CONTROL OF THE TONGUE IN VOWELS

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We have been investigating the way the tongue is used in making vowel sounds. Our object is to characterize vowels in an explanatory way, rather than in terms of arbitrary tongue shapes. The data for our analyses were obtained by cineradiology.Six subjects were photographed while saying ten sentences each of the form 'say h_d again'. The vowels in the frame were /i,ɪ,e,ɛ,æ,a,ɔ,o,ɷ,u/. Spectrograms (as in Figure 1)

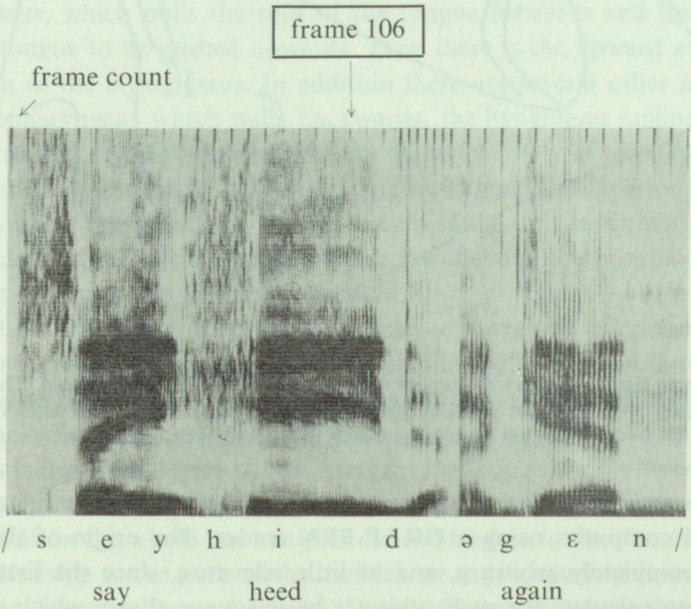

Fig. 1. Spectrogram of the phrase 'Say heed again' as said by subject 1, showing the digitally coded frame count, and the frame that was marked as being in the middle of the word *heed*.

were made of all 60 sentences. The spectrograms included at the top a digitally coded frame count which had been recorded at the time the photographs had been taken. This enabled us to mark each spectrogram at an appropriate point in the middle of

a vowel in a word, and to be able to locate the corresponding frame in the film. We then made tracings (as in Figure 2) of each of these 60 frames. The shape of the tongue was characterized in terms of six equally spaced points, starting from the root. We also marked the upper incisors and an arbitrary point on the floor of the nasal cavity. These points, shown as A and B on the figure, were used in lining up each of each subject's utterances.

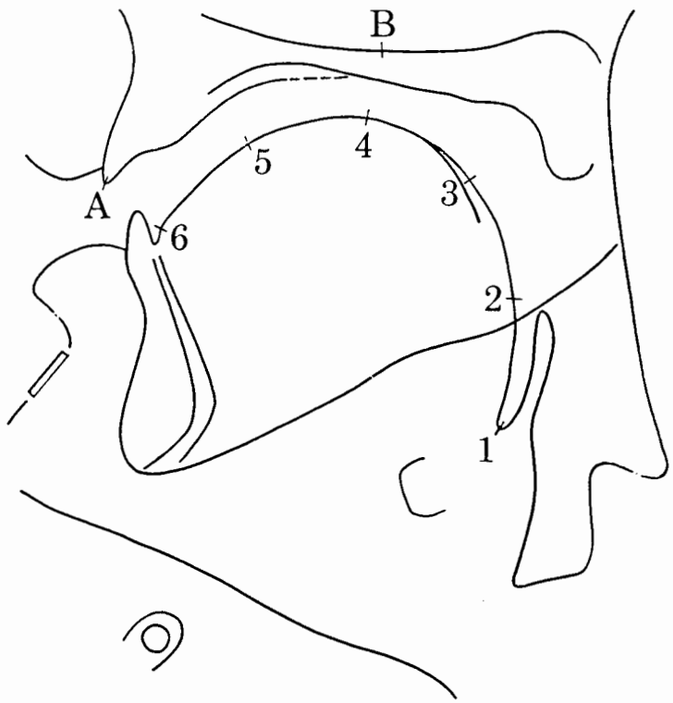

Fig. 2. A tracing from the x-ray of subject 4 in the middle of the vowel in *hid*. The numbers designate six equally spaced points starting from the root of the tongue. The letters indicate fixed points used in lining up each of the subject's tracings.

The (x,y) coordinates of each tongue point on each tracing were digitally recorded on a PDP-12 computer, using a GRAF-PEN reader. The origin of the coordinate system was completely arbitrary, and of little relevance, since the first stage in the analysis was to calculate for each subject a basic tongue shape, which was taken to be the mean of the shape in all ten vowels. All subsequent analyses were then concerned with tongue displacements relative to this basic shape.

The forces affecting the shape of the tongue are extremely complex. A simplified diagram of the major influences is shown in Figure 3. The first is the degree of jaw opening, an influence which was somewhat neglected till the recent work of Lindblom and Sundberg (1971). Next there is the action of the principal muscle of the tongue,

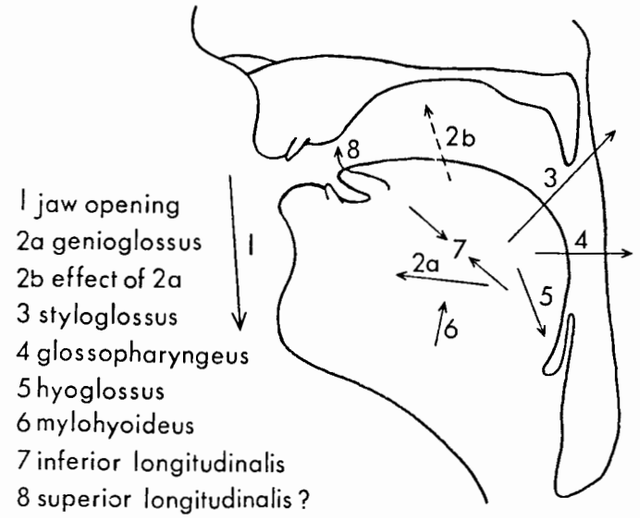

Fig. 3. A simplified diagram of the major influences on the shape of the tongue.

the genioglossus, which pulls the root of the tongue forwards and thus causes the front of the tongue to be pushed upwards. Then there is the upward and backward pulling action of the styloglossus. In addition there are several other muscles, such as the glossopharyngeus which pulls backwards, the hyoglossus pulling downwards and backwards, the mylohyoideus which lifts the whole body of the tongue, the inferior longitudinals which bunch the tongue lengthwise, and the superior longitudinals which are probably responsible for raising the tip of the tongue. Other muscles, such as the verticalis and the lateralis, and the muscles affecting the position of the hyoid bone, are not shown in this simplified diagram.

We looked for the factors underlying the tongue shapes by using the PARAFAC procedure for explanatory factor analysis (Harshman 1970). Figure 4 shows one factor that we found to be present. This factor indicates that as the points near the root of the tongue move forward, the points at the front of the tongue move up. The lengths of the arrows indicate the degree of influence (the loading) of the factor on each point. This factor is obviously very similar to the action of the genioglossus muscle as shown in Figure 3. But on the whole our analyses did not lead us to find factors which bear a simple relationship to the pulls of the muscles, or to jaw opening. It seems probable that the factor shown in Figure 4 may be the only feature of tongue shape used fairly consistently by each of the six subjects in our study. There is a great deal of variety in the way in which different individuals produce the tongue shapes required for the ten vowels. For example, three of the subjects differentiate between the vowels in *hid*, *head*, *had* by simply lowering the jaw while keeping the tongue fixed relative to the jaw; but the other three differ (and differ among themselves) in the degree to which they distinguish between these vowels by varying the position of the jaw, as

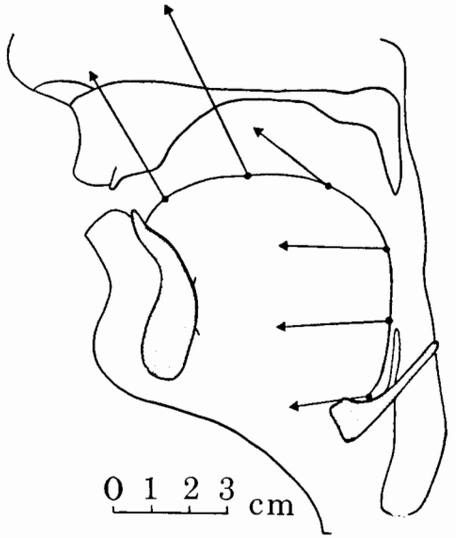

Fig. 4. Vectors indicating the degree and direction of influence of one factor on each point.

opposed to varying the position of the tongue relative to the jaw, presumably by using the mylohyoideus muscle.

There is also variation in the degree to which subjects bunch up the tongue lengthwise without increasing its height relative to the mandible, presumably by using the inferior longitudinal muscles. Three of the subjects (a different subset from any previously considered) have a very bunched, tense, shape of the tongue in *heed* and *hayed*, and a flatter, lax, shape in *hid*, *head*, *had*. A fourth subject has a tense shape in *hid*, as well as in *heed* and *hayed;* a fifth has it only in *heed;* and the sixth doesnot have two different shapes of the tongue in these front vowels. There are similar differences among the subjects in the number of shapes of the tongue that occur in back vowels.

In view of the variety of articulatory gestures that are found, it seems probably inadvisable to try to characterize vowels in articulatory terms. All these six subjects were considered by expert judges to have the same accents, and to be saying the same set of vowels. They were producing the same auditory/acoustic effects by different articulatory means. If we are looking for explanations of how vowels are used in languages we may not be able to do so in terms of tongue shapes. Instead we should probably consider the traditional term tongue height to be (inversely) equivalent to the height of the first formant, and the traditional term tongue fronting to be equivalent to the distance between the first formant and a weighted average of the second and higher formants. Lip rounding (which has not been considered in this paper) may turn out to be the only true articulatory feature which is appropriate in the characterization of vowels.

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REFERENCES

Harshman, R.
1970 "Foundations of the PARAFAC Procedure: Models and Conditions for an 'Explanatory' Multi-Modal Factor Analysis", *Working Papers in Phonetics* 16 (UCLA).
Lindblom, B. and J. Sundberg
1971 "Acoustical Consequences of Lip, Tongue, Jaw and Larynx Movement", *Papers from the Institute of Linguistics, University of Stockholm* 2:1-41.

DISCUSSION

KIM (Urbana, Ill.)
In view of your findings, would you propose a new set of variables or parameters of vowel classification in lieu of such traditional terms as HIGH, LOW, TENSE, etc.?

LADEFOGED
I am quite sure that we need a new set of phonological features for specifying actions of the tongue. These features must, of course, apply to consonants as well as vowels. As I indicated in the paper, I would retain the traditional vowel height and back-front feature (but with different definitions of the physical correlates). In the feature system I have proposed in my book, *Preliminaries to Linguistic Phonetics*(University of Chicago Press, 1971) I have included something equivalent to place of consonant articulation which is also applicable to vowels. At the moment I am not quite sure if a feature corresponding to the bunching of the tongue (advanced tongue root) is sufficient to account for the remaining phonetic and phonological data.

LINDBLOM (Stockholm)
Do you find any basis for saying that advanced tongue ROOT should be regarded as a quasi-independent parameter? In other words, given the point of constriction how much freedom is there for the rest of the tongue to move about?

LADEFOGED
A member of our UCLA Phonetics Laboratory group, Miss Mona Lindau, has been investigating the relation between tongue height and advanced tongue root in a number of different languages. I believe I am summarizing her results correctly in saying that she finds that some speakers of English have a good relation between advanced tongue root and tongue height, whereas others do not; and in other languages such as Igbo (of Nigeria), Ateso (of Uganda), and Twi (of Ghana) advancing of the tongue root appears to be an independent feature, so that two vowels could have the same tongue height, but a different degree of advancement of the tongue root.

SCULLY (Leeds)
Do you find any evidence of a pivoting effect in which the region of the tongue nearest to the velum is static, as seems to be indicated by the recent cineradiography data of J.S. Perkell? (*Physiology of Speech Production* [= M.I.T. Monograph 53] 1969).

LADEFOGED

Our data agree with this observation in the sense that the points on the tongue in the region of the soft palate move over considerably smaller differences than points in the region of the hard palate or points in the pharynx.

GRAHAM STUART (Silver Springs, Md.)

The report presented by Professor Ladefoged gives us concrete empirical evidence to confirm what we have for a long time believed must be the case, namely that raising the front part of the tongue by contracting the posterior fibres of the genioglossus NORMALLY advances the entire tongue body and increases accordingly the volume of the pharyngeal cavity. That the more open front vowels have higher first formants than their close counterparts results largely from openness being co-ordinate with tongue base retraction and reduced pharyngeal volume. However, it is easy to produce both [i] and [e] with the tongue tip and blade pressed against the palate, ensuring that the buccal cavity dimensions remain essentially unchanged for the two vowels. In this case retraction of the tongue body into the pharynx for the [e] is certainly effected by the hyoglossus. It is, moreover, clear from the cineradiographic films made by the Haskins group in the early 50's, showing the articulations of colloquial Arabic, that the Arabic apical emphatics are produced with a stretching of the tongue body so that the apex achieves alveolar occlusion, while the dorsum retracts helping to narrow the faucal orifice to the buccal cavity.

LADEFOGED

Dr. Stuart is undoubtedly correct in pointing out that there are many possible additional complications in controlling the shape of the tongue.