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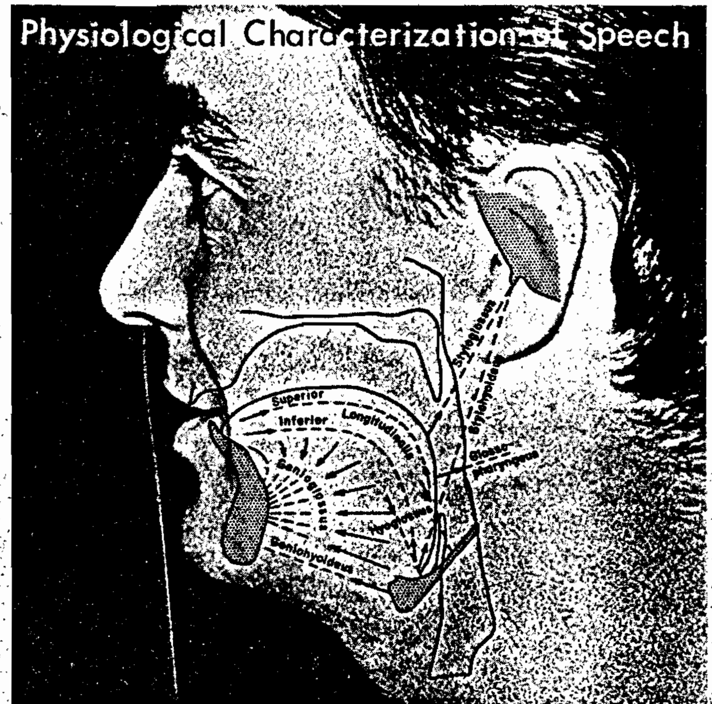
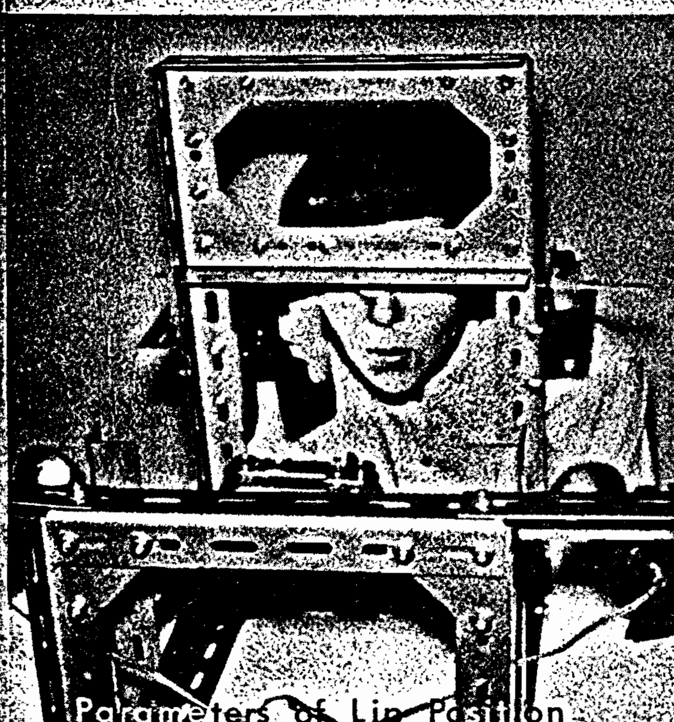
Measurement of the Vocal Tract



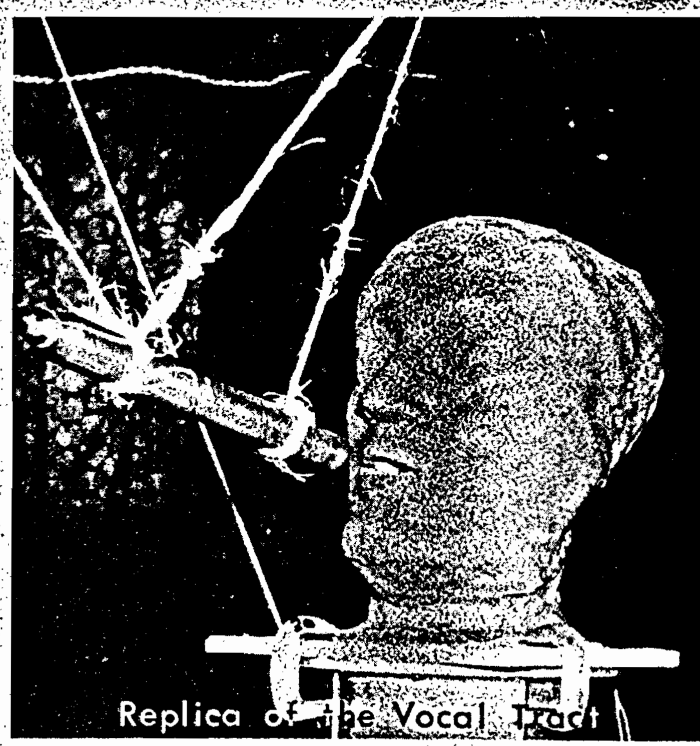
Physiological Characterization of Speech

WORKING PAPERS IN PHONETICS

University of California, Los Angeles
June 1964



Parameters of Lip Position



Replica of the Vocal Tract

Working Papers in Phonetics

June 1964

The Phonetics Laboratory is part of the English Department, University of California, Los Angeles. This Department provided the budget for ~~most~~ much of the instrumentation. The work reported here was also supported in part under USPHS Grant NB 04595-01, and in part through the UCLA Center for Research in Languages and Linguistics.

Introduction

The five working papers collected here reflect some of the research which has been carried out during the first year of a US PHS contract for "Physiological Parameters for Synthesizing Speech". Most of the rest of this first year was spent in discussions, planning, finding out the exact state of the articulatory speech synthesis work at MIT (we are very grateful to Professor K. N. Stevens and his associates for their constant cooperation and advice), trying out our own engineering designs, estimating how much of this research it would be advisable to try out on a computer as opposed to in hardware, and dealing with all the problems due to starting work in an almost non-existent laboratory.

Each of the five papers has been ascribed to a single author, and no acknowledgements to other members of the phonetics group have been included. But the group has worked together as a whole, and we could all be considered as responsible in part for all of the papers. In addition to the authors of the five papers, only one of whom (J. Anthony) has been directly supported by NIH funds, the following have also been associated with this work:

Elizabeth Uldall (University of Edinburgh), consultant during part of November 1963
Sven Ohman (KTH, Stockholm, and MIT), consultant during the month of April 1964
Frederick Michelman, Research Assistant
Philip Kramer, Senior Electronic Technician (until 6 March 1964)
Willie Martin, Senior Electronic Technician
Donald Truitt, Electronic Technician
Julia Haaker, Secretary

We would also like to acknowledge the assistance of Professor Hans von Leden of the Laryngeal Research Unit, UCLA, and Professor Isadore Rudnick of the Physics Department, UCLA.

P. L.

Physiological Characterization of Speech

Peter Ladefoged

There are basically four possible approaches to speech synthesis; one of these has not yet been tried. The four approaches arise because there are two independent dichotomies. In the first place a synthesizer can be controlled in terms of a limited number of parameters; alternatively the control signals can be derived from a complex pattern with no fixed number of variables being specified. Examples of the first kind of device are OVE II (Fant, et al., 1963) and PAT (Anthony and Lawrence 1962), both of which synthesize speech in terms of specific parameters such as the intensity and frequency of a pulse source, the frequency of the first three formants, etc. These synthesizers are ideal for experiments on the perception of speech of the kind which involve controlled variations of one or more parameters. The alternative aspect of this dichotomy is exemplified by the Haskins Pattern Playback synthesizer which is capable of accepting complex, largely unstructured, acoustic specifications. This device has provided a great deal of information about the perception of different acoustic patterns. However, it should be noted that although the control signals for the Pattern Playback are not given in parametric terms, the output of the device can be stated in this way. The signal must be composed of the first 50 harmonics of a 120 cps tone. So in one sense, this is a 50 parameter specification of speech. But these parameters are due to limitations in the machine. They are not chosen by the experimenter. We may therefore refer to it as a non-parametric speech synthesizer.

The second division among speech synthesizers is between those that are based on acoustic and those that are based on articulatory principles. Despite the fact that articulatory descriptions of speech are far more common than acoustic, the reverse is true of existing speech synthesizers. All the devices mentioned above try to reproduce the acoustic structure of human speech. Only a few intelligible simulations of the articulatory process have been built, the most recent of them being electronic analogs of the shape of the vocal tract (Rosen 1960, Dennis and Whitman 1964). When we consider these articulatory synthesizers in terms of the other dichotomy (parametric -- non-parametric) we find that they are all parametric only in that, for technical reasons, they specify the cross-sectional area of the vocal tract at a limited number of points along its length. They are similar to the Haskins system for playing back spectrograms in that the parameterization is best regarded as an artifact of the machinery. A speech synthesizer that operates in terms of true articulatory parametric control signals has not yet been constructed. The nearest approach lies in the possibility of using the M. I. T. synthesizer controlled by a digital computer operating on articulatory specifications of the shape of the vocal tract.

Before we consider ways of specifying the shape of the vocal tract, we should make a brief survey of the other factors which have to be considered if we are to build a speech synthesizer operating in terms of physiological parameters. There are at least four factors which have to be specified apart from those required for describing the positions of the tongue and lips. Firstly we must specify the power input to the glottal source; the value of this parameter may be correlated with the product of the air pressure and rate of flow of air in the trachea. Secondly we must specify the state of the glottis. In preliminary work it will probably be sufficient to consider only three discrete states of the vocal cords: the position for voiced sounds (vocal cords vibrating); that for voiceless sounds (vocal cords apart but still causing local turbulence in the airstream); and that for breathy voice (vocal cords slightly apart and with the edges loosely vibrating as in an intervocalic [h]). Thirdly, in the case of voiced sounds we must also state the value of another variable, which we may label "tension of the vocal cords". This is effected by several different muscles; but, as has been shown in a previous paper on some of the physiological parameters of speech (Ladefoged 1963), it is useful to consider the total effect of these muscles as a single factor. Fourthly we must specify the degree of velo-pharyngeal stricture.

We may now return to the parametric specification of the positions of the tongue and lips. Not much work has been done on the assessment of the validity of possible articulatory parameters. There are two well-known methods of specifying the shape of the vocal tract. The M. I. T. system (Stevens and House 1955) specifies the cross-sectional area of the vocal tract at the point of maximum constriction, the distance of this point from the glottis, and a factor representing the degree of lip-opening and protrusion. The more traditional method, which dates from the work of Bell (1867) and is best elaborated by Jones (1956) also specifies three variables: the position of the highest point of the tongue in the front-back and in the high-low dimensions, and the degree of lip-rounding. Neither of these two systems has been tested by seeing the extent to which a given specification can actually be used to predict the shape of the vocal tract as a whole; but there undoubtedly would be some difficulties with each of them in this respect. This point is illustrated by Figure 1 which shows the shape of most of the vocal tract in two pairs of contrasting vowel sounds in Igbo (a Nigerian language; the relevant phonology and an account of the cine-radiology technique used for obtaining these data are given elsewhere (Ladefoged 1964)). The members of each of these two pairs of vowels are acoustically very different from one another, as might be expected considering the narrowing of the pharyngeal part of the vocal tract in the case of the vowels shown with a dashed line. But specifications in either of the two ways discussed above cannot be used to predict these differences.

At this point it is worth considering what is the most interesting form of a set of articulatory parameters. The specifications we have discussed reflect coincident properties of the shape of the vocal tract, rather than intrinsic properties due to the organization of the anatomical structures. Describing articulations in terms of the highest point of the tongue or the point of maximum constriction of the vocal tract is rather like describing different ways of walking in terms of movements of the big toe or ankle. It might be possible to use such descriptions as approximate accounts of the position of the leg as a whole in many gaits; but any description of this kind is bound to be inadequate if it does not take into account the anatomical possibilities. We must now consider a method of specifying the shape of the vocal tract which does take some account of the anatomy. If we neglect, for the moment, the tip and blade of the tongue (perhaps regarding it as down behind the lower front teeth, as it often is in vowel sounds) we can describe the remainder of the vocal tract by stating the position of the center of the body of the tongue in an arbitrary coordinate system, providing we also state the length of the arc or pseudo-diameter at the center. This system, like the others, has not yet been evaluated. It is more complex in that it involves three variables as opposed to two for the body of the tongue. But it seems probable that it will be better able to account for data such as that shown in Figure 1. It also reflects the anatomical constraints on the shape of the vocal tract arising from the fact that the general position of th body of the tongue (the locus of the center point) can be moved in the mid-sagittal plane by the action of three or four extrinsic tongue muscles, which operate independently of the intrinsic muscles controlling the shape of the body of the tongue (roughly specified by the length of the arc).

The literature on the anatomy of the tongue is reported in an accompanyi paper (Olshtain 1964). Although there are some very informative research pape (Abd-el-Malek 1939, Dabelow 1951, Strong 1956), the discussions in the anatomy books which are specifically designed for students of speech are remarkably inadequate. Three such books have appeared in the last five years. In the 35 pages of _Anatomy and Physiology of Speech_ (Kaplan 1960) there are only three pages on the muscles of the tongue. Leith (not dated, 1960?) in his _Drawings of Anatomical Structures Involved in Speech_ has eighteen pages of diagrams of parts of the respiratory system but only four pages on the tongue. Shearer (1964) in his _Illustrated Speech Anatomy_ has an even smaller proportion of material devoted to the tongue. The only good account of the anatomy of articulation occurs in the more general books _Voice and Articulation_ (van Ripe and Irwin, 1958) and _General Phonetics_ (Heffner 1952); and even here the material is not arranged so as to make it possible to discuss articulatory parameters.

The comparative lack of attention given to the tongue is most surprising since its actions are obviously responsible for much of the information conveyed by speech. In English, for instance, the action of the larynx distinguishes only two classes of sounds (voiced and voiceless) and perhaps only four levels of pitch among the voiced sounds. The respiratory system probably separates out only stressed from unstressed syllables; and the soft palate only oral from nasal sounds. Even in the description of the lips we have to distinguish between only the closed position, the fricative position, and at most four degrees of lip rounding. But the tongue has a different position for at least sixteen sounds. From the point of view of signalling power, it is two or three times more important than the other parts of the speech apparatus. Yet we have very little real knowledge about the methods of producing the different gestures of the tongue.

The U.C.L.A. phonetics group has started a series of investigations on this problem (c.f. Hill 1964). Observations of high-quality X-rays, direct measurements, and comparison with anatomical dissections of cadavers indicate that the forces exerted by some of the muscles of the tongue during the pronunciation of the vowel [ə] in one subject are approximately as shown in the illustration on the cover.* The bulk of the inferior part of the tongue is formed by the genioglossus muscle, which is attached, in all the cadavers we have seen, to a comparatively small region in the center of the mandible. The fascia separating the muscles below (geniohyoideus and mylohyoideus) are indicated on the X-rays; and it is quite easy to determine the upper limit of the attachment of genioglossus to the jaw bone from dental impressions or by feeling with a forefinger down behind the lower front teeth. So we are reasonably certain that this muscle can pull the body of the tongue only towards an area half way between the chin and the lower front teeth. But, as the muscle may not function as a whole, we can think of it as exerting forces in the several directions represented by the arrows. We do not know what degree of control is possible, so the number of arrows shown in the figure is entirely arbitrary.

The upper part of the tongue is formed by the vertical and transverse muscles, and two pairs of longitudinal muscles. We have no data on the exact proportion of the tongue occupied by these muscles in this subject, since X-rays do not reveal the thin paramedian septum which separates them from genioglossus. Consideration of the thickness of the tip and blade of the tongue in this subject, and examination of cadavers, lead us to deduce that the area above genioglossus is probably approximately as shown. In a study of vowel sounds the most important muscle in this area is longitudinalis, which is responsible for the bunching up of the tongue lengthways.

A considerable proportion of each of the other muscles with which we are concerned lies outside the body of the tongue. The origins of the styloglossus muscles are at the styloid processes which are above the tongue on the skull approximately at the level of the ears. The actual positions are accurately known for this subject from the X-rays; and we can feel the course of the muscles as they come down behind the faucal pillars. It is only when they have entered the body of the tongue that we have no precise information about their whereabouts in this subject. The styloglossus muscles clearly form a sling which will lift the tongue upwards and backwards. They may be assisted in this action by the palatoglossus muscles which form the faucal pillars surrounding the uvula. But each of these is a much smaller muscle than styloglossus which is as much as one centimeter wide at the point where it enters the body of the tongue.

The body of the tongue may be pulled backwards and slightly upwards by the part of the superior pharyngeal constrictor muscle known as glosso-pharyngeus. This muscle originates in the back wall of the pharynx and

* Also reproduced in diagramatic form below Figure 1.

inserts into the sides of the tongue. Both it and styloglossus are opposed in their action of pulling the tongue up by hyoglossus which has its origins on the hyoid bone and consists of two thin sheets of muscle going up and entering the sides of the tongue; again we have no precise idea of where hyoglossus merges with styloglossus and the other muscles within the tongue; but clearly, provided the hyoid bone is prevented from going up, hyoglossus can be used to pull the body of the tongue down.

The illustration also shows two other pairs of muscles which affect the position of the tongue. Both pairs are attached to the hyoid bone. The body of the tongue may be raised by raising the hyoid bone through the contraction of stylohyoideus, which lies close to the styloglossus muscle; or it may be pulled upward and forward through the contraction of geniohyoideus, which parallels the lower fibres of genioglossus. The whole tongue may also be raised through the contraction of the mylohyoid muscles, which are not shown in this diagram. These muscles run from the sides of the mandible to the hyoid bone; they thus form the floor of the mouth. They originate about half way up the mandible which they follow downwards before turning towards the hyoid bone. Consequently they can lift the tongue considerably.

We may deduce the possible contribution of some of these muscles in the formation of a given vocal tract shape from a consideration of their lengths relative to their lengths in other positions. The length of a muscle can be measured fairly accurately when we know the positions of both the origin and the insertion. This is the case for muscles such as geniohyoideus and stylohyoideus, where the X-rays provide sufficient data. In the case of other muscles, such as genioglossus, hyoglossus, or styloglossus, where we know only the origins, our measurements of the lengths involve greater uncertainties. And for intrinsic muscles such as longitudinalis, we can make only very rough approximations.

Figure 2 shows deductions concerning the relative forces exerted by most of the muscles of the tongue in the formation of a series of vowel sounds based on the radiology data which is reproduced schematically in the upper part of the figure. The length of each muscle was measured and the force it exerts in producing a given vocal tract shape was assumed to be proportional to its degree of contraction relative to its greatest length. Thus in forming the shape for /e/ the anterior fibers of genioglossus are not contracted so much as the posterior fibers, which are acting with geniohyoideus to pull the hyoid bone upwards and forwards. Both styloglossus and stylohyoideus must also be active in this vowel, lifting the tongue up; and there must be considerable contraction of the longitudinalis and other muscles in order to produce the bunching up lengthwise. The vowel /ə/ has slightly greater action of the anterior and medial parts of genioglossus and a slight action of glossopharyngeus pulling the body of the tongue backwards. The main downward pull on the tongue in this vowel is probably exerted by hyoglossus. The pattern for the production of the vowel /a/ is fairly similar, except that the tongue is pulled more back and down by these two muscles, and there is also more action of longitudinalis increasing the curvature of the tongue. The vowel /o/ is interesting in that on the basis of these data it appears that the body of the tongue is considerably raised by the action of styloglossus, but this pull is not supplemented by the action of stylohyoideus, since the hyoid bone is not raised from the position it had for /a/. In the pronunciation of /o/ there is also the backward pull of glossopharyngeus, and the bunching up which can be associated with longitudinalis.

The conclusions suggested by Figure 2 should clearly be regarded as tentative hypotheses until they have been confirmed by other experiments. As Abd-el-Malek (1938) said, "The intricate interlacement of fibres of the intrinsic muscles of the tongue and hence the difficulty, or rather the impossibility, of throwing single muscles into contraction has been the cause of the prevailing uncertainty about the individual action of each of this group of muscles. It is not therefore improbable that some of the movements of the tongue are attributed to a certain muscle, when in reality they are affected by another." We must clearly seek further evidence before we can make any final statements about the action of the muscles of the tongue in producing different vowel sounds.

It is very hard to verify the statements made above by means of other experiments. One possibility is by recording electromyographically the action of the muscles. This approach is being used with some effect by members of the Haskins Laboratories (MacNeilage and Sholes, forthcoming), but there are difficulties in that it is often hard to make satisfactory recordings from individual muscles. An alternative method of verification is to build a replica of the vocal tract, using materials with similar mechanical properties to skin, muscle, bone and cartilage. We could then try to discover the forces which have to be exerted on the replica in order to move it into the various different positions. The construction of a device which can be developed for investigations of this kind is discussed in an accompanying paper (Anthony 1964).

We may now return to considering what is the best form of description of the vocal tract. The first answer is that it depends on the purpose of the description. From the speech pathology point of view, it might be advisable to try to make a specification in terms of the operation of the individual muscles. But from the linguistic phonetician's point of view, this seems unnecessarily redundant, since a movement in one direction is often the resultant of muscular pulls in two different directions. If we are interested in a description which has the maximum simplicity but nevertheless accounts for all the facts and is intuitively satisfying in that it reflects the anatomical possibilities, then it seems that the third form of description discussed above is more suitable.

In addition to considering the shape of the vocal tract as determined by the position of the body of the tongue, we must also consider parameters which will specify the position of the tip of the tongue. It may be possible to do this by a two-number specification; there is little data on this aspect of tongue shape. Finally the position of the lips must be expressed in terms of parameters; some suggestions in this respect are made in an accompanying paper (Fromkin 1964). It appears that a two-number specification may not be sufficient.

The whole of this model of the process of speech production could be verified by computer simulation; and some time in the future we hope to assess at least part of the model in this way. But we have decided not to rely entirely on computer verification for the moment, preferring instead to attempt to construct a replica of the vocal tract (as described in the next paper) and more direct physical analogs of the other parameters. We have already found several advantages to this course. Firstly we have been forced into taking more overt decisions, and realizing how much we do not know. The usual way of specifying the vocal tract shape when programming a computer is to state the cross-sectional area at a number of points. But in constructing a replica of a vocal tract we had to go back and consider the physiological data in far more detail. Thus in our model the tongue has to have a specific relationship to the side walls of the pharynx such that only certain kinds of changes in vocal tract shape are permitted. Secondly there are fewer assumptions in our approach, since we do not have to know the formal mathematical answers to all the acoustic problems in the process of speech production; thus, as specific examples, we do not have to assume that there are (or that there are not) only plane waves in the vocal tract, and we do not have to understand the acoustic results of complicated tongue shapes such as those in lateral sounds. Thirdly there are no approximations or effects due to sudden changes in the vocal tract area in our model, since our cross-sectional area varies continuously, and is not stated in terms of a number of sections as in the usual computer simulations. Fourthly there is a conceptual simplicity in the whole synthesis system, which makes it readily understandable by anyone who has worked in the field of phonetics. The speech synthesiser which has been most used in the past is the Haskins Pattern Playback (Cooper 1962). This device produces sounds from patterns looking like spectrograms; consequently it can be used by anyone who is familiar with elementary acoustic phonetics. It is not the most accurate speech synthesiser; nor has it been the only one available at the Haskins Laboratories. But it has produced the most experimental results because of its conceptual and operational simplicity. We hope to produce a speech synthesiser which uses an articulatory description of speech in an equally simple way. As the accompanying papers show, we are a long way from realizing this aim. But our attempts to get data and to build such a machine have already taught us a lot about speech.

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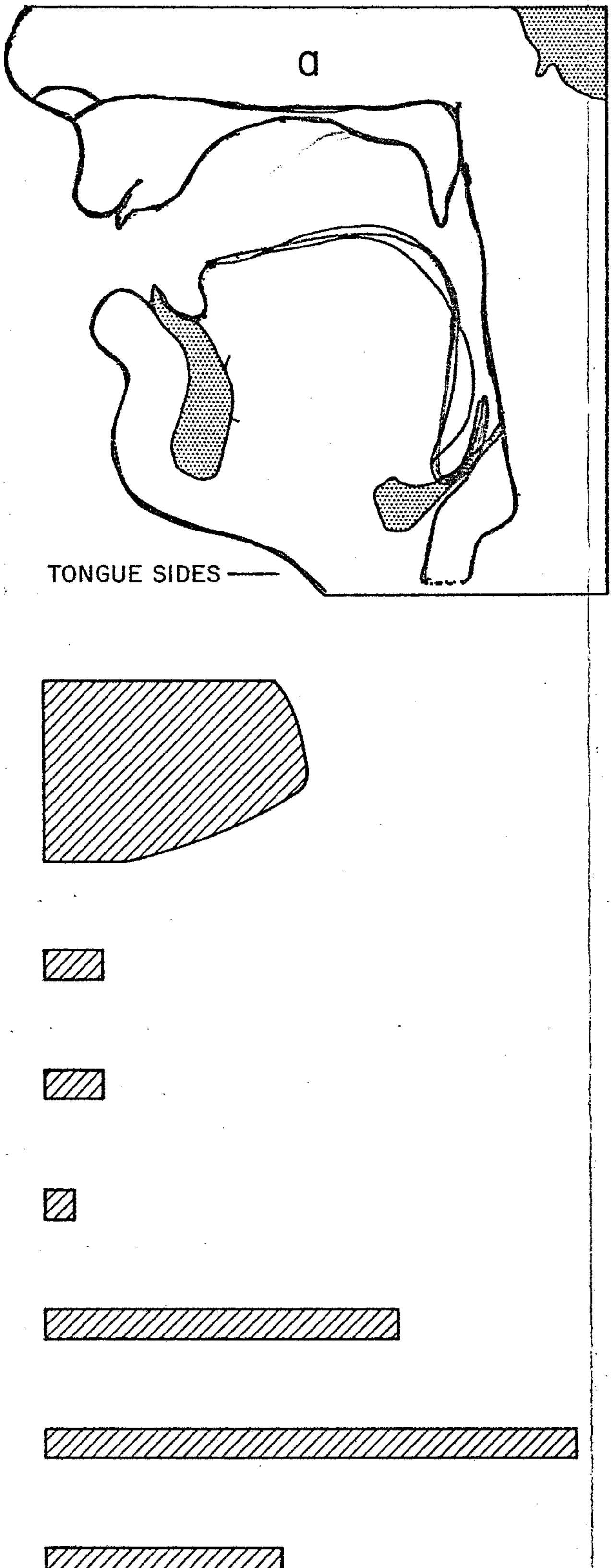

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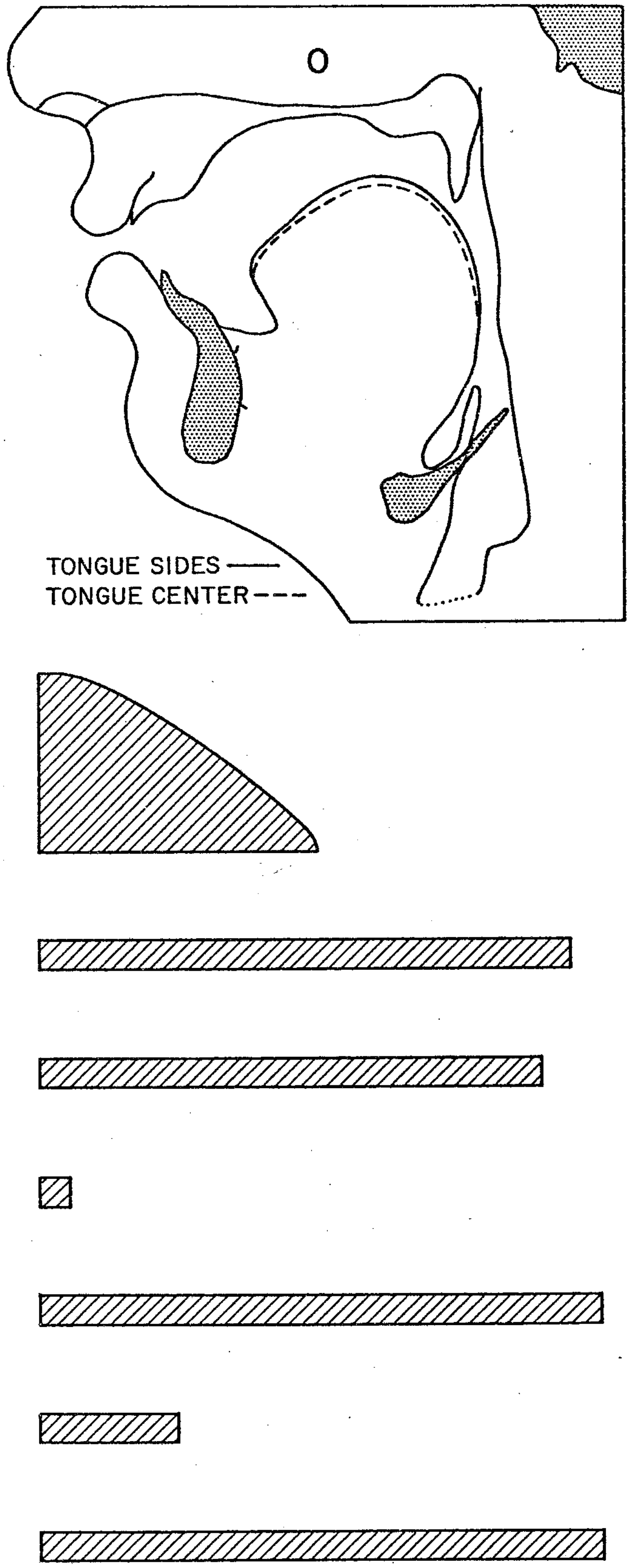

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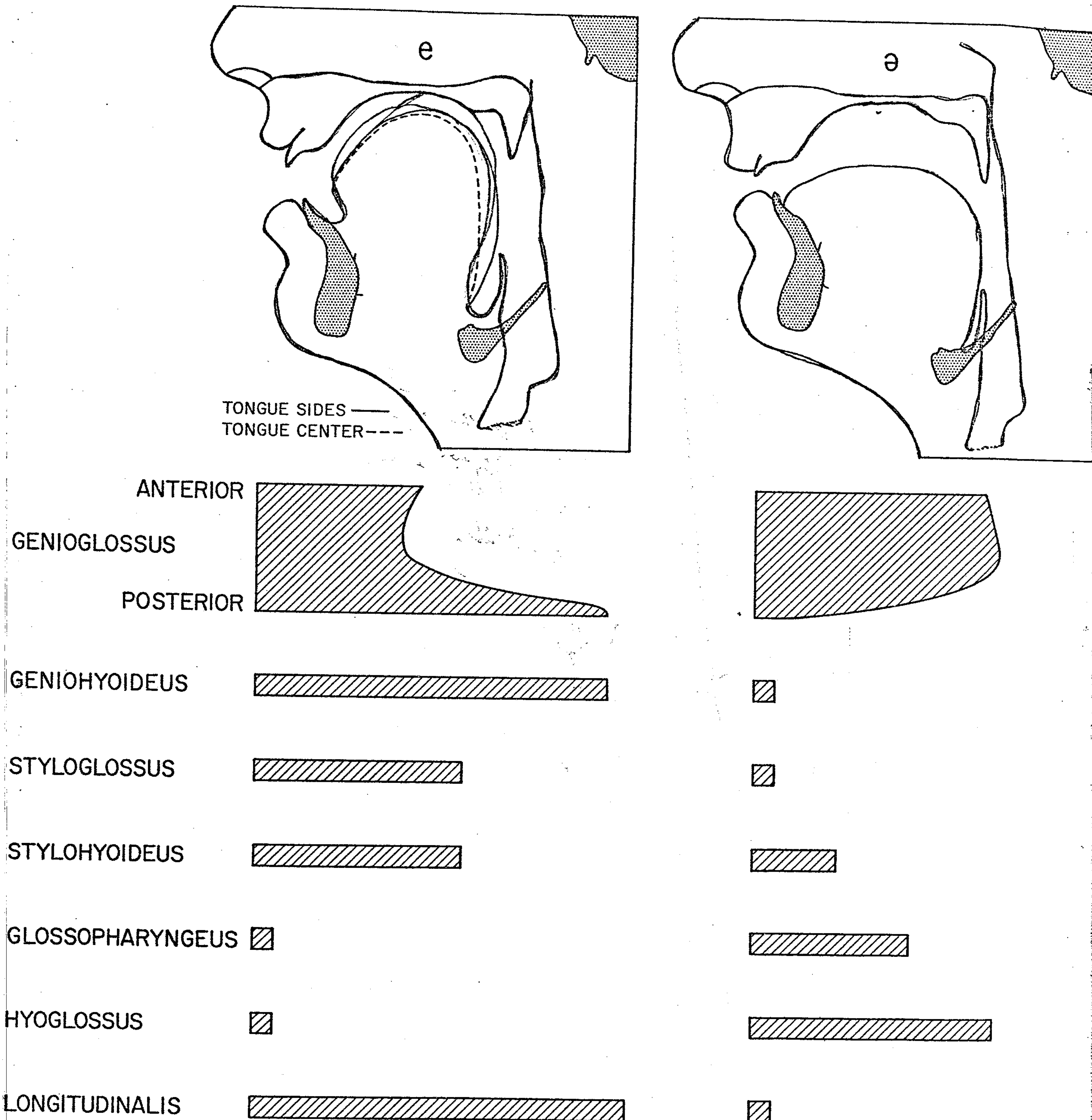

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HYOGLOSSUS
LONGITUDINALIS

Replica of the Vocal Tract

J. Anthony

This paper should be considered as a Progress Report on part of the proj outlined in the previous paper. We would like to build a replica of a vocal tract coupled to a simulation of the glottal source, largely so that we might gain some further insight into speech from the articulatory and physiological viewpoint. We would hope that the knowledge acquired in this way might be useful in solving some of the current problems in the analysis and synthesis of speech (Peterson 1963).

We are under no illusions regarding the difficulties of constructing a true and dynamic replica. But techniques and materials are available today that were not available two hundred years ago, when the first and last complet talking heads were made (Dudley and Tarnoczy 1950).

As the first phase of this work we have constructed a static replica of a given vocal tract shape. Next we hope to construct an articulatory replica in which the tongue position will be determined by a manual adjustment, and the lip position, soft palate movement and source control will be electro-mechanical. The larynx source will be a horn-driver loudspeaker.

In the next phase we hope to develop electromechanical control of tongue position and shape by a set of shape parameters, and also to replace the horn-driver by a more suitable source of the air-modulator type (Burgess and Salmon 1955).

There are three requirements in the building of a replica of this kind. Firstly we must have accurate measurements of a subject's vocal tract to serve as a model. Secondly we have to construct the replica from materials which would be most like that of a human vocal tract from an acoustic and physiological point of view. And thirdly we require an adequate source to serve as the input to the system.

We obtained measurements from full face and side view photographs of the subject saying four different vowels. Simultaneous lateral X-rays were taken of these same vowels; and laminagrams showing a cut in the plane of the first and second molars were also taken during another utterance of one of these vowels. The laminagrams could not be interpreted very accurately. Far better measurements of the cross-section of this part were obtained from dental impression material squirted into the subject's mouth while he was saying one of the vowels. These impressions also enabled us to record the position of the lips very accurately as shown in an accompanying paper (Fromkin 1964). From all these sources of data we have a quite accurate idea of the shape of the anterior part of the subject's vocal tract.

Apart from the lateral X-rays we originally had no idea of the size and shape of the subject's pharyngeal cavity. A search of the literature indicated that no one had made a complete series of direct measurements of the pharynx from the level of the arytenoids upwards. Most investigators have estimated the size, and then verified their figures by using them as part of the input to a speech synthesiser (Fant 1960, Wendahl 1957). It has been reported (Heinz and Stevens 1964) that a 20% error in the estimate of the cross-sectional area of the tract will cause only a 5% shift in formant frequency; consequently it would seem that this method of investigation will not lead to a replica sufficiently accurate for research on the actual articulations.

Our method for measuring the pharynx during the pronunciation of the vowel /a/ is shown in the illustration on the cover. The subject passed a thin catheter marked off in centimeter lengths of alternate colors through the nose into the esophagus. The catheter was then adjusted so that it ran down and lay against the middle of the back wall of the pharynx. It could then be used for making measurements in the vertical dimension. The length of the pharynx found in this way was checked against the X-ray data. The subject then came over a 4 cm. diameter front-silvered mirror which was arranged so that a bright beam of light was reflected down the pharynx.

When the subject was saying /a/ the experimenter inserted the specially constructed pair of calipers which can be seen in the illustration. The distance between the points at the distal end of these calipers can be varied, and the actual value read off on a scale at the experimenter's hand. Measurements were taken by extending the calipers under visual control to touch both sides of the pharynx. Measurements were made at centimeter intervals from the arytenoids to the faucal pillars.

At the present time we do not have a replica whose articulatory configuration can be changed. We have, though, made some study of flexible materials to simulate flesh and skin. One material in particular shows great promise. This is a hot melt vinyl, similar to that used for Walt Disney's mechanized figures at the World's Fair.

A prototype head, however, has been made with a complete oral but no nasal tract. Its core is a human skull having dimensions close to those of the subject, with the hard palate and upper and lower teeth replaced by casts in stone of those of the subject. A brass hyoid bone equivalent to the subject's has also been added. On this substitute structure the vocal tract and face have been constructed out of modelling clay.

Building this head has helped us to clarify our ideas concerning the problems of construction, and provided a rough test bed for acoustic measurement investigation. The replica is shown set up in an anechoic chamber in the last illustration on the cover.

Before describing measurements of the output of this replica, the requirements for the source function need to be considered. Firstly it should be able to supply volume velocities of up to 1200 cc/sec. (Flanagan 1958). Secondly its internal acoustic resistance should be of the order of 2 ρc or 80 acoustic ohms (Flanagan 1958, Van den Berg 1955). Thirdly if possible it should have a flat frequency response in terms of volume velocity against applied voltage.

The frequency response in terms of volume velocity and the internal resistance of three horn-drivers was measured by means of an acoustic line. The pipe diameter was 1/2 inch and the length was 15 feet, of which the last 5 feet was used for an acoustic wedge of lamb's wool. This termination was found to be within 10% of ρc. One can consider this line as representing fairly closely an infinite line. Measurement of pressure close to the driver was made with a Bruel and Kjaer 1/4 inch condenser microphone fitted flush with the inside of the tube.

Response A on Figure 1 is for one of the low-frequency low-power drivers, the Altec 730 A. Curve B is for the high-frequency high-power driver, the Altec 288 C, in this case with some equalization to approximate curve C which is a standard source spectrum envelope. Zero db for both curve A and B refers to 30 cc/sec rms which appears to be maximum that can be obtained from either of these speakers.

The internal resistance of the lamb's wool plugs used as acoustic resistances was measured by removing the acoustic termination from the line and replacing it with the driver, leaving the plug piece on the other end. Probe measurements of standing wave ratio throughout the frequency range gave an acoustic resistance which varied from 2.5 ρc at 500 cps to 1.2 ρc at 4000 cps. The accuracy of this method is limited because the other end of the plug is exposed to the air, but the acoustic resistance above 500 cps is certainly higher than that measured.

Figure 2 shows the output of the replica when referred to the standard source function decreasing at 12 db per octave (a double pole on the real axis at 200 cps). Using a Bruel and Kjaer 1 inch condenser microphone the output was drawn by the Bruel and Kjaer response curve tracer at 1 mm/sec.

If we can assume a 1/2 inch diameter pipe at the glottis, a calculation on the basis of the figures for /a/ given by Fant (1960) for the pressure at that point, gives a volume velocity of 30 cc/sec which is what was used for these measurements. On that basis the pressure found at 5 cm in front of the mouth is 7 db lower than his value, but if we can extrapolate for the difference in F1 frequency -- and this of course is a very rough calculation -- then there is quite good agreement.

The first point of interest is the magnitude of the bandwidths of the formants of the replica, which are approximately 70 cps for F1, 100 cps for F2, 150 cps for F3 and 200 cps for F4. These values are surprisingly high

APRIL 1964

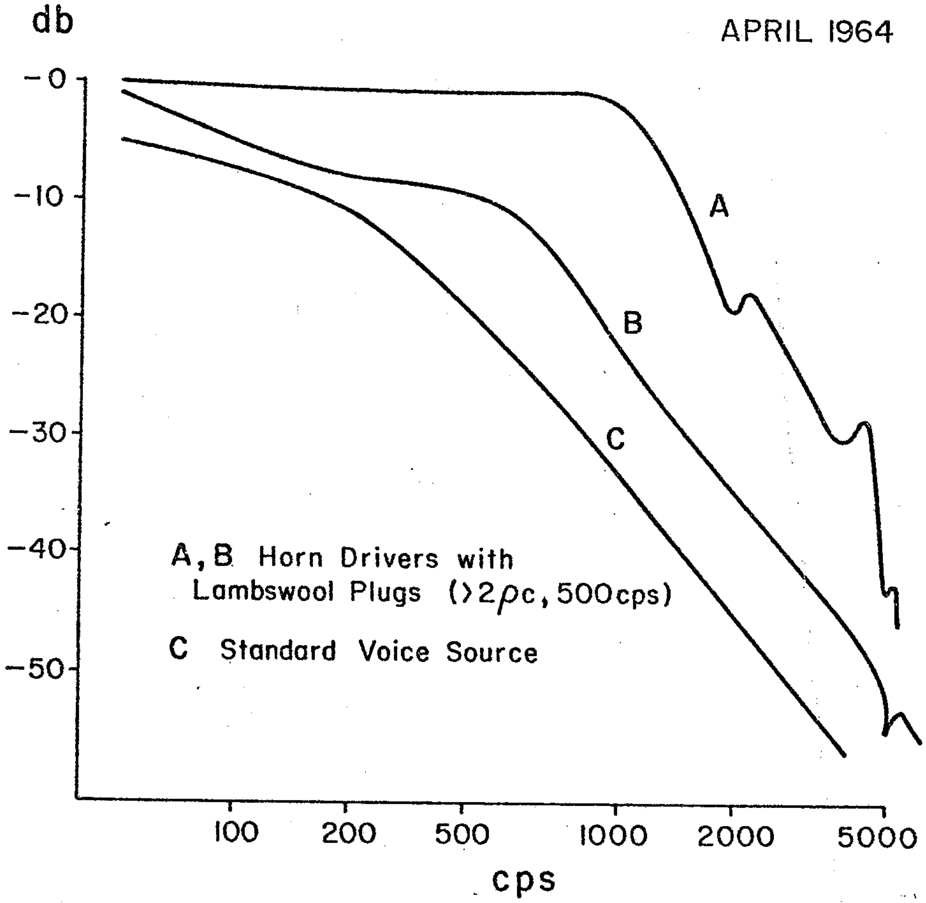

Figure 1

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RESPONSE OF FIRST MODEL (CLAY)
WITH STANDARD VOICE SOURCE

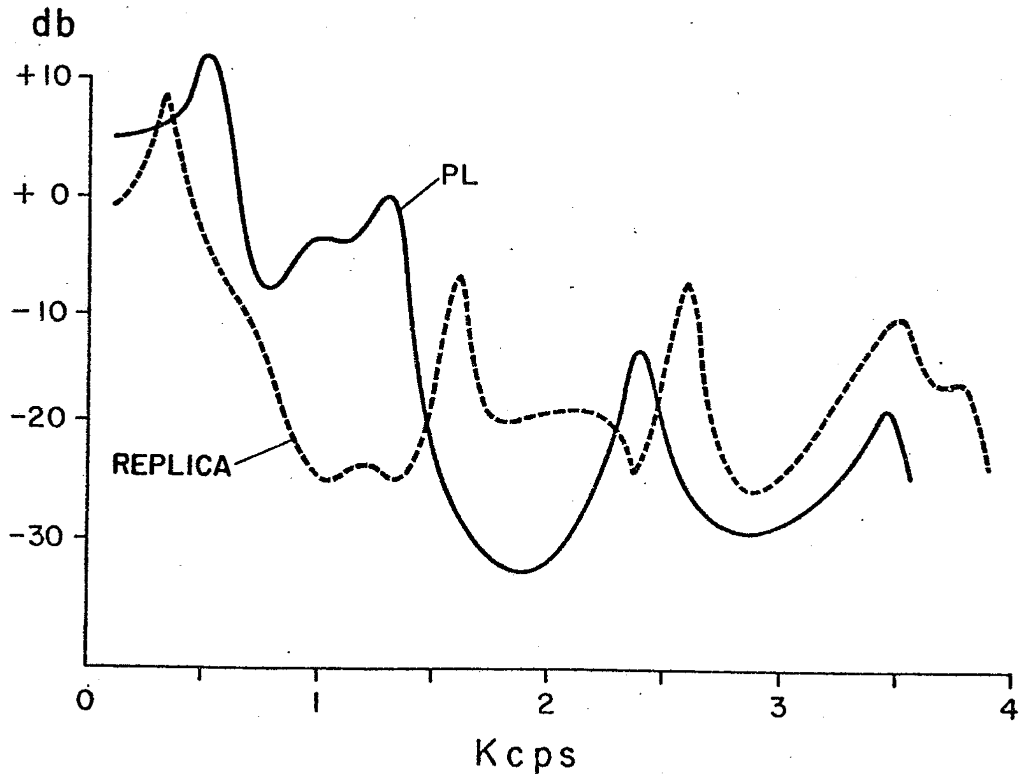

Figure 2

considering that the replica tract approaches a hardwall tube.

From a number of recordings and many spectrographic narrow bandc sections, the curve marked PL was chosen as being representative of the spectrum envelope of the original vowel. This is an actualeenvelope, however, not an average. The well-damped formant at 1 kcps is constant and is almost certainly due to nasalization of the vowel, since the X-ray shows the velum lowered and so some coupling to the nasopharynx.

The match between the curves is only fair. F1 of the replica is at 350 cps against 500 for the original. For F2, the replica is 300 cps too high. For F3 the difference is 200 cps.

The level of F3 and F4 is much too high, and this may reflect the findings of Fant (1960) and Van den Berg (1955), who concluded that the source spectrum falls off at a rate greater than 12 db per octave above 2000 cps.

The level between the formants is also too high, and this appears to be due to three peaks in the sound which originates not from the lips of the replica but from the enclosure of the source. Obviously, the design of this driver enclosure requires much more thought. A directional microphone as used by Van den Berg (1955) would also help. The driver, too, is quite inadequate for the purpose. Peak velocities fifty times greater are required, and a flat frequency response would make measurement much easier.

Under these conditions we cannot claim a very high accuracy for the curve, but the results are encouraging. At this state, at least we have a fairly good grasp of the problems involved in this project.

I would like to acknowledge the great assistance given by Professor Rudnick of the Physics Department at UCLA. Technical assistance was provided by Mr. W. Martin, to whom I am also very grateful.

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Parameters of Lip Position

Victoria Fromkin

This paper describes an investigation of some parameters of lip positions which occur during the articulation of a range of American English vowels. The aims of the investigation were 1) to measure a number of variables and to determine which, if any, might be used as suitable parameters for the specification of lip positions, and 2) to produce data which could be utilized in the construction of a physiological speech synthesizer.

Other approaches to the investigation of lip positions have been taken. Fujimura studied the movements of the lips in the production of bilabial stops and nasals by means of a stroboscopic technique (Fujimura 1961). The data were obtained from one speaker at one sitting. Measurements of mouth openings for four vowels in different consonantal contexts were given as functions of time.

Stevens and House, viewing the vocal tract as "an acoustic tube of variable cross-sectional dimensions" specified the mouth opening by a single number equal to the ratio A/1, with A equal to the area of mouth opening and 1 equal to the length of tube extending beyond the point 15 cm from the glottis (Stevens and House 1955). Idealized articulatory dimensions were used (Ibid, 487). The area of the mouth opening was determined by adjusting the parameters of a vocal tract analog until the sounds produced were satisfactory. The work of Fant follows a similar approach (Fant 1960).

The electromyographic work on the lips being done at Haskins Laboratory concerns the muscles or groups of muscles used in articulating speech. The present investigation, while concerned with the muscles associated with the different lip positions, is primarily concerned with a quantitative description based on actual measurements of the lips.

Procedure

At the beginning of the investigation attempts were made to measure the lips of a subject "in vivo" under natural speaking conditions. The presence of the measuring instruments altered the lip positions making it necessary to find other methods. Three kinds of data were used for measurement.

1. Standardized simultaneous frontal and lateral photographs were taken. The first sets of photographs revealed the necessity of building a special apparatus for this purpose. Slight movements of the head created variations which led to measurement errors. The frontal and lateral photographs printed in the *Atlas deutscher Sprachlaute* (Wangler 1958) showed this lack of standardization and thus could not be used as a source of data.

To correct this problem, the apparatus shown in the illustration on the cover was constructed. This put the subject in approximately the same position each time photographs were taken, as to the tilt of the head, the distance from the camera, the lighting, and the position of the head in relation to the side view mirror.

To calibrate each set of photographs, horizontal and vertical scales were placed in the same position and at the same distance from the camera as the lips. The ear pieces which set the distance of the head from the camera, and the nose piece which kept the head-tilt constant, were not so rigid as to cause the subject too much discomfort. This allowed for some variation in head position.

2. Stone casts of a subject's lips were made to compare the measurements taken on the two-dimensional photographs with a three dimensional replica.

The first impressions were made by the subject. This method was found to create distortions of the lip positions. A second method of obtaining impressions was found to be more satisfactory. The subject's lip area was squirted with dental impression material while each vowel was articulated. The lips were held steady until the impression material hardened. The impression included the teeth which were to be used as reference points. One set of impressions was cut in half at the center of the lips. A separator was inserted between the two halves and the impression then cast in stone. The cut was made to simplify the taking of certain measurements.

3. Lateral X-rays were made, care being taken to show the soft tissue. Frontal photographs were taken simultaneously. The X-rays and photographs were calibrated with a one-inch metal bar attached to the nose and under the chin.

Five subjects were used in the investigation. For one subject ten sets of simultaneous lateral and frontal photographs were taken. Each set included the vowels in the words *heed*, *hid*, *hay*, *head*, *had*, *hod*, *hud*, *herd*, *hawed*, *hoed*, *hood* and *who*. Some of these vowels are diphthongs; the position recorded was always that during the first part of the vowel. The sounds investigated will be designated as /i, ɪ, e, ε, æ, a, ʌ, ər, ɔ, o, ω, u/. Eleven X-rays were also taken of the same subject. These included all the above sounds except /ω/. Two sets of casts of this subject articulating the twelve sounds were made. Frontal and lateral photographs of four other subjects each articulating one set of these vowels were taken.

Figure 1 shows the dimensions which were measured. These are:

A - Horizontal width of mouth opening from forward most points of corners. Measurements were taken from frontal-view photographs and casts.

B - Vertical height of opening measured at midpoint of lips. Measurements were made on frontal-view photographs and casts. This dimension was also measured on the lateral X-rays as the minimal point of lip separation in the mid-sagittal plane.

C - Area of frontal mouth opening measured with a planimeter from frontal-view photographic tracings.

D - Distance between the forward most points of upper and lower lips measured on lateral photographs and X-rays.

E - Distance from upper front tooth to the line described in D, measured along a line joining bottom of front and back upper teeth. Measurements were made on X-rays and casts.

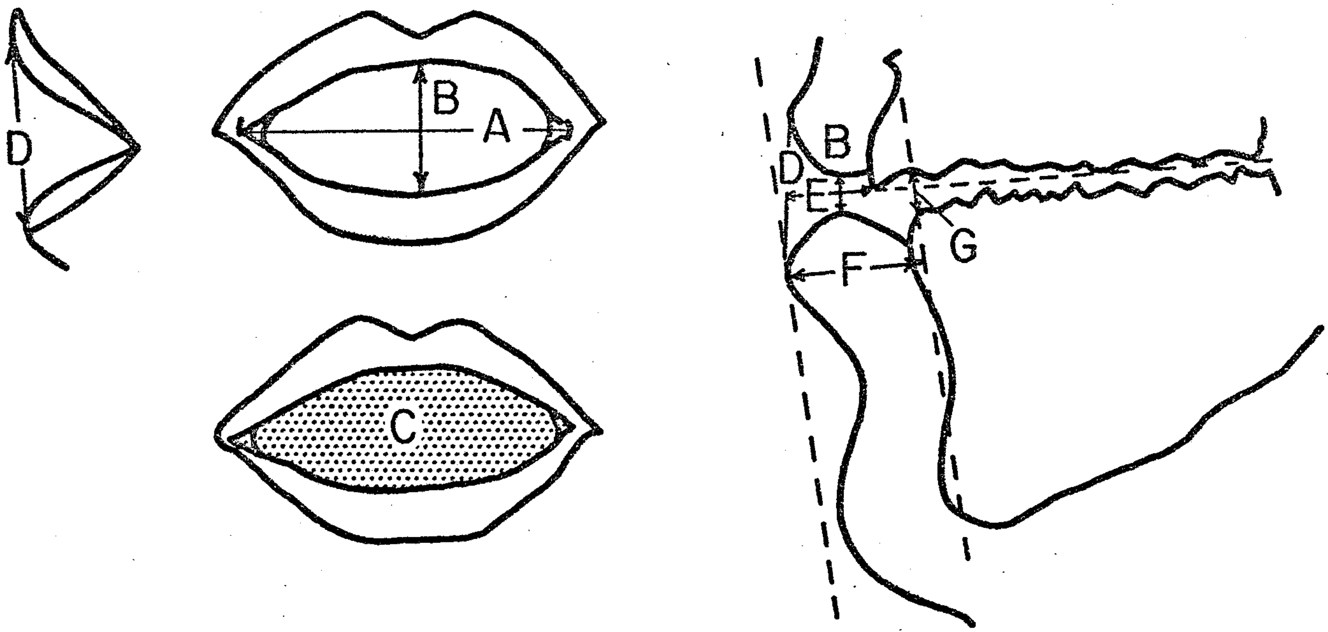
F - Distance from lower front tooth to outermost point of lower lip measured as the distance between a line drawn from a point on the jaw bone to the lower front tooth and a parallel line drawn tangent to the lower lip. The reference line was drawn on an X-ray tracing of the jaw and lower teeth which was then superimposed on all the other X-rays.

G - Distance between the upper and lower front teeth measured along the reference line as in F, to the line of the upper teeth.

Results and discussion

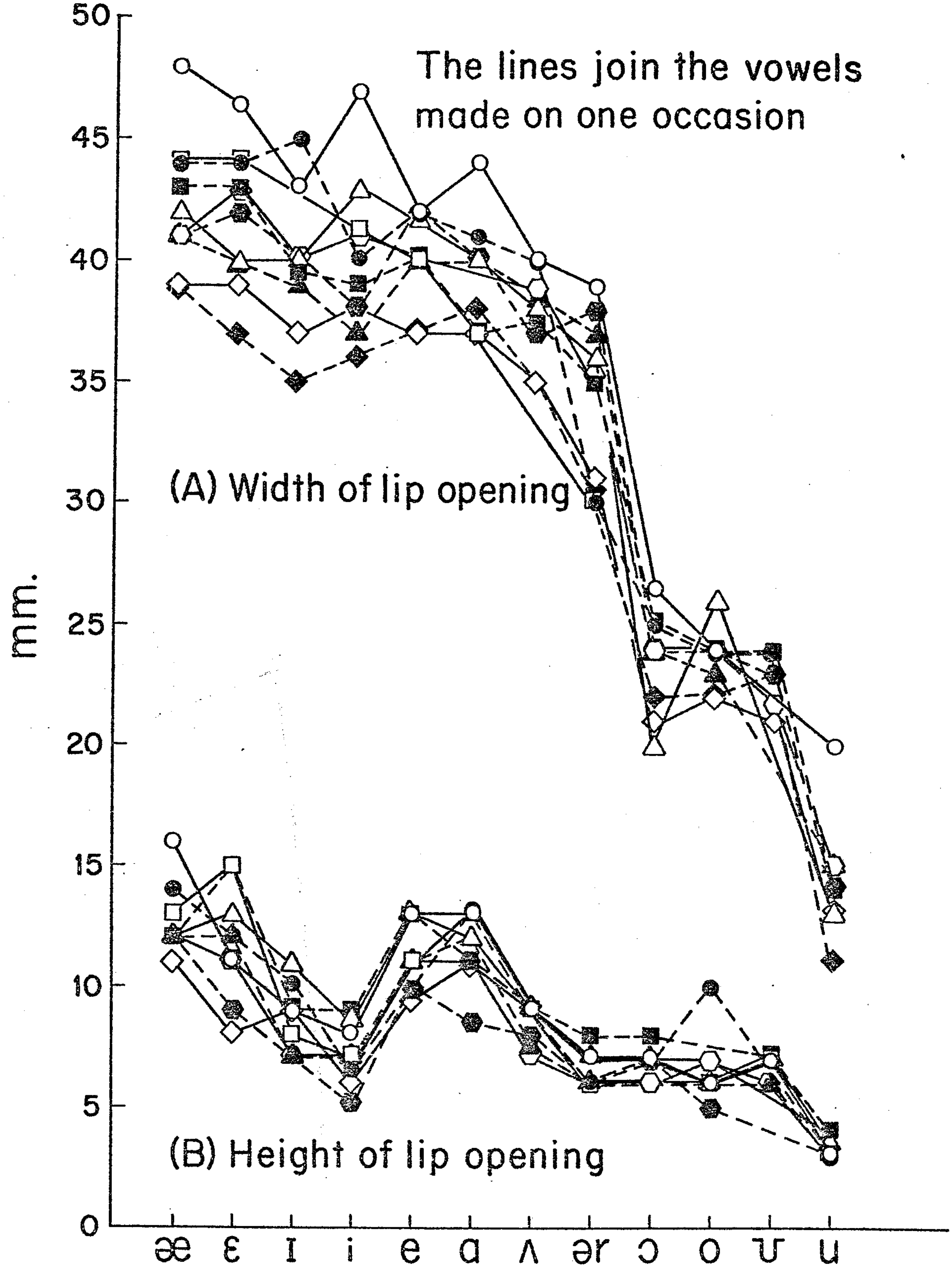
The data were examined for statistical consistency. Differences in the actual articulation of a given vowel on different occasions and measurement errors were not considered separately.

Figure 2 shows the dimensions A (width of opening) and B (height of opening) for the ten samples of each vowel as pronounced by the one subject. Although each point represents the articulation of a given vowel, and the vowels cannot be regarded as points on a continuum of vowel quality, the points representing vowels articulated on a single occasion have been joined together for visual convenience. The curves are quite similar, but show a slight displacement from each other. This displacement may be an actual constant difference in the articulatory positions, or may arise from slightly different lighting conditions or head positions.



(A) Width of lip opening
(B) Height of lip opening
(C) Area of lip opening
(D) Distance between outer-most points of lips
(E) Protrusion of upper lip
(F) Protrusion of lower lip
(G) Distance between upper and lower front teeth

Figure 1



50
45
40
35
30
25
20
15
10
5
0
mm.
The lines join the vowels made on one occasion
(A) Width of lip opening
(B) Height of lip opening
æ ɛ ɪ i e ɑ ʌ ər ɔ o ʊ u

Figure 2

The greatest absolute variation is found in vowels /æ, ɛ, ɪ, i, e, a/. The coefficient of variation for all vowels in the A dimension was less than 10%. However, for the B dimension this ranged from 8% to 22%.

The only vowel which is distinguished in each of these parameters from all the others is /u/; on all ten occasions both dimensions were at a minimum for this vowel.

The remaining vowels fall into groups. There is no statistical difference in the positions of the lips as measured by these two parameters for the vowels /ɔ, o, ω/, but these vowels form a group which is distinguished from all the other vowels with respect to the width of the lip opening. The vowels /i, ɪ, e, ɛ, æ, a, ʌ/ are not distinguished by this parameter, but there is a rank ordering with respect to the height of lip opening such that on a given occasion /i/ always has the minimum value and /æ/ or /ɛ/ always have the maximum value.

The averages of these same dimensions and the corresponding measurements for the other four subjects are shown on Figure 3. It may be seen that for each subject the vowel /u/ is distinguished in the same way as mentioned above in that it has the minimum value on both dimensions; but the rank ordering among the front vowels cannot be established.

It seems that lip positions do serve to distinguish sets of vowels (i.e. the front unrounded vowels from the back rounded vowels) but play little role in distinguishing between the vowels within any one group, except for /u/.

The relation between the height of lip opening (B) and the width (A) for the principal subject is shown in Figure 4. For the vowels /u, ω, ɔ, o, a/ the width of opening increases with the height. But for the front vowels the width of opening remains relatively constant while the height is increased. The central vowels /ʌ, ər/ fall somewhere between these two groups.

The same relationships for the other four subjects are shown in Figure 5. The data of Figure 4 are also shown here in broken lines to compare each of the subjects with the principal subject. It may be noted that the relationships remain the same, while the absolute values differ greatly from subject to subject.

The relationships which have been described can be correlated with the muscles which control the position of the lips. The height of opening for the front vowels is controlled by the position of the jaw. As the mandible is lowered in going from /i/ to /æ/ the opening increases. During the formation of the back vowels the height of lip opening is less dependent on the position of the jaw and is controlled rather by the action of the orbicularis oris, a continuous circle of muscles surrounding the lips,

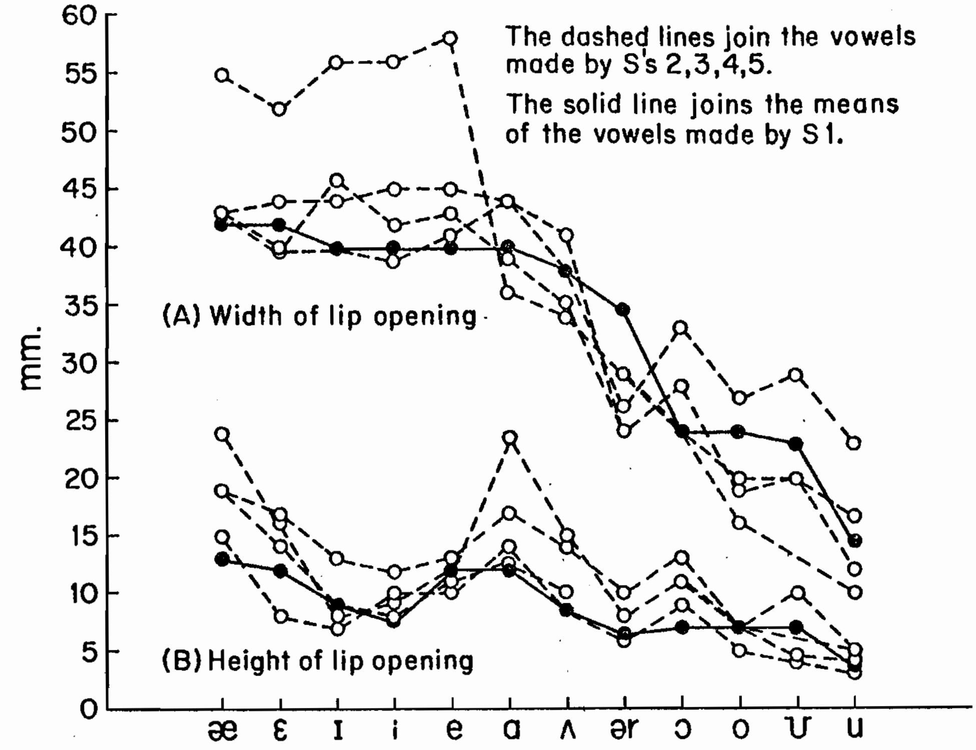


Figure 3

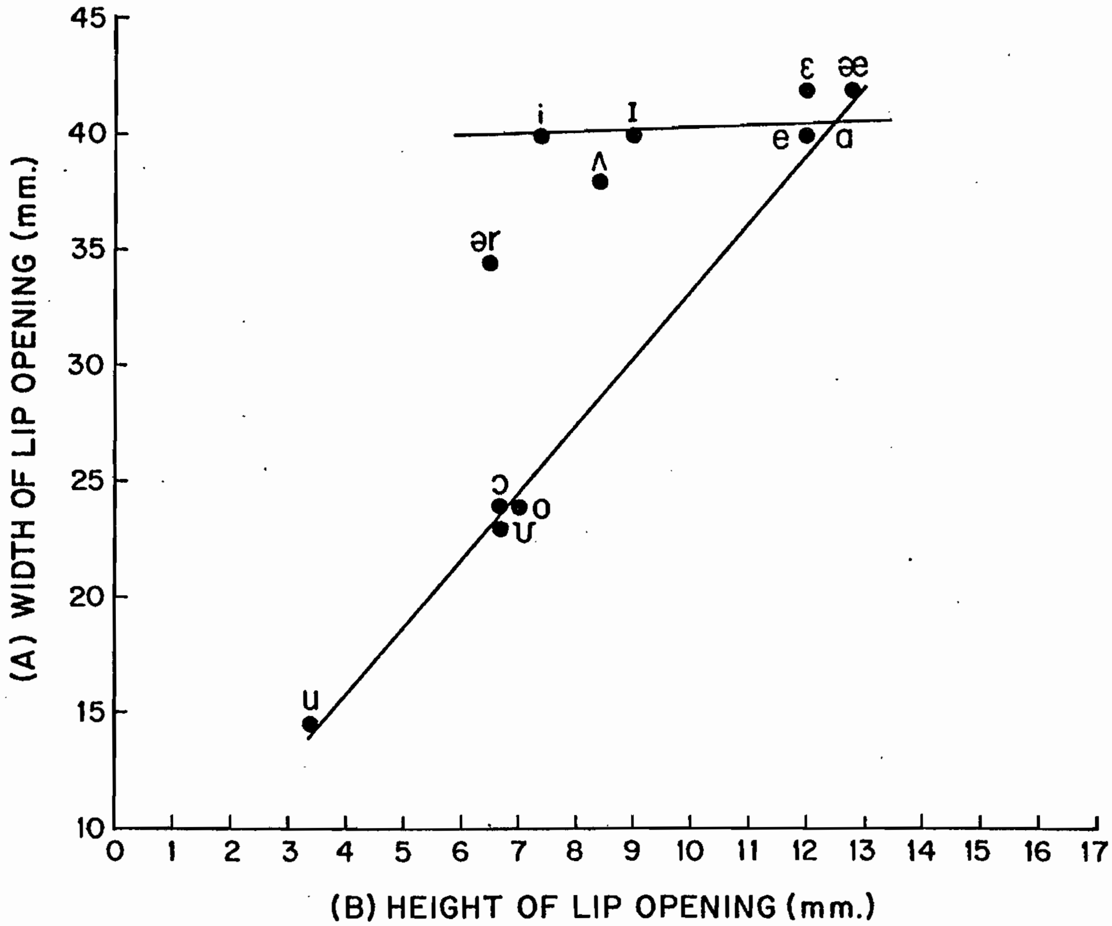


Figure 4

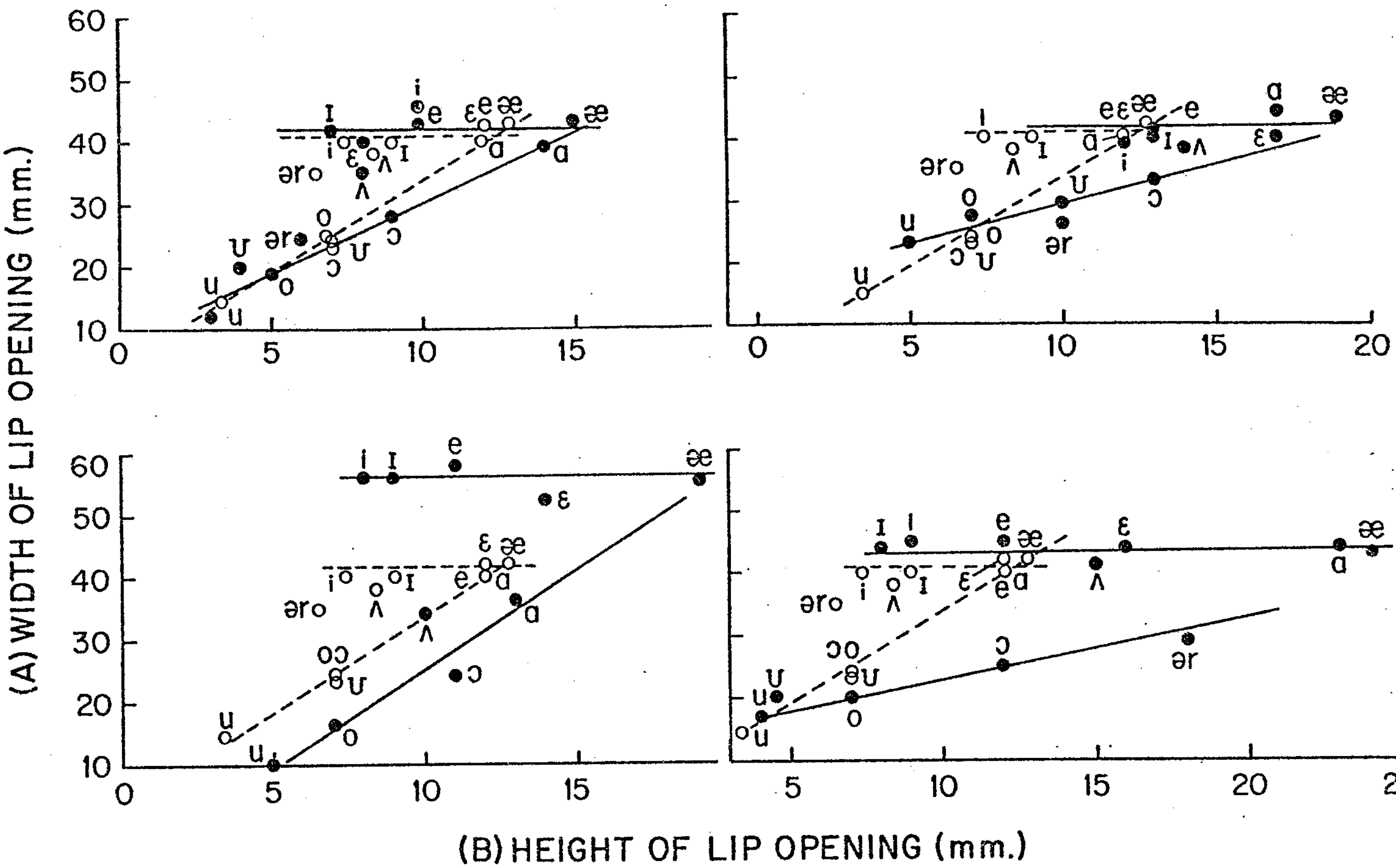


Figure 5

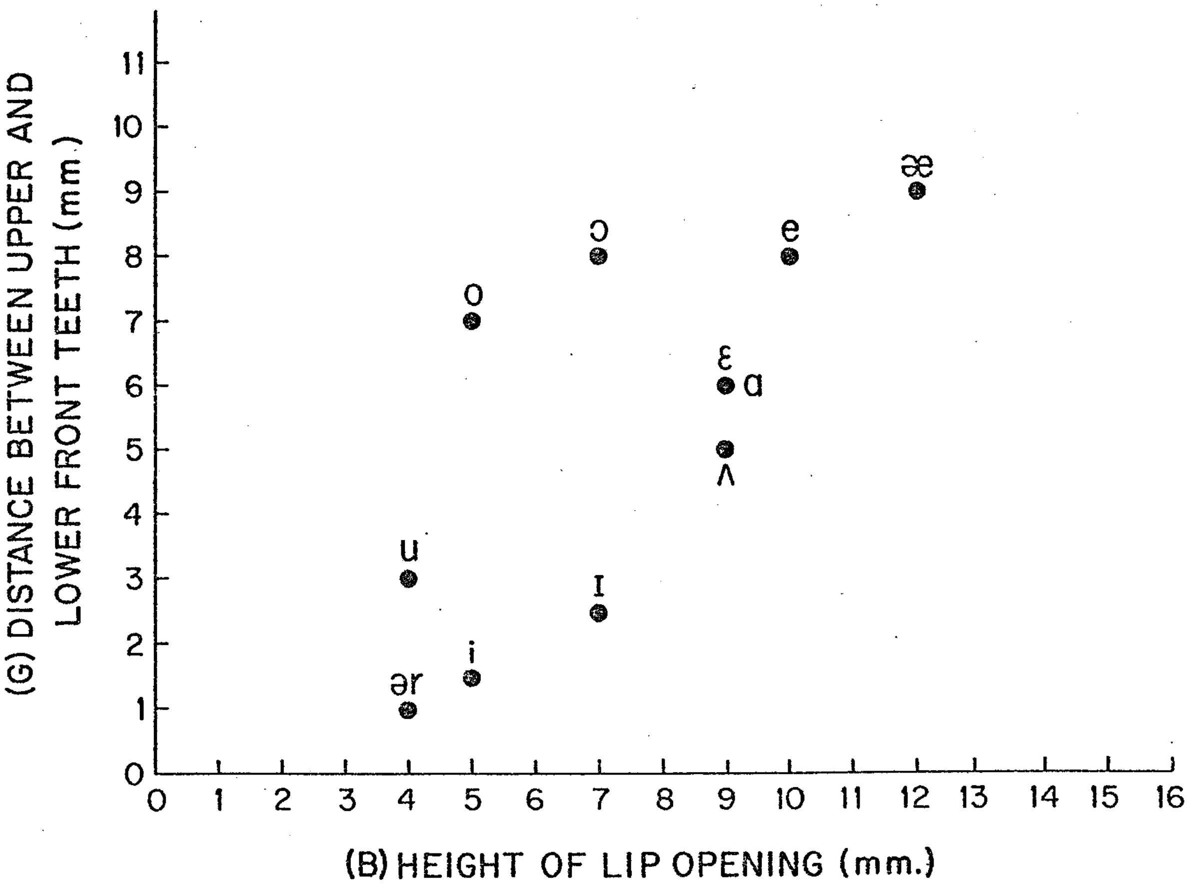


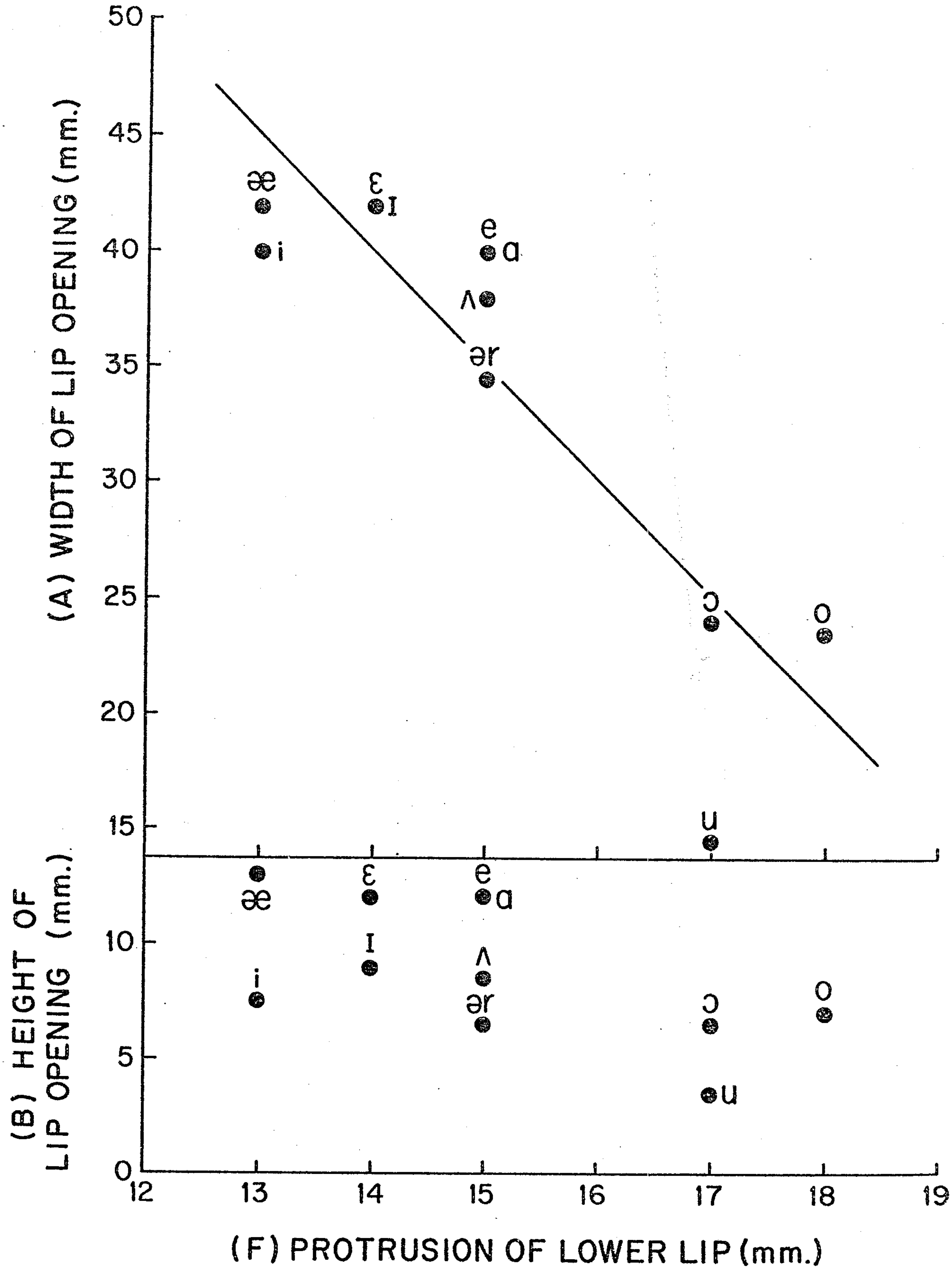
Figure 6

which pulls together like a purse string closing the lips, and pushing them forward (as in /u/). Some slight action of the orbicularis is present in the production of the central vowels /ʌ/ and /ər/.

The relation between the height of lip opening (B) and height of teeth opening (G) is displayed in Figure 6. It may be observed that although /ɔ/ and /ɪ/, and /o/ and /i/ have equal B dimensions, (7 mm. and 5 mm. respectively) the distance between the teeth for the back vowels (/ɔ/ = 8mm., /o/ = 7 mm.) is much larger than those for the front vowels (/ɪ/ = 2.5 mm., /i/ = 1.5 mm.). This demonstrates the action of the lip muscles in closing the lips in the back vowels; these muscles remain dormant for the front vowels.

To obtain measurements of the amount of the amount of protrusion of the lips, the distance between the teeth and the lips was measured. The greatest variation in distance between the upper teeth and lip taken from both X-rays and casts was 2.5 mm. for the entire range of vowels. The distance between the lower teeth and lower lip varied up to 5 mm. Protrusion therefore refers principally to the lower lip.

The lower part of Figure 7 shows the relation between protrusion and height of lip opening. It is not surprising that there is no simple correlation between these two factors, since the height of lip opening can be controlled by the raising and lowering of the jaw without the simultaneous action of the lip muscles which produce protrusion. The upper part of this figure shows the relation between protrusion and width of lip opening. In this case there is a trend towards a correlation ($r = -.1$) as indicated by the line on the figure. The action of protruding the lips is clearly often associated with the drawing of the lips together, pushing the corners of the mouth forward and thus decreasing the width and height. But protrusion need not be produced in this way; it is possible to push the lower lip forward without decreasing the widths of the mouth opening. This possibility accounts for the imperfectness of the correlation between protrusion and width of lip opening as demonstrated by the fact that the protrusions of /u/ and /ɔ/ are the same, but the widths and heights are very different. The protrusion of /u/ is due mainly to the action of the orbicularis muscle, which acts like a draw string around the lips, pushing them forward at the same time as pulling them together and decreasing the width and height of the lip opening. But the position for /ɔ/ involves less action of this muscle. The protrusion is due to some other action, which may be that of the depressor labii inferioris pulling the lower lip down and forward. The action of these two independent systems will also account for the fact that /ɔ/ and /o/ do not differ in width and height but do differ in degree of protrusion. It would appear, therefore, that protrusion must be stated as a third parameter in a detailed model accounting for the positions of the lips in American English vowels. But as a first approximation we may be content to predict the protrusion from the width of the mouth opening. This approximation is unlikely to be sufficient when we come to consider lip positions in consonants.



(A) WIDTH OF LIP OPENING (mm.)
(B) HEIGHT OF LIP OPENING (mm.)
(F) PROTRUSION OF LOWER LIP (mm.)
50
45
40
35
30
25
20
15
10
5
0
12
13
14
15
16
17
18
19
æ
i
ɛ
ɪ
e
ɑ
ʌ
ər
ɔ
o
u

Figure 7

We may summarize the muscular actions which work to vary lip positions in vowels as follows:

1a) The draw-string action of the orbicularis muscle which occurs in the back rounded vowels and to a lesser extent in the central vowels;

1b) The opposite action, involving the flattening and pulling back of the lips by the risorius and zygomaticus muscles in some of the front vowels;

2) The protrusion of the lower lip without much lip-rounding as in /ɔ/.

3) The raising and lowering of the jaw, which has most effect on the front vowels.

These findings are supported by some preliminary electromyographic studies and by evidence from the dissection of the lip muscles of a cadaver.

An important though not surprising linear relationship between the area of mouth opening (C) and the height-width product (AB) may be observed in Figure 8. It is of particular interest to note that the same quantitative relation holds for all the subjects measured, with $C = .7 AB$. Thus, given the height and width of mouth opening, the area of frontal mouth opening can be predicted without reference to the degree of protrusion.

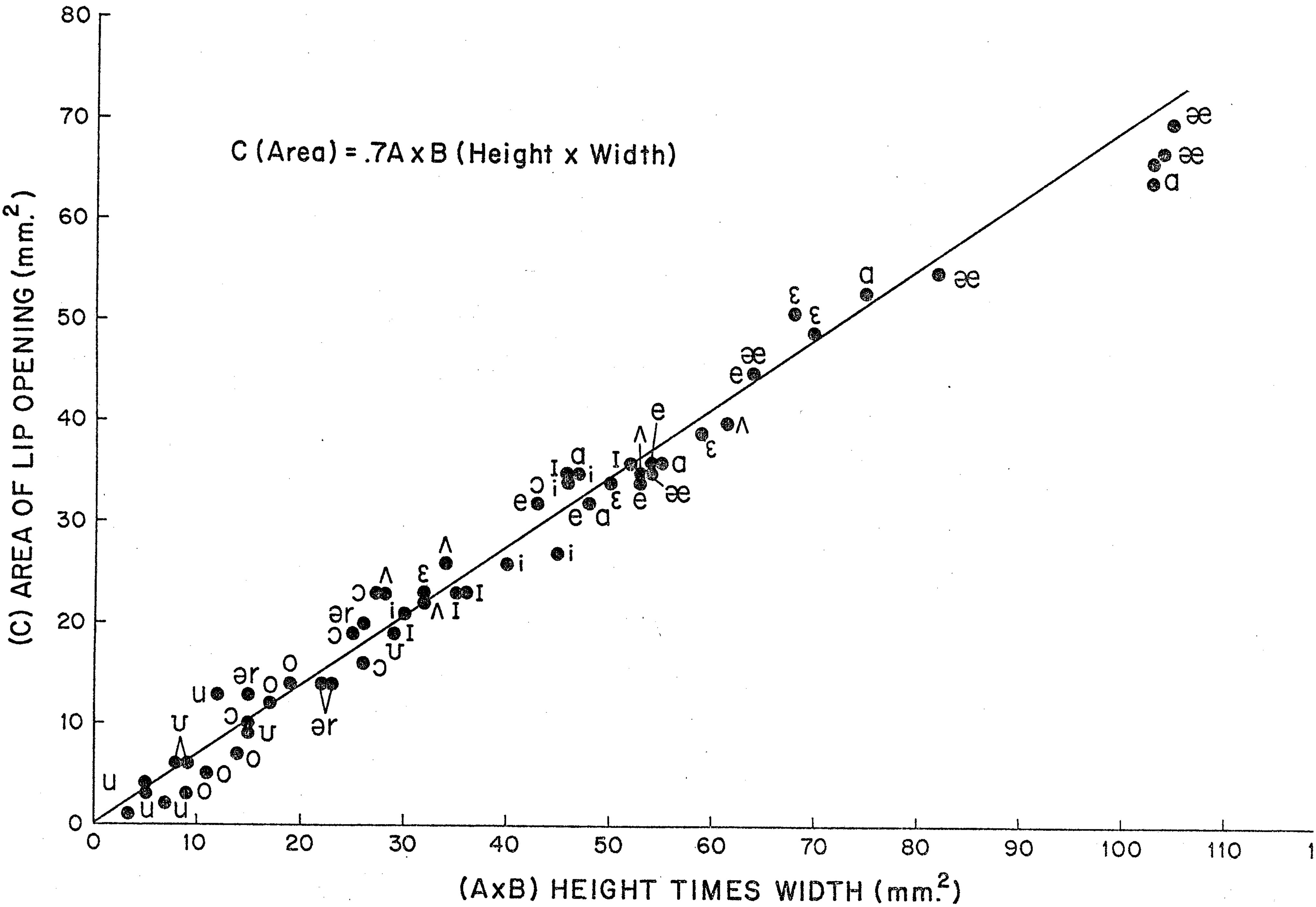
One last observation may be made. The difference between measurements D (maximum height) and B (minimum height) was found to be a constant for each subject. This difference represents the size and curvature of the lips and will therefore vary from subject to subject but remain the same for each.

Conclusions

For speech synthesis, investigation of static positions for vowel production must be seen as only the first step. A description of vowel lip positions based on actual physiological parameters would include height, width, and lower lip protrusion. For the simplest model, one might use only two parameters, height and width, as the major and minor axes of an ellipse, corrected so as to be equivalent to the actual area of the mouth opening of any vowel, protrusion being predicted from the width.

Acknowledgements

The writer is grateful for the assistance of Harold Edmundson and Sven Ohman.


C (Area) = .7A x B (Height x Width)
(C) AREA OF LIP OPENING (mm.²)
(AxB) HEIGHT TIMES WIDTH (mm.²)

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The Musculature of the Tongue

Kenneth C. Hill

0. Introduction. This sketch of the origins, shapes, and insertions of the muscles of the human tongue is done from the point of view of ultimately constructing a speech synthesizer based on the physiological parameters of speech. Some of these parameters must be parameters of tongue motion. Any statement of the articulatory movements of the tongue would most interestingly be expressed in terms of muscle contraction. Before we can posit such parameters of tongue motion, we must know pretty much where each muscle is located. A considerable search of the anatomical literature has not revealed any description of tongue musculature completely satisfactory for this purpose. This paper is an attempt to summarize from existing literature and from knowledge based on our own dissection of a human tongue

the locations and shapes of the tongue muscles. The works consulted directly for this study were: Abd-el-Malek (1939), Pernkopf (1963), Spalteholz (1933) and Van Riper & Irwin (1958). Dabelow (1951) and Strong (1956) had not come to our attention at that time.

0.1. Bilateral symmetry. The musculature of the tongue is bilaterally symmetrical. Each muscle is one of a pair; for each muscle on the left side, there is a corresponding one on the right side. Any statement about a muscle is to be understood as equally true of both members of the pair.

0.2. Extrinsic and intrinsic muscles. Tongue muscles are divided into two groups: extrinsic and intrinsic muscles. The extrinsic muscles are those tongue muscles that attach to structures outside the tongue, either directly to the skeleton, or to muscles exterior to the tongue. Intrinsic muscles are contained wholly within the body of the tongue and attach to other muscles in the tongue, to the skin of the tongue's surface, and to the fibrous septa of connective tissue inside the tongue.

0.3. Muscle nomenclature. Muscles are named according to their origin and insertion. A muscle's origin is taken, at times somewhat arbitrarily, as its more fixed attachment; its insertion is where it is attached to what it moves. The name of the origin is the first element in a muscle's name, and the name of the insertion is the other, as genioglossus, the muscle originating at the chin (genio-), inserting into the tongue (glossus). Intrinsic tongue muscles are exceptional, as are a few other muscles in the body. They are not named according to this scheme but are given descriptive names. The intrinsic tongue muscles are named according to their location and the orientation of their fibers; thus, the vertical muscle, the transverse muscle, and the superior and inferior longitudinal muscles.

0.4. Position terminology. "Superior" and "inferior" are anatomical terminology for 'higher' and 'lower', respectively. Also, "dorsal" and "ventral", in the lingual region, mean roughly 'higher' and 'lower'. "Anterior" and "posterior" are 'front' and 'back'. "Lateral": 'towards the side (left or right)' is opposed to "medial": 'towards the middle or median plane'.

1. The extrinsic attachments of tongue muscles. Tongue muscles are attached to the skeleton at the styloid process, mandible, and hyoid bone (Fig. 1.). The tongue is also attached to the muscular structures of the velum and the wall of the upper part of the pharynx.

The functions of the different muscles in the lingual region which are not properly tongue muscles, i.e., those that do not attach directly to the tongue, seem to be fairly clear, unlike the functions of the muscles directly having to do with the shaping and positioning of the tongue.

1.1. The hyoid bone is a horseshoe-shaped bone located under the root of the tongue. The epiglottis is attached to the hyoid by the hyoepiglottic ligament.

The position of the hyoid bone is determined by a number of muscles. The muscles connecting the hyoid to structures below it, as to the thyroid cartilage, which account for its downward motion, are not discussed here. Posteriorly, the hyoid bone is connected to the middle constrictor of the pharynx. This muscle might contribute to backward motion of the hyoid. The stylohyoid muscle and the posterior belly of the digastric muscle would account for backward motion of the hyoid (Fig. 1, 2.).

1.1.1. The stylohyoid muscle originates on the styloid process and inserts on the greater cornu of the hyoid (Fig. 2.).

1.1.2. The digastric muscle, as its name indicates, consists of two parts, or "bellies". These two, the anterior and posterior bellies, are joined by an intermediate tendon, which is attached to the hyoid bone. The posterior belly originates on the mastoid process (Fig. 1.), and the anterior originates on the inner side of the lower margin of the mandible, just lateral to the mandibular symphysis (Fig. 1,3.) Each belly of the digastric is innervated independently, so each can function independently of the other; the posterior belly, along with the stylohyoid muscle, serving to pull the hyoid upward and backward, and the anterior belly serving to pull the hyoid frontwards, or conversely, to pull the mandible downwards.

The hyoid bone also provides attachment for the mylohyoid and geniohyoid muscles, discussed below.

1.2. The mandible is really two bones, rather than the one its name might suggest. These two bones are joined in the center in front at the mandibular symphysis (Fig. 3.). In addition to its functions in speech, serving as a moving platform for the tongue in opening and closing the mouth, the muscles for which action are not discussed in this paper, the mandible also provides attachment for a number of muscles of direct relevance to the motions of the tongue (Fig.1.).

The anterior belly of the digastric muscle is the most inferior of the muscles in the sublingual region (Fig. 4.). It has been discussed above.

1.2.1. The mylohyoid muscle lies just above the anterior belly of the digastric muscle. It originates on the mylohyoidal ridge on the mandible, located near the superior margin. The muscle descends the wall of the mandible and, with its fibers in a transverse orientation, inserts into the raphe, or median line, where it meets the fibers of the mylohyoid muscle of the opposite side (Fig. 4.). Its posterior fibers attach to the hyoid bone (Fig. 3.). The mylohyoid could be said to form the muscular floor of the mouth. Its contraction would have two functions: to raise the floor of the mouth, and consequently the tongue, and also to bring the hyoid bone frontwards.

1.2.2. The geniohyoid muscle lies immediately superior to the mylohyoid (Fig. 4, 5.). Its origin is just superior to that of the digastric muscle at the front part of the mandible (Fig. 1.) Its fibers lie in a longitudinal orientation and insert into the most anterior part of the hyoid bone. The geniohyoid would serve to pull the hyoid frontwards, and slightly upwards.

The genioglossus muscle has its origin on the mandible above that of the geniohyoid. It is the only tongue muscle that attaches to the mandible, and is discussed below.

2. The extrinsic muscles are described individually below.

2.1. The genioglossus muscle, quite distinct from the geniohyoid, originates quite high up at the mandibular symphysis (Fig. 1.). The genioglossus radiates out from this rather small point, forming the bulk of the central and inferior portion of the tongue. It is the largest single muscle in the tongue. Its most anterior, or superior, fibers bend upwards and frontally at one extreme, and attach to the anterior arch at the tip of the tongue (Fig. 11.). Its most inferior, or posterior, fibers run longitudinally just superior to the geniohyoid muscle, but insert in the hyoglossal membrane, instead of directly into the hyoid bone (Fig. 5.).

2.2. The hyoglossus muscle originates on the side of the hyoid bone and inserts into the side of the tongue (Fig. 6.). Its insertion is lateral to the inferior longitudinal and glossopharyngeus muscles, and is medial and generally inferior to the styloglossus muscle, which interdigitates with the hyoglossus where they come into contact (Fig. 12.). The hyoglossus is a sheet of muscle tissue, easily separable into two overlapping parts. The posterior, and at the overlap more lateral, of these parts is joined laterally by descending and interdigitating fibers of the styloglossus. Most of the fibers of the posterior part continue into the body of the tongue, interdigitating with the lateral surface of the inferior longitudinal muscle (Fig. 13.). Once having entered the body of the tongue, the posterior fibers turn and run down towards the root of the tongue (Fig. 7.). The fibers of the anterior portion of the hyoglossus merge towards the tip of the tongue with the anterior fibers of the styloglossus and inferior longitudinal muscles, all of which together then insert into the anterior arch.

2.3. The styloglossus muscle runs from the styloid process (Fig. 1.) to the side of the tongue (Fig. 6, 8.). As it runs down and forwards, it splits into two branches, the upper and lower parts. The lower part is rather short and ends by interdigitating with the fibers of the lateral surface of the posterior section of the hyoglossus. The upper part runs forward along the hyoglossus towards the tip of the tongue, where its fibers interdigitate with the anterior part of the hyoglossus and with the inferior longitudinal muscle. The fibers of all these muscles then attach to the anterior arch. (The anterior arch is a thickening of the skin at the tip of the tongue; see below.) Where the styloglossus is still above the hyoglossus at the back of the tongue, above where it splits into its two parts, the fibers of the medial surface of the styloglossus interdigitate with the lateral fibers of the glossopharyngeus muscle (Fig. 8.). As the styloglossus runs along the tongue, the fibers of its upper margin interdigitate with the longitudinal muscle beside it (Fig. 12.). Further, the upper margin of the styloglossus provides part of the attachment in the tongue for the palatoglossus (Fig. 8.).

2.4. The palatoglossus muscle originates among the anterior muscles of the velum and merges with the medial fibers of the styloglossus and with the fibers of the dorsum of the tongue (Fig. 8.). The palatoglossus is seen in the mouth as the more anterior of the faucal pillars.

2.5 The glossopharyngeus muscle. The part of the superior constrictc muscle of the pharynx which attaches to the tongue is called the glossopharyngeus. The part of the superior constrictor muscle that is just above the glossopharyngeus can be seen in the mouth as the more posterior of the faucal pillars. The glossopharyngeus is a sheet of muscle that inserts intc the back margins of the tongue, interdigitating with the medial surfaces of the styloglossus and hyoglossus and the lateral surfaces of the longitudinal muscles. Upon joining the sides of the back of the tongue, the glossopharyngeus fibers descend to the root of the tongue, turning in an antero-ventral direction, and either interdigitate with the genioglossus and inferior longitudinal muscles and then attach to the hyoglossal membrane, or attach to the hyoglossal membrane directly (Fig. 8, 9.).

3. The connective tissue framework of the tongue includes the mucous membrane or skin of the dorsum and margins of the tongue and the septa contained within the tongue. These provide attachment for muscles inside the body of the tongue, and in the case of the hyoglossal membrane, attach the tongue to the hyoid bone.

3.1. The skin of the tongue itself is the point of insertion for many muscle fibers. At the tip of the tongue the skin is quite thick. Abd-el-Malek (1939) calls this thickening the anterior arch. It is easily visible in dissection. Removal of the skin from the dorsum of the tongue reveals no neat lie of muscle fibers because of the quantity of these fibers inserting into the skin.

3.2. The septa of the tongue are fibrous layers of connective tissue that serve to separate adjacent muscles, to provide attachment for muscles, and to contain nerves and blood vessels (Fig. 10.).

3.2.1. The median septum describes the median plane in the body of the tongue. The two genioglossi muscles are located either side of the inferior part of the septum (Fig. 12, 14.) and are here easily separable from each other. According to Abd-el-Malek (1939), the medial part of the transverse muscles attach to the median septum; and dorsally, although practically absent, the septum can be detected here and there between the two superior longitudinal muscles. At the tip of the tongue the median septum attaches to the anterior arch.

3.2.2. The paramedian septum surrounds the superior and lateral surfaces of the main body of the genioglossus muscle and marks the lower limits of the intrinsic tongue muscles. Although the main body of the genioglossus terminates at the paramedian septum, many genioglossus fibers penetrate it and interdigitate with the muscles lying dorsal and lateral to the septum. The paramedian septum becomes progressively stronger posteriorly, broadening out to become the hyoglossal membrane, which attaches the tongue at its root to the hyoid bone (Fig. 11.). The paramedian septum is attached medially to the median septum (Fig. 10.), marking the border between the ventral and middle parts of that septum. Laterally the paramedian septum descends to merge with connective tissue in the floor of the mouth.

3.2.3. The lateral septum is attached medially and posteriorly to the paramedian septum. Laterally it splits into two lamellae, one sheet of which, the lateral lamella, intervenes between the hyoglossus and the styloglossus, and the other, the medial lamella, between the styloglossus and the inferior longitudinal muscle (Fig. 12.). Anteriorly the lateral septum ends where the styloglossus and hyoglossus merge with the inferior longitudinal muscle.

4. The intrinsic muscles. In contrast with the extrinsic muscles, these muscles have no attachments outside the body of the tongue. They attach to other muscles, either to other intrinsic muscles or to extrinsic muscles as they enter the body of the tongue, and to the connective tissue framework.

4.1. The inferior longitudinal muscle is the only intrinsic muscle easily visible in dissection (Fig. 13.). Posteriorly it begins on the sides of the root of the tongue. There it interdigitates with the lateral and ventral fibers of the genioglossus and inserts into the hyoglossal membrane. As it runs up the sides of the back of the tongue, it interdigitates on its lateral surface with the glossopharyngeus, which finds there its major attachment (Fig. 9.), and with the anterior margin of the posterior part of the hyoglossus (Fig. 13.). The inferior longitudinal muscle runs forwards beneath the transverse and vertical muscles, joining at the sides with fibers of the superior longitudinal muscle. It is joined anteriorly by the anterior fibers of the styloglossus, hyoglossus, and genioglossus muscles, all of which together attach to the anterior arch. A bundle of fibers originating in the hyoglossal membrane near the lesser cornu of the hyoid and passing fairly free of the body of the inferior longitudinal muscle until its insertion into that muscle in the middle of the tongue is referred to as the chondroglossus muscle (Fig. 13.).

4.2 The superior longitudinal muscle is the most superior muscle in the body of the tongue, lying immediately under the dorsal skin. It is a thin sheet of muscle fibers in its anterior, posterior, and lateral parts. In the middle of the tongue it is more bulky. It runs back from the anterior arch at the tip to attach to the skin of the posterior third of the tongue with some fibers reaching down to the hyoglossal membrane. It extends from the median line, where here and there bits of the connective tissue of the median septum are detectable, to the edge of the tongue where it interdigitates with the most lateral fibers of the inferior longitudinal muscle. Throughout its extension, the superior longitudinal muscle is penetrated by fibers of muscles inferior to it that insert into the skin of the dorsum of the tongue (Fig. 14.).

4.3. The transverse muscle is a series of lamellae of muscle fiber extending out from the median septum. These leaves fan out such that the more superior ones go in a somewhat dorsal direction and the most inferior ones are directed downwards. Some fibers of the transverse muscle insert into the skin of the tongue's surface, while others end by attaching to the septa inside the tongue. Some transverse fibers interdigitate with fibers of the genioglossus and all interdigitate with fibers of the vertical muscle except where the transverse muscle extends farther anteriorly and posteriorly than does the vertical muscle. The transverse muscle lies superior to the paramedian septum and the inferior longitudinal muscle and inferior to the superior longitudinal muscle (Fig. 14.).

4.4 The vertical muscle. Together with the transverse muscle, this muscle forms a good part of the bulk of the tongue, especially the middle portion of the tongue. It occupies much the same space as does the transverse muscle and interdigitates with the several layers of the transverse muscle, but the vertical muscle does not extend so far forward or back as the transverse. The more medial fibers of the vertical muscle have a roughly vertical orientation, but towards the lateral edges of the tongue the fibers run downwards and outwards. The vertical muscle fibers attach either to the skin of the dorsal and ventral surfaces of the tongue, or to the various septa inside the tongue (Fig. 14.).

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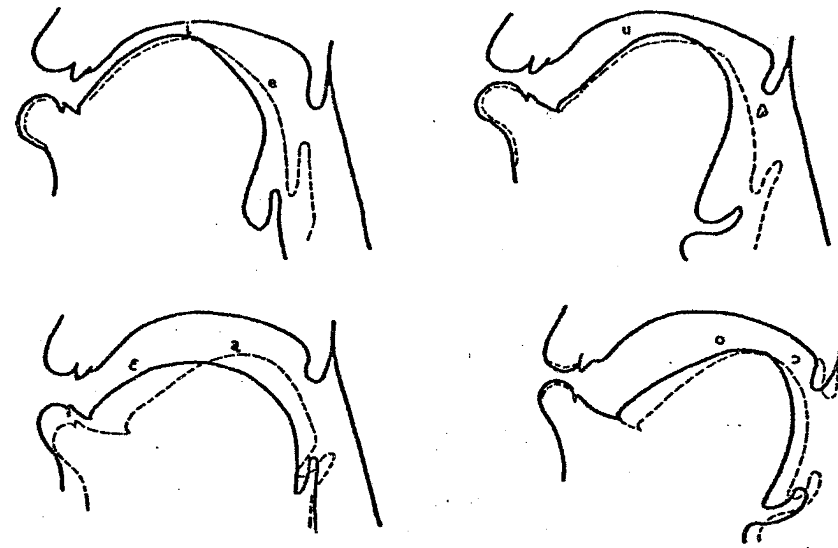
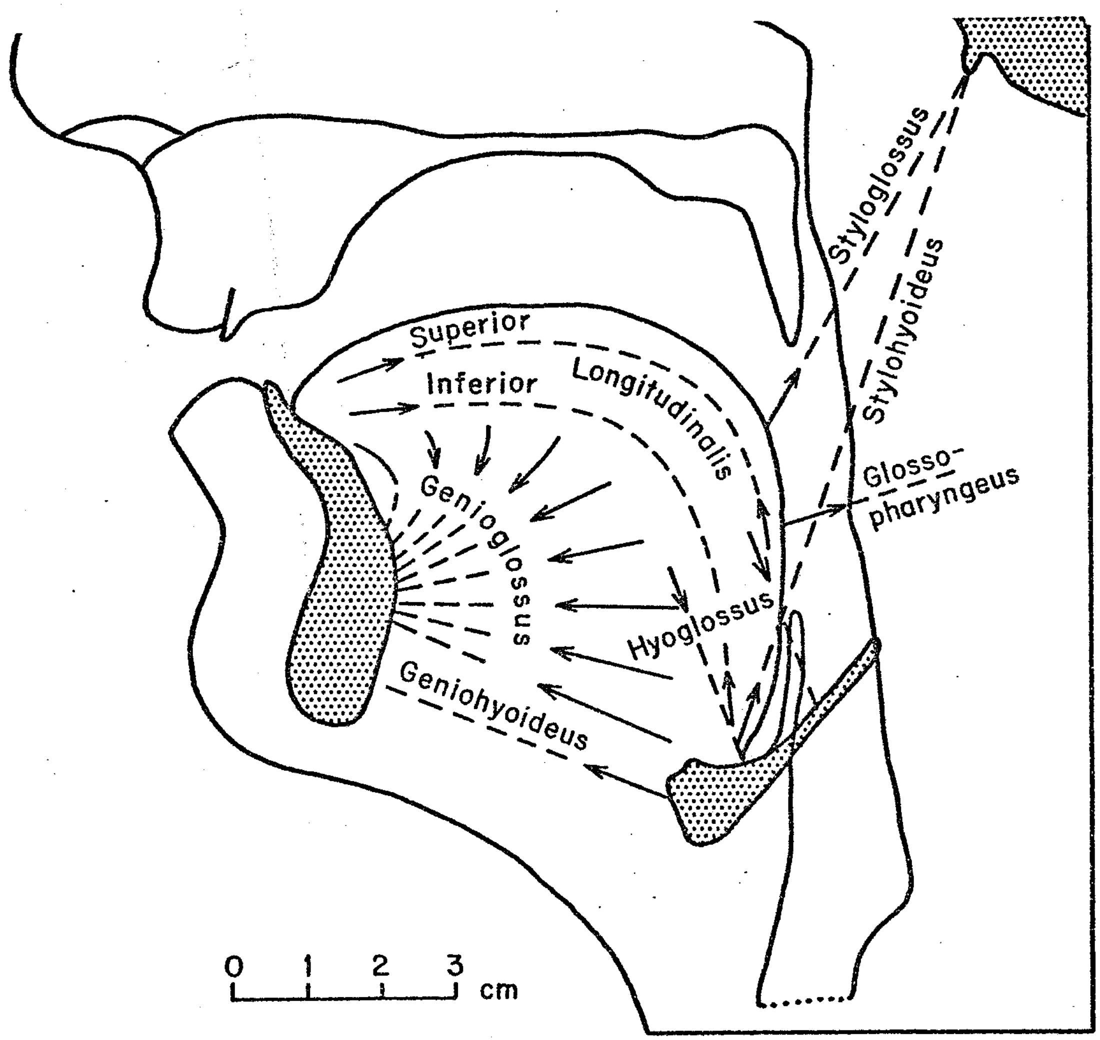


N.N.D. Okonkwo (Igbo, Onitsha):
óbì, ùbé, ḿbὲ, ḿbà, ḿbɔ̀, ébó, ɔbɔ̀, íbu
'heart, poverty, tortoise, boast, effort,
*person, it is, weight' 23 May 62

Figure 1



The illustration on the cover in diagrammatic form

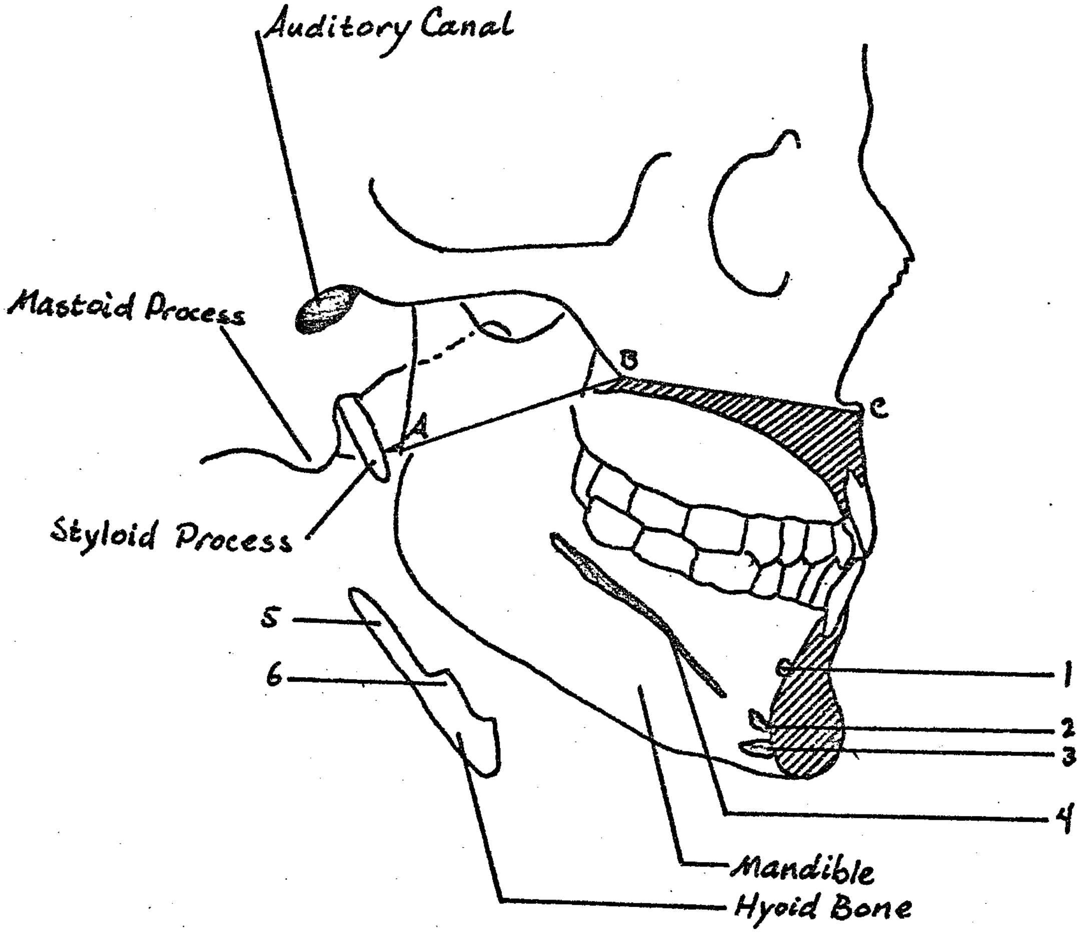


Fig. 1. Bones of the facial region viewed from the right. Below line ABC the skull and mandible are shown in median section. Areas of muscle attachments on the mandible are shown in red.

1 = Origin of genioglossus
2 = Origin of geniohyoid
3 = Origin of anterior belly of digastric
4 = Origin of mylohyoid (= mylohyoidal ridge)
5 = Greater cornu of hyoid bone
6 = Lesser cornu of hyoid bone

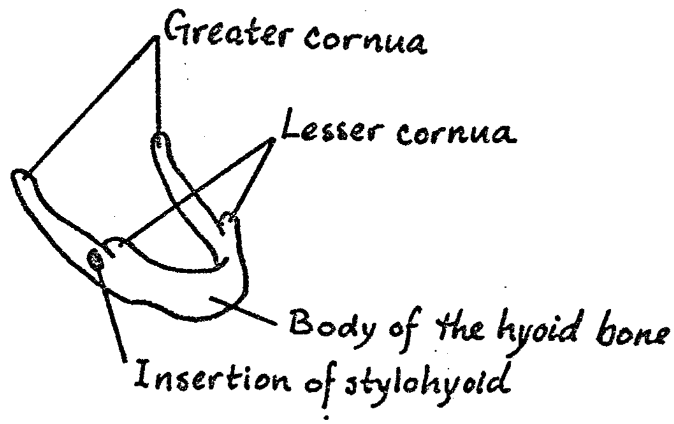


Fig. 2. Hyoid bone.

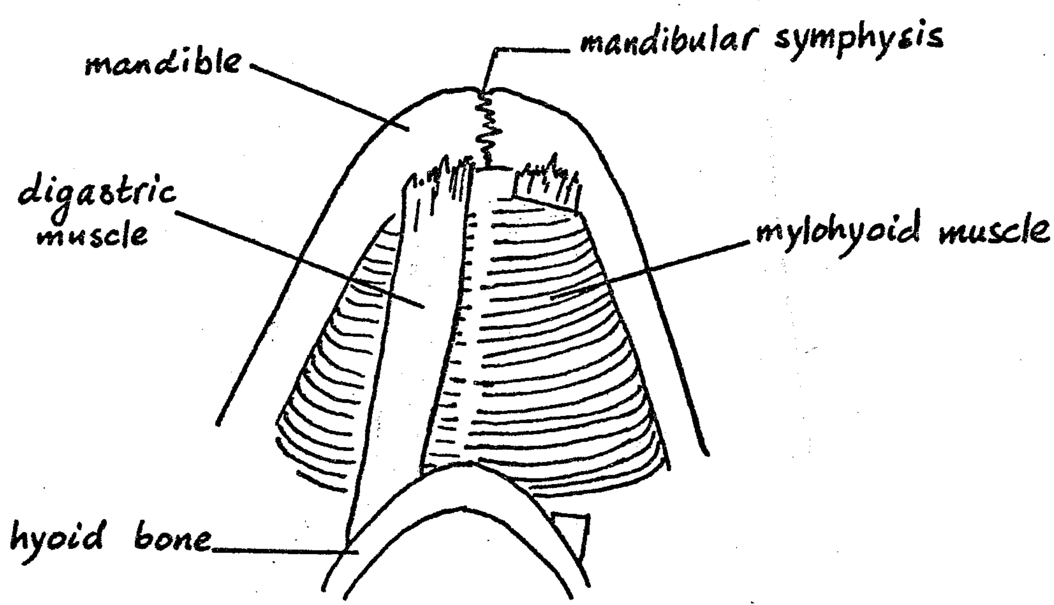


Fig. 3. Sublingual region viewed from below. Left digastric muscle has been cut.

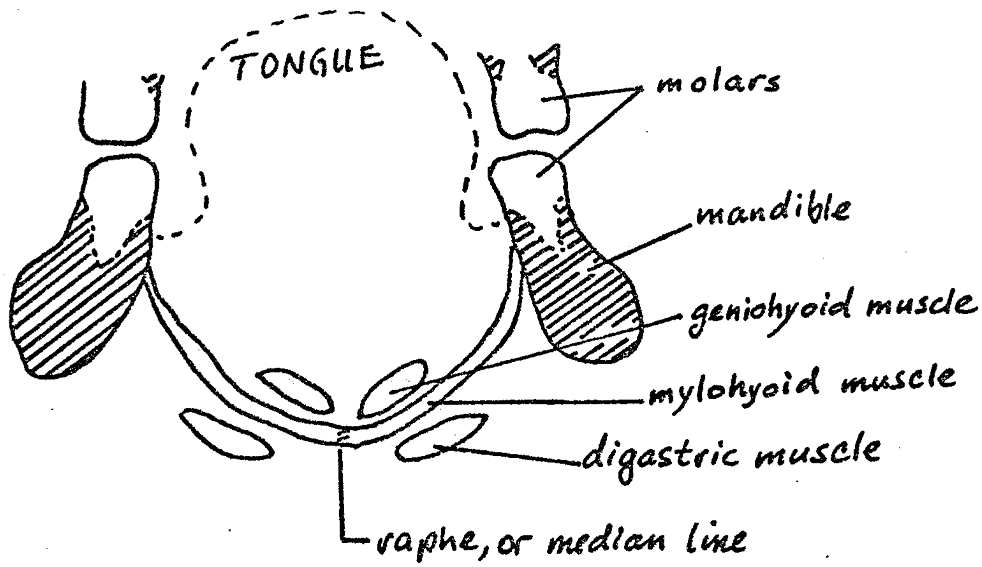


Fig. 4. Transverse section showing muscles of the sub-lingual region. The cut is through the second molar tooth. (After Pernkopf, plate 126.)

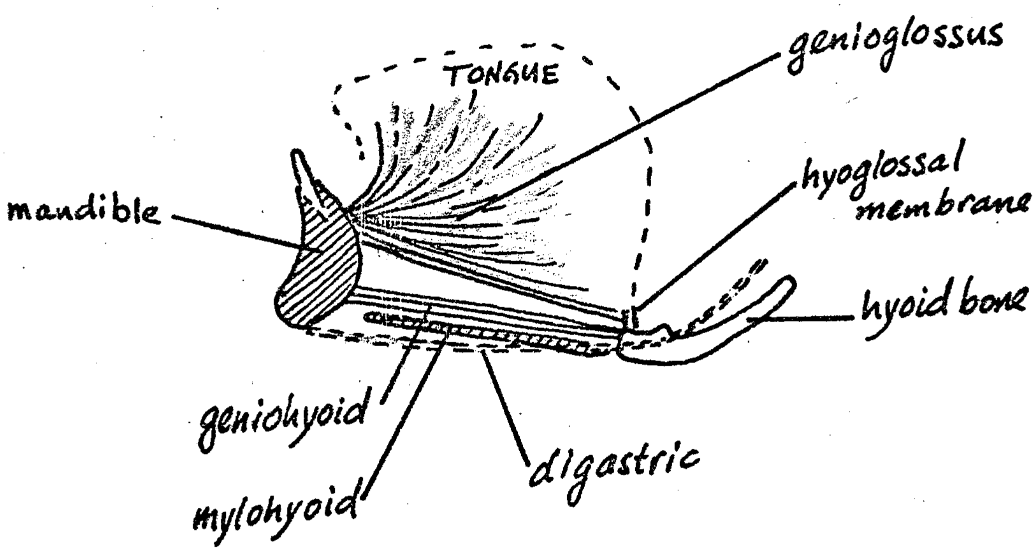


Fig. 5. View from the left side showing location of geniohyoid and insertion of the most inferior of genio-glossus fibers into the hyoglossal membrane.

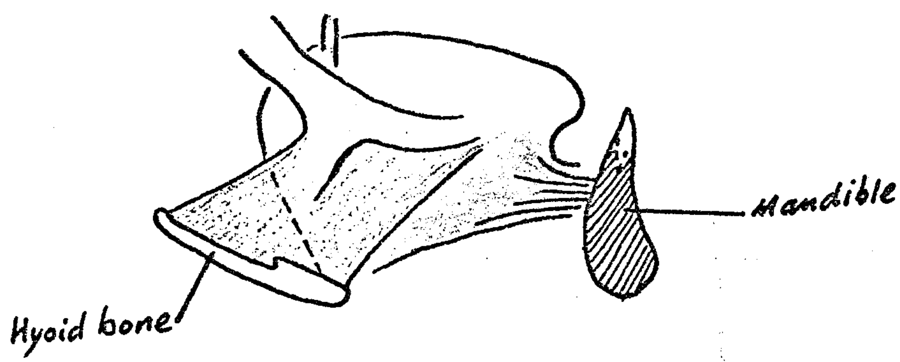


Fig. 6. View from the right side showing extrinsic muscles.

red = genioglossus
blue = styloglossus
green = palatoglossus
yellow = hyoglossus

(glossopharyngeus not shown)

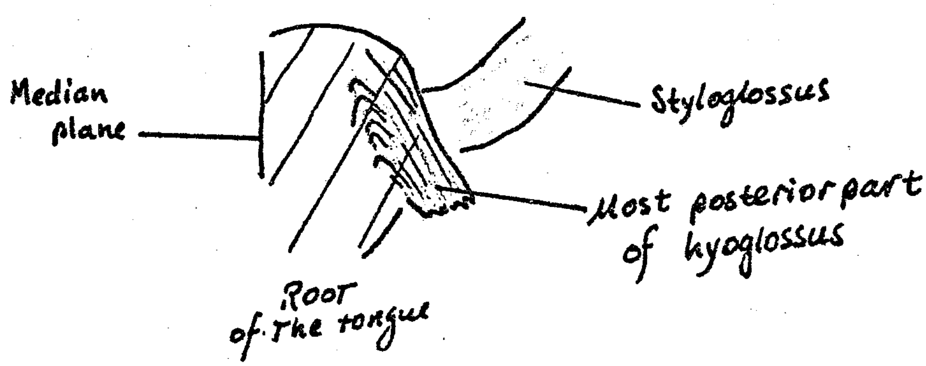


Fig. 7. Transverse section through the back of the tongue showing posterior hyoglossus fibers entering the body of the tongue and then turning to descend towards the root of the tongue. Viewed from behind.

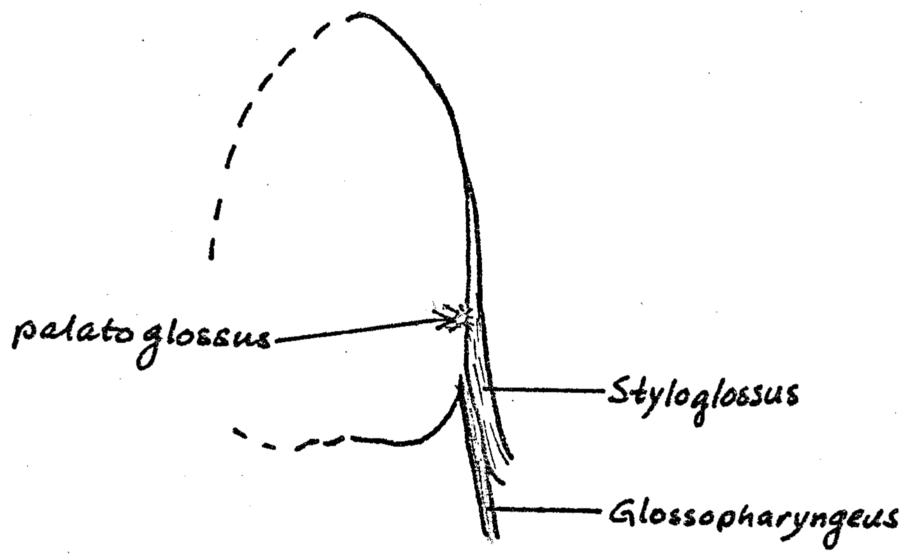


Fig. 8. Tongue seen from above showing insertion of palatoglossus and glossopharyngeus. Hyoglossus is covered by styloglossus.

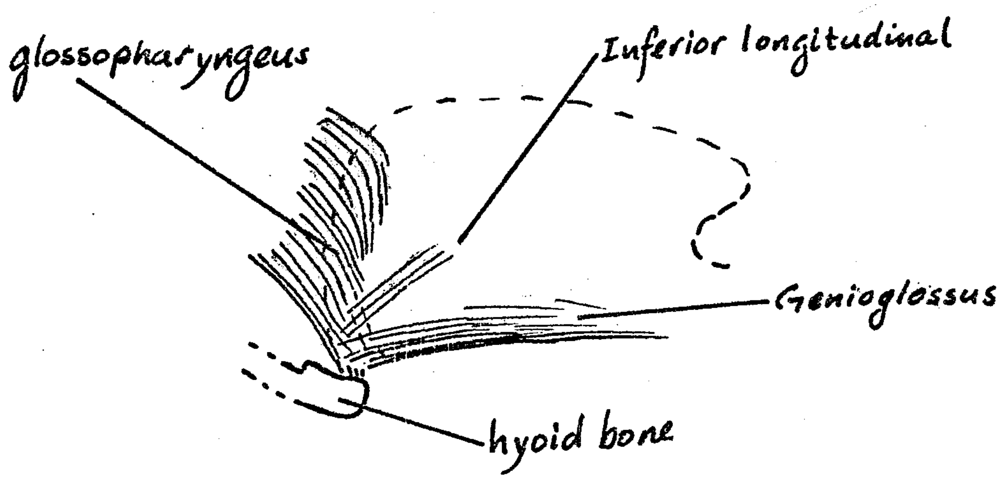


Fig. 9. Showing insertion of glossopharyngeus at the back of the tongue. Viewed from the right.

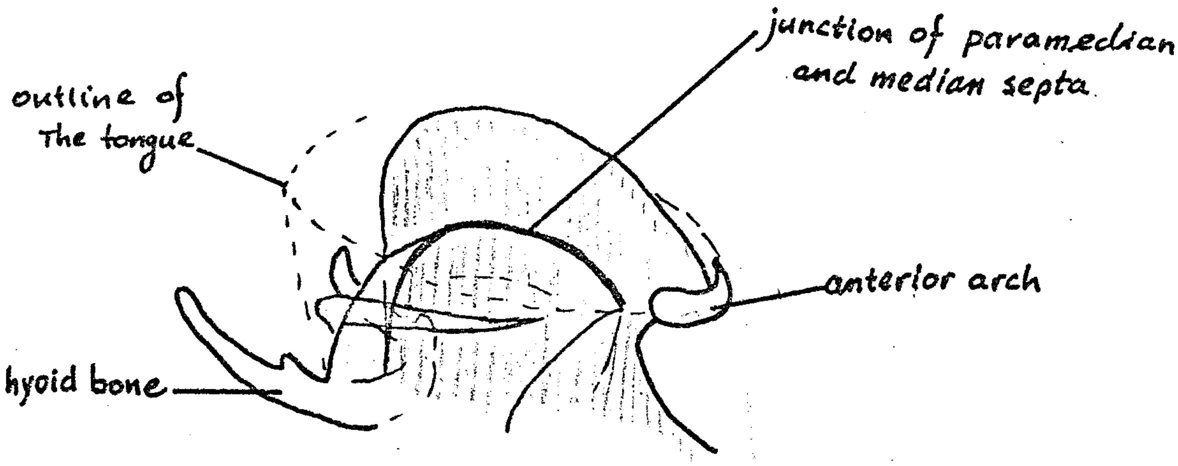


Fig. 10. The septa.

yellow = lateral septum (lamellae not shown)
blue = paramedian septum
red = median septum (dorsal part of median septum shown in broken red lines)

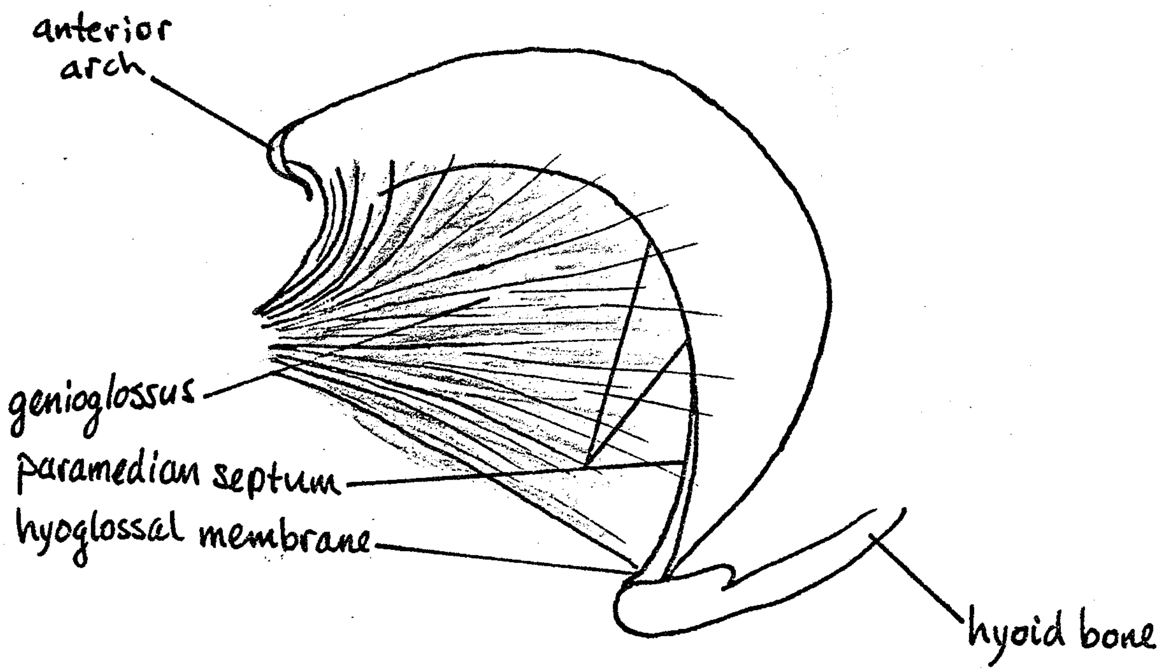


Fig. 11. Median section of the tongue viewed from the left.

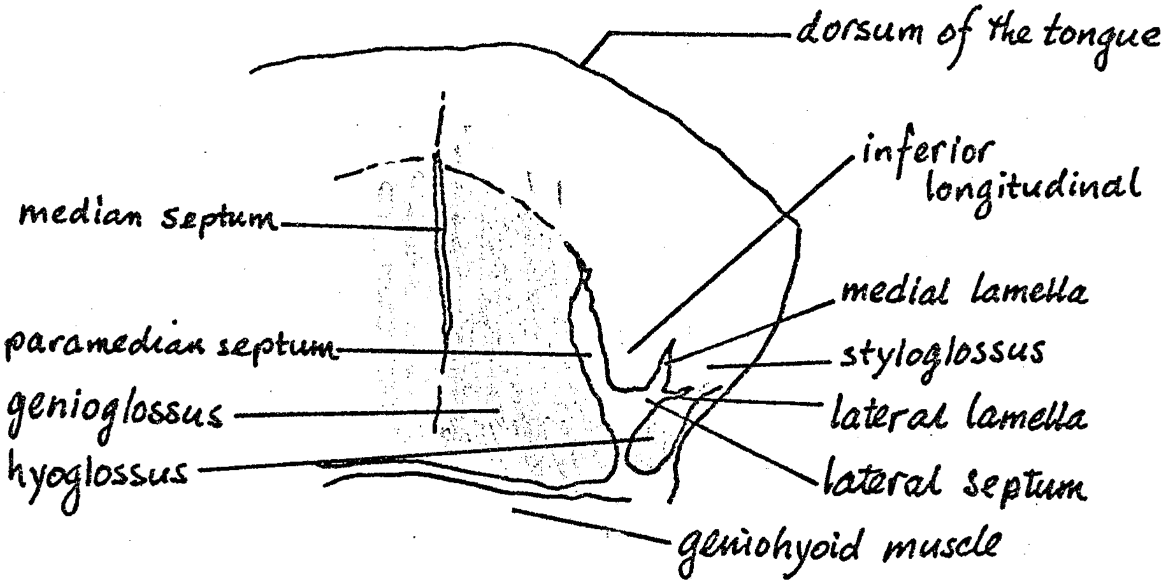


Fig. 12. Transverse section through the posterior third of the tongue showing the three septa and muscles. (After Malek, plate II, Fig. 6.)

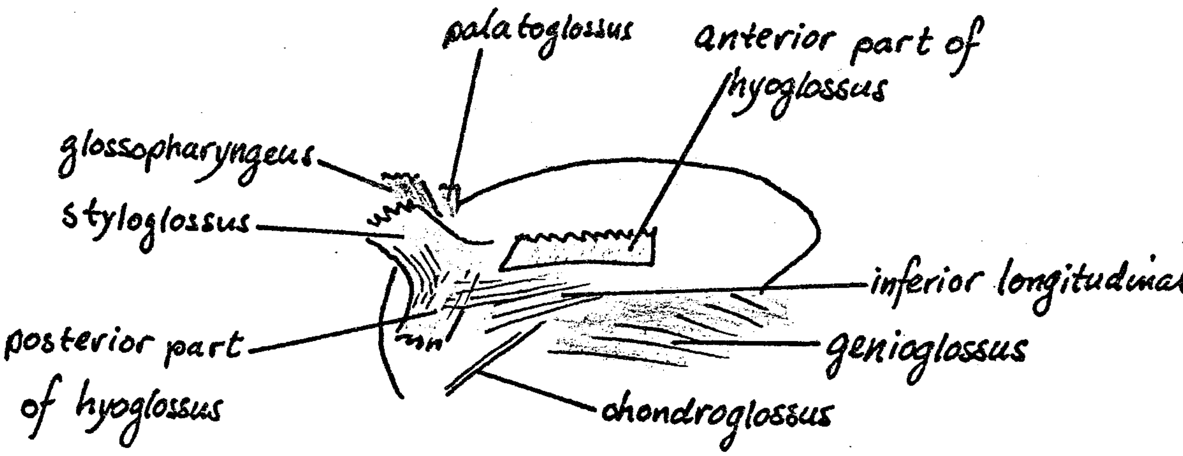


Fig. 13. View from the right side showing the anterior margin of the posterior part of the hyoglossus interdigitating with the inferior longitudinal muscle. The anterior part of hyoglossus has been reflected.

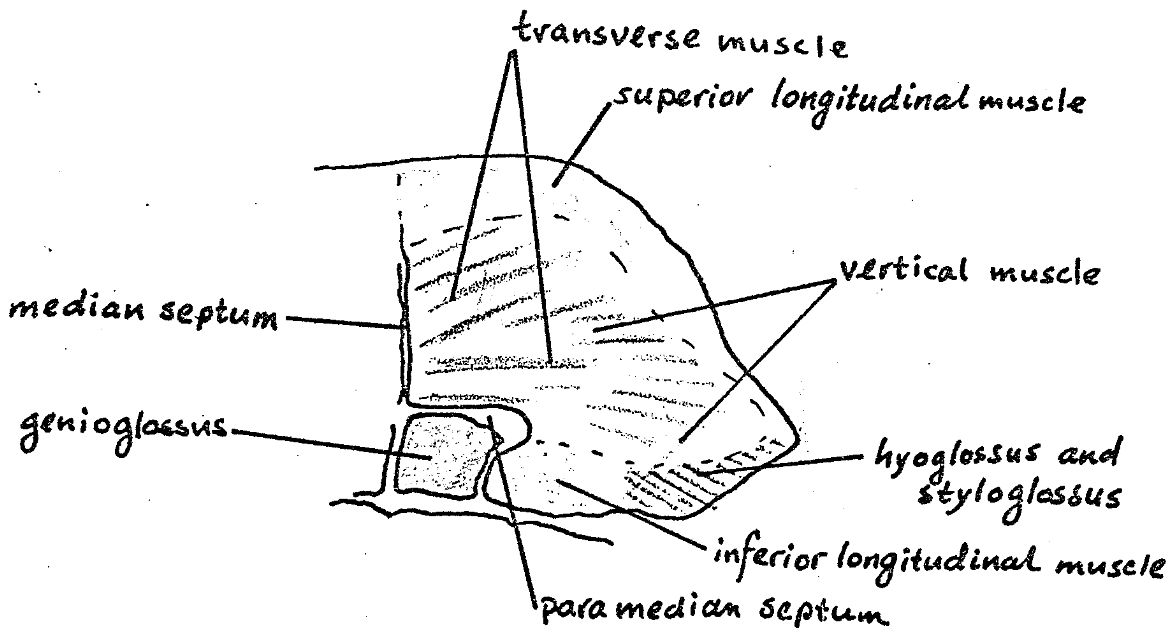


Fig. 14. Transverse section through the anterior portion of the tongue showing intrinsic muscles. (After Malek, plate I, Fig. 4.)

Annotated Bibliography

on the Muscles of the Tongue and Ancillary Structures

Elite Olshtain

This bibliography is intended as a working document for use in research by the UCLA Phonetics group. A number of references are included not because they are of any use in our present project, but because, despite their titles, they are not relevant; and we want to know this to save looking them up again. Some references on the pharynx have also been included.

1. Abd-el-Malek, S. (1938) "A contribution to the study of the movements of the tongue in animals, with special reference to the cat", Journal of Anatomy 73,15.

Experiments with cats. Stimulation of the hypoglossal nerve and observation of what muscle movements are caused by it. Interesting because of this special approach. The author gives the following conclusions:
1. Neither in cases of unilateral paralysis, nor in normal cases has the genioglossus muscle anything to do with contralateral deviation of the tongue. The action of this muscle is to pull the tongue to the floor of the mouth, protrude it, and deviate its tip to the same side.
2. The superior longitudinal muscle has been found to be the only contralateral deviator of the tongue as well as the only dorsi-flexor of its tip.
3. The inferior longitudinal muscle - aided by the styloglossus muscle and anterior fibres of hyoglossus and genioglossus muscles-is, besides being a homo-deviator, a ventroflexor of the tip .
4. Both the superior and inferior longitudinal muscles possess a bony attachment to the hyoid bone.

2. Abd-el-Malek, S. (1939) "Observations on the morphology of the human tongue", Journal of Anatomy 73,201.

The best description so far of the muscles of the tongue, based on dissections and experimental work. Most writers quote him as basic material on the tongue. A very good description is given of the septa of the tongue, which is usually not found in most anatomy books in such detail. The median, paramedian and lateral septa are described. The author also gives a very detailed description of the different muscles of the tongue, supported by diagrams and plates. This is by far a more detailed description than even the best anatomy books give. However, in this particular article there is no attempt to suggest the way in which the muscles of the tongue participate in the different movements of the tongue.

3. Abd-el-Malek, S. (1955) "The part played by the tongue in mastication and deglutition", Journal of Anatomy 89,250.

Although the article deals with mastication and deglutition rather than speech, the author gives a few interesting remarks as to the muscles and their movements. "Depression of the tongue near the mid-line and raising of its lateral margins are produced by contraction of the genio-and hyoglossi combined with bilateral action of the styloglossi(pl.1,fig.1, in which the tongue is also protruded to bring it within view of the camera). When the tip is turned sharply upwards the superior longitudinal muscles come to stand out as a pair of thick parallel bands lying mid-way between the median plane and the lateral margins of the tongue, and a weaker action of these muscles is involved in the formation of the trough-like 'preparatory' stage. When in addition the tongue is elongated a groove forms along its lateral margins, due to the strong action of the transverse musculature, which, by reducing the transverse diameter at a time when the vertical diameter is already restricted by the genio- and hyoglossi, forces the tongue to elongate in the longitudinal direction." (These conclusions were based on visual observations)

4. Alderisio,J.P. (1953) "An electronic technique for recording the myodynamic forces of the lip,cheek and tongue", Dental Research 32,548.

Interesting electronic device to measure the pressures exerted by the lips, cheeks and tongue upon various areas of the dental arch. No references to speech activity.

5. Arnold, G.E. (1957) "Morphology and physiology of the speech organs", Manual of Phonetics (L. Kaiser, ed.) North-Holland Publishing Co.: Amsterdam.

Discusses the tongue briefly, on p. 56 and 57. Mentions the hyoid bone as a support and insertion for muscles but states very definitely, that it does not have any distinct function. The genioglossus, according to Arnold, draws the back of the tongue forward and the protruded tongue backwards, which is basically what Gray says but in much less detail. The same thing is true about his description of the other muscles of the tongue.

6. Astley, R. (1958) "The movements of the lateral walls of the Nasopharynx: a cine radiographic study", J. Laryn. & Otol. 72,325.

Cino-radiography of the nasopharynx in frontal projection. The experiment is not very clear, and not useful for our purposes.

7. Baril, C., Moyers, R.E. (1960) "An electromyographic analysis of the temporalis muscles and certain facial muscles in thumb and finger sucking patients", Dental Research 39,536.

Interested in facial muscles. Interesting experiment of electromyography of the upper lip. p.538- lip is divided into six sections, surface electrodes on each, asymetry was proved from center to left or right. Casts were also used. Nothing about tongue muscles.

8. Barr, T. (1960) "The Tongue", Eye, Ear, Nose & Throat Monthly 39,641.
Nothing on muscles. Mainly on nerves.

9. Barrett, R.H. (1961) "One approach to deviate swallowing", Amerc. J. of Orthodontics p.726.
Nothing about muscles and their actions.

10. Bennett, G.A., Ramsay, A.J. (1941) "Experimental studies on the movements of the mammalian tongue", Anatomical Record 79,39.
Experiments in dissection of the tongue of anaesthetized dogs. During observation the following stimulations were produced: of the hypoglossal nerve and of the musculus genioglossus in different combinations. The results are stated in the author's summary:"The protrusion of the tongue is due to the action of the genioglossus and the intrinsic muscles. The genioglossus is concerned primarily in pulling the tongue forward in the mid-line while the intrinsic muscles protrude it contralaterally. partly, by means of a lengthening process..." The assumption is that the conditions found in the dissected animals are similar to the conditions in man.

11. Bergerhoff, W. (1961) Atlas of Normal Radiographs of the Skull Springer-Verlag: Berlin.
Skull X-rays from different angles and points of concentration. Useful for locating particular features in our own X-rays.

12. Bergman,R.A. (1962) "Light microscope observations of contractile units in human lingual muscle", Johns Hopkins Hospital Baltimore Bulletin 3,14.
"A consistent pattern of localized contractions has been seen in histological sections of the human tongue by light microscopy. The contraction band pattern is similar to those obtained by local (non-propagating) stimulation of isolated frog muscle fibers recorded by cinephotomicrography. The results are also consistent with light and electron microscope studies of contracted fibers. The regularity of the observations suggest that the contractile unit in the striated muscle of the human tongue is that area of the myofibil between two successive M lines." (author's summary)

13. Blom, S. (1960) "Afferent influences on tongue muscle activity. A morphological and physiological study in the cat", Acta Physiologica Scandinavica 49, Supp. 170.
Mainly concerned with the hypoglossal nerve. Survey of investigation in this field, but very few on human tongues. On tongue (of cat) p.16-21, muscles that are very similar to human tongue muscles but there is nothing helpful to us in this chapter.There are no muscle spindles in intrinsic or extrinsic muscles of the cat.

14. Blythe, P. (1959) "The relationship between speech, tongue behaviour and occlusal abnormalities", Dental Practitioner 10,11.
On behaviour of the tongue in lisping. No account of movements, only of positions.

15. Bosma, J.F. (1957) "Poliomyelitic disabilities of the upper pharynx", Pediatrics 19,5.
Mainly pharynx in connection with bulbar poliomyelitis.

16. Bosma, J.F. (1960) "Roentgenologic observations of motions of the upper airway associated with establishment of respiration in the newborn infant", Acta Poediatrica 49, Supp. 123.
On page 20 - dissections illustrating the musculature of the pharyngeal region including tongue muscles- in the term new-born infant. The article is concerned mainly with respiratory functions. Tongue movements during respiration move the epiglottis.

17. Bosma, J.F. (1961) "Comparative physiology of the pharynx", Congenital Anomalies of the Face & Associated Structures Charles C. Thomas.
As title indicates.

18. Bosma, J.F. (1963) "Oral and pharyngeal development and function", Dental Research 42,part 2.
In the young infant tongue and mandible move together in relation to the pharyngeal airway. Therefore, position of the mandible is important.

19. Cooper, Sybil (1953) "Muscle spindles in the intrinsic muscles of the human tongue", Journal of Physiology 122,193.
In experiments with human babies' tongues, muscle spindles were observed, but they were not equally distributed over the musculature. Numerous spindles are found in the longitudinal muscle. No spindles in the tip of the tongue. Spindles in the genioglossus - mainly in the base of the tongue. Intrinsic muscles get motor innervation from the hypoglossal nerve.

20. Cunningham, D.J. (1915) Text-Book of Anatomy (A. Robinson, ed.) William Wood and Co.: New York.
On pages 462-463 gives a brief description of the muscles of the tongue. There is very little on the actions of the muscles and their participation in the different movements of the tongue. Basically very similar to Gray but much less detailed.

21. Dabelow, R. (1951) "Preliminary studies of the tongue as a functional system," Morph. Jahrb. 91,33. (In German)
An anatomical investigation with many excellent photographs and diagrams. Disagrees with Abd-el-Malek (1939) [not cited in refrences] "The [median] septum is no fibrous dividing wall but a complicated linkage of the transverse muscles. The longitudinal musculature consists of bow-shaped pieces which are shortest near the surface and get longer as they get farther toward the depth. Those even deeper are completed by styloglossus fibers."

22. Draker, H.L. (1960) "Handicapping labio lingual deviations - a proposed index for public health purposes", Amerc. J. of Orthodontics 46,295.

Shows different instruments for measuring such handicaps, but only for teeth positions.

23. DuBrul, E.L., Sicher, H. (1954) The Adaptive Chin Charles C. Thomas: Springfield, Illinois.

This work deals mainly with the chin and the muscles connected to it. Muscles of the tongue are not discussed. It is interesting in as far as it shows the chin development in different animals and stages of man's development.

24. DuBrul, E.L. (1958) Evolution of the Speech Apparatus Charles C. Thomas: Springfield, Illinois.

As the title indicates, this is a description of the evolution of the speech organs in different animals and man. Most of the descriptions and pictures are based on actual dissections. The whole work deals with the general speech apparatus and gives no details of the tongue and its muscles.

25. Grant, J.C. Boileau (1962) Grant's Atlas of Anatomy The Williams & Wilkins Co.: Baltimore.

Figures on pages 544-549 show the mylohyoid, geniohyoid, suprahyoid regions with some textual explanations but very general ones. Figures 591-599 show tongue and floor of the mouth. For our purposes the figures in Pernkopf are clearer.

26. Gray, H. (1959) Gray's Anatomy (C.M. Goss ed.) Lea and Febiger: Philadelphia.

This text book gives a very detailed and useful description of all the muscles of the tongue as well as their function in the different movements of the tongue. Explanations are accompanied by good pictures. On page 432 - the digastricus, stylohyoideus, mylohyoideus and geniohyoideus are described. The stylohyoideus is perforated by the digastricus near its insertion into the greater cornu of the hyoid bone. It draws the hyoid bone upward and backward. The mylohyoideus raises the hyoid bone and tongue. The geniohyoideus draws the hyoid bone and tongue forward. On page 1234 there are sections of the tongue showing intrinsic and extrinsic muscles. The intrinsic muscles can be seen fairly well. On page 1236 actions of the tongue are described according to the directions of the different fibers in the muscles. Genioglossus - posterior fibers draw the rooot of the tongue forward and protrude the apex from the mouth. The anterior fibers draw the tongue back into the mouth. The two muscles together draw the tongue downward and make its superior surface concave from side to side. Hyoglossus depresses the tongue and draws down its sides. Styloglossus draws the tongue upward and backward. The glossopalatini draw the root of the tongue upward. Intrinsic muscles are mainly concerned in altering the shape of the tongue -- shorten, narrow and curve it in different directions. Longitudinalis superior and inferior tend to shorten the tongue. The superior also turns the tip and sides upward rendering a dorsum concave and the inferior pulls the tip downward and renders the dorsum convex. Transversum narrows and elongates the tongue and verticalis flattens and broadens it. On Page 1236 Gray quotes Macalister saying: "there is reason to believe that the musculature of the tongue varies in different races owing to the hereditary practices and habitual use of certain motions required for enunciating the several vernacular languages".

27. Heffner, R-M. S. (1952) *General Phonetics* Univ. of Wisconsin Press. Extrinsic muscles of the tongue described on page 33. Basic material with general mention of the movements.

28. Hollingshead, W. H. (1958) *Anatomy for Surgeons* Vol. 1 Hoeber-Harper. Chapter 7 in this book deals with "The jaws, palate and tongue." The extrinsic muscles of the tongue are described on page 378. The description is basically similar to Gray's, however in less detail. Very little is said about intrinsic muscles. As far as movements of the tongue, Hollingshead says only the following: the extrinsic muscles pull the tongue forward, backward, upward and downward while the instrinsic muscles change the shape of the tongue cupping it or bulging it.

29. Hollingshead, W. H. (1962) *Textbook of Anatomy* Hoeber-Harper. Pages 902-903 deal with the muscles of the tongue. This is a very general description but more detailed than in the previous reference. Basically there is nothing new in this work.

30. Kaplan, H. M. (1960) *Anatomy and Physiology of Speech* McGraw-Hill: New York.
Pages 251-254 deal with the tongue muscles. This description is again less detailed than Gray's but it can serve as a good starting point for beginners. Kaplan also makes some speculations on which muscles perform certain movements of the tongue, basically saying what Gray says. The chondroglossus muscle is explained as the part of the hyoglossus which originates from the lesser cornu.

31. Kawamura, Y. (1961) "Neuromuscular mechanisms of jaw and tongue movement", *Jour. Amer. Dental Assn.* 62,545.
General description of tongue movements. Says no more than usual anatomy books.

32. Krmpotic, Jelena (1961) "The chronometric neuromuscular index of the large hypoglossal nerve and its branches relative to the function of the tongue mastication, deglutition and phonation", *Rev. de Laryng.* 82, 1006. (In French).
Of little interest to us. Says Husson (without giving any reference) "has found five main positions of the tongue during the production of speech sounds". Some general remarks on the muscles involved in the formation of vowels (really just a listing). "The position of the tongue in the formation of consonants K. G. is produced by the contraction of the inferior longitudinal muscle"... "position of the tongue in pronouncing L contraction of the superior longitudinal muscle."

33. Kydd, W.L. (1957) "Maximum forces exerted on the dentition by the perioral and lingual musculature", Jour. Amer. Dental Ass. 55,646.
Special plastic measurement device to measure maximum forces of tongue exerted on teeth. Nothing about muscles or motions.

34. Lei,Lyu (1961) "Radiation of excitation from the respiratory center to the motor centers of the muscles of the tongue", Fiziol. Zh. SSSR Sechenov 47.7,88.
Impulses from the hypoglossal nerve cause the tongue to contract. Experiments with guinea pigs and cats. Motor center of the muscles of the tongue = nuclei of hypoglossal nerves.

35. Leith, W.R. (n.d.) Drawings of Anatomical Structures Involved in Speech Colorado State University: Fort Collins, Colorado.
Pages 25-28 give useful pictures of the tongue muscles and the area close to the tongue. There is no text. Although these drawings are helpful in themselves, it seems that Pernkopf is clearer.

36. Lerche, W. (1950) The Esophagus and Pharynx in Action Charles C Thomas: Springfield, Illinois.
The book deals with the esophagus, its outer and inner layers of muscles, its dimensions on page 20. The pharynx is discussed only in relation to the function of digestion. Does not seem useful for our purposes.

37. MacNeilage, P.F., Sholes, G.N. (1964) "An electromyographic study of the tongue during vowel production", (in MS).
"Surface electromyograms were recorded from 13 locations on the tongue of one subject during production of 17 different types of [p] - vowel - [p] monosyllables. Results were considered together with X-ray data on tongue action, and anatomical information on tongue musculature, in an attempt to describe the action of tongue muscles during vowel production." (Authors' summary)

38. Mashiko, N. (1960) "Studies on clinical electromyography. Electromyography of tongue muscles", Folia Psychiatrica et Neurologica Japonica 14,28.
The author states that till now there is insufficient electromyography on the muscles of the tongue firstly because of the complexity of these muscles, and secondly: "difficulties exist in such discomfortable feeling as inserting needles into the tongue. The author overcomes these difficulties by preliminary training and persuasion of the patient." "M. longitudinalis superficialis was chiefly selected and in some cases other tongue muscles were examined." "No essential differences between M. longitudinalis superficialis and profundus were seen."
A clinically oriented article, probably of little scientific value.

39. Nieberg, L. G. (1958) "An electromyographic and cephalometric radiographic investigation of the orofacial muscular complex", Amer. J. of Orthodontics 46, 627.
Only the abstract. This experiment seems to be good for lip and lip muscles (mandibular, mentalis, orbicularis, suprahyoid).

40. Pernkopf, E. (1963) Atlas of Topographical and Applied Human Anatomy Vol. 1. "Head and Neck". Saunders: Philadelphia.
On pages 136-141 very useful pictures of the tongue, its muscles and the area around it. No text. Seems to be the best atlas for our purposes.

41. Pons-Tortella, E. (1936) "Zur Entwicklung und der Muskulatur der Zunge beim Menschen", Zeitsch. f. Entwick. 105, 75.
Not seen.

42. Prinz, H., Greembaum, S. S. (1939) Diseases of the Mouth and their Treatment Lea & Febiger: Philadelphia.
Page 23 "The anatomy of the oral cavity". Page 31 "The tongue" which gives general anatomy and muscles are generally mentioned. Page 37 "Muscles of the tongue", very short passage explaining the extrinsic and intrinsic muscles. "The outer portion of the tongue is composed chiefly of longitudinal fibers. The central portion is composed chiefly of vertical and transverse fibers."

43. Rogers, J. H. (1961) "Swallowing patterns of a normal population sample compared to those of patients from an orthodontic practice", Amer. J. of Orthodontics 47, 676.
Gives a description of the swallowing act and what muscles are generally involved in it. There is no detail as to the function of each muscle nor is there any indication of how it is checked.

44. Rogers, A. P. (1918) "Exercises for the development of muscles of the face with a view to increasing their functional activity", Dental Cosmos 60, 857.
Not useful for our purposes.

45. Russell, O. G. (1928) The Vowel. The Ohio State University Press.
An X-ray study, but with insufficient precision (no scales on the illustrations) to make it useful for our purposes.

46. Russell, O. G. (1931) Speech and Voice Macmillan: New York.
An X-ray study, but with insufficient precision (no scales on the illustrations) to make it useful for our purposes.

47. Scully, J. J. (1960) "Cinefluorography studies of the masticatory movements of the human mandible", Amer. J. of Orthodontics 46, 306.
Research on the function of the mandible and its muscles in mandibular movements. (Abstract only)

48. Shearer, W.M. (1964) Illustrated Speech Anatomy Charles C Thomas: Springfield, Illinois.

Some elementary sketches of the tongue muscles on pages 59-60. Not very clear nor very explanatory and of a very general nature. Does not present anything new, in fact less than most anatomy books.

49. Sheppard, I.M. (1953) "Tongue dynamics", Dental Digest 59,117

Tongue habits (mainly abnormal ones) and their relation to dental deviations. Nothing about muscles.

50. Shelton, R.L., Bosma, J.F. (1960) "Tongue, hyoid and larynx displacement in swallow and phonation", J. of Applied Physiology 15.2

Cinefluorographic observations of the pharyngeal portions of the tongue and of the hyoid and larynx of ten persons, during deglutition and during phonation of the sound [m].

51. Sobotta, J., McMurrich, J.P. (1930) Atlas of Human Anatomy G.E. Stechert & Co.: New York.

Pages 286-292 deal with the tongue. General description of the muscles of the tongue with some very good illustrations, but on the whole does not say anything new that other anatomy books and atlases don't have.

52. Spalteholz, W. (1933) Hand Atlas of Human Anatomy J.B. Lippincott: Philadelphia.

Volume 3 pages 508-509 give pictures of the tongue muscles with explanations that are basic but quite clear and found in most anatomy books.

Lip muscles are generally described but again nothing more than in most anatomy books.

53. Stirk, A. (1958) "The Transverse Dimensions of the Nasopharynx in child and adult...", J. Laryngology and Otology 72,465.

A measuring gauge was used - with forceps structure and angled extremeties and a measuring calibrated arch. (p.466) Measurements in cm. of the lateral diameter of the nasopharynx.

54. Straub, W.J. (1960) "Malfunction of the tongue. The Abnormal swallowing habit, its cause, effects and results in relation to orthod. treatment and speech theraphy", Amerc. J. of Orthodontics 46,404.

Abnormal swallowing - improper tongue position due to bottle feeding. Page 417 "The tongue is pressed upward and backward by contractions of the mylohyoid and hyoglossus muscles".

55. Strong, L.H., Gold, E.M. (1950) "Force components of the tongue musculature with emphasis on the intrinsic fibers, especially those used in speech", Anatomical Record 106,86.

Not seen. Reference as given above is given by Strong (1956) but seems to be wrong.

56. Strong, L.H. (1956) "Muscle fibers of the tongue functional in constant production", Anatomical Record 126,61.

An important article, illustrated with excellent photographs of sections of the tongue. Carries on the work of Strong and Gold (1950) investigating how the intrinsic tongue musculature would deform the tongue to conform to the outlines of palatograms. Rather naive about palatograms and tongue positions, confusing effects due to consonants with those due to vowels. Consequently produces an odd hypothesis concerning the action of the transverse and vertical muscles which are supposed to act in a special way in consonants. Interesting critical review of the anatomical literature, showing some of the 19-th century sources of Gray, Cunningham and Spalteholtz. Mentions existence of Abd-el-Malek (1939) but pays no attention to his work, which (despite the mention) is not listed in the bibliography.

57. Tandler,J. (1923) Lehrbuch der Systematischen Anatomie Verlag von F.C.W. Vogel: Leipzig. (In German)

Pages 107-110 deal with tongue and tongue muscles. Description very general. Less than in most other anatomy books.

58. Travis,L.E.(1957) Handbook of Speech Pathology Appleton-Century-Crofts:N.Y

Chapter 21 by H.H. Bloomer: "Speech deffects associated with dental abnormalities and malocclusions". First part of this chapter deals with position of the tongue during phonation of different phonemes. Palatograms and X-rays are shown but these are small and no measurements are given but rather general shape. Muscles of the tongue are not mentioned. Second part of the chapter deals with abnormalities.

59. Tulley, W.J. (1956) "Adverse muscle forces - their diagnostic significance", Amerc. J. of Orthodontics 42,801.

Muscles of lips and face and tongue movements discussed only generally and concerning malocclusion and abnormal habits. Distinction made between innate formations and habits which may be corrected. Muscles of the tongue are not discussed.

60. Van Riper, C., Irwin,J.V. (1958) Voice and Articulation Prentice-Hall inc.: Englewood Cliffs, N.J.

Chapter 11 is very good for basic understanding of the functions of the mandible, hyoid bone and most important muscles. A very detailed and useful description, probably the best for beginners in this area especially interested in speech functions.

61. Weddell, G., Harpman,Lambley, Young, (1940) "The innervation of the musculature of the tongue", Journal of Anatomy 74,255.

Most experiments with animals. The problem in human tongue - it is not possible to examine in vivo. Experiments with rats by staining techniques. No sensory ends in the intrinsic muscles. Neuro-muscular spindles in hyoglossus and genioglossus.

62. Weihs, H. (1961) "Contribution to the diagnosis and therapy of voice disorders with special reference to respiration, tongue and laryngeal musculature", Folia Phoniatrica 13,13. (In German)

Not useful for our purposes.

63. Wildman, A.J. (1961) "Analysis of the tongue, soft palate and pharyngeal wall movements", Amerc. J. of Orthodontics 47,439.

Good reference for nasopharynx. Good literature survey and pictures. Page 453 discusses points of reference for measuring tongue positions. Mandible and hyoid bone are not good points of reference because not stable. Suggests relation to walls of the oral cavity: palatal plane. Nothing on function of tongue muscles.

64. Winders, R.V. (1958) "Forces exerted on the dentition by the perioral and lingual musculature during swallowing", Angle Orthodontist 28,226.

Measurement of pressure on teeth - exerted by the tongue. Not useful.