THE ROLE OF THE STRAP MUSCLES IN PITCH LOWERING

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INTRODUCTION

It has long been recognized that the extrinsic laryngeal muscles may participate in the control of fundamental frequency (F_0) during singing or speech. There is a large body of direct physiological evidence for this participation for the case of singing (e.g., Faaborg-Anderson & Sonninen, 1960). However, there are several reasons to expect that the extrinsic muscles are also involved in F_0 control--especially for F_0 lowering--during speech production. Recent studies of laryngeal control of F_0 falls in speech have implicated the cricothyroid and the strap muscles as the primary muscles involved in F_0 lowering (e.g., Atkinson, 1978; Erickson, 1976; Erickson & Atkinson, 1976; Simada & Hirose, 1971). Specifically, the cricothyroid shows decreased activity and the strap muscles increased activity during pitch falls. In this paper, we wish to examine the interaction between the cricothyroid and strap muscles in effecting F_0 fall in more detail, and in particular, to study their joint activity.

BACKGROUND

During speech or singing, fundamental frequency is determined primarily by activity of the intrinsic laryngeal muscles, and, to a lesser extent, by subglottal pressure (Baer, 1979; Hixon, Klatt, & Mead, 1971). Given that the vocal folds are in a voicing position (partially or fully adducted), and that sufficient subglottal pressure to maintain phonation has been produced, F_0 is determined to a substantial degree by the tension of the vocal folds, which is, in turn, determined by adjustments of the relative positions of the cricoid, thyroid, and arytenoid cartilages. Recent results have unanimously shown that the muscle whose activity is most directly related to F_0 is the cricothyroid (CT), a finding consistent with the anatomical fact that the cricothyroid muscle is best suited for increasing the distance between the anterior part of the thyroid cartilage and the arytenoid cartilages. The only muscles that could shorten this distance by action at the level of the folds themselves, however, are the laryngeal sphincter muscles--the thyroarytenoid (TA), and the muscles of the aryepiglottic sphincter. Of these, it is known that the activity of the internal part of the thyroarytenoid (the vocalis) is not usually positively correlated with F_0 lowering (Gay, Hirose, Strome, & Sawashima, 1972; Shipp & McGlone, 1971). Thus, if an active shortening-

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+Also The Graduate School, City University of New York.
Acknowledgment. This work was supported by NINCDS Grants NS-13617 and NS-13870, and BRS Grant RR-05596 to Haskins Laboratories.

[HASKINS LABORATORIES: Status Report on Speech Research SR-70 (1982)]

lowering mechanism exists, it must either involve the external part of the TA muscle or some more indirect action through the aryepiglottic sphincter muscles, or the action of the extrinsic laryngeal muscles.

Untrained singers allow the whole larynx to move upward during increases of F_0 and downward for decreases of F_0. There is also some evidence that similar tendencies occur, on the average, during speech intonation (Ewan, 1979). Since the vertical position of the larynx as a whole is determined by its extrinsic attachments, this constitutes evidence that the extrinsic muscles are activated with changes in F_0. There is direct electromyographic and clinical evidence that the extrinsic muscles are involved in the production of both the high and low extremes of a singer's F_0 range (Sonninen, 1956). Since the range of fundamental frequency employed during speech production usually lies near the low extreme of singing range, we might expect the extrinsic muscles to participate in F_0 lowering during speech.

A knowledge of the anatomy of the region and those few experimental facts available have been used to develop a number of theories to account for F_0 lowering; among these are (1) the passive relaxation theory (Zemlin, 1959), (2) the external frame function theory (Sonninen, 1956), (3) the vertical tension theory (Ohala, 1972), and (4) the laryngeal articulation theory (Lindqvist, 1972). In the first, the passive theory, F_0 lowering is said to result simply from relaxation of the F_0 raising musculature (i.e., cricothyroid) with no active gesture. In the second, the external frame function theory (which is the one we will be most concerned with here), F_0 lowering is thought to be brought about by a horizontal shortening of the vocal folds due to forces exerted by the external attachments to the larynx. In the third, the vertical tension theory, F_0 lowering is said to result from a lowering of the larynx; that is, the vertical height of the larynx is related to F_0 directly through vertical stretching of the surface membranes of the larynx, rather than by horizontal lengthening as in the external frame function theory. In the fourth, the laryngeal articulation theory, F_0 lowering is said to be brought about by the laryngeal and supra-laryngeal sphincter muscles opposing the cricothyroid muscle, so that both vocal fold shortening and supraglottal constriction result.

It is possible that several of the theories listed above may be "correct." That is, each of the possible mechanisms might be used at different times or in different combinations. However, it is clear that there are changes in the activity of the extrinsic muscles during speech production and that these muscles are capable of changing the configuration of the laryngeal cartilages.

Figure 1 shows a schematic side view of the larynx, indicating the major structures and their attachments. The three major structures important for F_0 control are the cricoid cartilage, the thyroid cartilage, and the hyoid bone. Because of the ligamentary and muscular attachments between these three structures, movement of any one of them produces changes in the forces exerted on the other two, in general causing them to move also. Each of the three structures also has attachments to other body structures. Therefore, any movement causes a readjustment of the forces not only that the three structures exert on each other, but also that external attachments exert.

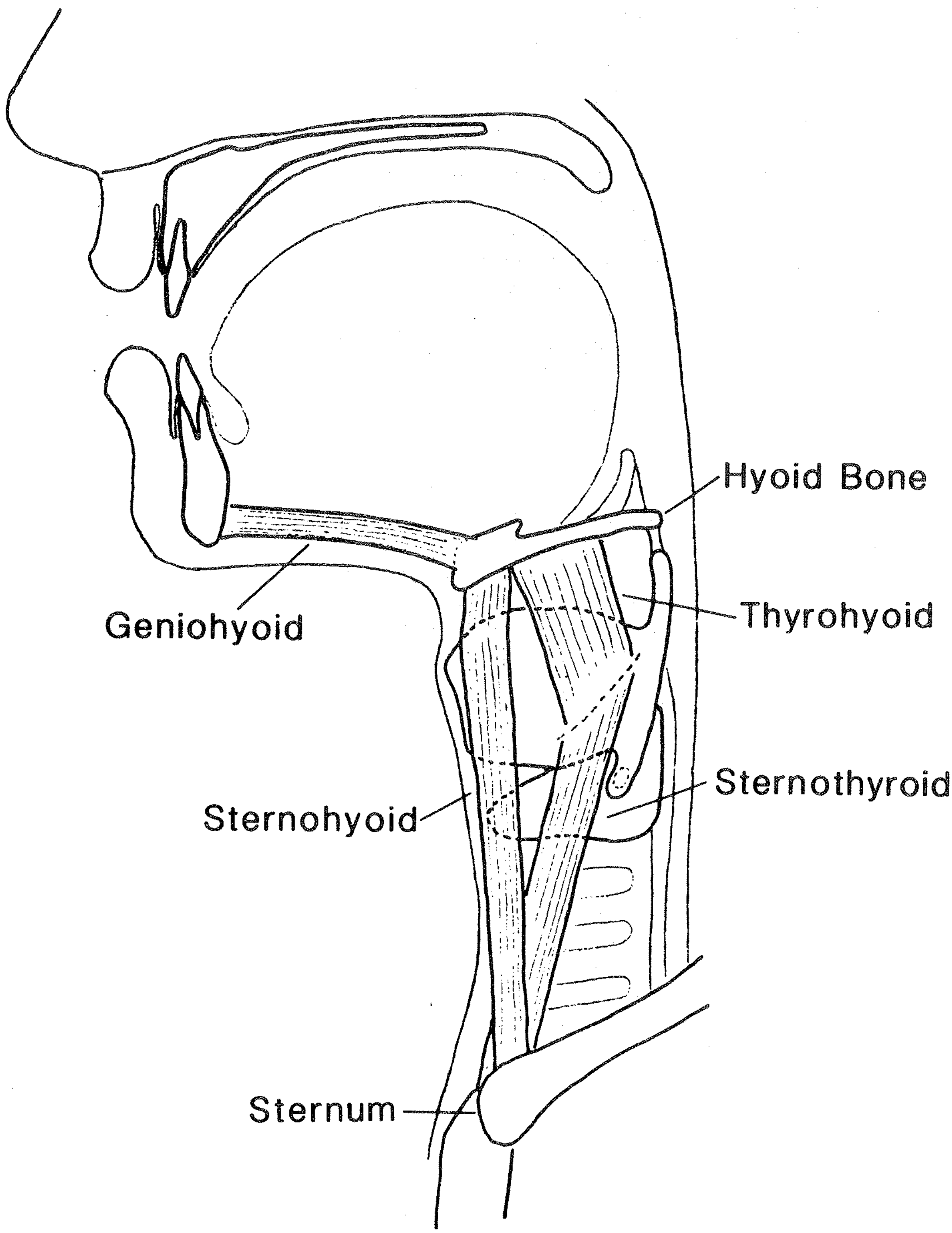

Figure 1. Lateral view of larynx and supra-laryngeal structures.

Specific theories of strap muscle action must be assessed within the framework of this biomechanical complexity. For example, Sonninen (1956), who simulated muscle action by pulling individual muscles in cadavers fixed in various head positions, found that a pull on the sternothyroid (ST) caused the thyroid cartilage to move and tilt forward slightly. Due to the attachment of cricoid and thyroid cartilage, a tug on one caused a movement of the other. "Contraction" of ST resulted in either lengthening or shortening of the vocal folds depending on the position of the head and cervical spine: "If the tilting of the cricoid cartilage exceeded that of the thyroid cartilage, the vocal cords shortened, if it was less, they lengthened" (p. 25).

While Sonninen believed, on anatomical grounds, that this anterior vector of movement might result from the contraction of any of the three strap muscles, i.e. the sternohyoid, the sternothyroid and the thyrohyoid, whether or not a vertical component was present, he did not investigate the problem. Later investigators have been in disagreement as to whether there is functional differentiation among the muscles. Collier (1975) and Hiki and Kakita (1976) report a difference, although Erickson (1976) does not. Moreover, the last-named study shows that all three straps appear to be associated with F_0 lowering in the low part of the F_0 range.

In the articles cited above, investigators have not always differentiated what is biomechanically possible from what is actually used as a maneuver for pitch control by speakers or singers. Further, speakers may differ from trained singers in what they do. In the study that follows, we have tried to look at reasonably common mechanisms in speakers without special training whose language calls for precise control. Hence, we have used speakers of Thai, a tone language, as subjects and compared them with speakers of English.

DESCRIPTION OF EXPERIMENTAL STUDY

In order to assess the role of strap muscles in F_0 lowering, we performed the following experiment with two Thai and two English speakers on utterances that showed falling F_0 contours.

We used the EMG and F_0 processing facilities at Haskins Laboratories and restricted our study to the cricothyroid (CT) muscle and the strap muscles. As mentioned earlier, there is no strong evidence for a differentiation among the strap muscles. But since the earlier literature, especially Hirano, Ohala, and Vennard (1969), has focussed attention on the sternohyoid (SH), we have given it special attention. However, in the case of Thai speaker PT, since SH proved not to be a good insertion, we examined the thyrohyoid (TH) muscle. The muscle insertions were performed by Hajime Hirose, using insertion techniques he has described (Hirose, 1971).

In Thai, we examined F_0 falls on words with two types of tones, the "falling" tone and the "low" tone, i.e., /baâ/, /biî/, /buû/, and /baà/, /biì/, /buù/. The words were spoken in a carrier phrase /əə-/, meaning "Yes, that is a ______." In Thai, these two tones begin their fall at a relatively high value of F_0, or a mid value, respectively.

In English, we examined falling F_0 contours from the words "Bev" and "loves" in the sentence "Bev loves Bob," with emphatic stress on one of the three words. The word is produced with intonation that falls from a high value, if it is stressed, or a mid value, if it is not. The particular samples used are those described in Atkinson (1973, 1978). We will describe the two types of F_0 falls in the two languages as "high falls" and "mid falls."

The two speakers for the English sentences were one native American (male), and one naturalized American (male) whose native language was Estonian, but who was a fluent1 speaker of English. The speakers for the Thai sentences were two native speakers (male) of the central dialect of Thailand (as spoken in Bangkok) who were students at the University of Connecticut. The two English speakers were sophisticated with respect to the literature on F_0 control: the two Thai speakers were not.

Previous studies (e.g., Atkinson, 1973; Erickson, 1976) indicate a typical pattern of CT and SH activity occurring with falling F_0 contours. Prior to the fall in F_0 the CT shows a decrease in activity, and after the fall, the SH shows an increase in activity. In order to determine whether the CT and SH could be in some way causing the fall in F_0, we examined the delay between onset of F_0 fall and onset of the decrease in CT activity on the one hand, and onset of the increase in SH activity on the other hand. This method was first reported in Atkinson and Erickson (1977) and Erickson (1976).

Schematic patterns of F_0, CT, and SH strap muscle activity are shown in Figure 2. The onset of F_0 fall is fairly abrupt, and easily determined by visual inspection for measurement purposes. The onset of strap muscle activity was also fairly easy to determine, since usually there was a low steady base level of activity, followed by a sudden increase. It was at the point where the EMG curve began to increase that the measurements were made for the strap muscles. The cricothyroid showed a clear peak or peaks of activity before it sloped off into a steady low level pattern of activity. It was at the point where the EMG curve began to descend that the measurements were made. We examined individual tokens of each of the four speakers: 30 tokens each for the Thai speakers, and 20 tokens each for the English speakers. Tokens in which clear peaks were not observed were discarded.

RESULTS

The distribution of delay times between the change in EMG activity and F_0 fall for high falls is shown in Figure 3. All four speakers show a pattern in which CT activity generally begins to decrease before F_0 fall. For three of the four speakers, strap muscle activity follows the onset of F_0 fall, while for the fourth, KO, it precedes it.

The data for the first three speakers suggest the following: (1) Since the CT is active prior to the F_0 fall, it is certainly possible that relaxation of the CT could be causal with regard to the initiation of F_0 lowering (2) Since the strap muscle is not active until after the F_0 fall, it is clearly not possible for the strap muscles to be causal with regard to the initiation of F_0 lowering.

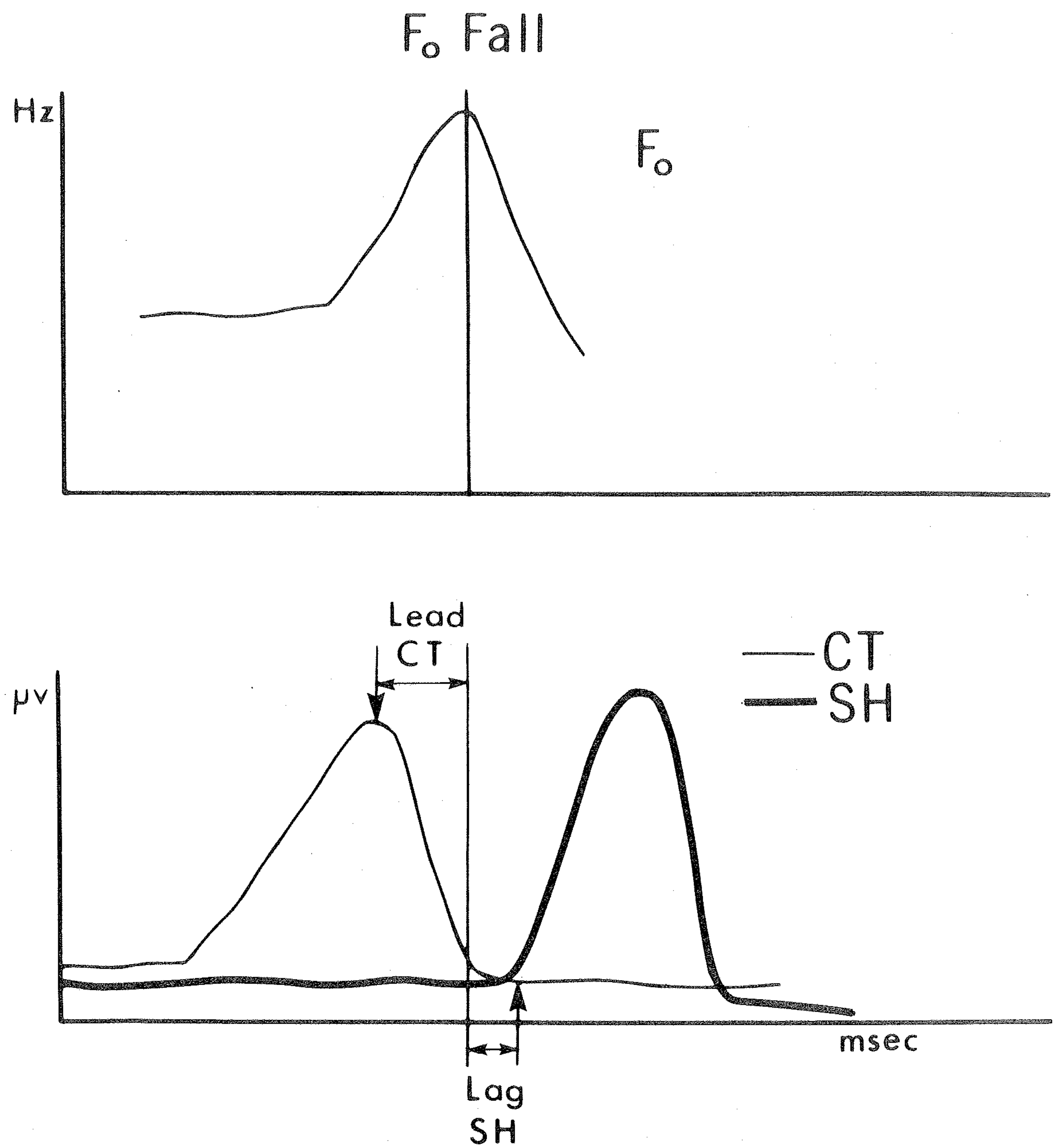

Figure 2. Schematic representation of cricothyroid and strap muscle activity in relation to F_0 fall.

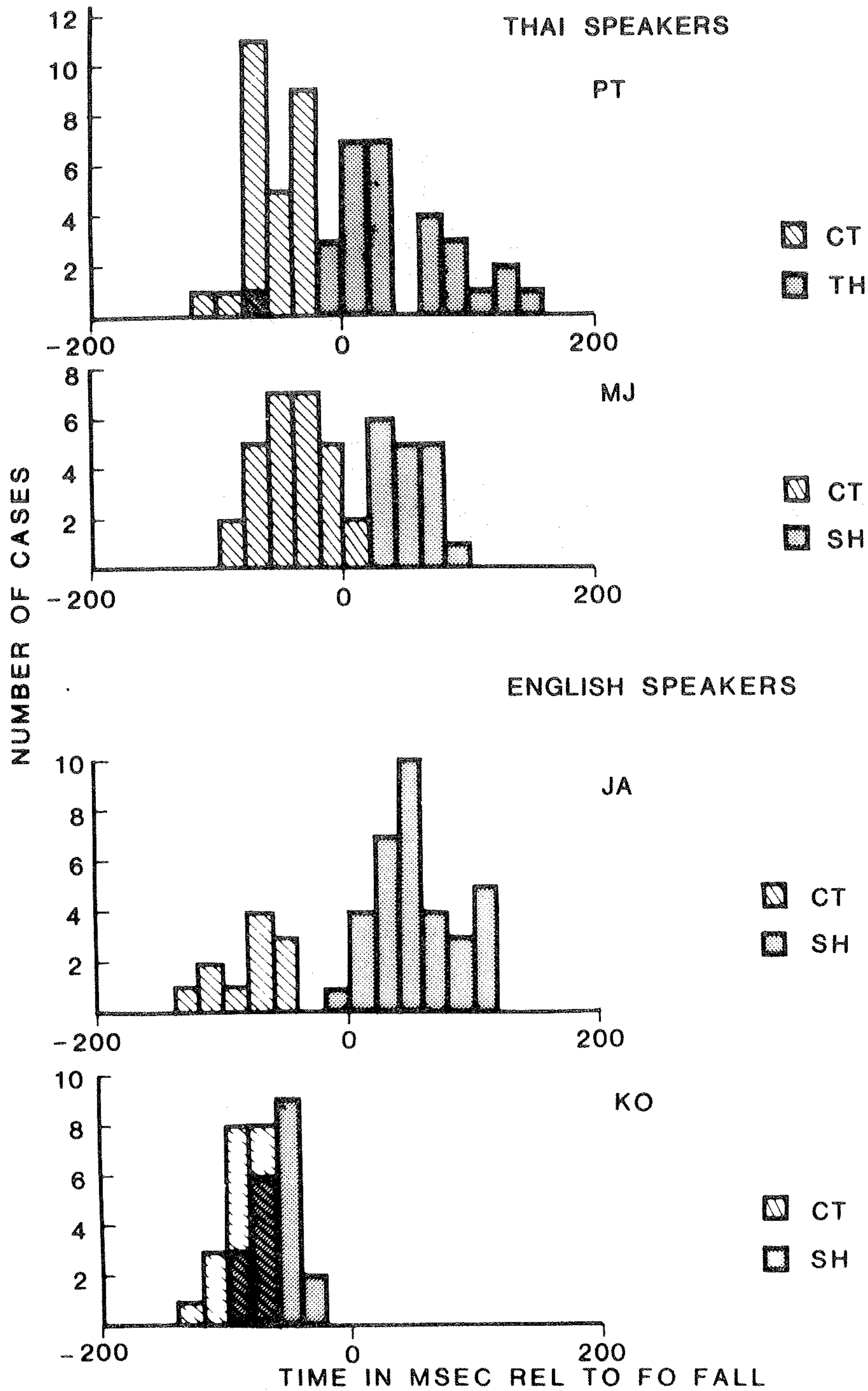

Figure 3. Data for high falls. Change in activity for cricothyroid and strap muscle activity in relation to F_0 fall.

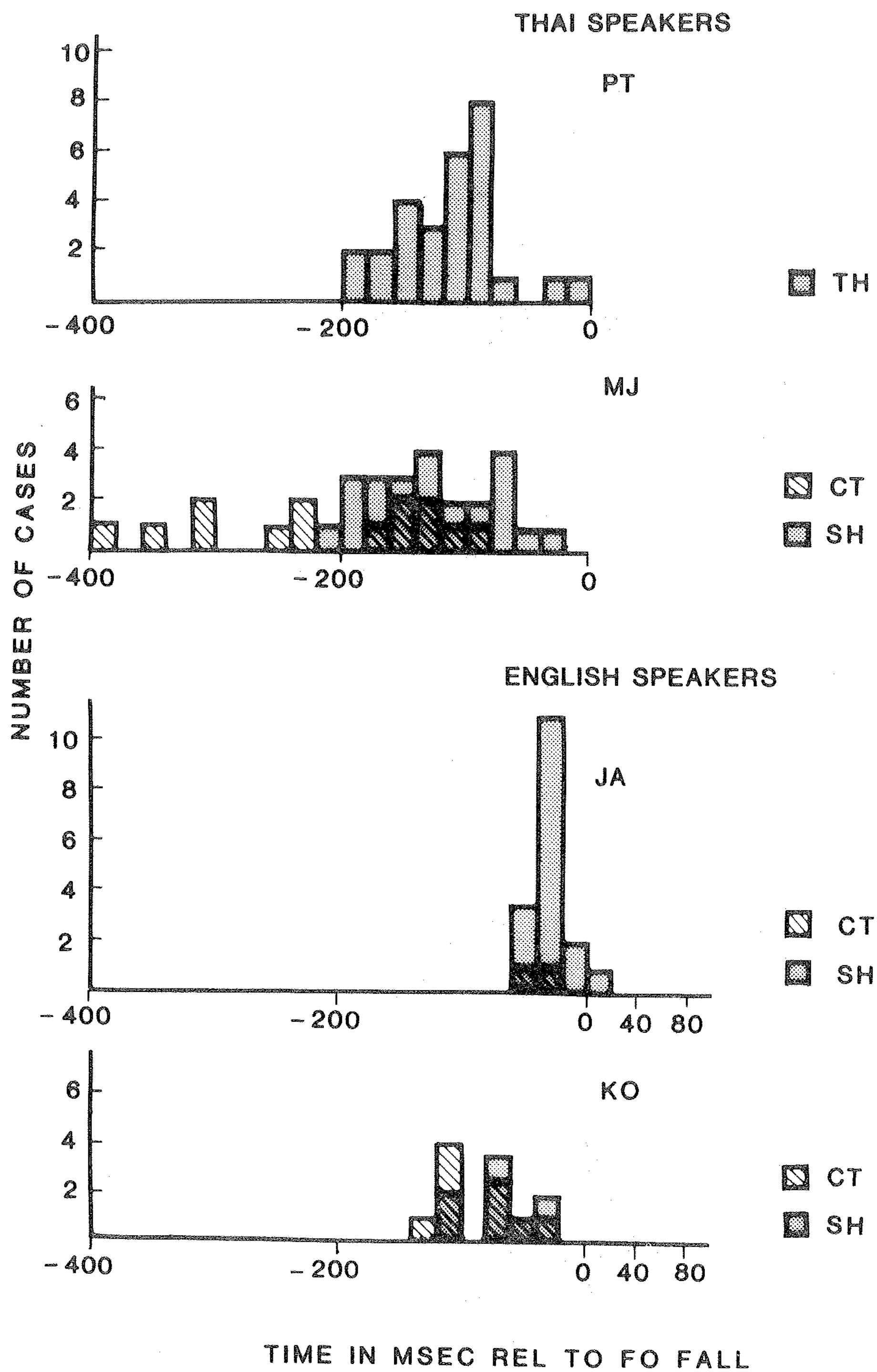

Figure 4. Data for mid falls. Change in activity for cricothyroid and strap muscle activity in relation to F_0 fall.

For the fourth speaker, KO, who does not follow the above pattern, we can conjecture that (1) the CT is probably causal with regard to the initiation of F_0 lowering, but (2) whether the strap muscle is causal also is not at all clear. The data on speaker KO may reflect an alternative F_0 lowering strategy.

Next, we consider patterns of F_0, CT, and strap muscle activity for mid-fall situations shown in Figure 4. In comparison with the patterns for high fall situations previously described, we note initially, that the cricothyroid muscle tends to show less dynamic changes in activity in mid falls than in high falls. This pattern has also been found by other experimenters. For instance, Rubin (1963) noted that CT activity is "virtually absent in lower frequencies, minimum just above this, and does not really become intense until transition to the middle register" (p. 1002). Given that the transitions in CT activity are far less abrupt for mid- to low-falls, we were not able to establish onset or offset points as readily. Hence, the number of cases for the mid-fall distributions is much smaller.

In examining the delay time measurements for mid-falls, displayed in Figure 4, we see the following pattern of strap muscle activity: Strap muscle activity starts to increase before the initiation of the F_0 fall. This contrasts strongly with the pattern of strap activity seen with high falls, where strap activity begins after initiation of F_0 fall.

The findings reported in this study lend themselves to certain interpretations concerning how the laryngeal muscles work to lower F_0. For one thing, it is obvious that CT and strap muscles act synergistically in lowering F_0. Simply speaking, the CT must be relaxed (or relaxing) before the strap muscles can participate in F_0 lowering. A more complicated statement emerges when we compare the patterns of CT-strap muscle activity for the two types of fall situations, i.e., high to low, and mid to low falls. A fall from high to low F_0 is initiated by relaxation of the CT, with the strap muscles showing activity well after initiation of the F_0 fall. However, a fall from mid to low F_0 is initiated by the strap muscles, with the CT playing relatively little role.

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FOOTNOTE

[1]The subject's speech was marked by some foreign interference. While he was not an ideal subject, he was the only volunteer for what seemed at the time (1973) a fairly formidable procedure. However, his productions were perceptually normal as to intonation contour and the interest here is not in the choice of English, but of any non-tone language.