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# Tongue Musculature and the Feature of Tension in English Vowels[1]

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*Abstract.* Electromyographic techniques were employed to discover which, if any, intrinsic and extrinsic tongue muscles displayed a difference in overall amount of activity corresponding to the traditional tense-lax distinction between members of the English vowel pairs /i – ɪ/, /e – ɛ/, and /u – ů/. Although some muscles revealed a consistent difference, most did not. Even for those muscles where a tense-lax difference was found, the data do not support the notion that tension was a necessary or sufficient differentia of production.

## *Introduction*

Phoneticians and phonologists generally agree in recognizing three pairs of vowels on the basis of the proximity of the members of each pair to each other in the vowel space. A typical delineation of these pairs, as adapted from BRONSTEIN [2], and shown in figure 1, consists of /i/ and /ɪ/, both high front vowels; /e/ and /ɛ/, both mid front vowels; and /u/ and /ů/, both high back vowels. There is far less agreement, however, as to what feature constitutes the essential difference between the members of each pair. Among the differentiae proposed are: *tongue tension*, in which the usually unspecified muscles of the tongue are said to be more tense (i.e., provided greater articulatory effort) for /i e u/ than for /ɪ ɛ ů/ [3]; *duration*, in which /i e u/ are said to be long vowels, whereas /ɪ ɛ ů/ are short; *diphthongization*, in which /i e u/ are said to be characterized by quality or color changes, whereas /ɪ ɛ ů/ are simple, monophthongal vowels [15]; *tongue height*, in which /i e u/ are simply said to be articulated with slightly higher tongue

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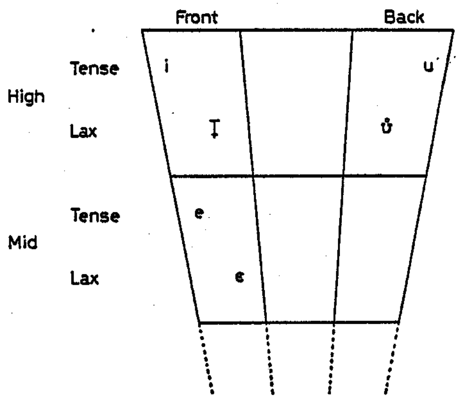



*Fig. 1.* Tense-lax vowel pairs, adapted from BRONSTEIN [2].

positions than /ɪ ɛ ů/ [6]; and *jaw opening*, in which /i e u/ are said to be articulated in a more close jaw position than /ɪ ɛ ů/ [7].

While any theorist may recognize the presence of most, if not all, of these features in the articulation of the vowel pairs, it is possible to select one feature as the essential one and to demonstrate logically that the other features are redundant or automatic reflexes of it. For example, one might argue that tongue tension is the primary differentiating feature, and that while tensing the tongue muscles for /i e u/ a speaker must necessarily increase the duration of the sound uttered, elevate the tongue surface because of the additional muscular contraction, and produce a vowel of changing color as a result of raising the tongue body during articulation. Analogous arguments might be framed to assert the primacy of any of the other features.

Among the differentiae mentioned above, duration, diphthongization, tongue height, and jaw opening can all be studied more or less directly by electromyographic procedures. These features are all, however, observable by other techniques as well. It is the tense-lax opposition which can be investigated by electromyography (EMG) as by no other means. The EMG curve, in terms of both its peak height and the total area beneath it, is probably the most direct measure of muscular tension available.

The purpose of this study of the feature of tension was to discover which, if any, of the muscles of the tongue were consistently more tense in the production of the purportedly tense vowels than in the production of the purportedly lax vowels. It was hypothesized that, because of their often antagonistic functions, not all of the extrinsic and intrinsic tongue muscles examined would exhibit a tense-lax opposition in the usually hypothesized direction; e.g., /i/ a tense vowel would display greater EMG activity than /ɪ/, a lax vowel.

This study and its results are preliminary in nature. Although the three subjects and six muscles investigated often provide reliable data which may be unequivocally interpreted, the experimenters feel that both a larger subject population and muscle inventory should be studied before any general conclusions are drawn.

## *Procedures*

The utterances used in this experiment consisted of the six vowels mentioned above, produced in a CVC syllable preceded by schwa. The syllable-initial consonant was always /p/. The final consonant was either /p/ or /b/. Between 15 and 20 tokens of each syllable type were averaged to produce the EMG curves. The EMG data were obtained from hooked-wire electrodes inserted into the various muscles by means of a hypodermic needle [5]. EMG signals and a voice trace were recorded on magnetic tape for subsequent data processing [11]. The onset of voicing for the interconsonantal vowel was used as a reference line-up point in the data manipulations and is indicated in the figures below as the zero point on the abscissa. The data for three subjects, all native speakers of American English, are reported here.

Three extrinsic and three intrinsic muscles of the tongue were studied. The extrinsic muscles included the genioglossus, the styloglossus, and the palatoglossus. The insertion to the genioglossus has been described by Hirose [5]. This muscle has been shown to be active in raising the bulk of the tongue, particularly for the articulation of the front vowels. Harris [4] has reported on the activity of the genioglossus for /i/ and /u/. Smith [14] has reported on the six vowels investigated here for two genioglossus electrode placements (anterior and posterior). While we believe that our insertion description corresponds more closely to the description of his anterior placement, our results conform more to those of his posterior placement.

The insertion to the styloglossus was made slightly inferior to the lateral margin of the posterior third of the tongue, and roughly parallel to the margin, but slightly medially. The depth of the insertion was approximately 5–10 mm. This muscle has been thought to 'draw the tongue upward and backward' [17]. Smith's [14] investigation of this muscle employed electrode placements into the pharyngeal wall at a point which, he believes, the styloglossus fibers course between origin and insertion. Our own placements are into a region where the fibers insert.

The insertion to the palatoglossus muscle has been described by Hirose [5]. This muscle has long been assumed to raise the back of the tongue when the velum is fixed [1, 8, 17]. Bell-Berti's [1] report on palatoglossus activity for /i/ and /u/, using the same insertions reported here and a similar phonetic frame for subjects' utterances, suggest that a better description of this muscle's function might be that it serves to narrow the opening to the oropharynx by approximating the anterior faucal pillars.

To our knowledge, no formal or informal results have been reported for the intrinsic fibers of the tongue, although our findings may be compared with those of MacNeilage and DE CLERK [9]. The insertion to the first of these intrinsic muscles reported on below, the inferior longitudinal, was made at the lower tongue surface near the back of the anterior third, approximately 1 cm from the lateral margin and roughly parallel to the lower surface of the tongue. The depth of the insertion was approximately 5 mm. The function of this muscle is presumed to be the shortening of the tongue tip [10, 17].

The second electrode placement into the body of the tongue cannot be specified as to muscle identity. It was made at the upper surface of the middle third of the tongue, between the midline and the lateral margin, to a depth of approximately 1 cm. The insertion was perpendicular to the tongue surface. Based on current anatomical information, it was assumed that most of the fibers contributing to the EMG signal from this electrode placement would be transverse and vertical. For want of a better name, this source of EMG activity will be termed the 'central fibers'.

The electrode insertion to the superior longitudinal muscle was made at the upper tongue surface near the back of the anterior third of the tongue, 1.5 cm from the lateral margin. The insertion was roughly parallel to the upper surface, but the needle was inclined slightly craniocaudally. The depth of the insertion was approximately 5 mm. Preliminary data for this muscle indicates that it is active in raising the tip or apex of the tongue, especially for alveolar and dental consonants. These data confirm the assumptions of VAN RIPER and IRWIN [16]. It seems to be inactive for many subjects, and, in fact, only one of the three subjects in this experiment displayed activity of any magnitude for this muscle during vowel articulation.

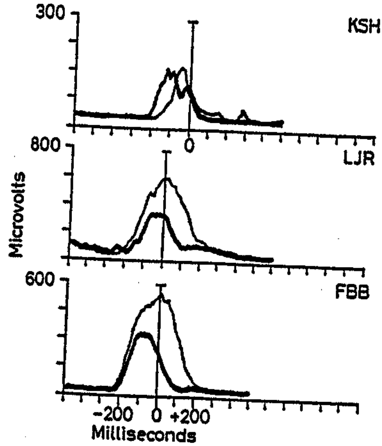
## *Results*

### *Extrinsic Muscles*

The data for the genioglossus muscle, which have been reported in part [4, 12], indicate that for all subjects there was greater activity for /i/ than for /ɪ/, for /e/ than for /ɛ/, and for /u/ than for /ů/ (fig. 2–4). For subject KSH the vowels /i/ and /e/ also exhibit greater duration of EMG activity than /ɪ/ and /ɛ/, and are further marked by a bimodal EMG curve which appears to be an indication of the diphthongal nature of these vowels. The back vowels for this subject (fig. 4) show less EMG activity than the front vowels, as expected. The durational difference between the back pair is evident, but the diphthongization, as revealed by the EMG signal, is less pronounced for /u/ than it is for /i/ and /e/.

For the front vowels (fig. 2, 3), subject LJR shows much the same picture as KSH in terms of tension and durational differences, although there is no clear evidence of diphthongization for /i/ and /e/.[2] The same may be said of the back vowels (fig. 4) for this subject. That

[2] That is, in the EMG signal. This is not to be taken to mean that this subject did not produce diphthongs. Spectrograms clearly reveal formant movements appropriate to the diphthongs usually associated with /i e u/. What is not evident in the EMG traces of this subject is a clear isomorphism with the formant movements, such as is evident for subject KSH.

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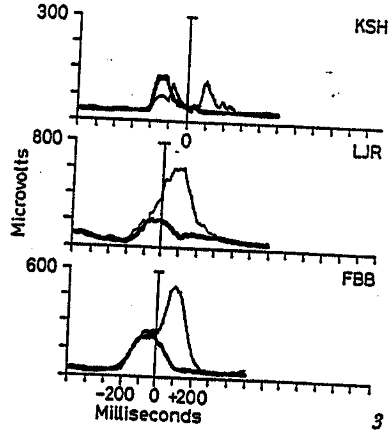


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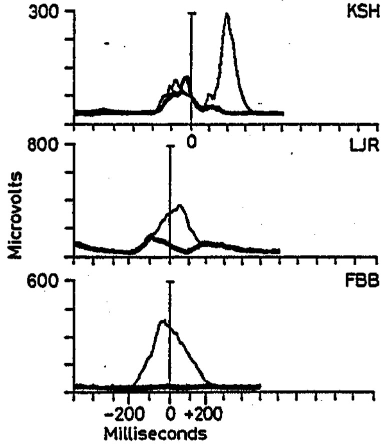
*Fig. 2.* Genioglossus activity for three subjects for the vowel pair /i – ɪ/. —— = i; —— = ɪ.
*Fig. 3.* Genioglossus activity for three subjects for the vowel pair /e – ɛ/. —— = e; —— = ɛ.

is, both peak and duration of the EMG curve are greater for /u/ than for /ů/, but the curve for /u/ is unimodal.

Subject FBB (fig. 2, 4) displays a pattern similar to that of LJR for /i – ɪ/ and /u – ů/. However, in the /e – ɛ/ (fig. 3) opposition, the EMG curve for /e/ is clearly bimodal and thus resembles those of /i e u/ articulated by KSH.

The styloglossus muscle, which is assumed to draw the tongue upward and backward, shows patterns of activity which differ considerably from those of the genioglossus (fig. 5–7). Only one subject, LJR, shows consistent tense-lax difference in the hypothesized direction, and this only for one vowel pair /i – ɪ/ (fig. 5). Subjects KSH and FBB show no consistent difference in either direction for /i – ɪ/ or for /u – ů/ (fig. 5, 7), but they do evidence slightly more styloglossus activity for the vowel usually termed lax in the /e – ɛ/ pair (where subject LJR shows no consistent difference; fig. 6).

Data for the palatoglossus muscle (fig. 8) were obtained for two of the subjects. As expected, the palatoglossus showed activity only for the back-vowel pair. For subject LJR greater activity is found for /ů/, the vowel usually referred to as lax, than for /u/, the vowel usually labeled tense. The data for this subject and for this vowel pair thus indicate a reversal of the tense-lax opposition as traditionally con-

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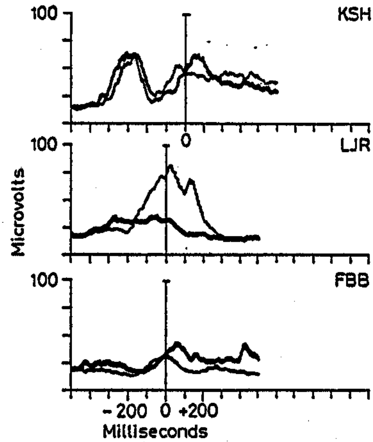


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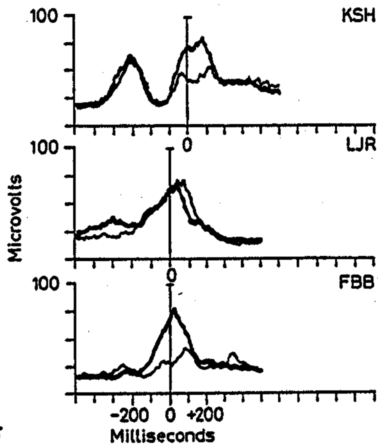
*Fig. 4.* Genioglossus activity for three subjects for the vowel pair /u – ů/. ——= u; ——= ů.
*Fig. 5.* Styloglossus activity for three subjects for the vowel pair /i – ɪ/. ——= i; ——= ɪ.

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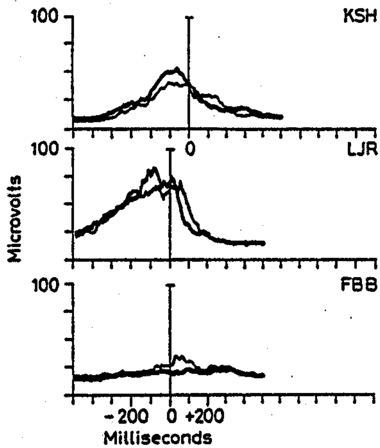


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*Fig. 6.* Styloglossus activity for three subjects for the vowel pair /e – ɛ/. ——= e; ——= ɛ.
*Fig. 7.* Styloglossus activity for three subjects for the vowel pair /u – ů/. ——= u; ——= ů.

ceived. They also, obviously, raise questions about the usually assumed function of the palatoglossus muscle mentioned above.

Very low levels of palatoglossus activity were found for subject FBB. There were no observable differences between the members of the /u – û/ pair for this subject for this muscle. The patterns of palato-

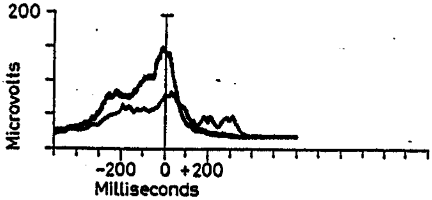


*Fig. 8.* Palatoglossus activity for subject LJR for the vowel pair /u – ů/. —— = u; —— = ů.

glossus activity for both subjects are consistent with results reported by BELL-BERTI [1].

*Intrinsic Muscles*

The inferior longitudinal muscle (fig. 9), on the other hand, displays just the type of tense-lax difference usually hypothesized. This muscle is thought to be active in depressing the tongue tip and shortening the body of the tongue [10, 17]. Data for this muscle were obtained for two of the subjects. Durational differences favoring the tense vowels and bimodal curves reflecting diphthongization in the tense vowels are found in the EMG traces for the inferior longitudinal for subject KSH, as they are for this subject's genioglossus muscle. For subject LJR there is consistently greater activity for /i e u/ than for /ɪ ɛ ů/. The data show more activity for the front vowels (and slightly more for /i/ than for /e/) than for the back vowels. In all, the inferior longitudinal data for this subject show a striking resemblance to the genioglossus data, with gross differences in total activity and duration between the curves of members of each vowel pair, but with no direct evidence of diphthongization. Similarly, the inferior longitudinal and genioglossus data for subject KSH are quite similar to each other, with easily observable, but less gross differences between total muscular activity for the vowels than are found in subject LJR. Data for the 'central fibers' were obtained for two of the subjects. The data for subject KSH for the 'central fibers' consistently revealed more activity for /i/ than for /ɪ/ and for /e/ than for /ɛ/. The data for the latter pair, however, display a difference in the overall pattern of muscular activity rather than in force of muscular contraction. It will be noted that the bimodal EMG curve for /e/ shows the clear evidence of diphthongization that is typical for this subject for the genioglossus and inferior longitudinal muscles. The second, higher peak for /e/,

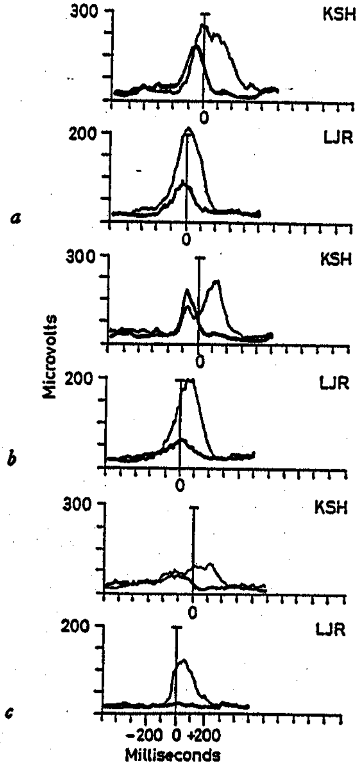


*Fig. 9.* Inferior longitudinal activity for subjects KSH and LJR for the vowel pairs /i – ɪ/ (a), /e – ε/ (b), and /u – ů/ (c). —— = /i, e, u/; —— = /ɪ, ε, ů/.

however, is barely higher than the single peak for /ε/. The /u – ů/ pair for this muscle and subject show a reversal of the hypothesized tense-lax difference, although the difference between the EMG curves is slight. This slight difference, however, is consistent from token to token.

The 'central fiber' activity for subject FBB is at a low level, with, however, a small and consistent difference between /i/ and /ɪ/ which is not in the hypothetical tense-lax direction. No difference is found in the /e – ε/ pair, and the muscle fibers appear to be inactive in the production of the back vowels.

The superior longitudinal fibers, which had previously shown no substantial activity for any subject during vowel articulation, dis-

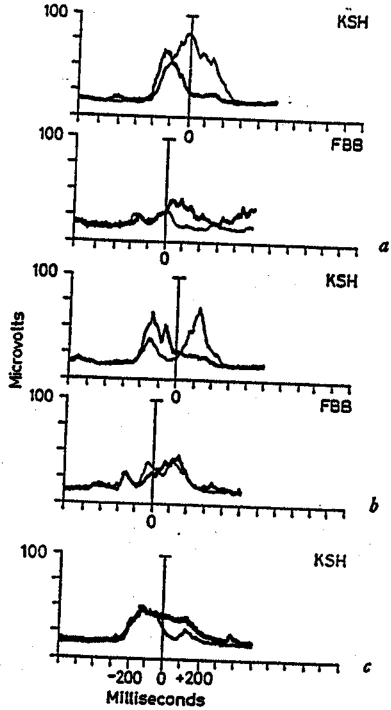


*Fig. 10.* Central fiber activity for subjects KSH and FBB for the vowel pairs /i – ɪ/ (a), /e – ɛ/ (b), and /u – ů/ (c). Symbols as in figure 9.

played surprisingly high levels of activity for subject FBB. A subsequent experiment with the same subject has replicated the results reported here for this muscle. The patterns of activity displayed in figure 11 can be seen to be quite inconsistent in terms of the tense-lax hypothesis from one vowel pair to another. Less activity for /i/ than for /ɪ/, and more for /e/ than for /ɛ/. There seems to be no difference between the members of the /u – ů/ pair, where the overall activity is greatest for this muscle. It should further be pointed out that the differences within the /i – ɪ/ and /e – ɛ/ pairs, though small, are consistent from token to token. The superior longitudinal muscle for subject KSH showed very little activity, with no consistent differences between members of the vowel pairs. Subject LJR showed no activity for this muscle in the articulation of vowels.

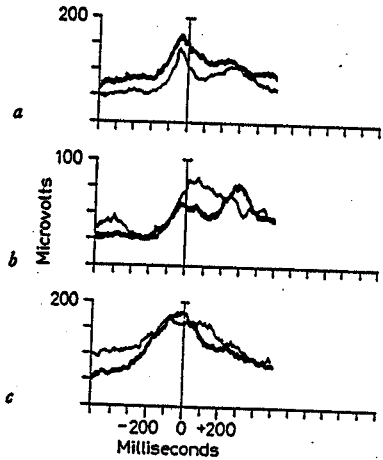


*Fig. 11.* Superior longitudinal activity for subject FBB for the vowel pairs /i – ɪ̵/ (a), /e – ɛ/ (b), and /u – ʉ/ (c). Symbols as in figure 9.

*Table I.* Tense-lax differences observed for each vowel pair by muscle and subject

| Muscle | Subject | Vowel pairs | | |
|---|---|---|---|---|
| | | /i – ɪ̵/ | /e – ɛ/ | /u – ʉ/ |
| Genioglossus | KSH | + | + | + |
| | LJR | + | + | + |
| | FBB | + | + | + |
| Styloglossus | KSH | 0 | – | 0 |
| | LJR | + | 0 | 0 |
| | FBB | 0 | – | 0 |
| Palatoglossus | LJR | | | – |
| | FBB | | | 0 |
| Inferior longitudinal | KSH | + | + | + |
| | LJR | + | + | + |
| Central fibers | KSH | + | + | – |
| | FBB | – | 0 | 0 |
| Superior longitudinal | KSH | 0 | 0 | 0 |
| | FBB | – | + | 0 |

Clear and consistent differences in the hypothesized tense-lax direction are indicated by a plus sign (+), regardless of their size, in order to reflect the binary nature this proposed phonological opposition. A minus sign (–) indicates a reversal of the hypothesized opposition. A zero indicates no substantial difference in muscular activity between the members of a vowel pair. Blanks indicate no muscular activity was observed for both members of a vowel pair, or the absence of data for either or both members of a vowel pair.

*Table II.* Matrix for feature of tension for each subject, vowel and muscle

| Muscle | Subject | i – ɪ | e – ɛ | u – ʊ |
|---|---|---|---|---|
| Genioglossus | KSH | + – | + – | + – |
| | LJR | + – | + – | + – |
| | FBB | + – | + – | + – |
| Styloglossus | KSH | – – | – + | – – |
| | LJR | + – | – – | – – |
| | FBB | – – | – + | – – |
| Palatoglossus | LJR | | | – + |
| | FBB | | | – – |
| Inferior longitudinal | KSH | + – | + – | + – |
| | LJR | + – | + – | + – |
| Central fibers | KSH | + – | + – | – + |
| | FBB | – + | – – | |
| Superior longitudinal | KSH | – – | – – | – – |
| | FBB | – + | + – | – – |

(+) Indicates presence of the feature: tense; (–) indicates absence of the feature. Blank cells indicate no muscular activity was observed for both members of a vowel pair, or the absence of data for either or both members of a vowel pair.

## *Discussion*

In conclusion, there is evidence for the traditionally hypothesized tense-lax difference in some muscles, namely the genioglossus and the inferior longitudinal (table I). It must be noted, however, that when such differences occur consistently, they are always accompanied by differences in the duration of the EMG signal and often by evidence of diphthongization for the tense member of a vowel pair.

For the other muscles investigated here, no consistent tense-lax opposition is apparent. Further, each subject evidences at least one reversal of the hypothesized tense-lax difference for one of the vowel pairs for one of the muscles studied. Finally, even when the data reveals a tense-lax difference for a given vowel pair, that same subject frequently reveals either no consistent difference and/or a reversal of the hypothesized difference (see, for example, the superior longitudinal muscle for subject FBB in table I), for another vowel pair.

Table II is a matrix for the feature: tense, showing the classification of each vowel for each subject and muscle studied.

Thus, although the tense and lax labels, as qualified in terms of certain muscles, might tentatively be assigned to vowel categories, the lack of consistency of the opposition in some muscles where it might be expected, and the persistence of other features which might serve as differentiae, make one hesitant to claim primacy for the feature of tension in distinguishing the members of the vowel pairs investigated here.


## *Zusammenfassung*

**Die Zungenmuskulatur und das Merkmal «gespannt» bei englischen Vokalen**

Mittels elektromyographischer Techniken ist versucht worden festzustellen, welche Muskeln der Zunge einen globalen Aktivitätsunterschied zeigen, der mit der traditionellen «tense-lax»-Opposition der englischen Vokalpaare /i – ɪ/, /e – ɛ/ und /u – ʊ/ übereinstimmen könnte. Die meisten Muskeln zeigten keinen systematischen Unterschied. Die Daten für die Muskeln, in denen sich ein solcher Unterschied zeigte, sind dennoch kein Beweis dafür, daß die Spannung einen notwendigen oder zureichenden Unterschied bei der Artikulation ausmacht.



## *Résumé*

**Les muscles de la langue et le trait «tension» des voyelles anglaises**

Des techniques électromyographiques ont été employées afin d'examiner quels muscles intrinsèques et extrinsèques de la langue montrent une activité d'ensemble différente qui pourrait correspondre à la distinction «tendu-relâché» traditionnellement attribuée aux membres des paires de voyelles anglaises /i – ɪ/, /e – ɛ/, et /u – ʊ/. La plupart des muscles ne montraient pas une différence systématique. En plus, les résultats concernant les muscles qui reflètent ladite différence, ne soutiennent pas la notion que la tension musculaire est une différence nécessaire et suffisante dans l'articulation.


## *References*


1 BELL-BERTI, F.: The velopharyngeal mechanism: an electromyographic study; PhD diss. New York (1973).
2 BRONSTEIN, A. J.: The pronunciation of American English (Appleton Century Crofts, New York 1960).
3 CHOMSKY, N. and HALLE, M.: The sound pattern of English (Harper & Row, New York 1968).
4 HARRIS, K. S.: Action of the extrinsic musculature in the control of tongue position: preliminary report. Haskins Lab. Stat. Rep. Speech Res. *25/26:* 87–96 (1971).
5 HIROSE, H.: Electromyography of the articulatory muscles: current instrumentation and technique. Haskins Lab. Stat. Rep. Speech Res. *25/26:* 73–86 (1971).
6 JONES, D.: The pronunciation of English (Cambridge University Press, Cambridge 1966).

7 KANTNER, C. E. and WEST, R.: Phonetics; rev. ed. (Harper & Row, London 1960).
8 KAPLAN, H.: Anatomy and physiology of speech (McGraw-Hill, New York 1971).
9 MACNEILAGE, P. F. and DE CLERK, J. L.: On the motor control of coarticulation in CVC monosyllables. J. acoust. Soc. Amer. *45:* 1217–1233 (1969).
10 PALMER, J.: Anatomy for speech and hearing; 2nd ed. (Harper & Row, New York 1972).
11 PORT, D. K.: The EMG data system. Haskins Lab. Stat. Rep. Speech Res. *25/26:* 67–72 (1971).
12 RAPHAEL, L. J.: An electromyographic investigation of the tense-lax feature in some English vowels. Haskins Lab. Stat. Rep. Speech Res. *25/26:* 131–140 (1971).
13 RAPHAEL, L. J.: An electromyographic investigation of the feature of tension in some American English vowels. Haskins Lab. Stat. Rep. Speech Res. *28:* 179–191 (1971).
14 SMITH, T. S. J.: Phonetic study of the function of the extrinsic tongue muscles; PhD diss. Los Angeles (1970).
15 TRAGER, G. and SMITH, H. L.: An outline of English structure (Battenberg Press, Norman 1951).
16 VAN RIPER, C. and IRWIN, J.: Voice and articulation (Prentice Hall, Englewood Cliffs 1958).
17 ZEMLIN, W. R.: Speech and hearing science, anatomy and physiology (Prentice Hall, Englewood Cliffs 1968).


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