AN ELECTROMYOGRAPHIC STUDY OF THE TONGUE DURING VOWEL PRODUCTION

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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. It proved possible in most cases to assign muscles, with some certainty, to the major features of myographic activity, and to indicate what function the muscle was serving. The results have particular relevance to theories of sequential speech production, and indirectly, theories of speech perception, as they provide a basis for description of how coarticulation of vowels with consonants involving the tongue takes place.

Very little is known about how the muscles responsible for articulation act in coordination during speech. This is unfortunate because such knowledge could play a critical role in evaluating recent speculation about the mechanisms of both speech perception (Liberman, 1957; Liberman, Cooper, Harris, and MacNeilage, 1962) and speech production (Stevens and House, 1963; Lindblom, 1963; Ohman, 1963), which include inferences about how the muscles of speech work.

Electromyography is an obvious method of studying muscle action but few myographic studies have been done to date, largely because of technical difficulties. Needle electrodes are painful to a subject, awkward to work with in rapidly moving tissue, and only sample a minute fraction of any total speech event. Surface electrodes record from a broad area, often containing several muscles whose relative contribution to the total signal is difficult to determine. Some important articulators such as the tongue and soft palate are relatively inaccessible to conventional electrodes of any kind. However, in the last few years, at Haskins Laboratories, a surface suction electrode has been developed which allows recording from the tongue and soft palate as well as from more exposed surfaces of the upper articulators (Harris, Rosov, Cooper, and Lysaught, in press).

Some studies have already been done using these techniques and their results have been summarized elsewhere (MacNeilage, 1963). It has been found from these studies that it is extremely difficult to make inferences about the basic motor organization underlying the obtained electromyographic patterns without knowing what muscles were acting and what the role of each

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muscle was. It was therefore desirable to make an attempt to deduce this information from the patterns of myographic activity. The attempt was made in the case of tongue muscle activity during vowel production. It was necessary to bring together information from several sources. First an attempt was made to learn, from descriptions of tongue morphology, the locations and relative sizes of the muscles directly controlling the tongue. Next the configurations the tongue mass assumes during vowel production were observed in high speed cinefluorograms. This led to inferences as to which muscles were capable of producing the observed tongue shapes. Finally, the electrodes which had recorded activity were noted for each vowel. Muscles that could have produced the accompanying tongue movement, and lay in the vicinity of the active recording electrodes, were assumed to have contributed to the production of the given vowel.

As the results will be discussed in terms of the actions of particular tongue muscles and muscle groups, a brief description of the musculature of the tongue may be useful. A detailed study of tongue morphology has been done by Abd-El-Malek (1939), and the present summary derives largely from that study. A description of the probable action of the muscles of the upper articulators during speech has been provided by Van Riper and Irwin (1958).

MUSCLES OF THE TONGUE

The tongue musculature has been divided into two groups: extrinsic, and intrinsic muscles. Each individual muscle described is bilaterally symmetrical about the median septum.

Extrinsic Muscles

A sketch of the distribution of these muscles is shown in Figure 1.

1. Genioglossus. This is the largest of the tongue muscles and constitutes the main bulk of the posterior portion of the tongue (near the epiglottis). It orginates at the point of the jaw (symphysis menti) and fans out into the whole anterior-posterior extent of the tongue. It inserts largely in the intrinsic musculature of the tongue but sometimes reaches as far as the superficial dorsal tissue. It inserts close to the middle of the tongue (the median septum) anteriorly, and its insertions also spread laterally in the intermediate and posterior areas. It is capable of acting to move the tongue towards the point of the jaw.

2. Hyoglossus. This muscle originates at the hyoid bone and runs upward, and anteriorly towards the tongue tip, with some fibers reaching the tip region. It inserts largely in intrinsic muscles, somewhat laterally to the midline of the tongue. Its action is to pull the tongue towards the hyoid bone if the hyoid bone is itself anchored in position by other muscles.

3. Styloglossus. This muscle originates at the styloid process near the ear, and enters the tongue at its lateral border at about the level of the ramus of the jawbone. A large part of it then runs ventrally towards the midline of the

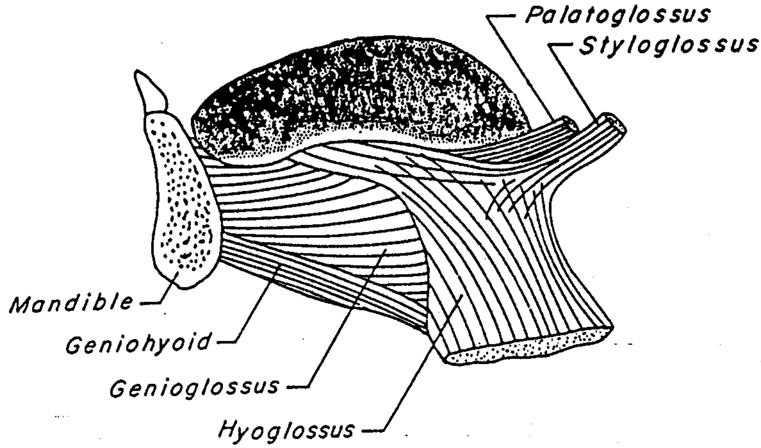


FIGURE 1. The distribution of the extrinsic muscles of the tongue and the geniohyoid muscle (after Sobotta and Uhlenhuth, 1957, p. 24).

tongue and anteriorly toward the tongue tip, the most anterior fibers interlacing with other muscles at the tip. A smaller part runs slightly posteriorly in the tongue and attaches to hyoglossal musculature. The role of this muscle acting alone is to pull the tongue back and up. It could also cooperate with the hyoglossus to pull the tongue back only.

4. *Palatoglossus.* This is a small muscle running from the lateral edge of the soft palate into the lateral border of the tongue. Its action is to lift the tongue, though because of its small size, its influence in speech may be relatively slight.

Intrinsic Muscles

These four muscles are arranged in three dimensions within the tongue, longitudinally, transversely, and vertically.

1. *Superior longitudinal.* This muscle runs the length of the tongue, lying, in general, closer to the dorsal surface than any other muscle. It is largest in bulk medially and in the middle two fourths of the tongue, where it is triangular in cross section (with the apex pointing ventrally). It narrows to a thin sheet at the most anterior and posterior extremities of the tongue.

2. *Inferior longitudinal.* This is a small muscle, oval in cross section, which also runs the length of the tongue. It is situated well below the dorsal surface of the tongue and is largely medial to the hyoglossus. With the superior longitudinal muscle, it acts to contract the tongue in the longitudinal dimension.

3. *Vertical.* This muscle runs from the ventral toward the dorsal surface of the tongue. Most of its fibers terminate ventral to the superior longitudinal muscle. It is thickest in the middle third of the tongue. It acts to flatten the body of the tongue.

4. *Transverse.* This muscle forms a good part of the thickness of the middle

third of the tongue. It originates at the median septum, ventral to the superior longitudinal muscle, and runs toward the lateral border of the tongue fanning dorsally and ventrally. The muscle extends more anteriorly and posteriorly than does the vertical muscle. Its role is to narrow the body of the tongue.

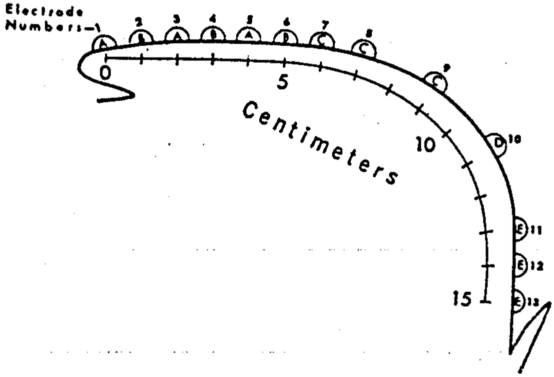


FIGURE 2. Distribution of the 13 recording electrodes along the tongue surface. The letters A to E inside the schematized electrode cups indicate the electrodes recorded from on each of the 5 runs.

METHOD

A single subject generated the data. Recordings were made at 13 electrode locations on the dorsal surface of the tongue along an off-center line extending from the tip to the vallecula at the root. No more than three electrodes were attached to the subject during any one of the experimental runs. The relative location of these electrodes and their distribution over the runs are shown in Figure 2.

During each run the subject repeated one-syllable utterances from a cue tape of his own voice. These monosyllables were of the shape [p] — vowel — [p], where vowel is one of seventeen vocalic nuclei. These include all the plain nuclei that occur under stress in the subject's north central dialect, and three of the stressed nuclei with [r] coloring. Table 1 is a list of the vowels studied, together with examples of words in which they occur. The notation used to represent the vowels is meant not to prejudice any of several possible phonemic interpretations. (Thus [ør] representing the nucleus of "horse" or "hoarse" suggests features in common with both [o] "coat" and [ɔ] "caught.") The cue tape contained a large number of tokens of each of these types in semi-random order; they followed each other at the brisk rate of one every second and a half.

The electrode signals were fed into a penwriter after being amplified, rectified, and then smoothed by a resistor-condenser circuit with a time constant of twenty-two milliseconds. Simultaneously, a parallel pen recorded literal voicing during the utterance. This signal came from a small vibration pick-up

TABLE 1. A list of the 17 vowels studied, with examples of words in which they occur. The vowels are listed in the order in which they are discussed in the text.

Simple vowels	Complex vowels
i "keyed"	ar "lard"
ɪ "kid"	ɸr "lord"
u "cooed"	e "laid"
ʊ "could"	ai "lied"
ɛ "Ked"	oi "Lloyd"
æ "cad"	o "load"
ʌ "cud"	au "loud"
a "cod"	
ɔ "cawed"	
ɝ "curd"	

placed against the thyroid cartilage. A detailed description of the kind of apparatus used is given elsewhere (Harris, Rosov, Cooper, and Lysaught, 1964).

Each electrode pen trace was sampled at a number of pre-selected points relative to three events in the pen trace of voicing: the burst of the initial [p], the onset of literal voicing, and the offset of literal voicing. The voltage reading at each sample point was averaged over 20 artifact-free myograms. Plots of average voltage during the course of an utterance are displayed in Figures 3 through 19.

The movements of this speaker's tongue during vowel production were studied on cinefluorograms recorded for another purpose (Abramson and Cooper, 1963). On that occasion, the subject was producing [p] – vowel – [b] monosyllables, not [p] – vowel – [p] monosyllables, but this circumstance probably has little effect on the general form of the tongue action during the vowel. Some parts of the tongue were not visible during the production of some of these vowels due to contrast difficulties. The locations of the rear wall of the pharynx, the lips, and the roof of the mouth were also not consistently visible. Nevertheless, much information on the positioning of the tongue was available, and some of this information is given in a series of sketches of single frames from X-ray sequences, in Figures 3 through 19, with the positions of the upper and lower teeth serving as reference points. An arbitrary grid has been superimposed on these sketches, to enable easy comparison of the relative position of the tongue for different vowels. The tongue outline drawn in solid lines shows the position of the tongue surface, as visible on the frame which showed its most extreme departure from the resting position. Areas of the tongue not circumscribed by solid lines represent estimates of the position of that part of the tongue surface. The temporal position of each sketched frame in relation to the onset of vocal cord activity is indicated on the figure for each vowel, by the arrow below the X-axis of the voltage curves. When there appeared to be two relatively distinct directions of tongue movement during a vowel, the extreme position reached during the first movement is shown in dashed lines, and its temporal position is shown by the broken arrow on the figure. The extreme position reached during the second movement is shown by the solid line.

RESULTS AND DISCUSSION

The following section consists of a presentation of the myographic results and an attempt to interpret them in terms of the two variables just discussed; the morphology of the tongue, and the nature of the tongue movement occurring in each case.

[i]

Figure 3 shows the average voltages from the 13 different electrode positions for the vowel [i] together with a sketch made from the X-ray film showing

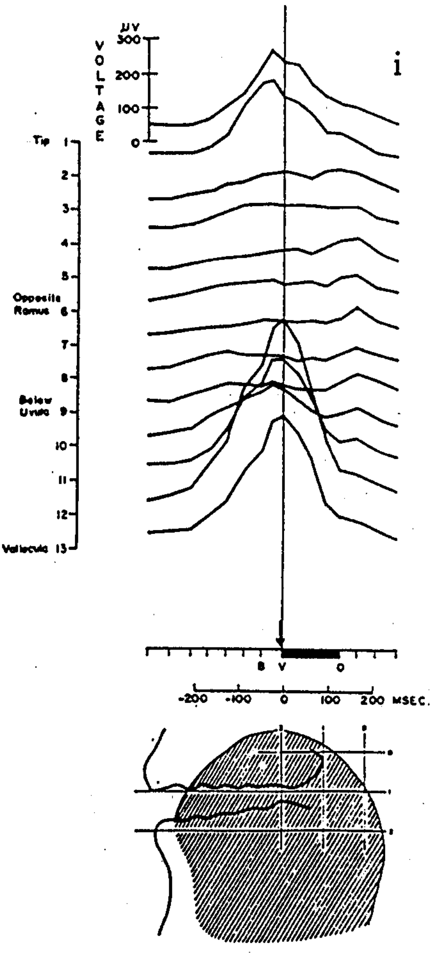


FIGURE 3. Average voltage patterns recorded from the 13 electrodes during the production of [pip], and a sketch of an X-ray plate showing the tongue at its extreme position for the vowel. The vertical arrow above the x-axis shows the point in time relative to the onset of vocal cord vibration (V) at which the X-ray slide was photographed. The label B below the x-axis refers to the moment of the initial [p] burst, and the label (O) to the offset of vocal cord vibration for the vowel.

other vowel. The action is also indicated by the high voltage peaks during [i] from the 4 back electrodes (10 – 13). These peaks are the highest recorded in the entire study, and must reflect the action of the posterior genioglossal fibers pulling this portion of the tongue toward the point of the jaw. The third peak, (c), following voicing, probably represents a slight, though rather widespread contraction of the genioglossus, serving to restore the tongue to its position of rest.

[ɪ]

Figure 4 shows the results for [ɪ]. Voltage levels for the main events here are a great deal lower than for [i]. This is related to the fact (shown in the X-ray sketches of the two vowels) that the tongue moves much less far

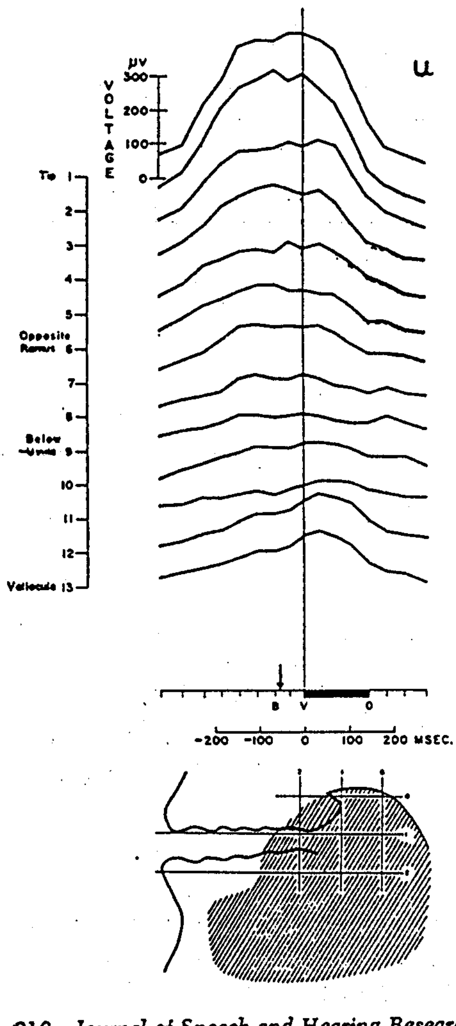


FIGURE 5. Average voltage patterns recorded from 13 electrodes during the production of [pup], and a sketch of an X-ray plate showing the tongue in its extreme position for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

from the position of rest for [ɪ] than for [i]. However the pattern of voltage peaks is somewhat similar to that for [i]. There is, (a) a slight peak before voicing in the two tip electrodes, (b) a peak before voicing in electrodes 10 to 13, and (c) a peak throughout the tongue, towards the end of voicing. The peak at the tip probably indicates slight tip retraction as in [i]. The peak before voicing at the root may be associated with slight forward movement of the back of the tongue and be produced by posterior genioglossal fibers, as in [i]. The peak visible throughout the tongue during voicing cannot be due to pulling down of the tongue by the genioglossus (as was the generalized peak shown in [i]) because the tongue was not moved to a very high position in the first place. The possible explanation of this peak will be deferred until the results of lower vowels are presented.

[u]

As Figure 5 shows, this vowel is accompanied by high voltages from several tongue front electrodes, with possibly two peaks, (one considerably before voicing, and one just after voicing) and possibly two peaks from electrodes 12 and 13. The early peak at the front of the tongue is probably produced by rather vigorous contraction of the longitudinal muscles, and of the styloglossus which would serve to move the tongue back and up. The second peak may be due to the anterior genioglossus controlling the back and up movement by an antagonistic pull in a frontward and downward direction. This type of action is a well known function of muscles. The two peaks from electrodes 12 and 13 occur also in [ʊ], the next vowel to be considered, and will be discussed there.

[ʊ]

The myographic pattern for [ʊ] (see Figure 6) is similar to that for [u] in that it has the two peaks from back electrodes, just mentioned, and a rather high peak considerably before voicing in several front electrodes. However the pattern differs from that for [u] in that the front pre-voicing peak is lower, there is scarcely any evidence of a second front peak such as [u] shows, and all peaks occur slightly earlier than in [u]. The front pre-voicing peak is probably due to action of the longitudinal muscles and the styloglossus, as in [u]. The virtual absence of a second front peak may be due to the fact that, as less upward movement is required for [ʊ] than for [u], (see X-ray traces) no definite antagonistic action of the genioglossus is required to control the movement, contrary to the case in [u].

The two peaks from back electrodes occurring in [ʊ] and [u] are difficult to interpret. Voltage levels in this area are somewhat higher for [ʊ]. It is possible that most of this potential comes from the hyoglossus, contraction of which would tend to move the tongue back and down. Voltage would then be lower for [u] than for [ʊ] in order to avoid too much counteraction of the required greater upward pull being exerted by the styloglossus. This

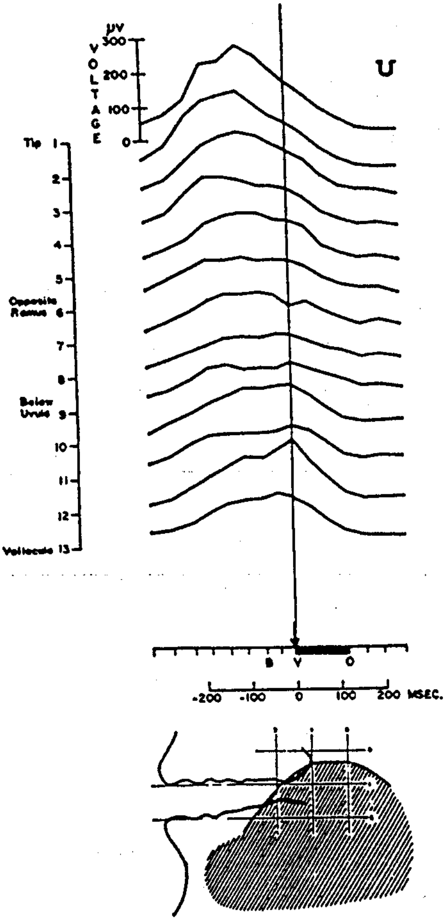


FIGURE 6. Average voltage patterns recorded from 13 electrodes during the production of [pʊp], and a sketch of an X-ray plate showing the tongue in its extreme position for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

hypothesis, however, does not explain the double peak shown by the back electrodes.

[ɛ], [æ]

As Figures 7 and 8 show, [ɛ] and [æ] have very similar voltage patterns, so they will be discussed together. Although they show very little voltage from front electrodes before voicing, there is some sign of a pre-voicing peak in electrodes 10-13. There is also a peak throughout the tongue during voicing. Voltage is generally higher for [æ] consistent with its requiring more movement of the tongue from the position of rest than does [ɛ]. The pre-voicing peak in the back electrodes is probably due to contraction of the hyoglossus, as was suggested for [ʊ] and [u] when describing [ʊ], which

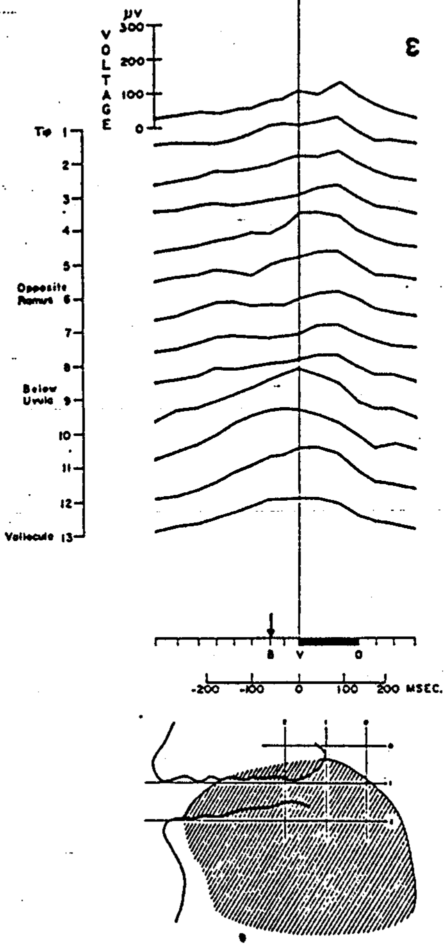


FIGURE 7. Average voltage patterns recorded from 13 electrodes during the production of [pɛp], and a sketch of an X-ray plate showing the tongue in its extreme position for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

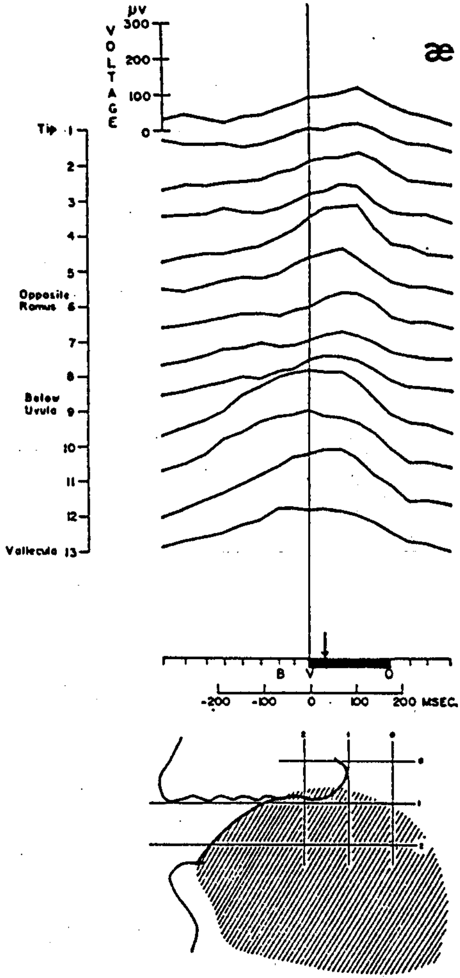


FIGURE 8. Average voltage patterns recorded from 13 electrodes during the production of [pæp], and a sketch of an X-ray plate showing the tongue in its extreme position for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

would tend to move the tongue down and back. The voicing peak throughout the tongue is similar to the one observed in [ɪ] and is possibly produced by the intermediate longitudinal musculature. Contraction of these muscles could be used to produce some bulging upwards of the middle third of the tongue.

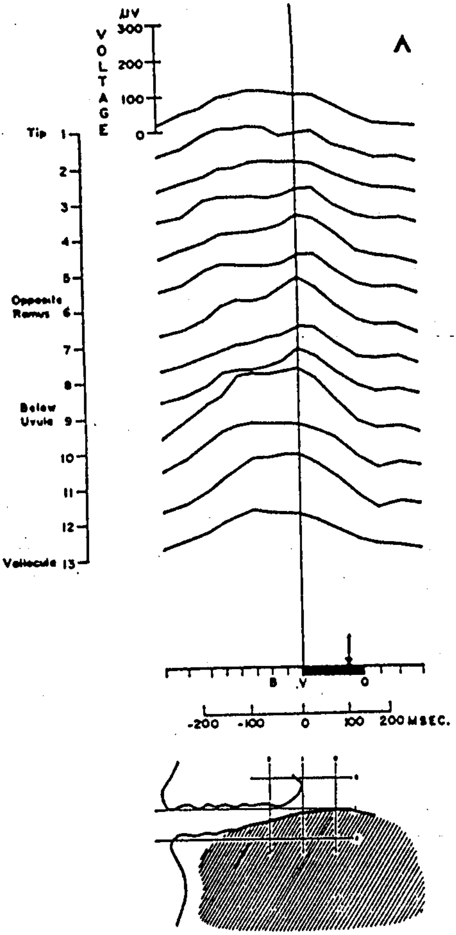


FIGURE 9. Average voltage patterns recorded from 13 electrodes during the production of [pʌp], and a sketch of an X-ray plate showing the tongue in its extreme position for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

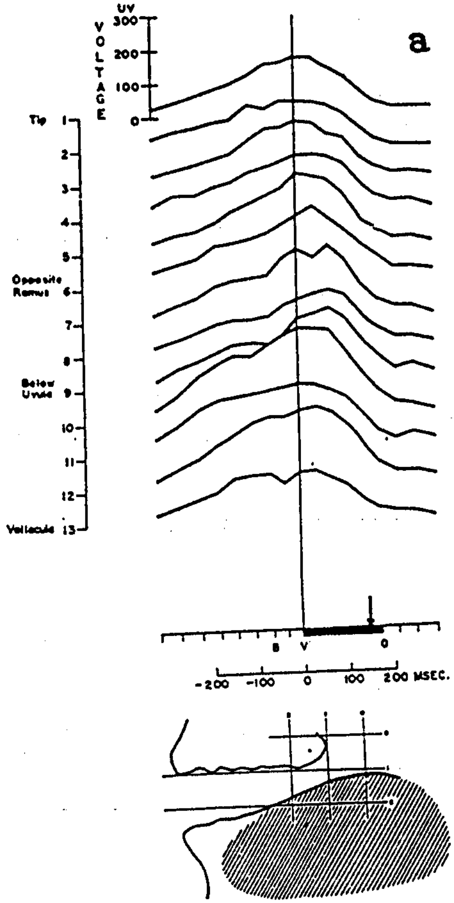
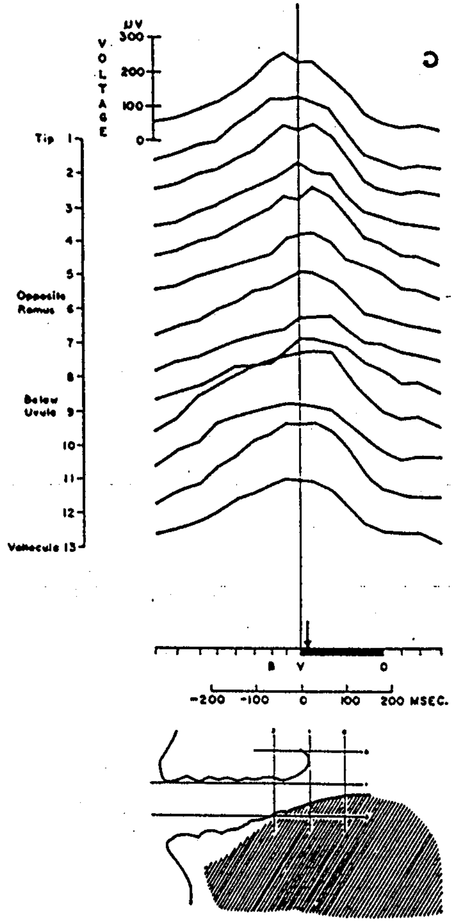


FIGURE 10. Average voltage patterns recorded from 13 electrodes during the production of [pap], and a sketch of an X-ray plate showing the tongue in its extreme position for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

[ʌ], [a], [ɔ]

These three vowels have much in common myographically (see Figures 9, 10, and 11), and much in common with the 2 vowels just discussed. All five vowels show the prevailing activity in the 4 back electrodes, and the peak during voicing throughout the tongue. But the present three vowels also show an early peak at the front of the tongue. This peak is much the earliest

FIGURE 11. Average voltage patterns recorded from 13 electrodes during the production of [pɔp], and a sketch of an X-ray plate showing the tongue in its extreme position for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.



in [ʌ] in which it is also the lowest. It occurs approximately at the onset of voicing in [a] and [ɔ] and is highest in [ɔ]. It presumably reflects contraction of the longitudinal muscles and possibly of the styloglossus. The prevoicing peaks at electrodes 10 to 13 probably represent the activity of the hyoglossus, as described before, in conjunction with the styloglossus to which it attaches. Again the activity here is least for [ʌ], as [ʌ] requires the least downward and backward excursion of the body of the tongue (see X-ray sketches). The voicing peak throughout the tongue is similar in form and timing to that seen in [ɛ] and [æ] and is similarly explained.

[ɝ], [ar], [ɔr]

These three vowels have, in their usual phonetic transcription, a common r-colored element. This similarity is reflected in the myographic records (see

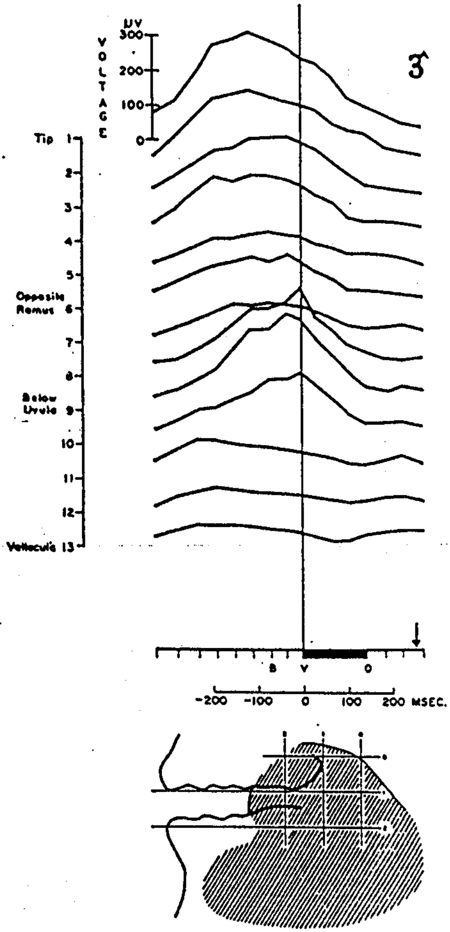


FIGURE 12. Average voltage patterns recorded from 13 electrodes during the production of [pɝp], and a sketch of an X-ray plate showing the tongue in its extreme position for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

Figures 12, 13, 14), but is accompanied by some detailed differences which can for the most part be related to differences in tongue movement shown in the X-rays of the three vowels. The two main myographic events common to the three vowels are: (a) relatively high voltages at front electrodes 1–4 mostly occurring before voicing, and (b) sharply spatially localized voltage peaks at electrodes 8-10. The voltages at the front electrodes probably reflect the retraction of the tongue front by the styloglossus and perhaps the longitudinal muscles. Progressively higher tongue front voltages occur through the series [ɝ], [ar], [ør] corresponding to a progression in the amount of backward movement of the tongue front during the earlier part of the vowels. Qualitative differences in the pattern of voltage change

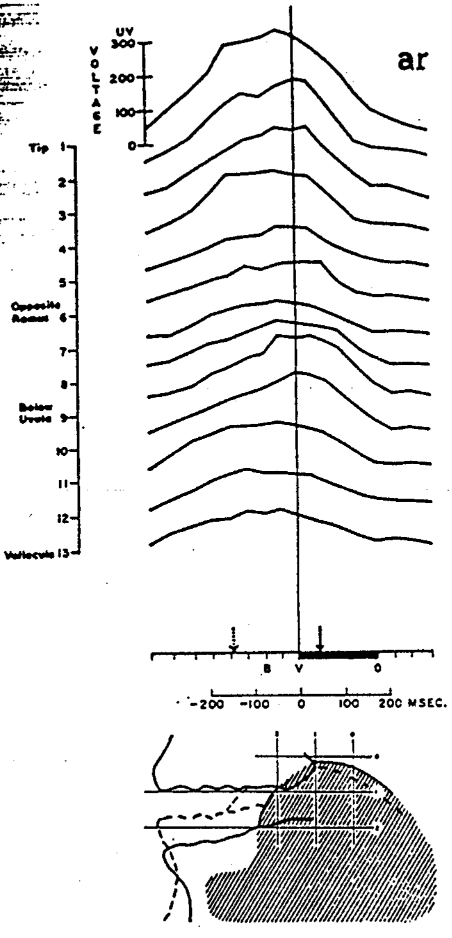


FIGURE 13. Average voltage patterns recorded from 13 electrodes during the production of [parp], and a sketch of an X-ray plate showing the tongue in its extreme positions for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

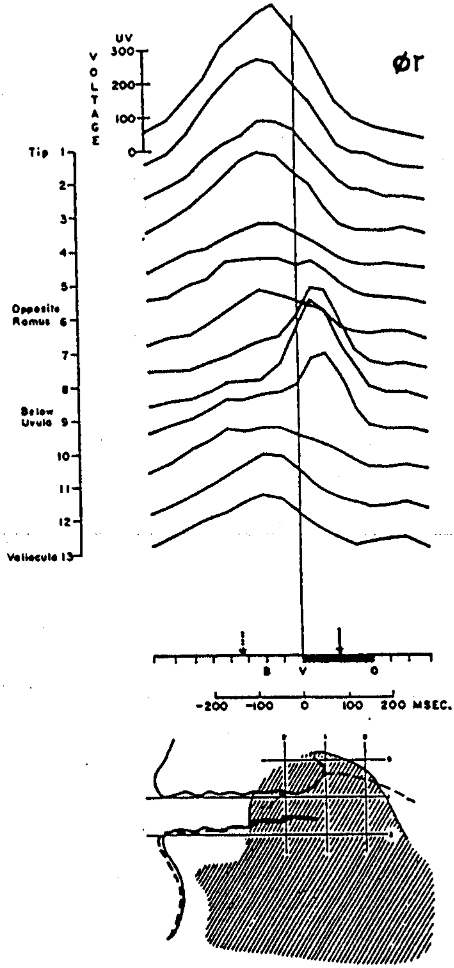
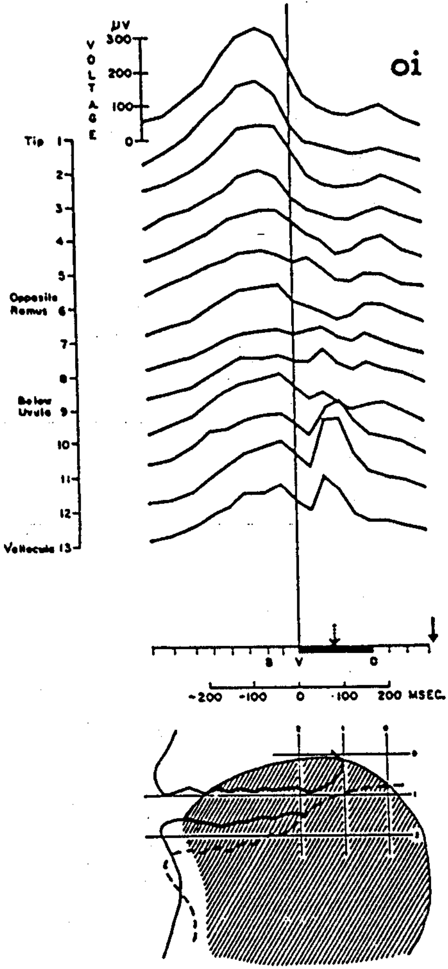


FIGURE 14. Average voltage patterns recorded from 13 electrodes during the production of [pørp], and a sketch of an X-ray plate showing the tongue in its extreme positions for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

are presumably related to differences in amount of backward movement as a function of time in the three vowels. The localized peak at electrodes 8-10 is progressively later through the the series [ɝ], [ar], [ør] and much sharper for [ør] than for the other vowels. These peaks probably accompany a selective contraction of the intermediate fibers of the genioglossus. This interpretation

FIGURE 17. Average voltage patterns recorded from 13 electrodes during the production of [poip], and a sketch of an X-ray plate showing the tongue in its extreme positions for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.



and 13. This peak may represent contraction of the hyoglossus, perhaps merely bracing the tongue against action elsewhere in [ɝ], but assisting in pulling the tongue down and back during the earlier parts of [ar] and [ɔr]. Such action for the latter two vowels would be analagous to that noted before voicing in the simple vowels [a] and [ɔ] respectively.

[e], [ai], [oi]

As Figures 15 to 17 show, these three vowels are characterized by: (a) progressively greater pre-voicing voltage at the front electrodes and at electrodes 10 to 13, as one looks from [e] to [ai] to [oi], (b) common sharp contraction at electrodes 11 to 13, reaching a peak somewhat earlier in [e] than in [ai] and [oi], and (c) a common small voltage peak just after voicing, obvious in all electrodes except 11, 12, and 13. The front pre-voicing voltages probably represent contraction of the longitudinal muscles retracting the front of the tongue, as the X-rays show such retraction to be virtually absent in [e] and greatest in [oi]. Such a progression of retraction has also been seen in the series [æ], [a], [ɔ]. Pre-voicing voltages at electrodes 10-13 may be due to hyoglossal contraction pulling the tongue down and back, as has been suggested in earlier cases where tongue position has been similar to that observed here before voicing. The peak of voltage during voicing at the back electrodes must result from genioglossal contraction, moving this part of the tongue towards the point of the jaw and indirectly causing elevation and forward movement of the tongue, anterior to the site of contraction. This action was also observed in [i]. The voltage peak after voicing must represent (as in [i] contraction of the genioglossus serving to pull the tongue back into the rest position. It is notable that only in the 4 vowels with a component of high front tongue movement (that is, [i], [e], [ai], [oi]) was there evidence of contraction to restore the tongue to a rest position after the vowel.

[o]

As Figure 18 shows, the main features of the voltage pattern for [o] are: (a) a rather high level of activity at the front of the tongue occurring before voicing, (b) pre-voicing peaks at electrodes 10-13, (c) a peak during voicing at the front electrodes, and (d) some sign of a peak during voicing at electrodes 11-13. The front pre-voicing peak relates to retraction of the tongue front produced by longitudinal muscles and the styloglossus. The action of the styloglossus does not result in the pulling up of the tongue at this stage (see dashed tongue outline in Figure 18) as its action appears to be antagonized by the action of the hyoglossus, reflected in electrodes 10-13. On the other hand, the peak at the tongue front during voicing reflects the almost direct pulling up of the tongue by the styloglossus that the X-ray tracings suggest, at this period of the utterance. The voicing peak at electrodes 11-13 may reflect the hyoglossus (which connects in part with the styloglossus) antagonizing this movement.

[au]

Figure 19 shows the myographic results for [au]. There is: (a) an area of pre-voicing activity at electrodes 10-13, and (b) a peak during voicing, highest at the front of the tongue but visible at all electrodes. The pre-voicing activity at the back of the tongue may reflect the hyoglossus pulling the tongue down and back. The voicing peaks would appear to reflect the same activities as in [o]; the direct pulling up of the tongue by the styloglossus, and an antagonistic action by the hyoglossus.

Another way of looking at the present results is to consider the general role of each particular muscle.

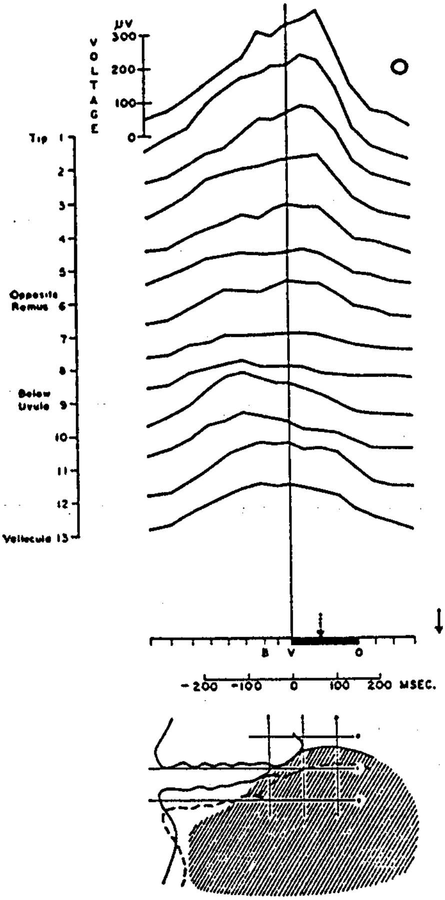


FIGURE 18. Average voltage patterns recorded from 13 electrodes during the production of [pop], and a sketch of an X-ray plate showing the tongue in its extreme positions for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

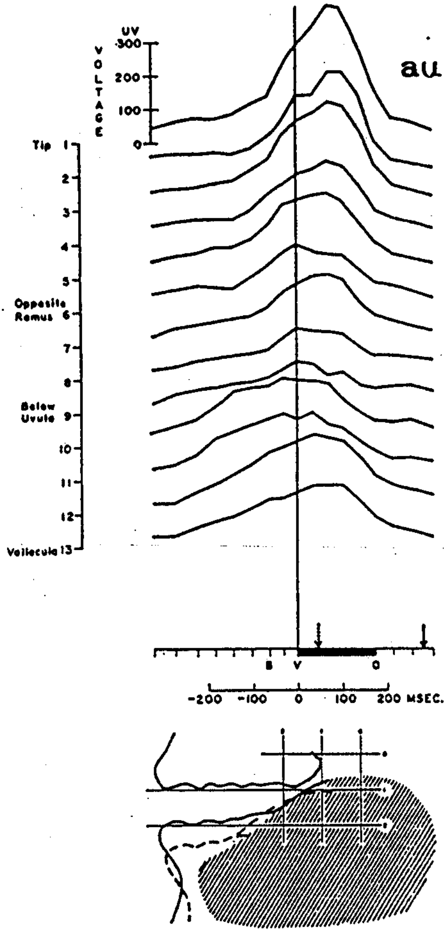


FIGURE 19. Average voltage patterns recorded from 13 electrodes during the production of [paup], and a sketch of an X-ray plate showing the tongue in its extreme positions for that vowel. An explanation of the labelling of the x-axis is given in the caption to Figure 3.

Genioglossus

Portions of this muscle appear to act selectively for three main purposes:

1. The posterior portion of the muscle contracts to move the posterior surface toward the point of the jaw (thus widening the pharynx) particularly for vowels which exhibit a high tongue front position ([i], [e], [ai], [oi]). Slight contraction of this portion of the muscle may also occur in vowels show-

ing high and relatively high back tongue positions, ([u], [ʊ], [o], [au]) and in relatively high tongue front position [ɪ].

2. The intermediate portion of the muscle contracts to draw the midsection of the tongue toward the point of the jaw in [ɝ], [ar], and [ør].

3. The anterior portion of the muscle contracts to antagonize the back and up movement of the tongue in [u].

In addition to these selective or localized actions, the muscle shows a rather general contraction, appearing to assist the return of the tongue to the resting position from high front positions.

Styloglossus

The major role of this muscle seems to be the drawing up and back of the tongue for the high and relatively high back vowels [u], [ʊ], [o], and [au], and the vowels [ɝ], [ar], and [ør]. It may serve in conjunction with the hyoglossus for the higher back vowels, and also when the tongue is moved back for vowels involving a relatively low position such as [ʌ], [a], [ɔ], and earlier phases of [ar], [ør], [ai], and [oi].

Hyoglossus

This muscle may serve in conjunction with the styloglossus as described above. It may also act by itself to move the tongue slightly back and down for [ɛ], and [æ].

Longitudinal muscles

Portions of these two muscles in the most anterior 2 cm. of the tongue appear to act selectively in bunching the tip of the tongue for [i] and [ɪ]. It is unlikely that the inferior longitudinal muscle is being recorded from at more posterior locations in the tongue, so no further speculation about its role will be made. The superior muscle may act in conjunction with the styloglossus on any occasion in which the styloglossus acts. The relative contribution of these two muscles cannot be determined from these data where there is a possibility that they are both acting. It appears that the portion of superior longitudinal muscle occupying the middle half of the tongue may act selectively to bunch that part of the tongue in [ɪ], [ɛ], [ʌ], [a], and [ɔ].

Palatoglossal, vertical, and horizontal muscles

No specific roles have been assigned to these muscles in the present interpretation although they may contribute to aspects of the observed muscle patterns. Studies of other utterances and recordings from the lateral ventral surface of the tongue, and the soft palate, should assist in clarifying the roles of these muscles.

GENERAL DISCUSSION

In summary, some of the main findings of the present study are as follows:

1. For most of the vowels, a muscle or a small number of muscles could be

isolated as primarily responsible foı the tongue movement. For example, posterior genioglossal contraction appeared mainly responsible for the high front vowel [i]; the high back vowel [u] seemed to be largely produced by contraction of the styloglossus and anterior longitudinal muscles; the lower vowels [ɛ], [æ], [ʌ], [a], and [ɔ] seemed to be produced by combined action of the intermediate superior longitudinal, and the styloglossus and hyoglossus muscles, with extra tongue tip retraction in some cases perhaps being mediated by the anterior longitudinal muscles. Muscles also apparently served supplementary functions on some occasions. For instance, the genioglossus served as an antagonist to the styloglossus in [u], and served to return the tongue to a resting position after high front vowels.

2. In many cases there was a direct relation between voltage levels and amount of tongue movement. For instance, the four vowels [ɪ], [ɛ], [ʌ], and [ʊ] generally showed lower voltages than comparable vowels involving tongue movements to adjacent positions; that is [i], [æ], [a], and [u] respectively). This is presumably a result of the former vowels involving less movement of the tongue from the resting position. Such a direct relation between voltage and movement was also visible in other cases where different vowels varied in the extent of movement of part of the tongue in a particular direction. An example of this was the increased voltage at the front of the tongue accompanying increasing tongue tip retraction in the [æ], [a], [ɔ] series, and in the [e], [ai], [oi] series.

3. Myographic patterns showed a close relation to the complexity of tongue movement in the various vowels. For vowels that appear to involve one predominant direction of tongue movement, such as [i] and [u], the main muscle contractions appear rather close together in time, with peaks at about the onset of voicing. For vowels such as [oi], and [øɪ] that obviously involve two distinct directions of movement, two relatively discrete periods of high activity were visible, one before, and one after voicing. Other vowels, such as [e], and [o], involving more than one simple movement, but not havings two distinct directions of movement, showed patterns which reflected this intermediate type of complexity.

The overall picture of the motor control of the tongue which emerges, is one which could have been expected from knowledge of the complexity of the tongue musculature and the speed and accuracy of the speech gestures in which it participates. The impression is not one of ballistic movements which are seen in more simple musculature, and result from sudden contractions of single muscles which cease abruptly some time before the movement ceases (Stetson and Bouman, 1935). It is rather of a complex pattern of finely graded changes in activity as a function of time, in which one or two of the muscles produce most of the movement, and others cooperate in movement, stabilize adjacent structures, or actively oppose the movement.

Insofar as the present interpretations of muscle action are acceptable, some success in the use of surface electrodes in study of the dynamics of articulation can be claimed. This is perhaps worth mentioning because considerable doubt has existed in the past as to whether surface electrodes had sufficient "resolving power" to show details of the actions of muscles. This study makes it seem likely that with sufficiently intensive sampling of the area and sufficient knowledge of the anatomy and the movement involved, much information can be gained from myography.

In addition to contributing to the basic theory of speech production, myographic information such as that presented here may be of considerable use in the understanding of articulatory defect. In the area of functional disorders of articulation for instance, little understanding of the causes of most defects has been gained, but defective motor coordination has been very widely suspected as an important variable, and the possibility of specific muscular defects has been suggested by some writers (pp. 733-738, Travis, 1957). Studies such as the present one provide normative data against which the muscle action of speech defectives could be assessed.

Shortcomings of the present study should not be overlooked. The interpretations given, and the relative emphases put on the different events have, in many cases, not been the only possible ones. This is perhaps particularly true of muscle action at the back of the tongue during [ɪ], [u], [ʊ], [o], and [au]. The vertical, horizontal, and palatoglossal muscles, which must play some direct role have been omitted from consideration as no evidence of the nature of their contribution has clearly emerged. Muscles influencing the hyoid bone and influencing jaw action must play an important indirect role in tongue action itself, and their contribution has not been considered. The result has therefore been far from a balanced or complete picture of the motor control of the tongue.

Shortcomings of the method of study should also be stressed. Voltage levels, even from a single muscle, depend on the distance of the motor units from the recording site. Therefore inferences from comparisons of voltage levels from different muscles cannot easily be made. Voltage levels depend too, on resistance offered by nonmuscular tissue between the site of action and the electrode. This resistance may not be equal throughout the dorsal surface of the tongue. When more than one muscle is contributing to the surface myogram, the fact that this is so, and the relative contributions of each muscle, are not easily discovered. The interpretations offered in this paper are sometimes affected by this difficulty.

Results from only one subject are presented here. What of other subjects? We have enough evidence to suggest that the muscles involved, the relative amounts of activity, and the timing of events show some similarity for one other subject with a similar dialect. Nevertheless, it seems probable that differences between subjects in relative tongue and cavity proportions will produce differences in the detailed muscle picture.

What relation do the present data have to the theoretical speculations outlined in the introduction? The Haskins group has assumed that a basic neural unit involved in perception and production approximates the phoneme in size. All the hypotheses mentioned in the introduction excluding that of Ohman, seem to be based, however implicitly, on the assumption that sequential speech production consists of the combining of series of discrete phoneme sized units according to certain timing rules. The present results have implications for all of the above assumptions because they would seem to be as close as possible to the uncontaminated peripheral results of hypothetical phonemic commands for the vowels. Therefore a study of the coarticulation of these vowels with consonants should show whether coarticulation is the combination of discrete articulatory units, or a reorganization of action.

SUMMARY

This study was an attempt to find out how the different muscles directly controlling the tongue operate during the production of vowels. Using suction electrodes, surface myograms were recorded from 13 locations spaced evenly along the dorsal surface of the tongue while one General American speaker produced several tokens of each of 17 different types of [p]–vowel –[p] monosyllables. Penwriter records of 20 tokens of each syllable type were averaged to give a record of mean voltage from each electrode position, as a function of time.

With the aid of cinefluorograms, and data on the distribution of the muscles controlling the tongue, it was usually possible to decide from the voltage patterns, which muscles were responsible for the major observed features of myographic activity, and to infer whether a muscle was serving a prime moving function, or acting as an antagonist or a bracer. Where a muscle produced movement in a comparable manner in a number of vowels, the amount of muscle activity accompanying each vowel was roughly proportional to the amount of tongue movement. Activity closely reflected complexity of vowel production with simple vowels (one movement) showing most activity during one time period, diphthongs (two movements) showing two distinct periods of high activity, and vowels not clearly in either category showing patterns intermediate between the two extreme types.

The results provide normative data on tongue muscle action for students of articulatory defect. They also have implications for present theories of speech production and perception as they would seem to be as close as possible to the uncontaminated peripheral results of discrete phonemic commands for the vowels which have been hypothesized by some authors. Therefore a further study of the coarticulation of these vowels with consonants would be of theoretical relevance, by showing whether coarticulation is the combination of discrete articulatory units, or a reorganization of action.

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