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B. RAISED AND LOWERED LARYNX - THE EFFECT ON VOWEL FORMANT FREQUENCIES

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Abstract

Raised and lowered larynx positions have been studied on two subjects and in a model experiment. Good qualitative agreement was found and it was concluded that the main effect stems from the shortening or lengthening of the pharyngeal cavity.

Introduction

Singing teachers generally agree that the larynx should be kept in a comfortably low position in singing, and voice troubles are often associated with a habitually raised position. Thus, the position of the larynx seems to be an important parameter in the control of the voice organ.

In this paper we shall report an investigation of how vowel formant frequencies are affected when the larynx is raised or lowered. Model experiments have been carried out in which a set of area functions corresponding to the Russian vowel system has been perturbed. These results are compared with formant frequencies observed in two subjects phonating with a high and a low position of the larynx.

Model experiments

Recently, one of the authors studied the effects of sex-related vocal-tract length variations on vowel formant frequencies (Nordström, forthcoming). The computer program used in that study calculates the formant frequencies up to around 4000 Hz from a given area function (based on the program described in Liljencrants and Fant, 1975). The program also facilitates for the user to implement perturbations of almost any conceivable type. Hence, the acoustic effect on the vocal-tract resonator of a raised/lowered larynx can easily be studied by means of this computer program, provided that we know what perturbation a shift in larynx height causes.

Obviously, a raised/lowered larynx will shorten/lengthen the pharynx. Moreover, assuming a pharynx wall volume, we can postulate a narrowing/expansion of the lower part of the pharynx when the larynx is pulled upwards/pressed downwards.

The area functions used in the Nordström study (based on Fant, 1960) were perturbed in four different ways*. Fig. III-B-1a shows a simplified area function with a point of division between mouth and pharynx in the velar region. This point was chosen where there is a discernible dip in all the area functions. The extension seen to the left corresponds to the laryngeal tube, i.e. the sections immediately above the glottis, a portion of the vocal tract which is the same for all the vowels.

One type of perturbation (illustrated in Fig. III-B-1b and III-B-1c) was to shorten/lengthen the original area functions by 1.5 cm in the pharyngeal cavity. The length changes were uniformly distributed over the entire "pharynx" of the area function, i.e. from the point of division to the glottis.

The shortened/lengthened area functions were then perturbed so as to simulate the "constant volume" criterion postulated above. The cross-sectional areas in the two lowest centimeters of the pharynx, just above the larynx tube, were reduced/expanded by the square of the length perturbation ratio (illustrated in Fig. III-B-1d and III-B-1e).

The resulting formant frequencies can be studied in Fig. III-B-2a. The effect of the length change alone on the frequency of the first formant is very small in [i] and [u], but it rises with increasing first formant frequency. Thus, while the first formant of [i] changes from 227 Hz to 246 Hz (high larynx) and 211 Hz (low), we find the corresponding values to be 640 Hz, 705 Hz, and 580 Hz in [ɑ]. Inversely, the effect on the second formant is largest in [i] and smallest in [ɑ] among the vowels examined. These data agree well with estimates that can be made from Fant's measurements (cf. Fant, 1960, p. 170) involving a 0.5 cm shortening of the pharynx cavity. Combined length and area change generally adds little to the results of the length shifts. Narrowing/expansion of the cross-sectional areas in the lower pharynx raises/lowers the first and second formant frequencies slightly in all the vowels.

As regards the third and fourth formants (see Fig. III-B-2b), most vowels are affected in a similar way by the length change. The shifts are of similar magnitudes. In [o] and [i], however, the fourth formant

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* The Russian vowel [ɨ] is not included here because it has no direct equivalent in the Swedish vowel system.

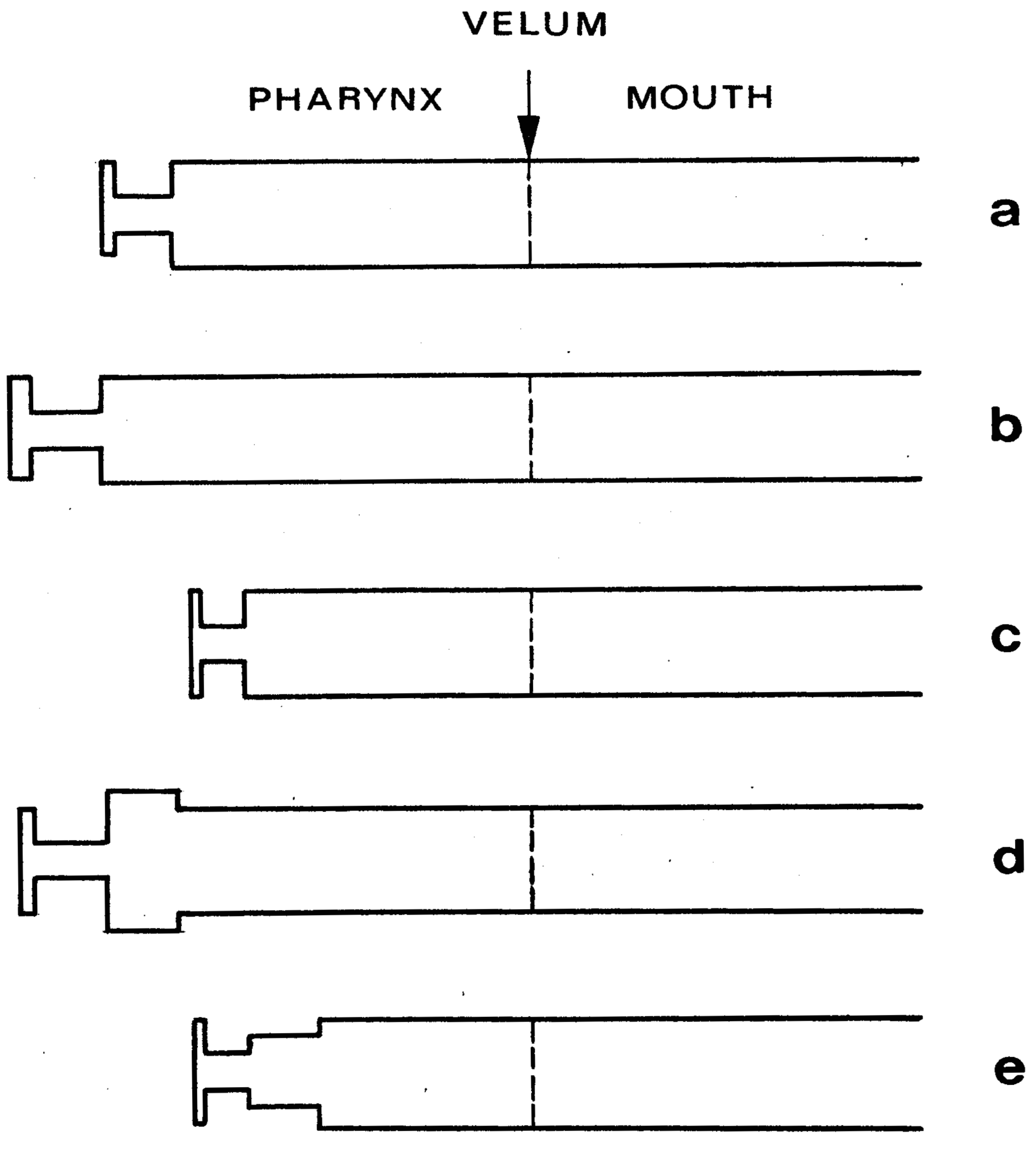


Fig. III-B-1. Schematized vocal-tract area functions used in the model experiments;
a: unperturbed configuration,
b and c: perturbations of the pharynx cavity length,
d and e: perturbations of the pharynx cavity length and the cross-sectional areas above the larynx tube (constant wall volume criterion). See text.

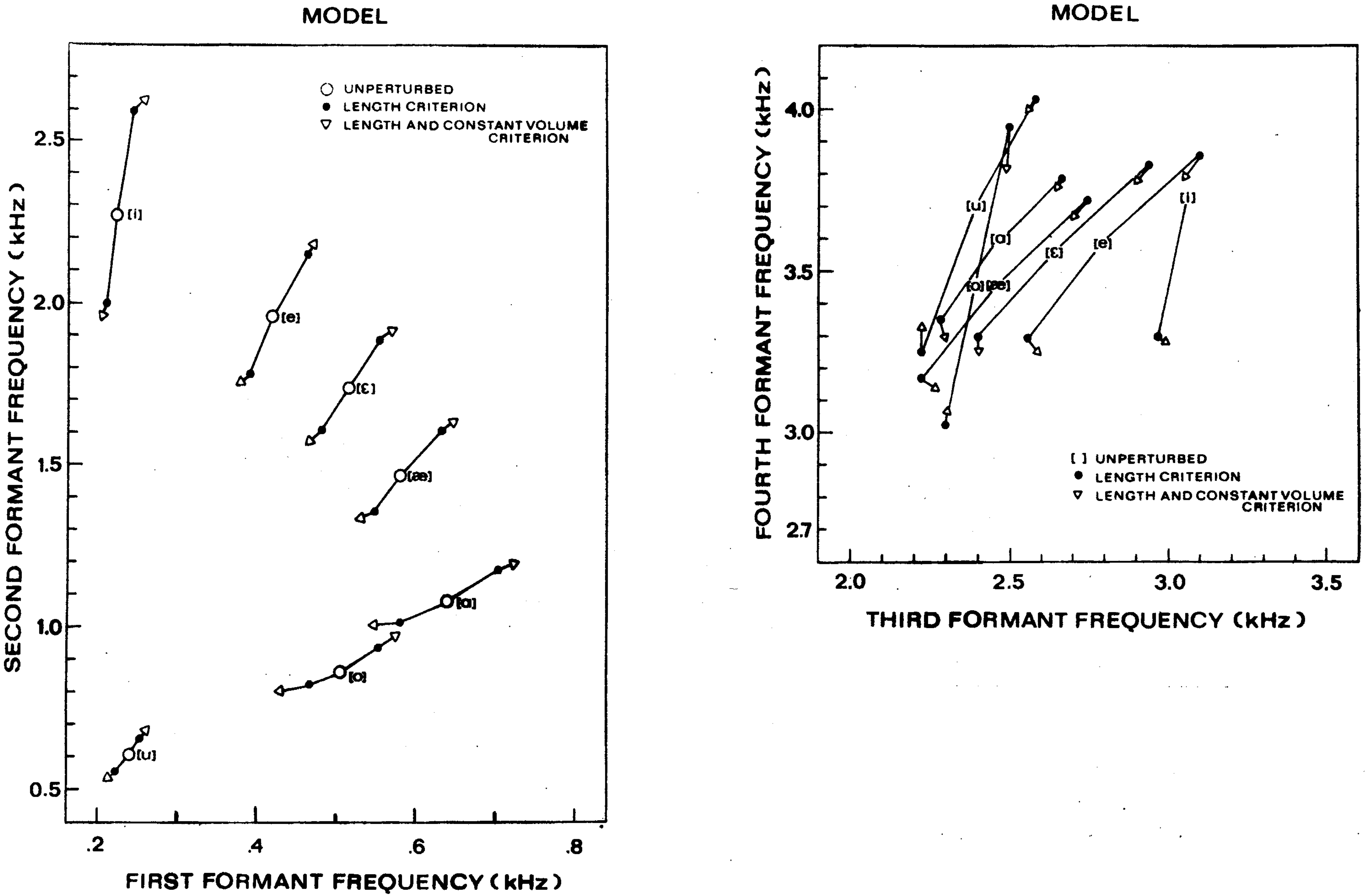


Fig. III-B-2. Formant frequency values from the model experiments. The fourth formant frequencies of [i] with "raised larynx" exceed the calculating range of the computer program.

changes more than the third. The effect of a decrease/increase in cross-sectional area in the lower pharynx differs between vowels, but it is small in all cases. The reason for the drop in the fourth formant frequency, observable when this formant is close to 4000 Hz, would be that the narrowing is located at a point in the area function where the standing wave of this formant has a pressure node ($f=4000$ Hz $\Rightarrow \lambda/4 \approx 2$ cm $\approx$ larynx tube length).

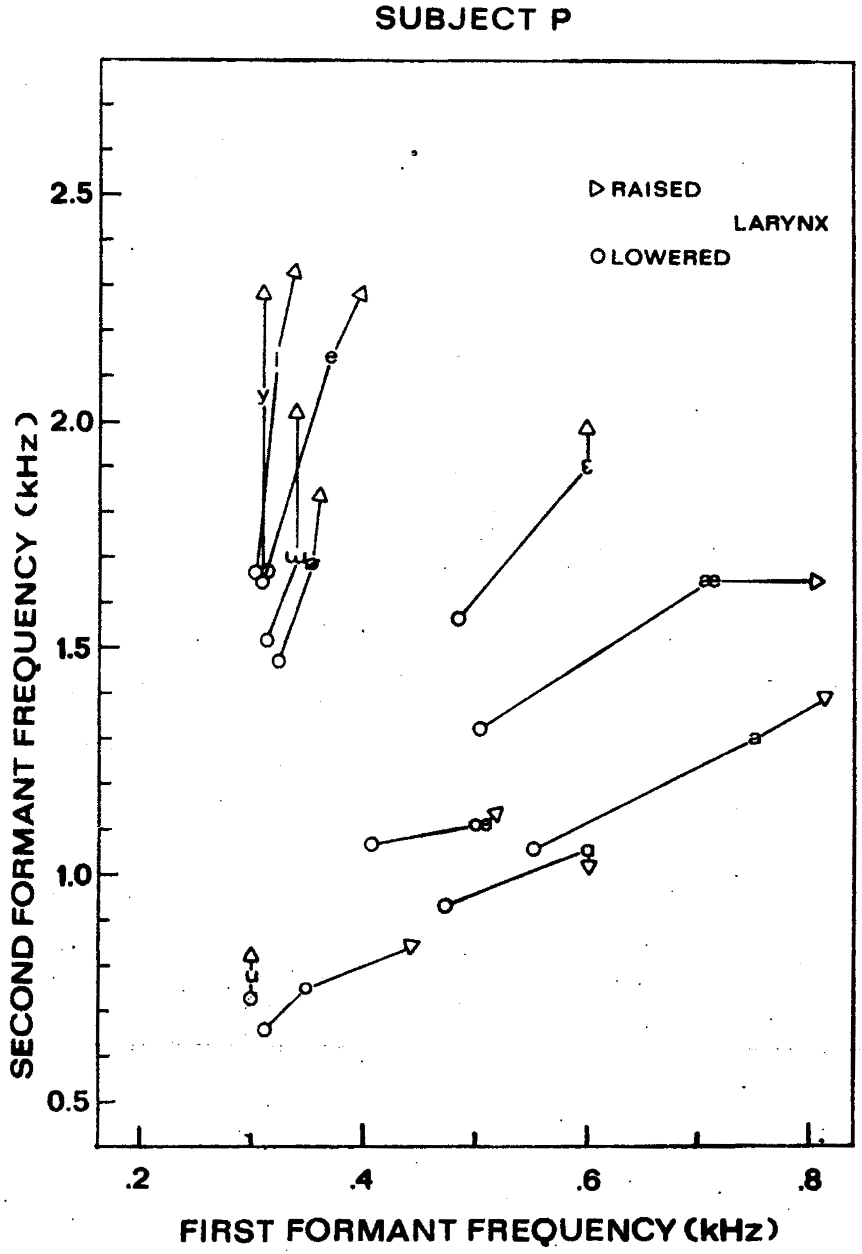
Subjects

Two subjects, one phoniatrician (P) and one singer (S), participated in the experiment. Both have developed a fair control over the positioning of their larynges. Using normal speaking voice pitch, they sustained twelve Swedish vowels (including three allophones) twice, first with raised and then with lowered larynges. They kept a finger on the thyroid cartilage in order to check the larynx position. Informal estimations showed that, on the average, the subjects managed to displace the larynx about 1.5 cm up or down from the normal position. The vowels were recorded in an anechoic room. In addition to the vowels, the singer sang a song under the same experimental conditions.

The formant frequencies of the isolated vowels were estimated from spectrograms. The results are listed in Table III-B-I and plotted in Figs. III-B-3a-b. The major trend common to both subjects is that the first formant frequency of close front vowels is almost unaffected, whereas the second formant rises considerably when the larynx is raised. Vowels with lower second formant frequency exhibit substantial increases in both the first and the second formants. In this respect, then, there is good qualitative agreement between the model and the data from the subjects. As regards the third and fourth formants, the subjects differ from each other even qualitatively (cf. Table III-B-I). In subject P a change from normal to low larynx positions is associated with a drop in the third and fourth formant frequencies. On the other hand, in several vowels, a rise does not occur when the larynx is raised from a normal to a high position. In normal larynx position in subject S the third formant frequency is astonishingly low as compared with the cases of both raised and lowered larynx. It is well known that the frequency of the third formant is particularly sensitive to the frontmost part of the mouth cavity (Fant and Pauli, 1974). If we assume that subject S retracts his

Vowel (IPA-symbols)	Larynx position	SUBJECT P F_1 (Hz)	F_2 (Hz)	F_3 (Hz)	F_4 (Hz)	SUBJECT S F_1 (Hz)	F_2 (Hz)	F_3 (Hz)	F_4 (Hz)
u	H	300	830	2700	3250	360	750	2870	3660
	N	300	780	2650	3350	340	760	2100	3250
	L	300	740	2450	2900	350	700	2550	3100
o	H	450	850	2750	3350	400	700	2750	3060
	N	350	750	2650	3450	410	700	2200	3260
	L	310	650	2360	2950	340	700	2500	3050
ɑ	H	600	1020	2500	3300	650	1040	2650	3360
	N	600	1060	2550	3300	570	970	2210	3250
	L	470	930	2450	2900	490	940	2400	2950
a	H	820	1400	2200	3260	810	1250	2610	3570
	N	750	1300	2500	3370	660	1130	2460	3350
	L	550	1050	2500	2960	540	1000	2500	2910
æ	H	810	1650	2500	3500	760	1800	2550	3650
	N	710	1650	2500	3340	670	1550	2310	3640
	L	500	1320	2300	2940	520	1150	2400	2950
ɛ	H	600	2000	2500	3720	530	2030	2700	3570
	N	600	1900	2650	3600	500	1760	2370	3500
	L	480	1560	2130	2850	450	1300	2430	3000
e	H	400	2300	2950	3770	400	2100	2970	3660
	N	370	2140	2680	3670	330	1960	2550	3450
	L	310	1650	2470	3000	300	1520	2450	3000
i	H	340	2350	2970	3830	350	2200	3280	3800
	N	320	2130	3000	3750	300	2000	3100	3600
	L	300	1650	2670	3150	230	1560	2660	2960
y	H	310	2300	3000	3500	340	2120	2750	3320
	N	310	2050	2650	3000	300	1900	2590	3250
	L	310	1640	2480	2880	270	1540	2510	2850
ɯ	H	340	2040	2550	3040	340	2030	2550	3400
	N	340	1700	2350	2960	310	1700	2270	3300
	L	310	1500	2150	2760	270	1440	2300	2930
ø	H	360	1860	2400	3170	390	2020	2530	3330
	N	350	1680	2350	2940	350	1700	2300	3350
	L	320	1470	2250	2810	350	1550	2240	3000
œ	H	520	1130	2650	3270	530	1160	2620	3250
	N	510	1120	2500	2970	400	1020	2320	3340
	L	400	1070	2330	2870	370	970	2400	2950

TABLE III-B-I. Formant frequencies of the subjects observed in high (H), normal (N), and low (L) larynx position.



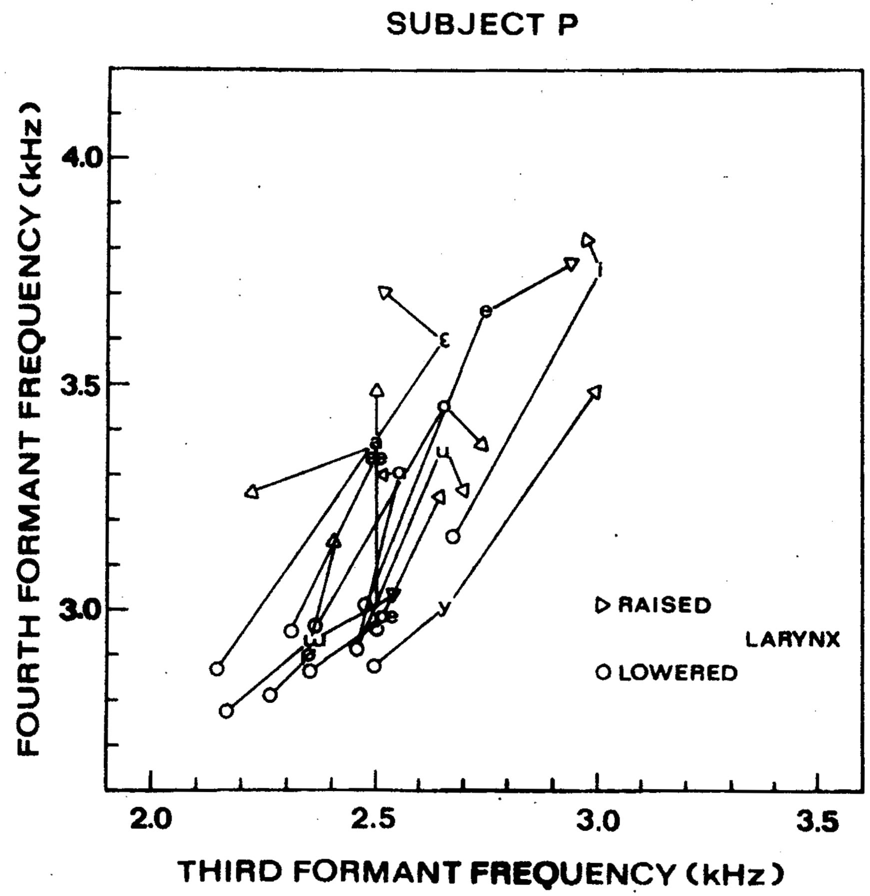


Fig. III-B-3a. Formant frequency values for raised and depressed larynx observed in subject P. The vowel IPA symbols show the values associated with normal larynx position.

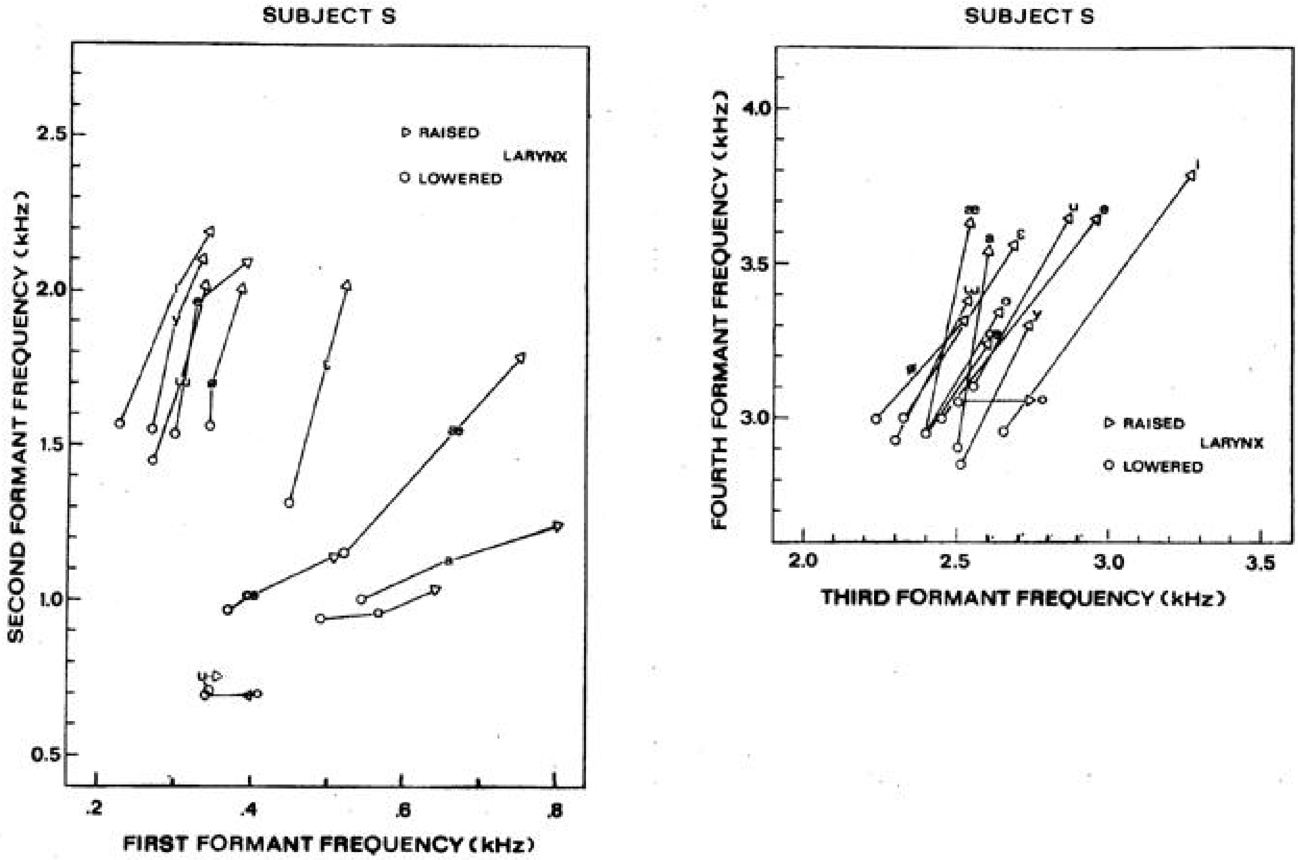


Fig. III-B-3b. Formant frequency values for raised and depressed larynx observed in subject S. The vowel IPA symbols show the values associated with normal larynx position.

tongue slightly in phonating with normal larynx position the low values of the third formant frequency can be explained. When he raises his larynx, the tongue is lifted upwards and is very likely to reduce the volume in the same part of the mouth. Hence, the third formant frequency can be expected to be high. When the larynx is lowered this subject is likely to resort to his singing habits including not only a low larynx position but also a fronted position of the tongue tip. The last mentioned gesture effectively closes the cavity behind the lower incisors and raises the third formant frequency which in turn adds to the amplitude of the "singing formant" (cf. Sundberg, 1974). Thus, it seems plausible that the normal values are not fully comparable with the values obtained when the larynx was raised and lowered in subject S. Rather, we have reasons to assume that the values pertaining to high and low position of the larynx are more comparable. Therefore, in Fig. III-B-3b the values of the normal larynx height have been omitted. The trend, common to both subjects and evident in Figs. III-B-3a and III-B-3b, is that both the third and fourth formant frequencies tend to rise as the larynx is raised.

Long-time-average-spectra (LTAS) have been found to provide information related to voice quality (see e.g. Jansson and Sundberg, 1975). Vowels phonated with raised and lowered larynx differ greatly in quality, and above we have found them to differ with respect to formant frequencies. As the peaks in a long-term-average-spectrum of the voice are dependent on the time average of the formant frequencies we would expect that these peaks differ depending on the position of the larynx. This assumption is confirmed by Fig. III-B-4, which is a long-time-average-spectrum of the singer (subject S) singing the same song twice, once with raised and once with lowered larynx. The first peak rises from 400 Hz to 650 Hz, the second peak from 900 Hz to 1500 Hz, and the third peak from 3000 Hz to approximately 3500 Hz. Thus it is possible that such types of differences between two LTAS:s stem from differences in larynx position.

It must be pointed out, however, that it is asking too much to have the subjects alter the larynx height without changing the positions of any other articulator since the major articulators (lip, tongue, jaw and larynx) are connected by tissue and muscles. Nevertheless, the patterns seen for the subjects are to a large degree reflected by the model experiments. This suggests that the main acoustic effect of a shift in the larynx height can be explained by the resulting pharynx length change.

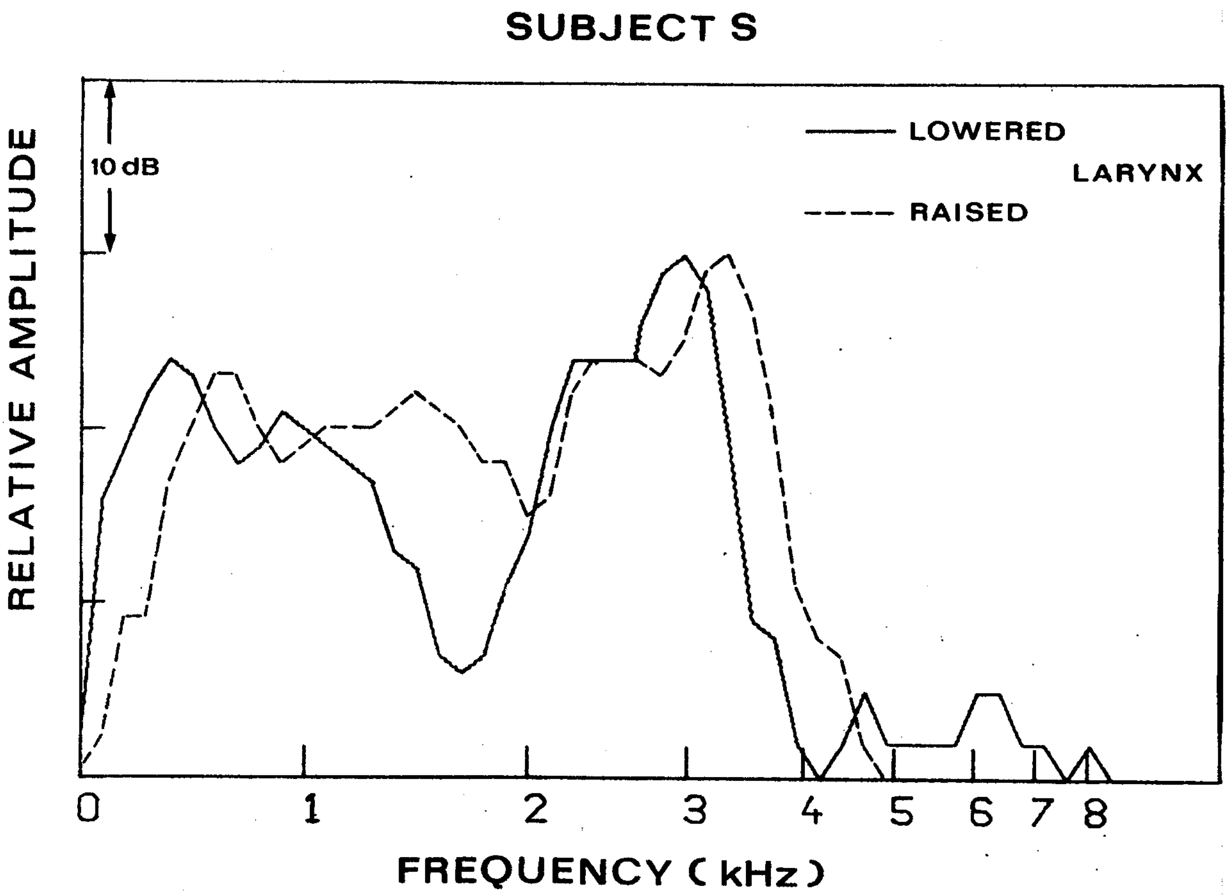


Fig. III-B-4. LTAS of a song sung by subject S with high and low larynx position.

A minor point regarding the model experiments is that the results given here are not corrected for the losses due to the impedance of the walls of the vocal tract. This factor is speaker-dependent and has not been fully examined yet. The effect is small, however (Fant, personal communication), and does not significantly influence our results.

Conclusions

Above we have found a qualitative agreement between the behavior of a vocal tract model and two subjects. This agreement suggests that the first order effect on the formant frequencies of a shift in larynx position stems from the shortening/lengthening of the pharynx cavity. The effects on the formant frequencies of a raised larynx are: 1) a substantial rise in the second formant frequency in high front vowels, 2) a rise in both the first and the second formant frequency in open vowels, 3) a combined rise in several vowels of the third and the fourth formant frequencies. These effects on the formants can be identified in long-time-average-spectra of phonations with raised and lowered larynx. The question of how the positioning of the larynx influences the glottal source characteristics is open to future investigations.

Acknowledgments

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