Observations on tongue contour length in spoken and sung vowels

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I. SPEECH PRODUCTION

A. OBSERVATIONS ON TONGUE CONTOUR LENGTH IN SPOKEN AND SUNG VOWELS

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Abstract

Lateral X-ray pictures are examined showing the articulation of Swedish long vowels as produced by a singer in speech and singing. Special attention is payed to the positions of the tongue root and the glosso-epiglottic fold and to their dependence on articulatory parameter such as larynx height and tongue shape. Given the information on the tongue dorsum position and the larynx height the position of the glosso-epiglottic fold is shown to be predictable. As a consequence of this finding a rule for the generation of pharyngeal vocal tract shapes has been developed. Also, estimates of tongue contour lengths can be derived for arbitrary vowel configurations.

1. Introduction

In a previous article an articulatory model of the vocal tract was presented(1). The model is capable of producing vowels given the values of six parameters: tongue body position, tongue body shape or bulging, jaw position, larynx height, and the two variables describing the condition of the lip muscles. The empirical basis of the procedure for deriving tongue contours consisted of lateral X-ray pictures of a subject producing steady-state Swedish vowels. This procedure included an ad hoc routine for generating a midsagittal contour in the region of the tongue root using a distance measured between the back pharynx wall and the tongue root. This distance gave the anterior-posterior position of the epiglottis for which a fixed contour was used. This contour was then adjusted along a vertical dimension to agree with any given position of the larynx. In the measurements of formant frequencies which were made with the aid of the electrical line analogue LEA, variation of larynx height was performed in a rather crude fashion by simply altering the number of length sections in the pharyngeal region.

One purpose of the present paper is to improve these procedures and to bring them into closer agreement with physiological facts. A second purpose is to provide a set of data on how the length of the midsagittal tongue contour varies in vowel articulations and to establish some of the factors that underlie this variation. Our interest in this parameter
2. Measurements

A set of lateral X-ray pictures of a subject producing eleven spoken and nine sung vowels was examined with respect to midsagittal tongue contour length. These pictures were the same as those used in earlier articles\(^{(1,4)}\). The subject was a trained singer.

The tongue length was measured from the apex of the tongue tip contour to the glosso-epiglottic fold. The data obtained in this way are presented in Fig. 1-A-1. Two important observations can be made. First, there is a rather wide range of variations for the different vowels: from 11.4 cm for a spoken [ɛ] to 13.7 cm for a sung [i]; thus a variation amounting to about 20%. Second, the tongue lengths pertaining to spoken vowels tend to be shorter than their sung counterparts e.g., the tongue lengths for [i] and for [u] are both 1.1 cm shorter in speech than in singing.

In a previous investigation\(^{(4)}\) it was observed that male singers tended to lower their larynges in singing as compared with speech. One factor affecting the length of the tongue can therefore be assumed to be the vertical position of the larynx. The larynx height was measured in the following way. A coordinate system was devised the y-axis of which approximated the back pharynx wall whereas the x-axis touched the lower edge of the upper incisors. Larynx height was defined as the distance from the x-axis to a point on the middle of the glottis contour.

The tongue lengths shown in Fig. 1-A-1 are plotted against larynx height in Fig. 1-A-2. The data show considerable scatter indicating that the larynx height cannot be the only factor influencing the tongue length. A more careful examination of the data points suggests that the tongue length is dependent on several factors in a rather complex way, one of these factors being larynx height.

The larynx is attached to the glosso-epiglottis fold by means of passive structures. The vertical position of this fold can consequently
OBSERVED TONGUE LENGTH

Fig. 1-A-1. The midnasal tongue contour length as measured from the apex of the tongue.

VOWEL

Spoken Sung

OBSERVED TONGUE LENGTH (cm)
Fig. I-A-2. The tongue contour lengths given in Fig. I-A-1 plotted as a function of larynx height.
be assumed to vary in a simple manner as a function of larynx height. Using the coordinate system described above the vertical position of the fold was also measured. In Fig. I-A-3 the result is plotted. It is seen that in a first approximation this vertical position is linearly dependent upon the larynx height. Thus, in this subject, the vertical distance between the midpoint of the glottis and the fold is 2.9 cm approximately. When the larynx is very low such as in the sung vowels /y, u, ø/, this distance increases. This can be interpreted to indicate that the tissues joining the larynx and the glosso-epiglottic fold are stretched. Fig. I-A-3 demonstrates that the vertical position of the glosso-epiglottic fold can be predicted given the larynx height.

It appears reasonable to assume that the horizontal position of the glosso-epiglottic fold should depend mainly on the position of the tongue. For instance, when the tongue body has a pharyngeal position, such as in back low vowels, the glosso-epiglottic fold can be expected to have a more posterior location than when the tongue body is high and fronted as in an /i/. The horizontal positions of the glosso-epiglottic fold and of a point situated at a distance of 11 cm from the tongue tip along the tongue contour were measured relative to the y-axis of the coordinate system mentioned above. The relationship between these two measures is illustrated in Fig. I-A-4. It appears possible to predict the horizontal position of the fold given the tongue contour information with a fair degree of accuracy. A horizontal displacement of the glosso-epiglottic fold of 1 cm is associated with a horizontal displacement of the point on the tongue dorsum of about 3 mm.

An estimate of the length of the midsagittal contour of the tongue can now be made using the above results and provided that we know the position of the larynx and the location of a fixed point on the tongue dorsum relative to the maxilla and other fixed structures. The position of this point can be expected to vary as a function of both tongue and jaw movement. To derive the tongue length estimates we have computed the position of the glosso-epiglottal fold using the larynx and tongue dorsum dependences established above. We have then connected the point on the dorsum with the glosso-epiglottal fold by means of a straight line. Assuming that the location of the anterior 11 cm of the tongue contour is
Fig. I-A-3. Relation between the vertical locations of the gloso-epiglottic fold and the glottis observed in the articulation of spoken and sung vowels.
Fig. I-A-4. Relation between horizontal locations of the glosso-epiglottic fold and a position 11 cm from the tongue tip and the tongue dorsum.
known we find that the straight line approximation of the posterior part of the tongue contour - which in some cases exceeds 3 cm in length - yields fairly good results in comparison with the observed contour lengths. The maximal error amounts to 6 mm. 4 mm is the maximum error due to the straight line approximation of the tongue root contour.

The results reported above allow the generation of tracings of lateral X-ray pictures where the larynx height is varied systematically in an articulatorily realistic fashion. The procedure would be as follows:

1) Define the vertical position of the glottis.

2) Calculate the vertical position of the glosso-epiglottic fold using the relationship given in Fig. I-A-3.

3) Compute the horizontal position of the glosso-epiglottic fold using the horizontal position of the point on the tongue dorsum at a certain distance from the tongue tip (Fig. I-A-4).

4) Join this point with the point at the glosso-epiglottic fold by means of a straight line.

5) Complete the generated tracing by inserting the epiglottis contour.

Conclusions

The length of the midsagittal contour of the tongue has been shown to vary between 11 and 13.5 cm in a material consisting of both spoken and sung Swedish vowels. We have tried to show that at least for the present material this variation can be accounted for in terms of larynx height and articulatory parameters that determine the position of the tongue dorsum (such as the mandible as well as those controlling tongue movement proper).

Our investigation appears to suggest that the tongue contour between the tongue tip and the glosso-epiglottic fold exhibits some elasticity. The tongue is somewhat stretched when the tongue tissue is raised and/or when the larynx is depressed. The site of this spring-like property cannot be determined from our measurements but anatomical considerations make it seem likely that at least some of it should be attributed to the posterior portions. Also the tissues joining the glosso-epiglottic fold with larynx can be compared to a spring. However it appears to be stiffer than that of the tongue issues.
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References


