

An Electromyographic Study of Laryngeal Adjustments During Speech  
Articulation: A Preliminary Report

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INTRODUCTION

The aim of the present study is to examine the electromyographic activities of the intrinsic laryngeal muscles during speech articulation. Electromyographic (EMG) study of the laryngeal muscles in relation to the laryngeal articulatory mechanism is, at present, still in the preliminary stages mainly because of technical difficulties in obtaining reliable data without disturbing the natural movements of the articulatory organs. In the present study, an attempt was made to insert hooked-wire electrodes into the posterior cricoarytenoid and the interarytenoid perorally by indirect laryngoscopy in order to achieve accurate electrode placement while preserving natural articulatory activity. Percutaneous insertion, similar to that previously described in the literature (Hirano and Ohala, 1969; Hirose, in press), was used for EMG recordings from the rest of the laryngeal muscles. The activities of five intrinsic laryngeal muscles were, thus, systematically examined with special reference to the articulation of American English.

EXPERIMENTAL PROCEDURES

EMG recordings were made using hooked-wire electrodes. In order to insert the electrodes into the posterior cricoarytenoid (PCA) and the interarytenoid (INT), a peroral approach was attempted using a specially designed needle holder which permitted insertion of the electrodes into the target muscles by indirect laryngoscopy under topical anesthesia. Insertion of the electrodes into the cricothyroid (CT), the thyroarytenoid (VOC), and the lateral cricoarytenoid (LCA) was performed percutaneously. More detailed description of the insertion techniques, including preparation of the electrodes and the route of insertion, as well as a description of the data-recording system and computer processing, are elsewhere in this Status Report (Hirose, 1971; Port, 1971).

The present experiment was performed on two subjects, both native speakers of American English; for one subject, two separate recordings were made, thus giving three sets of final data. The subjects were required to read randomized lists of stimulus words ten to sixteen times each. Table I lists the muscles examined and the types of stimulus words used in each experiment.

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TABLE I  
MUSCLES EXAMINED\*

Subject 1 (LL)	Subject 2 (LJR) Series A	Subject 2 (LJR) Series B
posterior crico-arytenoid (PCA)	PCA	PCA
interarytenoid (INT)	VOC	lateral cricoarytenoid (LCA)
thyroarytenoid (VOC)	CT	00
cricothyroid (CT)	sternohyoid (SH)	sternothyroid (ST)
	orbicularis oris (OO)	superior constrictor (SC)
		genioglossus (GG)
		geniohyoid (GH)
		mylohyoid (MH)

\*For Subject 1 and for series A of Subject 2, an attempt was made to record from five intrinsic muscles simultaneously. However, unsatisfactory recordings were obtained for the LCA of Subject 1 and for the LCA and INT of Subject 2. For series B of Subject 2, only the LCA and the PCA were selected as representatives of the intrinsic laryngeal muscles.

TYPES OF STIMULUS WORDS

Subject 1 (LL)	Subject 2 (LJR) Series A	Subject 2 (LJR) Series B
əC <u>Ap</u> C: p,b,s,z,h	əC <u>Ap</u> C: p,b,t,d,k,g,f,v,s, z,θ,ð,ʃ,ʒ,ç,j,h	əC <u>ip</u> C: b,s,z,t,d,h
b <u>AC</u> ə C: p,b,s,z,h	b <u>AC</u> ə C: as above	əp <u>VC</u> V: I,i,v,u,ε,e, C: p,b,t,d,k,g,s,z
əb <u>AC</u> C: p,b,s,z,h	əb <u>AC</u> C: as above	
ʌb <u>əC</u> C: p,b,s,z	ʌb <u>əC</u> C: as above	meaningful words:
p <u>Ap</u> ə	p <u>Ap</u> ə	a pit                      a sit
h <u>Ap</u> ə	h <u>Ap</u> ə	a bit                      a fit
		a spit                     a cap
		a split                    a gap
		a hit                      a fan
		a van
number of stimulus types = 20	number of stimulus types = 69	number of stimulus types = 77

## RESULTS

Each of the EMG curves in Figures 1 through 3 represents a computer average of ten to sixteen utterances. The line-up point (0 on the time axis) in these samples was selected at the voice offset of the stressed vowel before the final stop consonant. The timing marks for the acoustic signals in each figure were obtained by averaging values measured from oscillographic records.

### Posterior Cricoarytenoid (PCA)

The general EMG pattern of the PCA clearly demonstrates the voiced/voiceless contrast. In the case of [əpʌp] in Figure 1, for example, the EMG activity of the PCA starts to decrease approximately 250 msec prior to the onset of initial [ə]. The activity then begins to increase 100 msec before the stop closure of [p], reaching the peak 110 msec prior to the stop release, and immediately begins to decrease with the production of the stress vowel [ʌ]. Approximately 110 msec prior to the voice offset, it shows a steep rise again for the final [p].

In [əbʌp], on the other hand, the PCA activity stays low throughout the voiced period from the initial vowel to the stressed vowel, including intervocalic [b]. It should be noted, however, that the EMG curve ascends slightly 110 msec prior to the release of [b], then descends again approximately at the time of the release, and finally rises steeply starting 40-50 msec before the voice offset.

The general patterns of PCA activity described above are also found in Figures 2 and 3.<sup>1</sup>

### Interarytenoid (INT)

The INT showed a reciprocal pattern of activity when compared to the PCA in relation to the voiced/voiceless contrast.

As illustrated in Figure 1, INT activity in the case of [əpʌp] begins to increase 250 msec prior to the initial vowel production, reaching its peak when PCA activity reaches its valley. In general, the INT shows a sort of inversion of the pattern of PCA activity throughout the utterance.

For the articulation of [əbʌp], the INT shows more or less continuous activity for the voiced segments after the initial rise in activity, but there is some decrease in activity for intervocalic [b] as compared to the neighboring vowel segments.<sup>2</sup>

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<sup>1</sup>The question of differences in the amplitude or the duration of the averaged EMG activity for the same phoneme with respect to phoneme environment will not be considered in this paper.

<sup>2</sup>The tendency of INT activity to be lower for voiced consonants than for vowel segments was more clearly revealed in the case of voiced fricatives, whose data are not shown here.

Superimposed Averaged EMG Signals of the Intrinsic Laryngeal Muscles of Subject 1 for the Utterances [əbʌp] and [əbʌp]

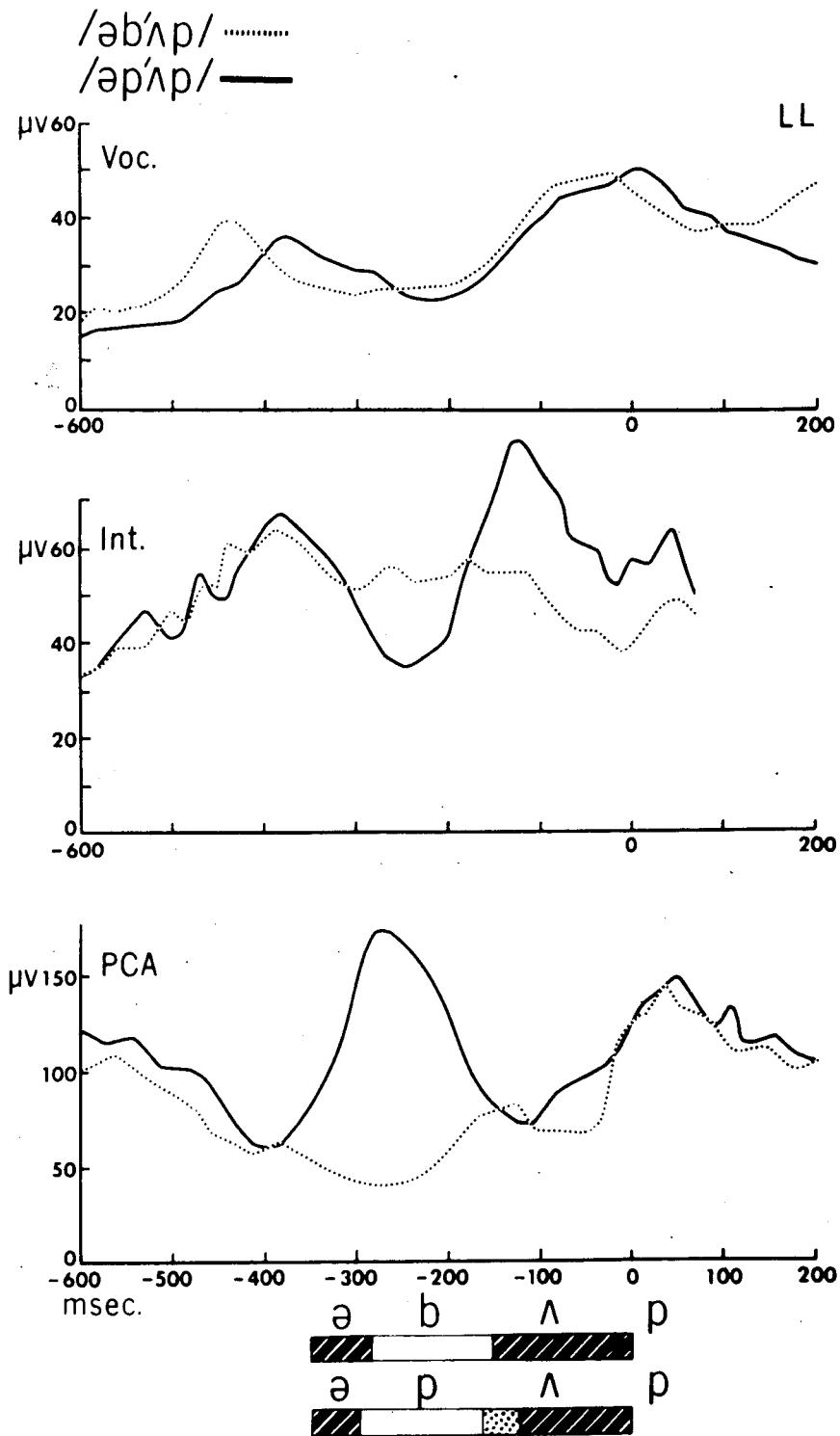


Fig. 1

Note: From top to bottom, traces represent the signals of the thyroarytenoid, the interarytenoid, and the posterior cricoarytenoid. The line-up point (0 on the abscissa) indicates the voice offset of the stressed vowel before the final stop closure.

Superimposed Averaged EMG Signals of, from Top to Bottom, the Orbicularis Oris, the Posterior Cricoarytenoid, the Cricothyroid, and the Thyroarytenoid of Subject 2, Series A, for the Utterances [əpʌp] and [əbʌp]

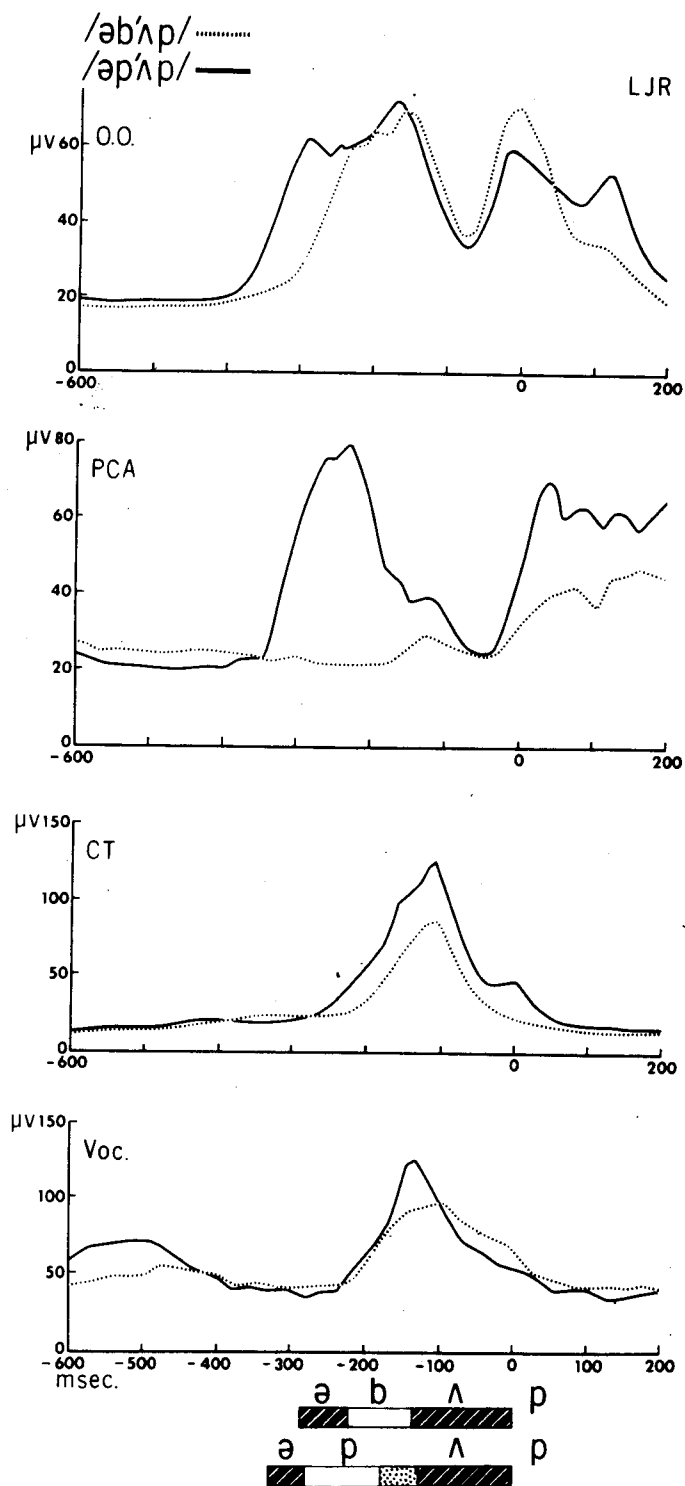


Fig. 2

Superimposed Averaged EMG Signals of, from Top to Bottom, the Orbicularis Oris, the Sternohyoid, the Lateral Cricoarytenoid, the Posterior Cricoarytenoid, and the Superior Constrictor of Subject 2, Series B for the Utterances [əbit] and [əpit]

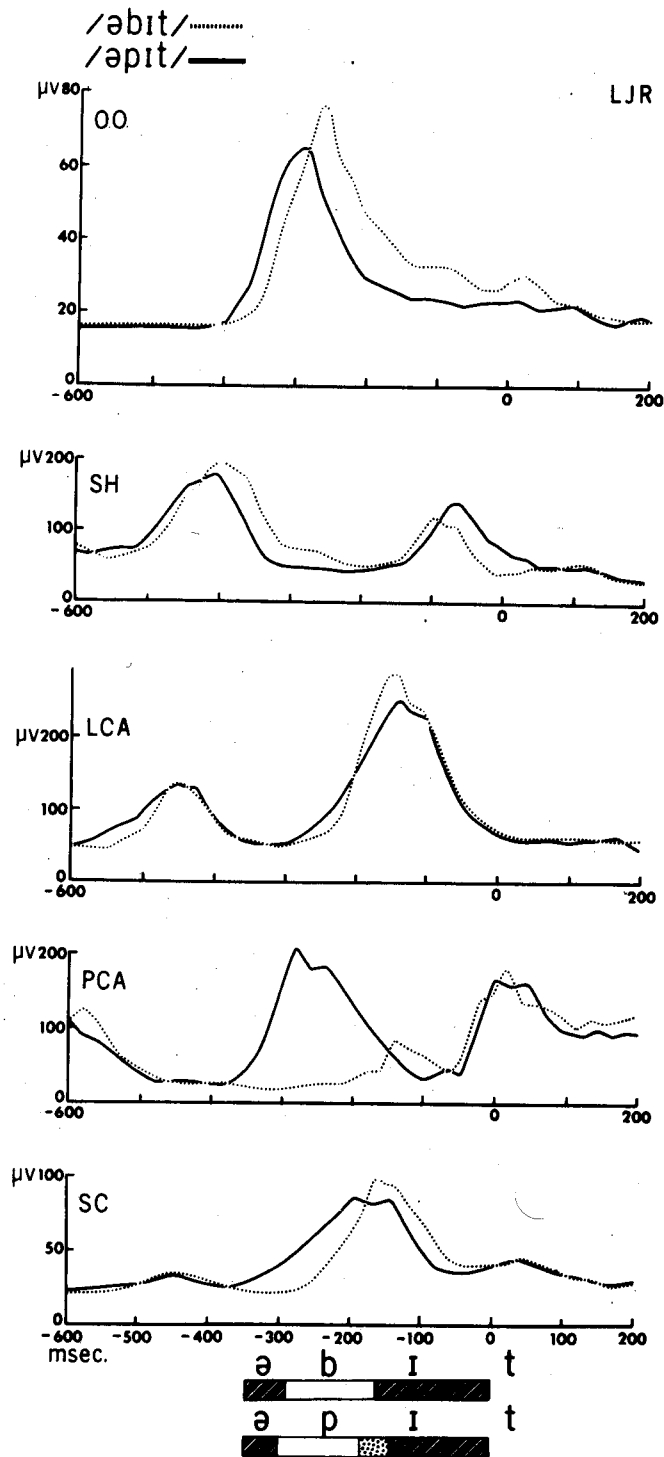


Fig. 3

INT activity for the stressed vowel [ʌ] is higher after voiceless [p] than after voiced [b] as illustrated in Figure 1.

#### Thyroarytenoid (VOC) and Lateral Cricothyroid (LCA)

The general patterns of EMG activity of the VOC (Figures 1 and 2) and the LCA (Figure 3) are different from those of the PCA or the INT with regard to the voiced/voiceless contrast. The most consistent findings on these two so-called adductors are that EMG activity decreases for the consonant segments regardless of the voiced/voiceless distinction and that the activity shows a definite increase for vowel segments, particularly for the initiation of voicing and for stressed vowels.

#### Cricothyroid (CT)

The CT (Figure 2) shows a temporary increase in EMG activity for the stressed vowel but presents no consistent differences in relation to the voiced/voiceless contrast.<sup>3</sup>

#### EMG Activity of the Other Articulatory Muscles

The orbicularis oris (OO) showed increasing activity for [p] and [b] articulation, as we would expect from findings of previous studies (Fromkin, 1966; Harris et al., 1965; Tatham and Morton, 1969). For [p], its activity starts to increase synchronously with, or 30-40 msec before, the increase in PCA activity (Figures 2 and 3). The duration of its activity for intervocalic [p] varies from that of the PCA.

EMG activity of the superior constrictor and the sternohyoid, included in Figure 3, will not be discussed here.

#### COMMENT

Since the introduction of the use of hooked-wire electrodes which is usually combined with the percutaneous insertion technique, a considerable number of reports have accumulated on laryngeal muscle activity during speech and singing. In general, these studies, with related anatomical and modeling work, support the classical division of the intrinsic laryngeal muscles into three functional groups--abductor (PCA), tensor (CT), and adductor (INT, LCA, VOC<sup>4</sup>). However, little attempt has been made to clarify the function of the laryngeal muscles in consonant articulation.

In particular, participation of the PCA in speech has not been systematically studied, although the function of the PCA as a respiratory muscle has been

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<sup>3</sup>The peak amplitude of the CT is apparently higher for the stressed vowel following the voiceless consonant [p] than for that following the voiced [b]. The difference is, however, not consistent for other sets containing a voiced/voiceless contrast, whose data are not shown here.

<sup>4</sup>The thyroarytenoid is generally believed to have an adducting effect, as well as a shortening and tensing effect, on the vocal fold.

well documented (Pressman, 1942; Suzuki and Kirchner, 1969). As far as PCA activity in phonation is concerned, Faaborg-Andersen (1957) reported that EMG activity of the PCA decreases during sustained phonation. Kotby and Haugen (1970), on the other hand, observed increasing activity of the PCA during phonation and postulated that the PCA is not solely an abductor muscle. Dedo (1970) also reported increasing activity in the PCA during phonation in some of his clinical cases. The data of these authors are concerned exclusively with sustained vowel phonation, the fundamental frequency of which was not definitely specified.

Hiroto et al. (1967) examined laryngeal muscle activity for some Japanese words containing an intervocalic fricative [s] and stated that there was a temporary change in the electrical activity of all the intrinsic laryngeal muscles, except for the cricothyroid, corresponding to voiceless consonant articulation. What they observed in their data was an apparent increase in PCA activity accompanied by a decrease in the activity of the adductors for articulation of the intervocalic [s]. Hirano and Ohala (1969) showed one example of a raw EMG record of the PCA, illustrating increasing activity for release of glottal stops with reciprocally decreasing activity in the INT.

In the present study, it was clearly revealed that the PCA actively participates in the laryngeal articulatory adjustments, particularly for the voiced/voiceless distinction. There is a consistent increase in PCA activity for voiceless consonant production regardless of the difference in phonetic environment.<sup>5</sup>

In addition to gross adjustment of the glottal condition, as in voiceless consonant articulation, the PCA also appears to participate in finer adjustments, as is seen near the end of the [b] segment in Figures 1, 2, and 3 where the glottis seems to be slightly opened by minor PCA activity to permit a possible escape of air through the narrowed glottis.

The laryngeal gestures necessary for consonant production should require rapid muscle adjustments in both the abductor and the adductor groups of the larynx. Although there is some controversy about the contraction properties of the PCA of experimental animals (Hast, 1967; Hirose et al., 1969; Mårtensson and Skoglund, 1964), the present data suggest that the human PCA is able to execute fast contraction equivalent to that of the adductor muscles in laryngeal articulatory adjustments.

In a study of EMG activities of the laryngeal muscles in singing (Gay et al., 1971), we observed that PCA activity is generally suppressed during sustained phonation except for the very end of voicing in low and medium frequency ranges in the chest register and in falsetto, while it increases for high chest voice phonation. The increasing PCA activity in the latter condition may reflect the counterbalancing function of the abductor for the strong contraction of the adductors, as suggested in previous literature (Pressman, 1942; Suzuki and Kirchner, 1969). Another possibility is that different kinds of motor units are participating in the execution of muscle contraction in different conditions of phonation, since there is evidence, at least in animal experiments, that the PCA consists of several kinds of motor units (Suzuki and Kirchner, 1969).

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<sup>5</sup>The increase in PCA activity for voiceless consonants is not so marked when the voiceless consonant is in absolute initial position, as in [pəpə]. Such data are not shown here.

Although the function of the PCA, particularly in sustained phonation, should be a subject for further investigation, the role of the PCA as an abductor in speech articulation is demonstrated in the present study.

The present data indicate that there is apparently reciprocal activity between the PCA and the INT. In this sense, the INT can be considered to be a representative adductor of the vocal fold. As described above, there is an apparent difference in the degree of INT activity for vowel segments depending on the preceding consonant. Since the EMG activity represents the muscle action necessary for obtaining effective force or displacement, the degree of the activity should be higher if, for example, the displacement is larger. The glottal width is obviously larger in the articulation of voiceless consonants than in the articulation of voiced consonants, as observed in recent fiberoptic studies (Sawashima, 1968, 1970). Therefore, it is reasonable that the activity of the INT, which is responsible for adducting the vocal fold, should be greater after voiceless consonants accompanying the more widely abducted glottis.

The fact that INT activity is apparently less for voiced consonants than for vowels indicates that there is a difference in laryngeal adjustment between vowel and voiced consonant.

It should be noted that the other laryngeal adductors, the LCA and the VOC, appeared to be activated only for vowel production. It is possible that the LCA and the VOC are not merely adductors of the vocal fold and that there is functional differentiation within the group of so-called adductor muscles. The lesser activity of the LCA and the VOC for the production of voiced consonants than for vowels again suggests a difference in glottal adjustments between these two phonetic conditions. If these adductors are less active for voiced consonant production than for vowel production, the glottal closure, and possibly the tension of the vocal folds, should tend to be less in the former condition. Table II illustrates a combination of the activities of the functionally different laryngeal muscle groups as a possible physiological correlate for different phonetic conditions.

TABLE II

	Abductor	Adductor	
	PCA	INT	VOC LCA
vowel	-	++ <sup>*</sup>	+~++ <sup>*</sup>
voiced consonant	-	+	-
voiceless consonant	+	-	-

\* ++ represents high activity, while + indicates moderate activity. In the INT, for example, EMG activity was evident both for the vowel and for the voiced consonant but more so for the vowel. In the VOC and the LCA, the degree of EMG activity for vowel production apparently differs depending on the prosodic condition, i.e., it is higher (++) for stressed vowels.

The present report is based on the analysis of the limited amount of data processed thus far. A more detailed report will follow with reference to laryngeal articulatory adjustments. The effects of phonetic environment and phonetic categories on laryngeal muscle activity will be further considered.

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