids.

Evolution of language and speech has also made use of a functional differentiation of the sphincter muscles which has enabled a fine control of pitch and phonation types. This we will discuss in the following section. The role of the extrinsic muscles on laryngeal articulation is less known; probably they take an important part in the regulation of pitch and possibly also in the protective closure\(^{12}\). However, it seems reasonable to assume that even for pitch regulation the intrinsic laryngeal muscles (including crico-thyroidus) are of primary importance and we will restrict our discussion to these muscles.

**Laryngeal speech functions**

So far we have discussed the basic laryngeal mechanisms. Breathing, protection, and phonation have been considered. Now we will turn to the question how these mechanisms may be utilized in speech.

The speech posture of the larynx is with the vocal folds in voicing position. In this position the vibrations of the vocal folds are most easily sustained but if the air velocity is sufficient they can also vibrate in a more
open position. The laryngeal speech gestures are dynamic in their nature and they appear as a modulation of the speech posture.

Three functions of the larynx of communicative importance are discussed here: to devoice, to change the quality of the voice, and to control the pitch. There are two types of devoicing gestures which seem to be used by speakers of any language. These are the glottal abduction gesture, that is an articulation towards the open position of the larynx (breathing position), and the laryngeal closure gesture, which is articulated towards the closed larynx position (protective closure), see Lindqvist, ref. 1. An example of an almost complete laryngeal closure is given in Fig. I-A-1.

The muscles activated for the abduction gesture are the posterior crico-arytenoidei and for the adduction gesture the inter-arytenoideus. The laryngeal closure gesture is performed by activating all sphincter muscles as described in the previous section. The degree to which these gestures are invoked in speech is determined by the acoustic results aimed at, and they never reach the breathing or completely closed position. In voiced context a more extreme laryngeal closure gesture results in a voiceless interval, and is generally referred to as a glottal stop.

As already pointed out, the vocal folds may vibrate even in a somewhat open position if the air-velocity through the glottis is sufficient. Accordingly, abduction gesture performed to suppress the voicing in voiced context may cause excessive loss of air. The abduction gesture is therefore effective as a devoicer only in combination with an oral constriction while the glottal stop gesture can be used as a devoicer independent of other articulators\(^\text{13}\).

The glottal abduction gesture and the laryngeal closure gesture can also be used to change the quality of the voice. According to our hypothesis these gestures are independent at a motor command level and different combinations of them may be used as phonatory types of laryngeal articulations in different languages. A small degree of glottal abduction tends to decrease the closed phase of the vocal fold vibrations (increase the open quotient). The acoustic consequence of this is a reduction of the amplitude of the higher harmonics\(^\text{14}\) and that the voice obtains a more or less noisy character. In phonetic terms this type of voicing is often referred to as lax voice or breathy voice\(^\text{15}\). A laryngeal closure articulation has a
quite different effect on the quality of the voice. The increase of the activity in the ary-epiglottic sphincters results in a shortening and thickening of the vocal folds and if the activity in the vocalis muscles was not increased, this would result in a lowering of the pitch. However, as defined earlier a laryngeal closure gesture is accompanied by an increased activity in the vocalis muscles. This activity counteracts the effect the shortening of the vocal folds has on the pitch. The vocal folds are also pressed together which cause them to vibrate with a decreased open quotient. A more extreme articulation results in irregular periodicity of the vibrations or in a complete suppression of the vibrations, depending of the pressure drop across the glottis.

The consequence on the acoustic signal is increased intensity of the higher harmonics, similar to the effect of an increase in the subglottic pressure. This type of voice is often referred to as tense voice. The a-periodicity gives the voice a rough character and this is often called creaky voice or creak (see Ladefoged, 1967, and Catford, 1964, ref. 15), depending on the degree of aperiodicity.

The same acoustic features in combination with consonant articulation are often described as laryngealized sounds and sometimes also as glottalized sounds. We choose to use the term laryngealization to define a laryngeal articulation towards the laryngeal closure. A glottal stop is then an extreme case of laryngealization (16).

The evolution of language and speech has made use of an independent pitch control mechanism by a functional differentiation among the sphincter muscles of the larynx. For regulation of the pitch it is essential to have control of the activity of the vocalis muscles, independent on a motor command level, of abduction and laryngealization gestures. The hypothesis has been put forward that laryngealization in combination with low vocalis activity is used as a mechanism for producing a low pitch voice as in the Swedish word accent (see ref. 1). More recent data collected with fiberoptics seem to verify this hypothesis (17). These data also indicate that a laryngeal closure can be performed without the assistance of activity in the vocalis muscle. We suggest that this type of laryngeal closure, which is similar to laryngealization but with no activity in the vocalis muscles, should be called laryngeal constriction. According to
our observations this is the normal gesture for producing low pitch and accordingly a part of the pitch control mechanism. A laryngeal constriction has the effect of shortening the vocal folds and thus to make them thicker which is necessary for producing low pitch voice. If the larynx is constricted to a high degree a kind of low pitch creaky voice will be produced\(^{18}\). In Fig. I-A-2 four selected frames from the fibrescope film registrations are shown. These frames are typical for low and high pitch phonation in speech. Glottal abduction at low and high pitch is also shown. It can be seen in Fig. I-A-2 that the larynx can be constricted even if the glottis is abducted.

The quality of the voice can also be changed in another way which at its extreme articulation results in whispering. Whispering may physiologically and psychologically be characterized as a combination of glottal abduction and laryngeal constriction (low pitch). The abduction gesture causes the arytenoids to separate slightly and the laryngeal constriction tends to pull the arytenoids forwards and the tubercle of the epiglottis backwards towards the arytenoids leaving an opening between the vocal processes and more or less separated vocal folds. If the glottal opening is small the airflow through the glottis is effectively modulated by the vibrating vocal folds and a type of low pitch breathy voice will be produced.

Conclusions

The above description of the laryngeal speech gestures deviates in some important respects from the traditional view of the function of the larynx in speech. The new concept on which the above described model is built can be summarized as follows:

1. The laryngeal speech functions are discussed as developed from more basic, phylogenetically older laryngeal functions related to breathing, protection, and phonation.

2. Beside adjustments that are postural in nature only three, on the motor command level, independent mechanisms are identified. These are the pitch control mechanism, the glottal abduction mechanism, and the laryngealization mechanism.

3. Different phonatory types used in languages may be produced with combinations of these mechanisms. Whispering can also be explained with reference to these laryngeal speech mechanisms.
Fig. I-A-2. Selected frames from a fiberscope film registration of connected speech, showing the larynx for low (a) and high (c) pitch. Glottal abduction at low (b) and high (d) pitch is also shown.
**Ladefoged's phonatory types** in relation to laryngealization and glottal abduction

<table>
<thead>
<tr>
<th>Adduction</th>
<th>Glottis</th>
<th>Abduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>All languages</td>
<td>Indonesian</td>
<td>Gujarati</td>
</tr>
<tr>
<td>Voice</td>
<td>Lax voice</td>
<td>Breathy voice</td>
</tr>
<tr>
<td>Korean</td>
<td>Kumam</td>
<td>Creaky voice</td>
</tr>
<tr>
<td>Tense voice</td>
<td>Murmur</td>
<td>Whispering</td>
</tr>
<tr>
<td>Creak</td>
<td>Kumam</td>
<td></td>
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<tr>
<td>Hausa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glottal stop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All languages (but not phonemic)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Catford's phonatory stricture-types** in relation to laryngealization and glottal abduction.

<table>
<thead>
<tr>
<th>Adduction</th>
<th>Glottis</th>
<th>Abduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td>Lax voice</td>
<td>Breathy voice</td>
</tr>
<tr>
<td>Normal glottal (Voice)</td>
<td>Breathy voice (Breathy voice)</td>
<td>Voiceless</td>
</tr>
<tr>
<td>Tense voice</td>
<td>Ligamental</td>
<td>(Whispery voice)</td>
</tr>
<tr>
<td>(Voiced creak)</td>
<td>Arytenoidal</td>
<td>Whispering (Whisper)</td>
</tr>
<tr>
<td>Creak</td>
<td>Ventricular (Creak)</td>
<td></td>
</tr>
<tr>
<td>(Stop)</td>
<td>Glottal stop</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 1-A-3.** Tentative two-dimensional descriptions of laryngeal articulation of phonatory types used in different languages. According to more recent findings the vocalis activity may be illustrated separated from laryngealization in a third dimension (Lindqvist, 1969).
4. The glottal stop gesture is interpreted as a gesture towards the protective closure and laryngealization is defined with reference to this basic laryngeal mechanism.

5. A mechanism for controlling low pitch and downward pitch inflection is described which makes use of the ary-epiglottic sphincters.

There are, of course, some uncertainties regarding the validity of the suggested model due to lack of EMG-data. This is especially true for the ary-epiglottic sphincters which have not been discussed previously in connection with speech production. Also the role of the extrinsic laryngeal muscles is not considered in the present model.

However, our model seems to account for the most essential functions of the larynx. The described physiological and acoustical relations between low tone, laryngealization, and glottal stop may give a better understanding of dialectal variations and historical changes in languages using low tone. One example of such variation is the different realizations of the word intonation in Danish, from low tone, extremely low tone to glottal stop. Another example is the historical change that seems to have taken place in the Peking dialect of Chinese. In this case a final laryngealized stop consonant has developed into a glottal stop which in turn has developed into a low falling tone.

Two examples of how this model can be used for linguistic purposes are shown in Fig. I-A-3. This figure shows tentative two-dimensional descriptions of laryngeal articulation of phonatory types used in different languages, suggested by Ladefoged and by Catford (see ref. 15). The two dimensions used are the glottal abduction and laryngealization. A better description can be made with the vocalis activity in a third dimension, although the present simplified description seems to capture the most essential linguistic facts.

References
(3) Intrinsic allophones occur by definition due to coarticulation with the context. An interesting question is if language ever make use of compensatory articulation in specific context in order to maintain certain acoustic features. J. Lindqvist, Intern report 31.1.1969 (in Swedish). It can, for instance, be shown that the interaction from articulatory

(4) Laryngeal features are not discussed since in our opinion the abstractions made in feature systems are not capable of giving a full understanding of the speech processes. The theories of distinctive features have also resulted in a concentration of too much effort on the descriptive needs of the linguist instead of on finding the limitations and intrinsic characteristics in the speech mechanisms which in itself may have explanatory power. Lindblom, B.: "Phonetics and the description of language", to be publ. in the Proc. of the VIIth International Congress of Phonetic Sciences, Montreal, by Mouton & Co. (forthcoming).


(6) The epiglottis, which is a rudiment, does not function as a lid to close the larynx as sometimes is stated. Only the lower part, the tubercle of the epiglottis, takes part in the closure. However, the laryngeal closure gesture has a tendency to obscure the view of the larynx by a backward tilt of the epiglottis.


(8) The opinion that the human larynx is a three-tied sphincter (Pressman, 1954) is according to our observations wrong. The third level of laryngeal closure should, according to that hypothesis, be at the level of the false vocal folds. The size of the false vocal folds varies between different individuals and it is not unusual to find subjects that can put their false vocal folds into contact and even phonate with them. However, this is not very common and cannot be regarded as a basic laryngeal function. On the other hand, the false vocal folds may play a secondary role in the protective closure and act as a cushion to complete the closure between the tubercle of the epiglottis and the arytenoids. The false vocal folds contain only few muscle fibers and the positioning of these folds is determined by the surrounding structures like the ary-epiglottic sphincters. (See Pressman, J.J.: "Sphincters of the larynx", A.M.A. Arch. of Otolaryngology 59 (1954), pp. 221-236.)


(10) Unfortunately speech researchers have paid no attention to these muscles and no EMG-data on their functions are available.


(13) The hypothesis has been suggested that a stiffening of the vocal folds in combination with glottal abduction is used as a mean to stop vocal fold vibrations for the production of voiceless consonants (Halle and Stevens, 1971). Even if such an articulation should give the expected result it is not likely that it occurs due to the functional organization of the laryngeal muscles. Furthermore EMG-measurements have shown that the activity in the vocalis muscles is generally decreased for consonant articulations (Hirose, ref. 9). Halle, M. and Stevens, K.N.: "A note on laryngeal features", MIT, QPR No. 101 (1971), pp. 198-211.


(16) Both the glottal abduction gesture and the laryngealization gesture are covered by the linguistic feature "glottal stricture" (Ladefoged, P.: "The three glottal features", Working Papers in Phonetics 2 (UCLA), 1972, pp. 95-101). This description of what is going on may satisfy some linguistic purposes, but for a complete theory about speech and language, a more detailed description of the use of the larynx is needed.

   In another feature system used by Halle and Stevens (1967, ref. 13) the term "constricted glottis" is used to represent an adjustment which "causes the vocal cords to be pressed together and the glottis to narrow or to close". In our opinion the mechanism behind this type of articulation is laryngealization as defined in this paper. However, we prefer the term laryngealization, because it does not emphasize what happens with the glottis and the general use of the word seems to be in accordance with our definition.

(17) Lindqvist, J.: "Laryngeal articulation studied on Swedish subjects", this issue of the STL-QPSR.

(18) A glottal stop gesture is generally accompanied by a creaky onset and offset of voicing. Thus extreme low pitch and glottal stop have both acoustical and physiological similarities, which may explain, for instance, the dialectal variation in the realization of the Danish "stød".