How is pitch lowered?

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Abstract

Is the pitch of voice lowered a) by the active contraction of some laryngeal muscles, b) by the relaxation of those muscles that raise pitch, or c) by both mechanisms? Evidence will be presented which supports (c). Specifically, electromyographic recordings point to the sternohyoid muscles' participation in pitch lowering, independent of their activity in other speech gestures, e.g., jaw opening. Further, there is evidence of a probable causal correlation between larynx height and pitch of voice (which accounts for the sternohyoids' activity in pitch lowering). Vertical movements of the larynx, it will be argued, change the pitch of voice by changing primarily the vertical, not the anterior-posterior, tension of the vocal cords. (Research supported by the National Science Foundation and a University of California Faculty Research Grant).

The elevation of the fundamental frequency or pitch of voice is known to be accompanied by contraction of the cricothyroid muscle assisted by the vocalis, the lateral cricoarytenoid, and so on. But how is pitch lowered? There are two possibilities: either the muscles that raise pitch are relaxed, or there exists a certain muscle or set of muscles which by contracting actively lower pitch. Previous electromyographic evidence, such as that shown in figure 1, gave evidence that when pitch is lowered the level of activity of the cricothyroid decreases. This figure shows the activity of the cricothyroid and sternohyoid muscles during the utterance by me of the phrase "Bev bombed Bob." Fundamental frequency is shown at the top. The cricothyroid of course shows increased activity at high pitch and decreased activity at low pitch. However there is also increased activity of the sternohyoid during lowered pitch. This led us (Fromkin and Ohala 1968, Ohala, Hirano, and Vennard 1968, Hirano and Ohala 1969, Ohala 1970) to conclude that the sternohyoids (and perhaps other muscles) actively participate in lowering pitch. Also it is clear that there is for all speakers a certain middle pitch level which can be maintained without contraction of the cricothyroid and yet pitch can be lowered below that level. This also argues for the existence of an active pitch lowering mechanism.

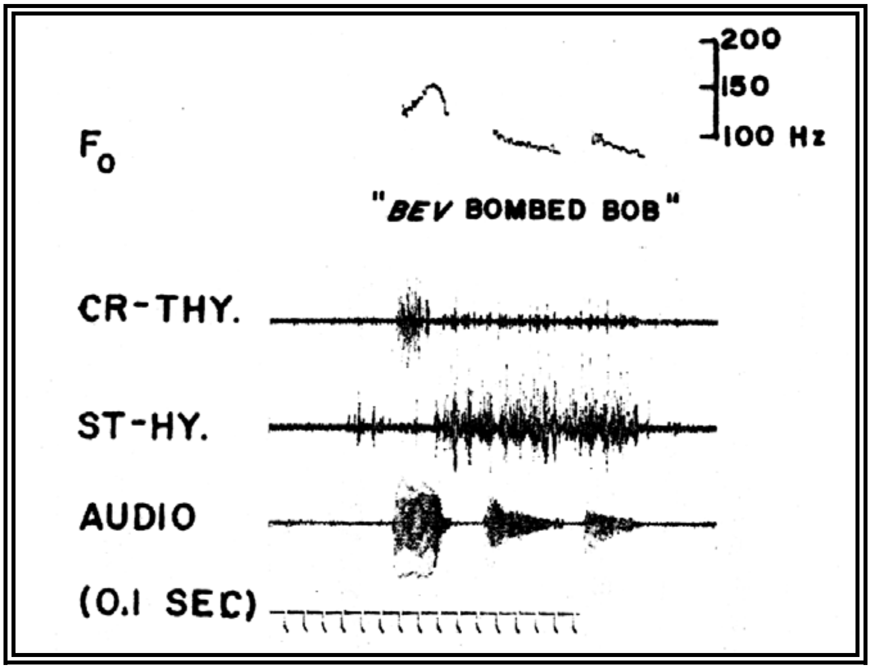

Fig. 1.

However it was shown later that the sternohyoid is also active for certain segmental speech gestures such as Jaw lowering, and tongue retraction (Ohala and Hirose 1969). This apparently led some writers to conclude that the claim that the sternohyoid participates in pitch-lowering could be dismissed or at least ignored (Lieberman et al. 1970). However it is not difficult to demonstrate that the sternohyoid can participate in more than one speech gesture. Figure 2 shows the activity of this muscle in one subject during simple jaw opening without any accompanying voice or other change in the speech articulators. At top is prolonged jaw opening; at bottom repeated Jaw opening and closing. When the Jaw is opened or kept open, the sternohyoid is active. The probable reason for this can be seen from figure 3. On the left is shown how the chief jaw-opening muscle, the digastric, is attached at one end to the cestoid process, loops through a ligamental attachment on the hyoid bone and connects to the inside of the mandible at the other end. These structures are represented schematically on the right. Contraction of the digastric produces the force AC which results in the vector force AD which pulls the jaw down. However contracting the digastric also produces the force IJ which tends to raise the hyoid bone. This would tend to reduce the vector force AD. To counteract hyoid bone elevation, the sternohyoid must contract to produce the force IL which opposes IJ.

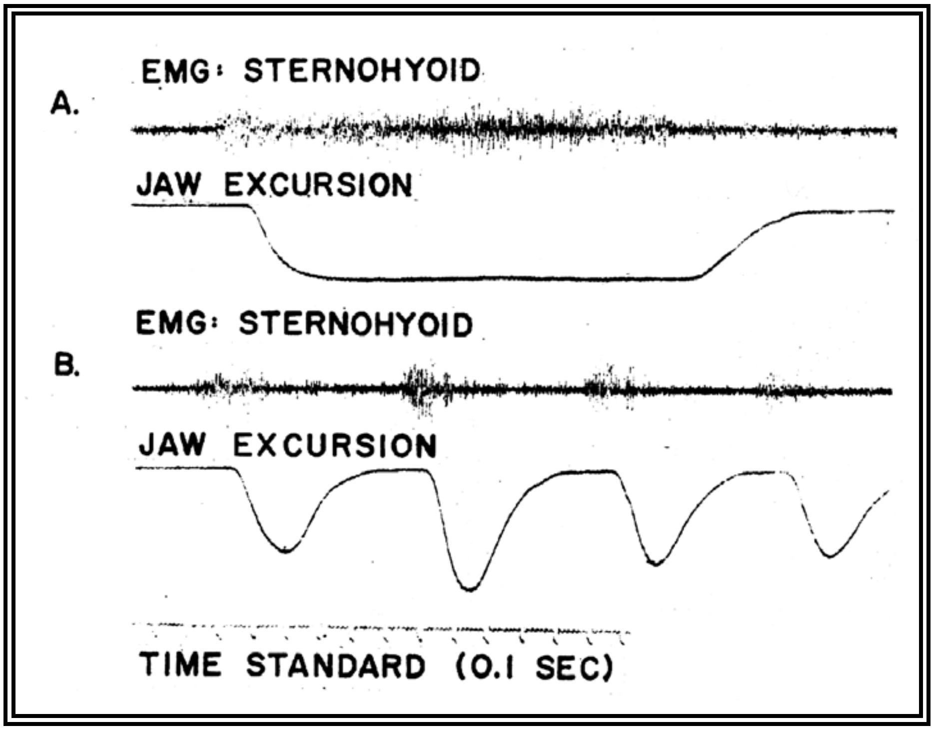
A.
EMG: STERNOHYOID
JAW EXCURSION
B.
EMG: STERNOHYOID
JAW EXCURSION
TIME STANDARD (0.1 SEC)

Fig. 2.

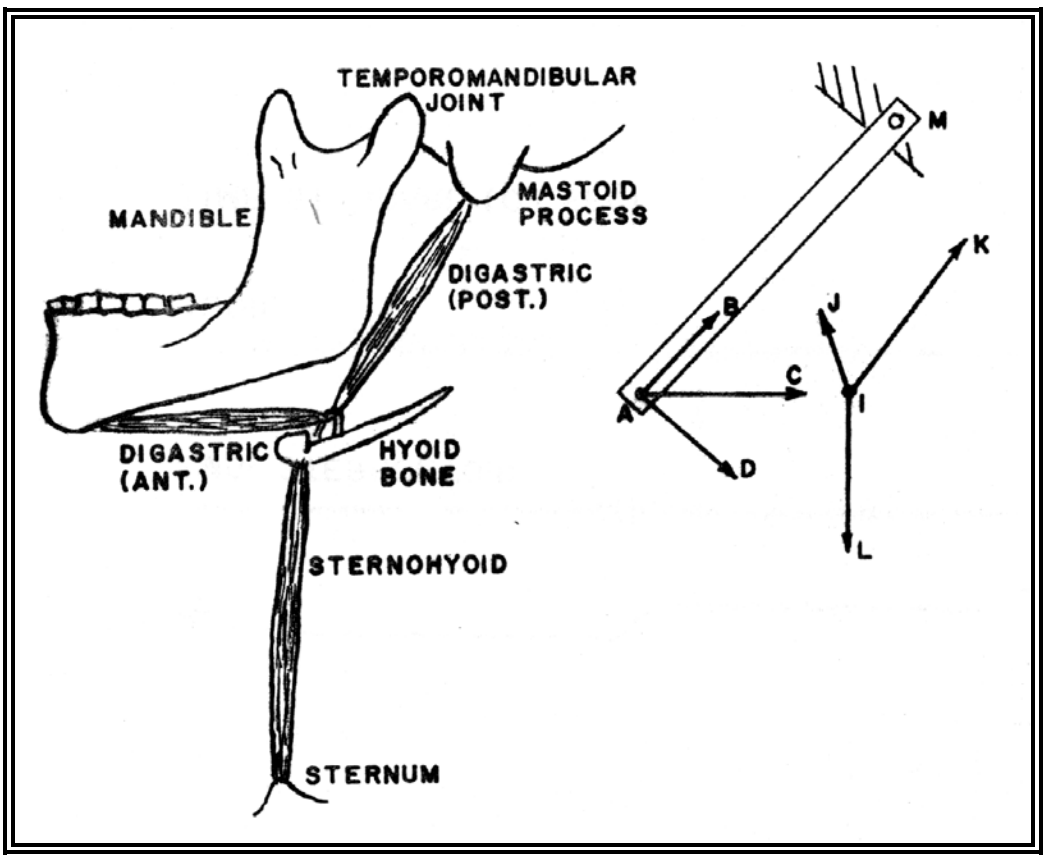
TEMPOROMANDIBULAR JOINT
MANDIBLE
MASTOID PROCESS
DIGASTRIC (POST.)
DIGASTRIC (ANT.)
HYOID BONE
STERNOHYOID
STERNUM
M
B
C
A
D
J
K
I
L

Fig. 3.

By eliminating jaw or tongue movement and varying only pitch the sternohyoid's participation in pitch lowering can be demonstrated as in figure 4. With jaw and tongue held immobile a lowering of pitch also shows increased activity of the sternohyoid.

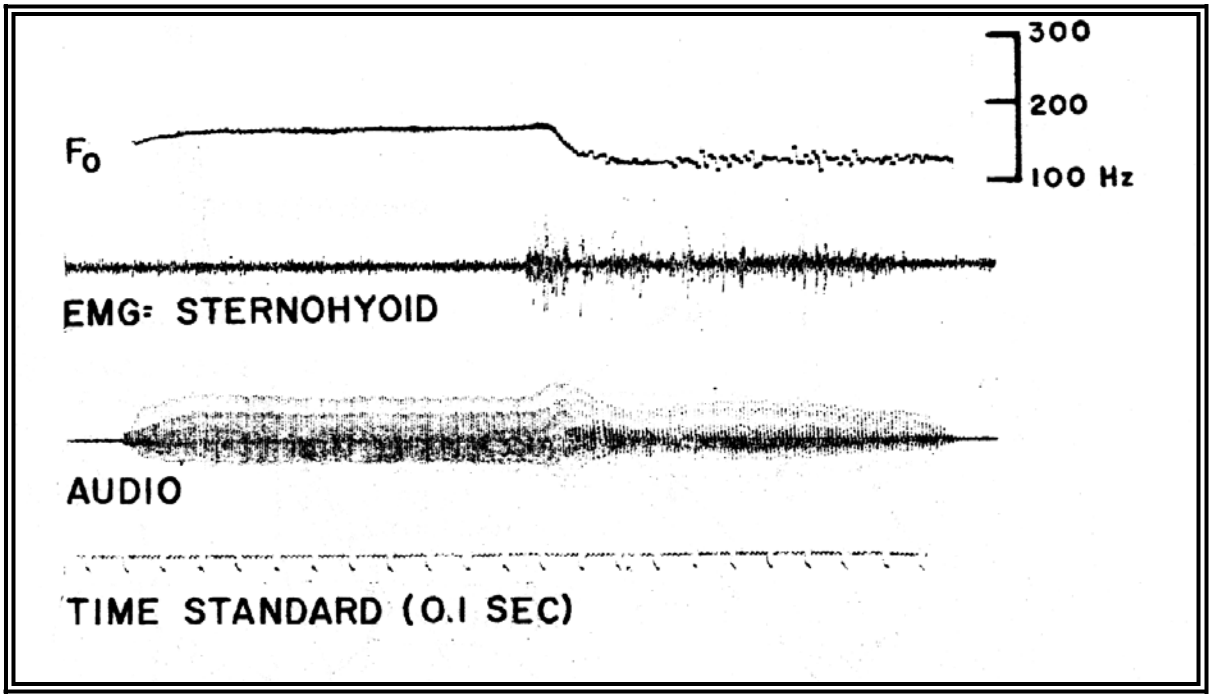

Fig. 4.

In figure 5 is shown the activity of the sternohyoid when both pitch and jaw position are varied. Jaw opening on a low-pitched syllable involves considerably greater muscle activity than jaw opening on a high-pitched syllable.

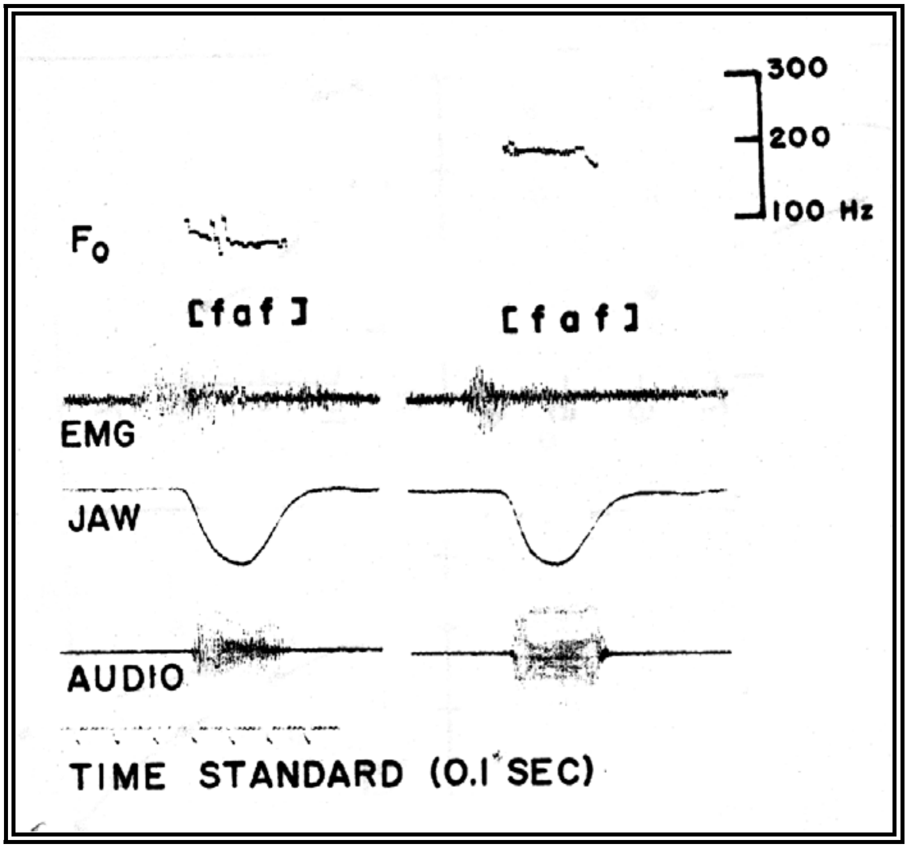

Fig. 5.

Still we might think that the involvement of the sternohyoid in pitch lowering is only coincidental and casual unless we can show why this muscle should be active for this gesture. It seems obvious that it must have something to do with the fact that the larynx and hyoid bone height correlates quite well with pitch. The literature has been full for several centuries with this qualitative observation. An analysis of some of the quantitative observations of this relation reveals a remarkably lawful covariation between the two. Figures 6 to 10 show the correlation between either larynx or hyoid bone elevation (or both) and fundamental frequency. They were obtained by plotting published numerical data or by plotting new measurements made on published raw data. They all show rather convincingly that the elevation of the larynx-hyoid bone complex is proportional to the log of the fundamental frequency—or if one prefers, one could say it varies inversely and linearly with the pitch period.

Figure 6 presents graphically the correlation between hyoid bone elevation and fundamental frequency from data published by Perkell (1969).[1] This plots 4 of the 13 utterances Perkell provides data for. On the left are the two utterances showing the best correlation between these two parameters; on the right are the two showing the worst correlation; all other cases are intermediate in their degree of correlation. As expected there are some perturbations of hyoid bone elevation due to segmental environment but the correlations with F0 clearly overrides this.

[1] I thank Joe Perkell for kindly sending me a taped copy of the audio signal accompanying the cine-x-ray data published in his book; from these I was able to derive the fundamental frequency using narrow band spectrograms.

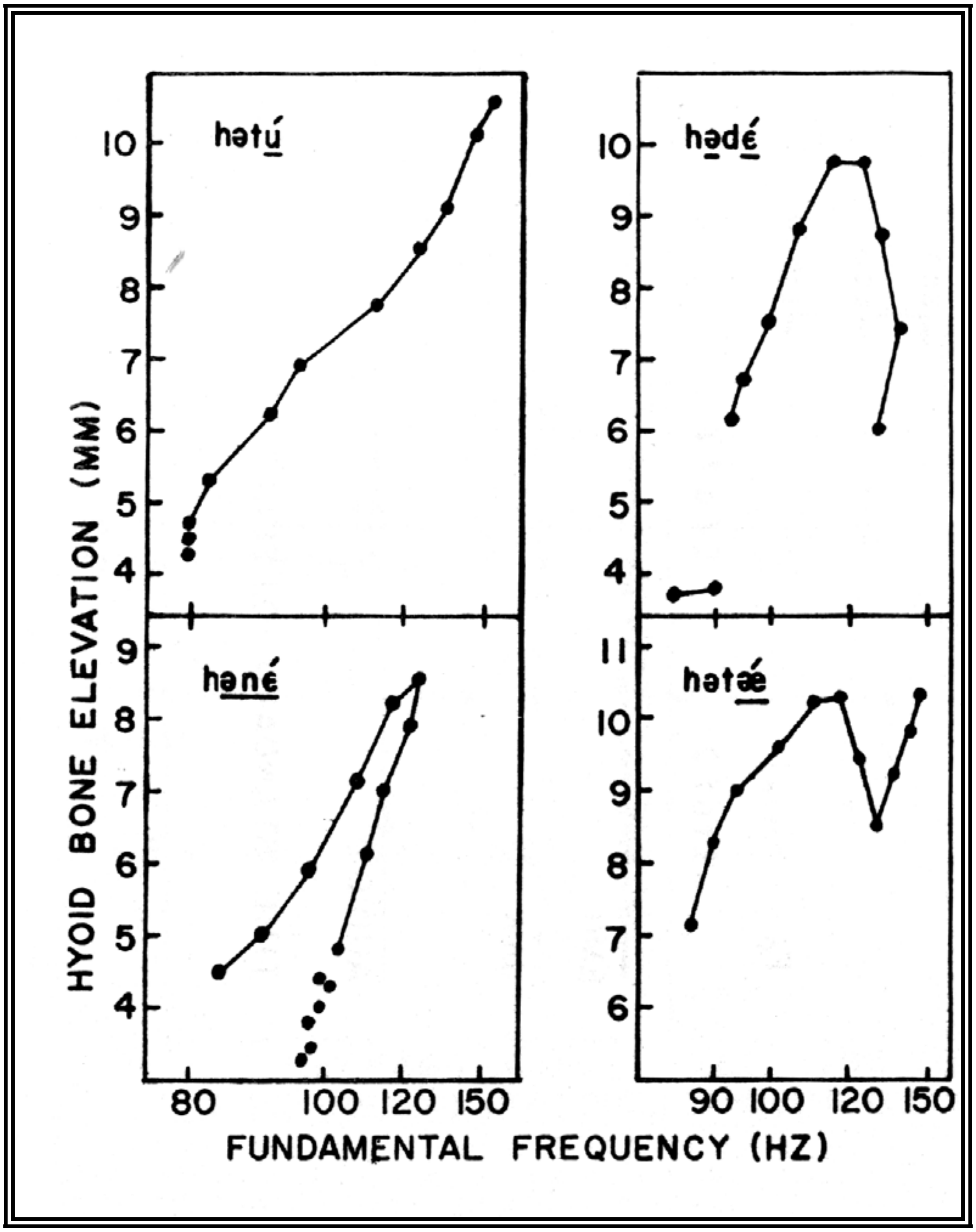

Fig. 6.

Figure 7 presents data obtained from Amenomori (1960). It shows, again, that although there is some effect of the vowel articulation on hyoid bone elevation, the correlation with pitch is much larger.

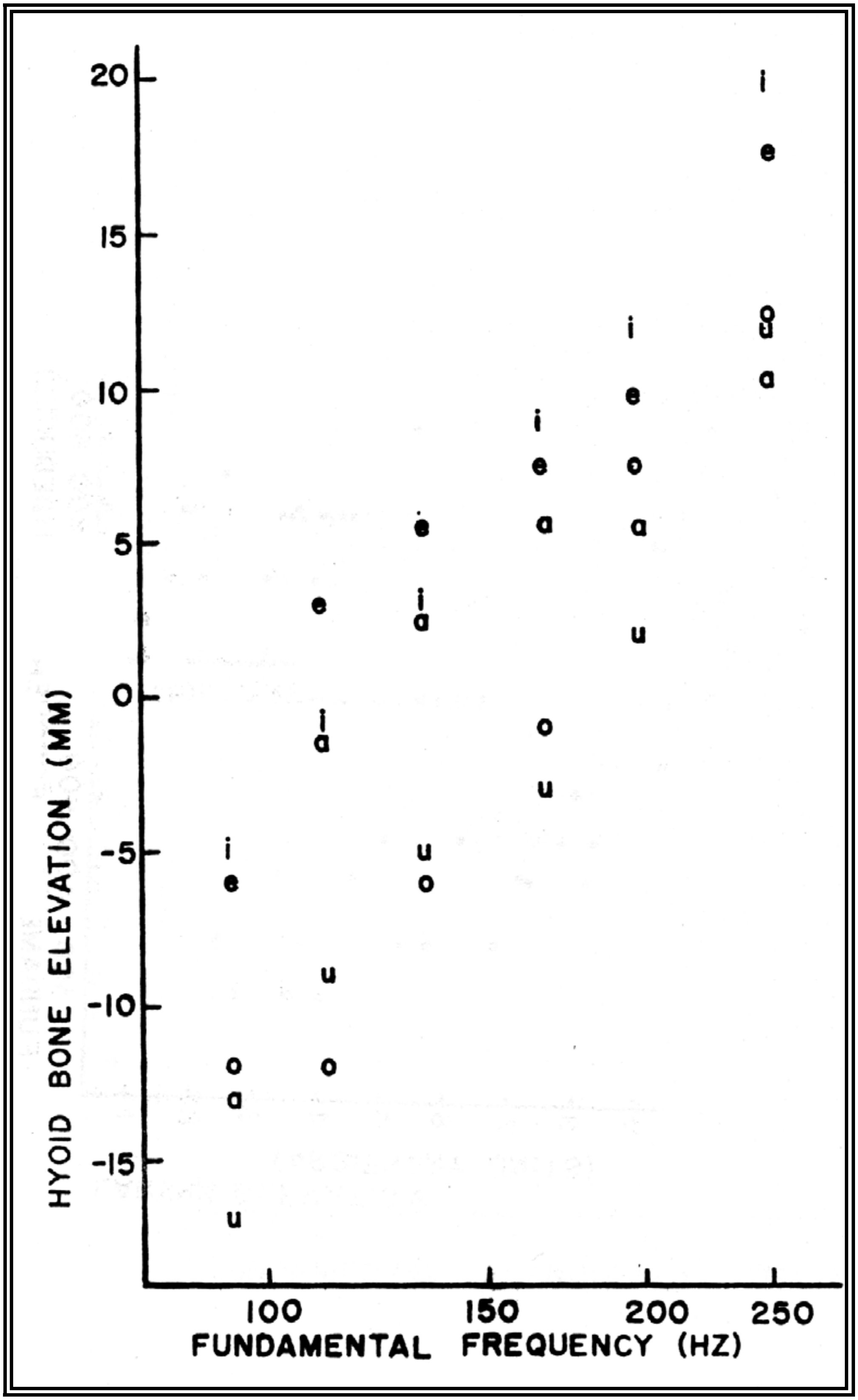
HYOID BONE ELEVATION (MM)
FUNDAMENTAL FREQUENCY (HZ)
20
15
10
5
0
-5
-10
-15
100
150
200
250

Fig. 7

Figure 8 shows measurements obtained from raw data published by Inoue (1931) who transduced larynx height by an ingenious mechanical device. He did not provide a separate record of F0 but since the vertical larynx displacement was shown for two Japanese songs whose melodies are known, information on the pitch associated with a given larynx height could be deduced.

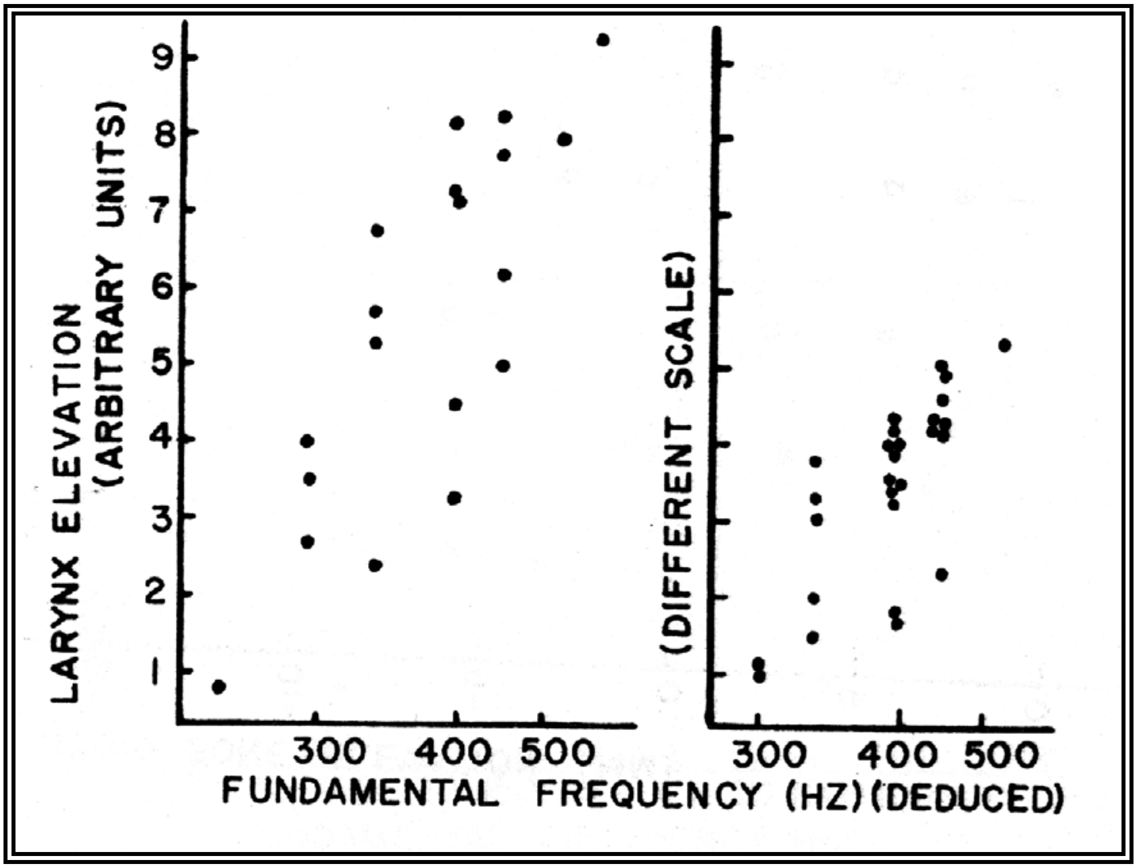

Fig. 8.

Figure 9 shows data measured from graphical traces of larynx height and F0 published by Vanderslice (1967).

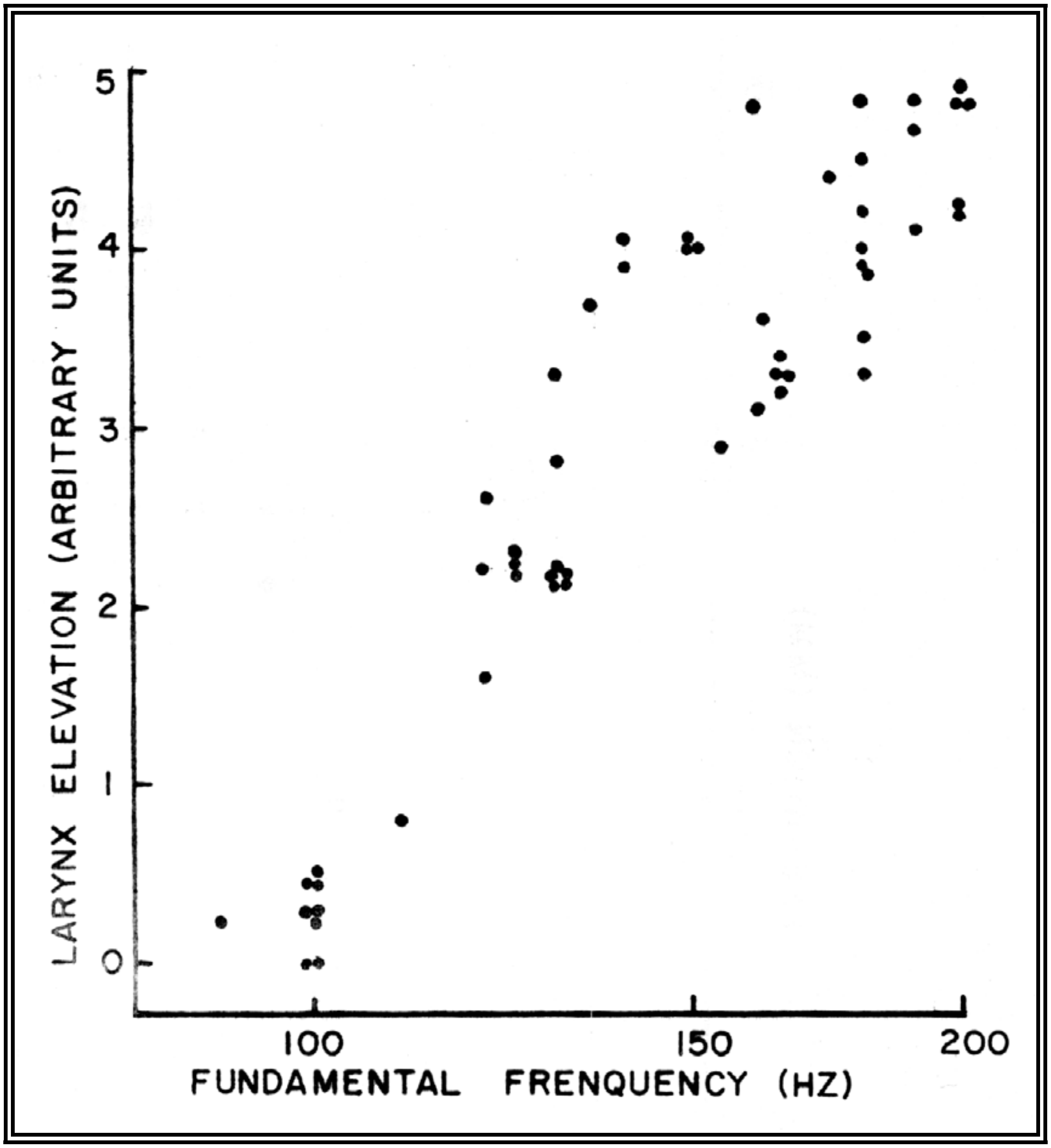

Fig. 9.

Figure 10 presents a plotting of numerical data published by Curry (1937).

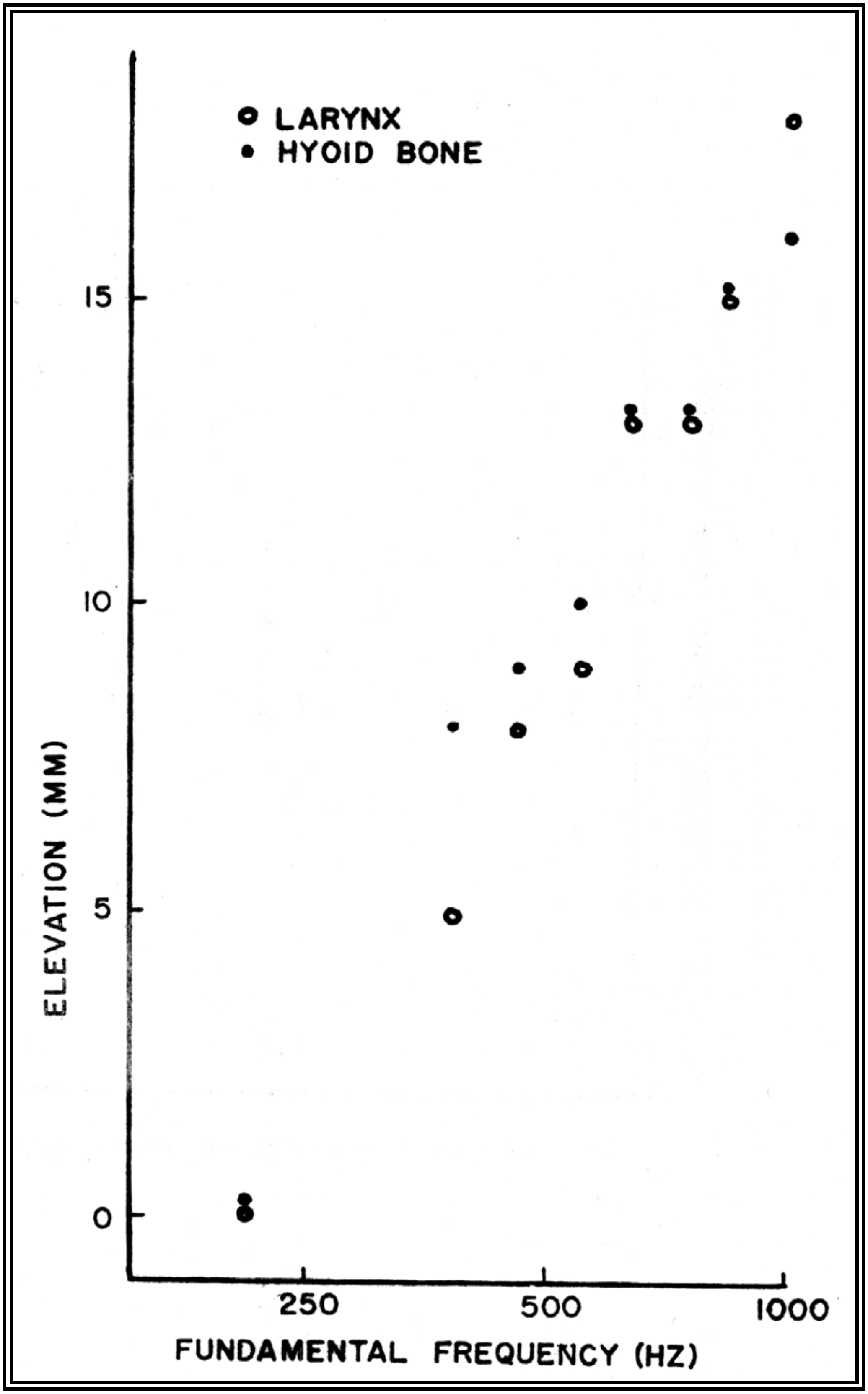
LARYNX
HYOID BONE
ELEVATION (MM)
0
5
10
15
250
500
1000
FUNDAMENTAL FREQUENCY (HZ)

Fig. 10.

And, of course, other authors such as Sonninen have published data showing the good correlation between pitch and larynx-hyoid bone elevation.

This evidence suggests that the relation between the elevation of the larynx-hyoid bone complex and fundamental frequency is not casual but causal and that the sternohyoid (no doubt along with other muscles) helps control this elevation.

There are various theories regarding how larynx height affects pitch. I can't review them all here but I think circumstantial evidence rules out some of them. For example some have proposed that the larynx is elevated to assist in the lengthening and anterior-posterior tensing of the vocal cords. However, lateral x-rays published by Arnold (1961) (figure 11) reveal that a patient with bilateral paralysis of the cricothyroid muscles was still able to change pitch from 110 to 164 Hz apparently by raising the larynx although the width of the cricothyroid space remained unchanged. This suggests the pitch changing effect of larynx displacement is independent of that due to changes in the anterior-posterior tension.

Fig. 11.

Others have suggested that the vocal cords are anchored more securely to the esophageal apparatus, that is, in the posterior region, than they are in the anterior region. Elevation of the larynx, then, would have the effect of stretching the vocal cords. But this would also predict that upon elevation the vocal cords would tend to slant downward in the anterior to posterior direction. Published lateral x-rays reveal no such slant.

I think it is reasonable to conclude that vertical displacement of the larynx affects pitch by changing the vertical tension in the vocal cords. That is, that elevation of the larynx causes increased tension in the vocal cords since the trachea pulls down on the tissue whereas depression of the larynx causes less tension and more flabbiness in the vocal cords since the laryngeal tissues are being compressed.

Tomograms published by Arnold (figure 12) tend to give circumstantial support to this. As pitch is raised the laryngeal ventricles open up, that is, the separation between the ventricular folds and the vocal cords increases, suggesting greater vertical "pull" in the tissue.

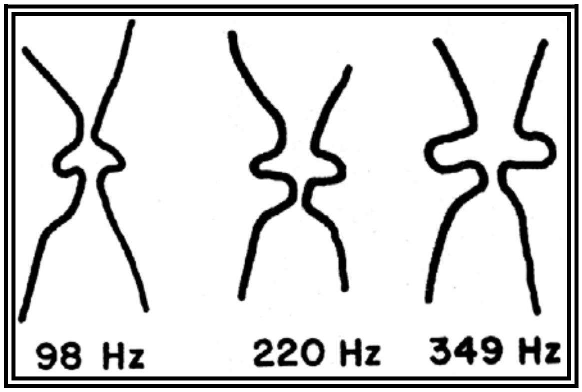

Fig. 12.

This also ties in nicely with the common observation of generally higher pitch being associated with high vowels such as /i/ and /u/ vs. lower pitch for low vowels such as /a/. Tomographic investigations of van den Berg (1955) and Shimizu (1960) accordingly reveal a wider laryngeal ventricle for high vowels as opposed to low vowels.

To sum up: although the text books emphasize that pitch is adjusted mainly by controlling the anterior-posterior tension of the vocal cords, consideration ought to be given to the effect on pitch of tension changes in the vertical direction.

References

Amenomori, Y. (1960) Significance of the hyoid bone in phonation (analysis of the suspension mechanisms of the larynx). (In Japanese) *Oto-rhino-laryngology Clinic* (Kyoto) 53:ll7-l44.

Arnold, G. E. (1961) Physiology and pathology of the cricothyroid muscle. *Laryngoscope* 71:687-753.

Berg, Jw. van den (1955) On the role of the laryngeal ventricle in voice production. *Folia Phoniatrica* 7:57-69.

Curry, R. (1937) "The mechanism of pitch change in the voice" *Journal of Physiology* 91:254-258.

Fromkin, V. and Ohala, J. (1968) Laryngeal control and a model of speech production. Preprints of the Speech Symposium, Kyoto, 1968. Reprinted together with oral version of paper in: *Working Papers in Phonetics*, No. 10, UCLA, November 1968, pp. 98-110.

Hirano, M. and Ohala, J. (1969) Use of hooked-wire electrodes for electromyo-graphy of the intrinsic laryngeal muscles. *Journal of Speech and Hearing Research* 12:362-373.

Inoue, 0. (1931) Two methods of pitch-recording devices. (In Japanese.) *Study of Sounds* 4:57-60.

Lieberman, P., Sawashima, M., Harris, K. S., and Gay, T. (1970) The articulatory implementation of the breath-group and prominence: crico-thyroid muscular activity in intonation. *Language* 46:312-327.

Ohala, J. (1970) Aspects of the control and production of speech. *Working Papers in Phonetics*, No. 15, UCLA, April 1970.

Ohala, J., Hirano, M., and Vennard, W. (1968) An electromyographic study of laryngeal activity in speech and singing. Paper B-l-2 in:, Tokyo, 1968. Reprinted together with oral version of paper in: *Working Papers in Preprints of the 6th International Congress on Acoustics Phonetics*, No. 10, UCLA, November 1968, pp. 126-134.

Ohala, J. and Hirose, H. (1969) The function of the sternohyoid muscle in speech. Reports of the Autumn 1969 meeting of the Acoustical Society of Japan, pp. 359-360. Reprinted in: *Annual Report No. 4, institute of Logopedics and Phoniatrics,* University of Tokyo, Japan, June 1970, pp. 41-44.

Perkell, J. (1969) *Physiology of speech production*. Cambridge: M.I.T. Press.

Shimizu (1960) On the motions of the vocal cords in phonation studied by means of the high voltage radiograph movies. (In Japanese.) *The oto-rhino-laryngological Clinic* (Zibi-inko-ka Rinsyo) 53:446-461.

Vanderslice, R. (1967) Larynx versus lungs: cricothyrometer data refuting some recent claims concerning intonation and archetypality. *Working Papers in Phonetics*, No. 7, UCLA, pp. 69-79.