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Laryngeal Control in Vocal Attack

An Electromyographic Study

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Introduction

The mechanism of laryngeal control for different types of vocal attack[1] has long been a subject of interest in the fields of laryngology and experimental phonetics. Three types of vocal attacks are generally recognized; (1) breathy or aspirate, (2) soft or simultaneous, and (3) hard or glottal. Various experimental techniques have been used to investigate these types of vocal attack–high-speed cinematography [15, 20], aerodynamic study [12–14], and electromyography (EMG) of the intrinsic laryngeal muscles [3, 4, 13, 18]. Among these, electromyography is particularly useful, as it provides the most direct information on the actions of the individual muscles responsible for vocal attack. Most of the previous studies in laryngeal physiology generally support the classical division of the intrinsic laryngeal muscles into three functional groups: abductor, adductor and tensor. However, there still are many unanswered questions concerning the function of individual laryngeal muscles in different modes of laryngeal adjustments.

The first EMG study of vocal attack was attempted by Faaborg-Andersen [1], who compared the activity of the vocalis (VOC) and cricothyroid (CT) in the production of /hop/, /bop/, and /op/, representing breathy, soft, and hard attack, respectively.[2] He stated that the time interval between the start of the increase in activity in the two muscles and the onset of the tone

[1] The term 'attack' usually refers to vocal initiation in singing; if we use this classification, to refer to speech utterances consisting of /C+V/ sequences, breathy attack should be equivalent to the utterance initiated with /h/, soft attack to that with voiced consonant, and hard attack to that with glottal stop.

[2] These test utterances can be transcribed phonetically as [hɔp], [bɔp], and [ʔɔp], respectively.

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(Δt) was greater for hard attack than for either the breathy or soft attacks in both muscles.

KOIKE [13] later examined the EMG activity of the VOC and the CT in his extensive study of vocal attack and claimed that Δt was largest for hard attack, but that values were variable for soft and breathy attacks. He also claimed that the amplitude of the prephonatory activity of these two muscles seemed to serve as a more reliable index for differentiating the type of vocal attack than Δt values.

HIRANO [4] repeated the first two studies using trained singers who were asked to begin phonation on a signal. He was unable to distinguish Δt values for the three vocal attack conditions. He suggested, rather, that the mode of activity of the adductors (the lateral cricoarytenoid [LCA] and VOC in his case) of the larynx, particularly during the prephonatory period, is the most essential factor for differentiating the type of vocal attack.

These previous EMG reports dealt solely with the adductor and the tensor groups of the larynx and no attempt was made to clarify the participation of the abductor muscle, the posterior cricoarytenoid (PCA) in vocal attack. Furthermore, most previous studies were based on the observation of limited numbers of raw EMG traces. It would seem reasonable, then, that a detailed, systematic EMG study of all the intrinsic muscles of the larynx is needed to provide a complete description of the muscle control mechanism of vocal attack.

The purpose of the present study was to investigate systematically the actions of all the intrinsic laryngeal muscles in different types of vocal attack. Particular attention was directed to comparing the temporal characteristics of the EMG activity patterns for the abductor and adductor muscles.

Procedures

Subjects. Subjects were four adults, three male and one female, all native speakers of American English. The femal subject (A.P.) was a trained singer. For each subject, an attempt was made to record from the five intrinsic muscles simultaneously. However, this goal was reached for only two of the four (L.J.R. and L.L.). Unsatisfactory recordings were obtained for the PCA and the CT of one subject (T.G.), and the PCA, the interarytenoid (INT) and the VOC of A.P.

Recording and processing of data. Conventional hooked-wire electrodes [5, 7], consisting of a pair of insulated platinum-iridium alloy wires with a short hook at the tip, were used in the present experiment. The wires were threaded in a hypodermic needle and inserted into the muscle with the needle. After the tips of the wires were located in the muscle, the needle was withdrawn, leaving the wires in place. The electrodes were inserted percutaneously through the skin of the anterior neck into the LCA, VOC and CT, while the insertions into the PCA and the INT were made perorally by indirect laryngoscopy under topical anesthesia. A specially designed curved probe was used for the peroral insertions. The basic data-processing procedures followed in the present experiment were to collect EMG data for a number of tokens of each type of vocal attack and, using a digital computer, average the integrated EMG signals at each electrode position. EMG data were recorded on a multi-channel tape recorder, together with the acoustic signal and digital code pulse (octal format). This pulse was used for identifying each utterance for the computer during processing. In the present experiment, the line-up point for averaging was the onset of voicing of each utterance. A more detailed description of both the data-recording and data-processing techniques can be found elsewhere [3, 8, 10, 16].

Experimental conditions. Isolated monosyllabic words [ha], [ba] and [ʔa] were used to represent breathy, soft and hard attacks, respectively. The subjects were required to repeat each test utterance 16 times. Vocal intensity and frequency were kept at normal levels.

Results

Figure 1 shows the averaged EMG curves of the five intrinsic laryngeal muscles for subject L.J.R. It is clearly demonstrated in this figure that the pattern of activity of the individual laryngeal muscles differs depending upon the type of vocal attack.

In *breathy attack*, PCA stays active throughout the prephonatory period up to the point immediately before the onset of voicing (in this example, the activity starts to decrease approximately 150 msec before the onset of voicing). Its activity then decreases steeply and remains suppressed during the period of voicing. Conversely, the activity of the other four muscles appears to be suppressed during the prephonatory period, and then increases steeply when PCA activity begins to decrease peaking at about the time of voice onset.

In *hard attack*, PCA activity decreases well before the onset of voicing. PCA then shows a transient increase in activity just before the onset of voicing, after which it is suppressed again for the period of voicing. The adductors, LCA in particular, show a very characteristic pattern of activity for hard attack. LCA activity increases markedly long before (in this example more than 700 msec prior to) the onset of voicing and stays high during the prephonatory period. It then shows a steep fall immediately before the onset of voicing, followed then by a less pronounced rise for the voicing period. INT, VOC and CT also show activity during the prephonatory period, followed by a fall at approximately the onset of voicing.

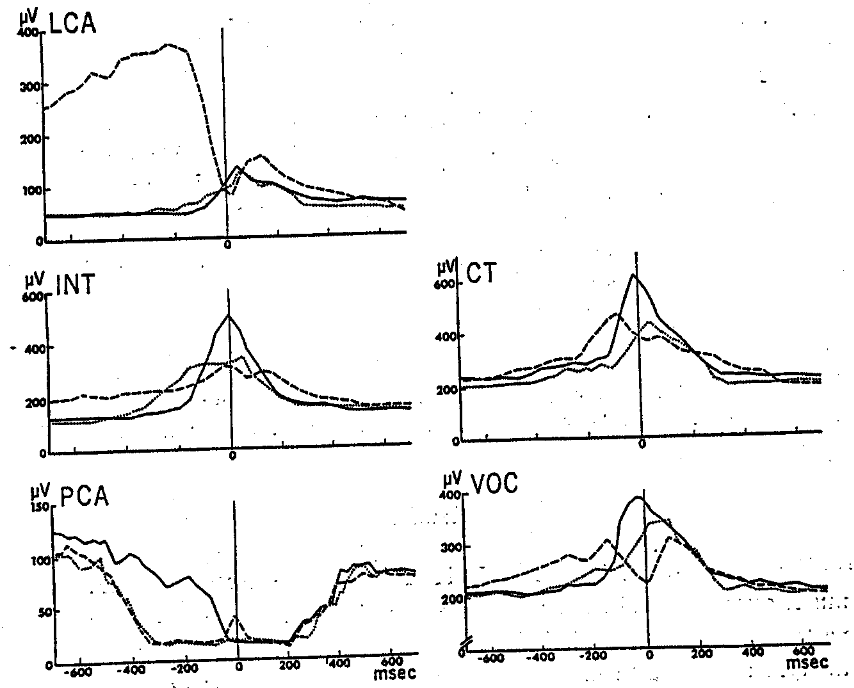

Fig. 1. Averaged EMG curves (in microvolts) of the intrinsic laryngeal muscles of subject L.J.R. for three different types of vocal attack. Zero on the time axis, for this and all subsequent curves, is the onset of voicing. —— [ha]; ······ [ba]; - - - - [ʔa].

In *soft attack*, PCA activity is suppressed throughout the prephonatory period. The general pattern of activity of PCA in soft attack is similar to that in hard attack, except that there is no temporary increase before the onset of voicing. The activity of the adductors and CT increases gradually, reaching a peak after the onset of voicing.

The pattern of activity of the individual laryngeal muscles examined in the other three subjects was essentially similar to that observed in the first subject.

Figure 2 illustrates the averaged EMG curves of a second subject (L.L.) for three types of vocal attack. The temporal characteristics of PCA activity of the second subject are quite similar to those of the first subject with respect to the following points: (1) In breathy attack, PCA stays active throughout the prephonatory period up to the moment immediately pre-

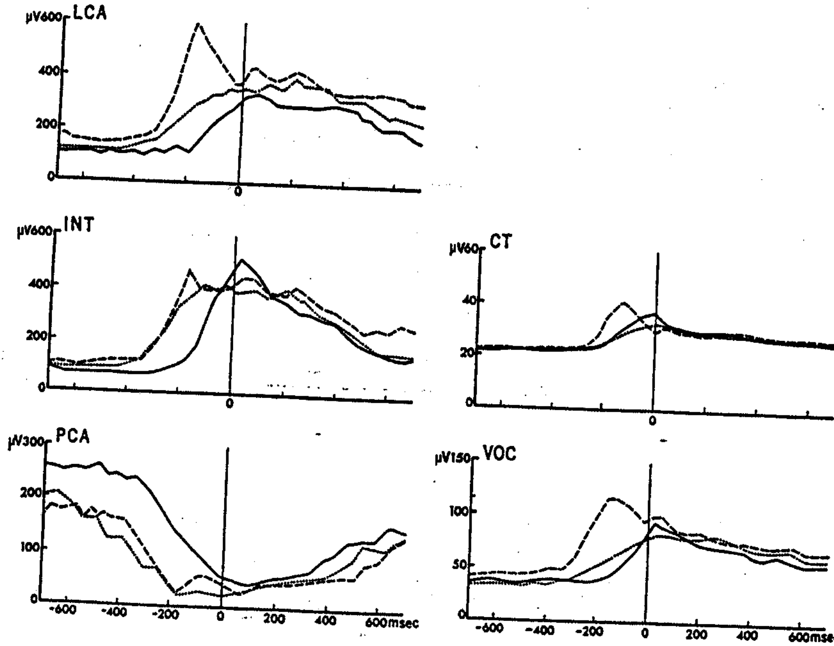

Fig. 2. Averaged EMG curves of the intrinsic laryngeal muscles of subject L.L. for three different types of vocal attack. —— [ha]; ······ [ba]; ---- [ʔa].

ceding the onset of voicing, after which it shows a steep fall. (2) In soft and hard attack, PCA activity starts to decrease well before the onset of voicing. For hard attack, there is a transient increase before the voice onset, while for soft attack, it stays suppressed throughout. (3) PCA activity is higher for the prephonatory period than for the period of voicing, regardless of the difference in the type of vocal attack.

When we compare the temporal characteristics of adductor activity of the second subject to those of the first subject, it is observed in both cases that adductor activity in breathy attack remains suppressed during the prephonatory period and then increases steeply for initiation of voicing. In hard attack, LCA shows a marked increase in activity during the prephonatory period in the second subject, too, although the timing of the onset of the increase is somewhat later than that in the first subject. In soft attack, the adductors show a gradual increase in activity toward initiation of voicing. In the second subject, however, the increase starts earlier than in the case of breathy attack.

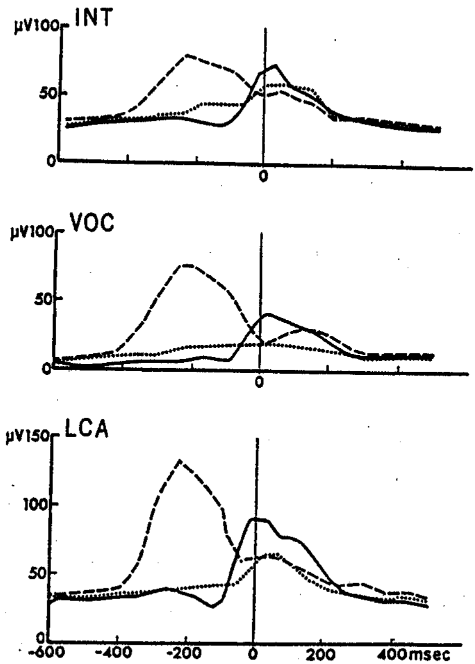

Fig. 3. Averaged EMG curves of the intrinsic laryngeal muscles of subject T.G. —— [ha]; ······ [ba]; ---- [ʔa].

Figures 3 and 4 show the averaged EMG curves for subjects T. G. and A. P. respectively. In subject T. G., all the adductors show more or less similar temporal characteristics for each type of vocal attack. In hard attack, in particular, both INT and VOC also showed considerable prephonatory activity, followed by a fall immediately after. There is a general tendency of gradual increase in activity in soft attack. It is noted in breathy attack that there is temporary suppression of activity preceding the steep rise for initiation of voicing for all the three muscles. The temporary dip in activity just before steep rise in breathy attack is also found in subject A.P., both in LCA and CT. The general pattern of LCA activity of subject A.P. for each type of vocal attack is essentially similar to that of subject T.G., though the activity increases more steeply near the voice onset, both for breathy and soft attacks.

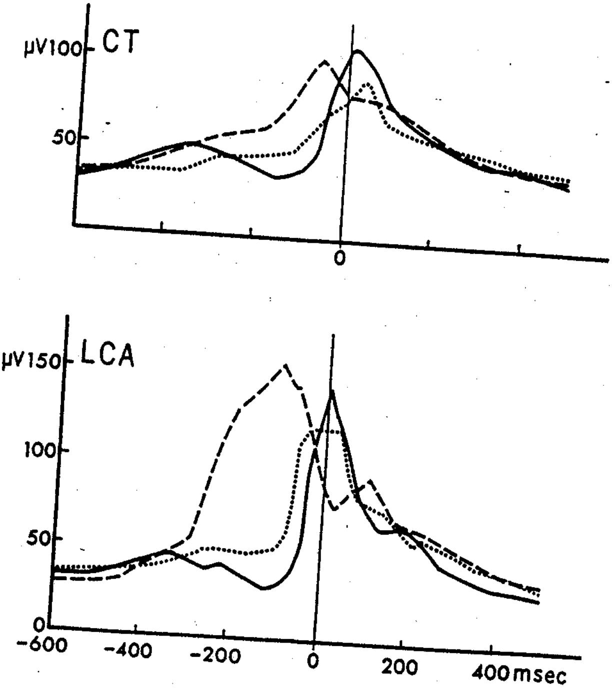

Fig. 4. Averaged EMG curves of the intrinsic laryngeal muscles of subject A.P. —— [ha]; ······ [ba]; – – – – [ʔa].

Discussion

The present study revealed that coordinated actions of the abductor and adductor muscles of the larynx characterize each type of vocal attack.

In breathy attack, PCA shows a characteristic pattern during the prephonatory period, where it stays active until just before the onset of voicing. It has been observed by both high-speed cinematography [20] and by fiberoptic observation [17] that the glottis remains open during the production of initial [h]. Presumably, the relatively high prephonatory activity of PCA in conjunction with low adductor activity is the physiological correlate of the open glottis for initial [h] production. The activity of the adductors in breathy attack appears to increase toward the onset of voicing as in soft attack. However, it shows a steeper increase near voice onset in the former. HIRANO [4] stated that the adductors often show a temporary dip in activity preceding the steep rise in breathy attack in singing. In the present study, it appears that there is a temporary dip in LCA activity in breathy attack in subjects T.G. and A.P. (fig. 3 and 4), but the finding is not consistent for the others. The dip may well be interpreted as a temporary suppression of adductor activity for the production of [h], which has begun increasing slightly in order to maintain preparatory muscle tonus. Also, differences may exist between singing and speech articulation in the degree of preparatory muscle tonus as well as of temporary suppression for [h] production. It is worthy to note further that the maximum value of INT activity is higher in breathy attack than in the other two attacks[3]. It is generally agreed that EMG activity grossly represents the muscle action necessary for obtaining effective force or displacement, although either isometric or isotonic condition in a strict sense are hardly expected in reality. As we reported elsewhere [9], the INT is considered to play a principal role in glottal adduction during speech. Since glottal width immediately prior to voice onset is obviously larger in breathy attack, it should be reasonable to expect that in order to accomplish the larger displacement for the glottal closure after [h], INT activity must necessarily be higher. On the other hand, the activity of the LCA or the VOC is not always higher for breathy attack than that for soft attack. This would suggest that these two muscles are not simply adductors of the vocal cords but might have additional functions, such as supplying medial compression or tension to the vocal folds.

What appears to characterize hard attack is the temporal pattern of LCA activity. The marked increase in LCA activity during the prephonatory period appears to be related to the strong medial compression or constriction of the glottis prior to release. A steep fall in LCA activity accompanied by a brief pulse of PCA activity appears to be the physiological mechanism controlling abrupt glottal release after the period of constriction. In subject T.G., VOC and INT also appear to contribute to strong constriction of the glottis during the prephonatory period.

It is characteristic in soft attack that PCA activity decreases gradually toward the onset of voicing, while the adductors appear to show gradual increase in activity for initiation of voicing. In the present study, the test utterance which was used for soft attack was initiated by [b]. It is conceivable, therefore, that the vocal folds hardly start vibrating before articulatory release, even if they are adducted near to the midline. There may, however,

[3] Subject T.G. showed highest INT activity for hard attack during prephonatory period. However, INT activity for voicing appears to be highest in breathy attack.

be a difference in the action pattern for 'soft attack', depending on whether the utterance is initiated by a voiced consonant or a vowel.

In their recent study on the activity of the intrinsic laryngeal muscles in voicing control in speech, the present authors reported that PCA and INT show a reciprocal pattern of activity in voicing control of speech [9]. It was revealed that PCA shows marked activity for the production of a voiceless consonant, while INT is suppressed. Conversely, INT generally shows higher activity for the production of vowels and voiced consonants, while PCA is reciprocally suppressed. It was further revealed that the other adductors, LCA and VOC, show a different pattern of activity in voicing control when compared with INT. Namely, LCA and VOC showed increasing activity for vowel production, while appearing inactive for consonant production regardless of the voiced vs. voiceless distinction, at least in that particular context.

In the present study, it is shown that INT shows a different pattern of activity in vocal attack from that of LCA or VOC in subjects L.J.R. and L.L. In subject T.G., on the other hand, the three adductors show more less similar temporal patterns of activity, in which participation of INT in tight glottal closure in hard attack appears more dominant than in the other subjects. There seems to be very little difference between the activity patterns of LCA and VOC in either of our two studies. The present data suggest that there is no qualitative but perhaps some quantitative difference in their activity patterns. In previous studies, HIRANO *et al.* [6] have suggested that the two muscles function differently in register control for trained singers; differences between their results and ours may be due to the different tasks of the two groups of subjects. In any event, further study on various vocal maneuvers is needed to determine any possible functional differentiation within the adductor muscle group of the larynx.

CT is generally considered as a prime pitch-raiser, acting by tensing the vocal folds [2, 3, 11, 19]. GÅRDING *et al.* [2] reported that there is apparent antagonism between VOC and CT in the production of a glottal stop in one of their two Swedish subjects, in whom CT activity appeared to be suppressed at the moment of maximum activity of VOC for the period of glottal closure. However, their data might not be comparable to the present data because the test utterance used in that particular experiment included variations of word accent and intonation in addition to glottal stop productions. The apparent suppression of CT activity in their data can be correlated to the falling in pitch toward the period of glottal closure. The present study revealed that CT shows more or less similar patterns of activity with VOC in subjects L.J.R.

and L.L., and with LCA in subject A.P. with respect to the difference in the type of vocal attack when pitch is not changed.

In the present study, the measurement of so-called Δt was not attempted because of the ambiguity in defining the onset of EMG activity relative to the onset of the acoustic representation of voicing. For example, it is not unusual to observe in raw EMG records of the intrinsic laryngeal muscles a good amount of continuous resting discharge even during the period of silence between utterances. Thus, it appears difficult to define the onset of EMG activity from the raw EMG traces and, as a result, it is difficult to specify general rules for these measurements.

On the other hand, the temporal patterns of averaged muscle activity present in this paper certainly give no less information than simple comparisons of Δt, and can be considered as more appropriate for comparisons of such activity patterns. As shown in the previous figures, it is generally observed that laryngeal muscle activity, except for that of PCA, starts to increase earlier for hard attack than for the other two. This confirms findings reported in previous reports. However, what seems to differentiate among the various types of attacks is not simply the prephonatory activity of the adductors but rather the overall activity patterns of all the intrinsic laryngeal muscles. In other words, different coordinated actions of the intrinsic laryngeal muscle systems, working in reciprocal fashion, determine each type of vocal attack.

Summary

Multichannel EMG recordings were obtained from the intrinsic laryngeal muscles of four American English speakers for three different types of vocal attack: breathy, soft and hard. The data were processed by a digital computer to obtain an average indication of overall muscle activity. The results indicate that the three different types of vocal attack are characterized by coordinated actions of the abductor and adductor muscles of the larynx, and further, that these muscles work in reciprocal fashion for each type of attack.

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