THE RELATIONSHIP OF VOCAL FOLD THICKNESS TO ABSOLUTE FUNDAMENTAL FREQUENCY OF PHONATION[1, 2]

HARRY HOLLIEN

There is indication that the cross-sectional dimensions of the vocal folds correlate closely with the absolute fundamental frequency of phonation irrespective of the pitch range and/or laryngeal size of a given individual.[3] Accordingly, it was the purpose of this study to investigate the hypothesis that an important determinant of absolute fundamental frequency of phonation is the mass or thickness of the vocal folds as shown by cross-sectional area or mean thickness measurements obtained from laminagraphic X-rays.

PROCEDURE

Subjects were six adults; three males and three females. They were chosen on the basis of age (19-33 years), absence of voice disorders and the ability to produce specified vocal tones easily. The range of fundamental frequencies (including falsetto) that each subject could produce was determined by standard procedure and may be seen in Table 1. In order to test the hypothesis stated above, it was felt that subjects should be reasonably disimilar from one another with respect to pitch range and voice classification. Accordingly, subjects were chosen in order that (within a sex) high, medium and low pitched voices were represented.

Equipment included a Keleket Selecto-plane laminagraphic X-ray unit with a Multicron 200 milliampere generator and a Dynamax No. 40 X-ray tube with a one millimeter focal spot. Travel distance of the X-ray gun was 20 inches and exposure time was one second in duration. In addition, current and voltage settings of 25 mas and from 70 to 75 kilovolts, respectively, were used. Target-film distance was 32 inches and subject-to-film distance varied from 13 to 16 centimeters. A special Auer film pack with high speed screens was used to allow for five coronal cuts (.5 cm apart) along the anteroposterior dimension of the vocal folds.

Subjects were required to produce six pitches within their normal[4] pitch register.

[1] A more complete version of this paper has been submitted to *Journal of Speech and Hearing Research*.

[2] This research was supported by National Institutes of Health grant B2164.

[3] Hollien, Harry, and Curtis, James, F., "A Laminagraphic Study of Vocal Pitch", *Journal of Speech and Hearing Research*, 3 (1960), 361–371.

[4] The term "normal register" as used here includes the full range of pitches that an individual can

	Men			Women		
	ALM	AMM	AHM	ALF	AMF	AHF
Lowest Pitch	C_2	D_2	F_2	C_3	E_3	F_3
Highest Pitch	C_5	F_5	F_5	E_6	C_6	A_6

Table 1. Pitch ranges of the six subjects including falsetto. Values are to the nearest simitone on the equal tempered scale.

Frequency Level	Experimental Conditions								
	Men only			All Subjects			Women only		
In cps	123	147	165	220	262	294	349	392	440
In tones	B_2	D_3	E_3	A_3	C_4	D_4	F_4	G_4	A_4

Table 2. Vocal frequency levels produced by subjects.

These pitches are listed in Table 2, both in cycles per second and in musical tones. It will be noted that since both men and women were used, only three of the vocal pitches were common to all subjects. This was because the overlap of the pitch ranges was limited between the men and women. Accordingly, while six pitches were common to all men and the same number to all women, only three were common to all subjects.

During a given experimental condition, subjects were cued to the proper pitch by means of a newly calibrated Hewlett-Packard 200-AB audio-oscillator. Vocal intensity was controlled by standard procedure. Laminagrams were made of subjects phonating the specified vocal pitches and care was taken to control vocal pitch, vocal intensity and subject position. Measurements were made on that laminagram closest to anteroposterior midpoint of the vocal folds. Two measurements were made, one of the area of vocal fold projection from the laryngeal wall reference line and the other of mean vocal fold thickness. Both of these measurements have been described in a previous report.[5]

RESULTS

Table 3 presents the measurements of vocal fold mean thickness lateral to the laryngeal wall reference line (the date for area are not included in this report). In the rows are the thickness values for each of the stated frequencies and in the columns the same values for each of the six subjects. It will be noted that measurements were made on

produce from the lowest note sustainable up to that tone which necessitates a "break" into the falsetto register in order to vocalize a higher pitch. Normal register undoubtedly includes what some authors have referred to as both head and chest registers.

[5] Hollien, Harry, and Curtis, James F., "A Laminagraphic Study of Vocal Pitch", *op. cit.*

Frequency Level		Mean Thickness in mm					
		Male Subjects			Female Subjects		
cps	tones	ALM	AMM	AHM	ALF	AMF	AHF
123	B_2	9.66	8.58	8.70	—	—	—
147	D_3	8.81	7.38	7.19	—	—	—
165	E_3	7.69	6.50	6.36	—	—	—
220	A_3	7.54	5.72	5.58	7.37	6.14	6.67
262	C_4	6.78	5.20	5.16	6.04	5.88	5.88
294	D_4	6.32	5.35	4.96	5.41	5.06	4.82
347	F_4	—	—	—	4.76	4.22	4.70
392	G_4	—	—	—	4.00	4.22	4.00
440	A_4	—	—	—	4.70	4.22	3.65

Table 3. Measurements of the mean thinkness of the vocal folds mesial to the laryngeal wall reference line.

	Correlation coefficient r	t test		
		df	t	$t_{.01}$
Area (in mm²)	−.75	34	6.61	2.58
Thickness (in mm)	−.91	34	12.79	2.58

Table 4. Correlation coefficients and *t* test of the relationship between absolute fundemental of phonation and the measures of vocal fold cross sectionall area and mean thickness.

all subjects for the three middle frequencies. From these data, it may be seen that, as expected, the mean thickness of the vocal folds decreased with increases in the fundamental frequency of phonation. Only two reversals (one each for subjects AMM and ALF) were evident throughout the entire table.

Table 4 presents the statistical computations for evaluating the trends in vocal fold thickness. It will be noted that both a correlation coefficient and a *t* test of that statistic were computed for both mean thickness and cross-sectional area (as stated the raw data for area are not included in this discussion). Examination of Table 4 will reveal that both *r*'s are negative and very large. The results of the *t* tests indicate that both are significant at the 1% level of confidence. In summary, the results of these statistical tests suggest that there is a very high negative correlation between the cross-sectional measures of the vocal folds and the absolute fundamental frequency of phonation.

Figure 1 presents the mean thickness of the vocal folds for all six subjects plotted against the absolute fundamental frequency of phonation. Rather than presenting this figure as a scattergram, each subjects' trends are reported independently. Examination of Figure 1 will reveal that, if one or two points are ignored, the remaining fall very closely into line. As a matter of fact, a single curve could be fitted to all

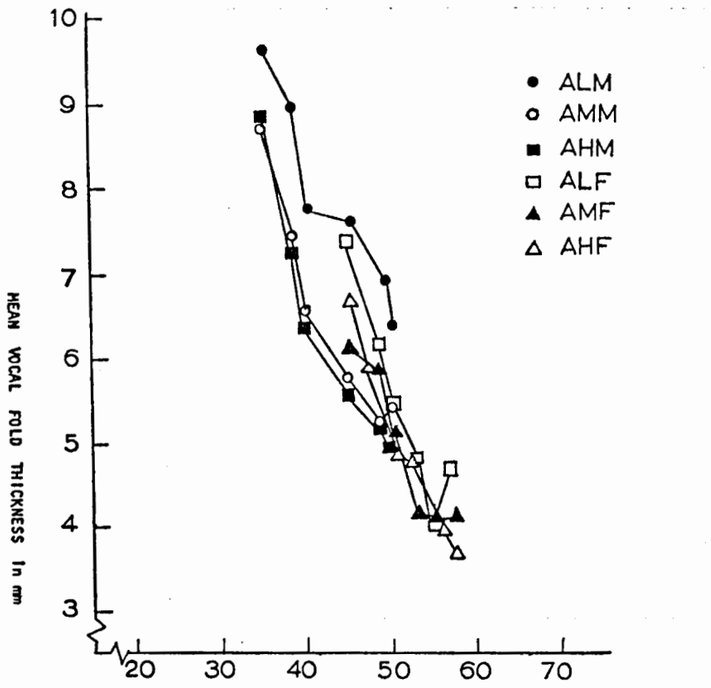

Fig. 1. Mean vocal fold thickness of the six subjects as a function of absolute frequency level.

of the points without doing any substantial violence to the data. In short, these curves show visually a relationship between vocal fold thickness and absolute frequency that transcends any difference in laryngeal anatomy among the subjects. More remarkably still, this relationship seems to predominate over any of the intersex differences in laryngeal anatomy, including differences in general laryngeal size and vocal fold length. Thus, the hypothesis that vocal fold thickness is an important determinant of vocal frequency would seem to be supported.

CONCLUSIONS

In summary, the results of this research permit the following conclusions: a) as expected the cross-sectional area and especially the mean thickness of the vocal folds were systematically reduced with increases in the fundamental frequency of

phonation, and b) the hypothesis that an important determinant of the absolute fundamental frequency of phonation is the thickness of the vocal folds, was supported. Finally, the results of this research would seem to support the aerodymanic theory of voice production.

Wichita, Kansas