RESPIRATORY AND PHONATORY MEASURES OF NORMAL ADOLESCENT MALES

By

Mary Finger Twitchell

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Audiology and Speech Sciences

1985

ABSTRACT

RESPIRATORY AND PHONATORY MEASURES
OF NORMAL ADOLESCENT MALES

By

Mary Finger Twitchell

The importance of respiratory and phonatory measures -- such as air flow rate, phonation volume, phonation time, and vital capacity -- have been shown to provide important information about the functioning of the larynx during phonation for normal and dysphonic voices. Most of these investigations have provided normative vocal function measures for adult subjects or, to a lesser extent, for young children. The present study sought to extend this research to adolescent males during voice mutation.

Subjects for the study were 10 adolescent males in each of three groups -- 11, 13, and 15 years. Eight measures of vocal function were obtained. These included direct measurements of vital capacity, phonation volume, and maximum phonation times for the sounds of [ɑ], [s], and [z] and indirect measurements of mean air flow rate, phonation volume/vital capacity ratio, vocal velocity index, and phonation quotient. Measurements were obtained using a recording respirometer and an audio tape recorder. Performances were compared among these age groupings and

with previously reported norms of adults and younger children.

While the three groups were different in terms of vital capacity and fundamental frequency, there was a lack of significant differences on all other measures among the three age groups with the exception of the phonation volume and phonation quotient performances of the 15 year olds.

The obtained measures of the adolescent males were different from those that have been reported for adults and young children. Adolescent males, especially 15 year olds and some 13 year olds displayed manifestations of a mild vocal dysfunction: high air flow rate; phonation volume/vital capacity ratio raised beyond normal limits; somewhat shortened phonation time. The vocal dysfunction displayed was indicative of a hypo-tensive mode of phonation with a reduced glottal resistance and/or a greater expiratory effort. These results were similiar to measures obtained from patients displaying incomplete glottal closure. Although a vocal function disturbance was exhibited by these male adolescents acoustical perceptual parameters were not affected. The obtained measures are felt to reflect normal laryngeal readjustments associated with a stage of pubertal voice change.

To John and Tony
who are teaching me
the joys and frustrations of adolescence

ACKNOWLEDGEMENTS

The author wishes to acknowledge and express her sincere appreciation to the many people who have helped in various ways in the completion of this study and degree:

To Dr. Leo V. Deal for having the faith and confidence in me to provide this opportunity to complete the degree and for providing the kind of encouragement and advice necessary during the development and completion of this thesis.

To Dr. Joseph McFadden, President of the University of South Dakota, for allowing me to take advantage of the opportunity to complete the degree.

To Dr. Paul Cooke and Dr. Michael Casby for contributing ideas and suggestions during the development of this study and for their helpful editoral suggestions on this manuscript.

To Dr. James Lewis, my colleague at the University of South Dakota, for giving me not only his invaluable statistical knowledge and guidance but for his time, patience, and support.

To my most cooperative and understanding adolescent male subjects for their enthusiastic participation in this study.

TABLE OF CONTENTS

Chapter		Page
	LIST OF TABLES	vi
I	INTRODUCTION	1
	Method of Assessment	8
	Maximum Phonation Time	8
	Vital Capacity	9
	Mean Flow Rate	10
	Phonation Volume	10
	Phonation Volume/Vital Capacity Ratio	11
	Vocal Velocity Index	11
	Phonation Quotient	12
	S/Z Ratio	12
	Children	13
	Statement of the Problem	18
II	REVIEW OF LITERATURE	21
	Anatomy and Physiology of the Larynx	22
	Phonational Frequency Range	26
	Developmental Changes in Mean Fundamental Frequency	31
	Other Vocal Characteristics of Pubertal Voice Change	35
	Change of Vocal Quality	40
	Correlates of Vocal Change	41
III	METHOD	49
	Subjects	49
	Instrumentation	50
	Procedure	52
	Respiratory Task	52
	Vital Capacity	52
	Phonation Tasks	53
	Maximum Phonation Duration of Sustained [ɑ]	53
	Maximum Phonation Duration of Sustained [s] and [z]	53
	Speech Sample	54
	Voice Change Scale	55
	Measurements	55

Respiration and Phonation 55
Vital Capacity 55
Phonation Volume 56
Maximum Phonation Time 56
S/Z Ratio 56
Mean Airflow Rate 56
Volume Velocity Index 56
Phonation Quotient 57
Phonation Volume/Vital Capacity Ratio . . 57
Fundamental Frequency Analysis 57

IV RESULTS 59

Respiration and phonation measures 59
Vital Capacity 60
Phonation Volume 60
Maximum Phonation Time 65
Mean Flow Rate 68
Phonation Volume/Vital Capacity Ratio . . 71
Vocal Velocity Index Index 74
Phonation Quotient 74
S/Z Ratio 79
Fundamental frequency 82
Voice Change Scale 85
Voice Change Scale Totals 86
Averaged Voice Change Scale Score 89
Individual Voice Change Scale Responses . 92
Relationship to Measures of
Vocal Function 94

V DISCUSSION AND CONCLUSIONS 98

Maximum Phonation Time 100
Mean Flow Rate 101
Phonation Volume 104
Phonation Volume/Vital Capacity Ratio 104
Vocal Velocity Index 108
Phonation Quotient 110
S/Z Ratio 112
Voice Change Scale 114
Relationship to Vocal Function
Measurements. 117
Conclusions 118
Recommendations for Further Research 122

APPENDIX A 124
APPENDIX B 126
APPENDIX C 130

LIST OF REFERENCES 139

LIST OF TABLES

Table		Page
1	Summary of Maximum Phonation Time for adult speakers with different vocal pathology.	5
2	Mean Flow Rate (in cc/sec) for various vocal pathologies.	6
3	Mean values on 7 vocal function measures for normal children as reported in selected studies	14
4	Mean and standard deviations of sustained phonation measured in seconds for children and adolescents	16
5	Mean, range, and standard deviation values of vital capacity	61
6	Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on the measures of vital capacity	62
7	Mean, range, and standard deviation values of phonation volume	63
8	Summary of Analysis of Variance to evaluate differences in mean phonation volume between 11, 13, and 15 year-old adolescent males	64
9	Mean, range, and standard deviation values of maximum phonation time	66
10	Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on the measures of Maximum Phonation Time	67
11	Means, ranges, and standard deviations of air flow rates during sustained phonation	69

12 Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on the measures of mean air flow rates 70

13 Mean, range, and standard deviation values of phonation volume/vital capacity ratio 72

14 Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on the phonation volume/ vital capacity ratio . . . 73

15 Mean, range, and standard deviation values of Vocal Velocity Index (VVI) 75

16 Summary of Analysis of Variance on the Vocal Velocity Index (MFR/VC) of 11, 13, and 15 year-old males 76

17 Mean, range, and standard deviation values of the Phonation Quotient (PQ) 77

18 Summary of Analysis of Variance on the Phonation Quotient (MPT/VC) of 11, 13, and 15 year-old males 78

19 Mean, range, and standard deviation values of [s], [z], and s/z ratios 80

20 Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on the s/z ratio 81

21 Mean, range, and standard deviation of the Fundamental Frequency (Hz) 83

22 Summary of Analysis of Variance to evaluate differences between Fundamental Frequencies of 11, 13, and 15 year-old males 84

23 Mean, range, and standard deviation values of the Voice Change Scale total scores 87

24 Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on the Voice Change Scale total scores 88

25 Mean, range, and standard deviation values of the averaged Voice Scale score 90

26 Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on averaged Voice Scale scores 91

27 Correlation of Averaged Voice Change Scale Score to Measurements of Vocal Function (11 year old adolescent males) 95

28 Correlation of Averaged Voice Change Scale Score to Measurements of Vocal Function (13 year old adolescent males) 96

29 Correlation of Averaged Voice Change Scale Score to Measurements of Vocal Function (15 year old adolescent males) 97

CHAPTER I

INTRODUCTION

Two requirements for the production of sounds are a source of energy and a vibrating element. The primary source of energy for speech production is air provided by the lungs, and the primary vibrating element is the vocal folds. The essence of efficient phonation is the coordination and balance between these laryngeal and expiratory forces. The synchrony necessary to regulate the voice quality, pitch, and loudness requires a skillful control of function in opposing musculatures.

Pathological changes in the physical condition of the larynx that give rise to changes in acoustical-perceptual parameters of voice can be reflected in changes in the manner that the vocal folds valve the respiratory air flow during phonation. The apparent simplicity of the air column, its accessibility, and its relation to the vocal apparatus have stimulated research to understand this process of voice production. One of the outcomes is the clinical application of aerodynamic and acoustic measures, frequently referred to as tests of vocal function (Yanagihara, Koike, and von Leden, 1966).

A series of investigations (Isshiki, 1965; Isshiki, Okamura, and Morimoto, 1969; Isshiki and von Leden, 1964; Koike and Hirano, 1968; Ptacek and Sander, 1963a; Yanagihara and Koike, 1967; and Yanagihara, Koike, and von Leden, 1966;) have suggested that the variables of maximum phonation time, air flow rate, and phonation volume provide important information about the functioning of the larynx during phonation. They state that measurement of these parameters helps to describe the relationship between the clinical-perceptual aspects of a voice disorder and selected physiological and acoustical correlates of the voice. Results of their investigations on normal speaking adults are summarized as follows:

1) Maximum vowel duration was a function of both voice intensity and frequency (Ptacek and Sander, 1963b).

2) Mean duration differences between vowels prolonged at soft, moderate, and loud intensities were relatively small when the phonations were at low fundamental frequencies or uncontrolled for fundamental frequency (Isshiki, 1964; Issiki, 1965; Ptacek and Sander, 1963a).

3) Vowel productions of subjects with relatively long phonations were judged to be less breathy than those with shorter phonations (Ptacek and Sander, 1963b).

4) Maximum phonation time was longer in males than females. The differences were attributed in part to the greater male vital capacity (Ptacek and Sander, 1963a; Yanagihara and Koike, 1967).

5) Maximum phonation times were directly related to the vital capacities (Isshiki, Okamura, and Morimoto, 1969).

6) Air flow was higher in males (mean = 115 cc/sec)

than females (mean = 100 cc/sec) (Yanagihara, Koike, and von Leden, 1966). Isshiki and von Leden (1964) found somewhat higher values.

7) There was an inverse relationship between flow rate and maximum phonation time (Yanagihara and Koike, 1967; Yanagihara et al., 1966).

8) The total volume of air used during phonation varied in proportion to the amount of vital capacity (Yanagihara, et al., 1966). Isshiki et al. (1969) found total volume of air to be substantially smaller than the vital capacity even for longest sustained phonation.

9) Vital capacity showed specific value in accordance with subject sex, height, and weight (Yanagihara et al., 1966).

10) The mean flow rate during phonation showed little variability among different subjects and no specific relation to the fundamental frequency and intensity of the individual voice sound (Yanagihara et al., 1966, 1967).

11) Mean flow rate during the longest phonation was a function of the glottal condition (resistance) and the expiratory force (Isshiki, 1965).

Comparable measures obtained on adults with vocal pathologies showed specific changes for the variables of air flow rate and maximum phonation time. For example, Isshiki, Okamura, and Morimoto (1969); Hirano, Koike, and von Leden (1968); Koike and Hirano (1968); and Yanagihara and von Leden (1967) reported that an increase in air flow rate and a decrease in maximum phonation time are usually associated with vocal pathologies. The changes reported in air flow and maximum phonation time for speakers with vocal pathologies are summarized from several studies and are presented in Tables 1 and 2.

The results summarized in Tables 1 and 2 support the general notion that pathological functioning of the larynx can be differentiated from normal functioning to some degree through information about air flow and maximum phonation time. Since phonation is a complex process, a single criterion obtained from indirect measurement techniques -- such as air flow rate or phonation time -- is not sufficient to describe adequately the valving function of the larynx (Isshiki et al., 1969). While these measures have been used successfully to provide quantitative information regarding laryngeal functioning for phonation, they do not differentiate between various pathological conditions. It has been suggested (Isshiki et al., 1969; Koike, Hirano, and von Leden, 1968) that the aerodynamic measures of phonation volume and rate of air flow be used in junction with measures of maximum duration of phonation for an understanding of laryngeal behavior and for clinical indices of vocal mechanism functioning.

Table 1

Summary of Maximum Phonation Time for adult speakers with different vocal pathology.

Vocal Pathology	Mean Phonation Time (sec)	Investigators
Paralytic Dysphonia	5	Arnold (1955)
	3-15	Luchsinger & Arnold (1965)
	14.0	Hirano et al. (1968)
Unilateral Paralysis	Reduced	Yanagihara and von Leden (1968)
Tumors of Larynx	Reduced	Yanagihara and von Leden (1968)
	18.9	Hirano et al. (1968)
Vocal Nodules	Reduced	Yanagihara and von Leden (1968)
	21.4	Hirano et al. (1968)
Polyp	14.8	Hirano et al. (1968)
Inflammation	Normal	Yanagihara and von Leden (1968)
	15.8	Hirano et al. (1968)
Spastic Dysphonia	17.3	Hirano et al. (1968)

Table 2

Mean Flow Rate (in cc/sec) for various vocal pathologies.

Pathology	N	Mean	Range	Investigators
Laryngeal Nerve Paralysis				
	10	442	246-915	Yanagihara and von Leden (1967)
Intermediate	?	845	680-1150	Issihiki and
Paramediate	?	346	192-621	von Leden (1968)
	13		53-621	Hirano et al. (1968)
Intermediate	19	353		Iwata et al. (1972)
Paramediate	16	249		
Bilateral	7	234		
Laryngitis				
	11	133	91-184	Yanagihara and von Leden (1967)
	?	173	53-440	Isshihiki and von Leden (1968)
	5		155-349	Hirano et al. (1968)
	68	150		Iwata et al. (1972)
Nodules/ Polyp	8	154	115-224	Yanagihara and von Leden (1967)
	18		39-379	Hirano et al. (1968)
Nodules	23	177		Iwata et al. (1972)
Polyp	18	162		

Table 2 (continued)

Pathology	N	Mean	Range	Investigators
Tumors				
Small	?	189	81-420	Isshiki and von Leden (1964)
Large	?	259	189-385	
Neoplasm	10		59-518	Hirano et al. (1968)
Papilloma	11	227		Iwata et al. (1972)
Malignant	13	170		
Contact Ulcer				
	?	144	82-204	Isshiki and von Leden (1964)
	5		40-152	Hirano et al. (1968)
	5	69		Iwata et al. (1972)

Methods of Assessment

The methods of assessing various parameters of vocal function are briefly defined and discussed in the following sections.

Maximum Phonation Time (MPT)

Maximum phonation time is defined as the length of time (in seconds) that a vowel can be phonated on one exhalation at a given pitch and loudness level. A speaker is instructed to take as deep a breath as possible then to phonate a vowel for as long as possible on one exhalation. Maximum phonation time for adults is reported to vary between 25-35 seconds for males and 15-25 seconds for females for vowels phonated at levels within the normal speaking frequency and intensity range (Hirano et al. 1968; Luchsinger and Arnold, 1965; Van Riper, 1954). Ptacek and Sander (1963a) found these values varied as a function of vocal pitch, loudness, and sex. The majority of studies of maximum phonation time have not studied different conditions of pitch and loudness but have attempted to control for these variables by asking subjects to phonate at a normal or comfortable pitch and loudness. This simple test, performed at normal pitch and loudness, provides information about the functional state of the entire respiratory system, including the degree of glottal closure during phonation (Aronson, 1980). The assumption made is that a reduced maximum phonation time indicates poor glottal valving with resultant

air wastage. A significant reduction below normal levels can be related to inadequate voice production. Isshiki et al. (1969) cited Sawashima's study (1966) published in the Japanese Journal of Logepedics and Phoniatrics showing that phonation lengths below 15 sec in adult males and below 10 sec in adult females should be regarded as pathological. Gould (1975) stated that maximum phonation time gives an indication of the overall status of laryngeal functioning, of tension in the larynx, and of any neuromuscular disability. A short phonation time with a large air flow suggests a neuromuscular deficit such as laryngeal nerve paralysis. Gould added that a sharply fluctuating air flow may suggest an unstable voice-producing mechanism.

Vital Capacity (VC)

Maximum inspiration followed by the expiration of all the air within the lungs that is possible voluntarily is called the vital capacity (Zemlin, 1981). This measurement provides information regarding the functional state of the respiratory system. Vital capacity is a function of body size and correlates most highly with body height. During childhood, vital capacity values are similar for boys and girls of similar age, height, and weight (Cook, Helliesen and Agathon, 1958). The vital capacity is about 4,800 cc for adults males and about 3,500 cc for adult females (Koike and Hirano, 1968; Koike and von Leden, 1968).

Mean Flow Rate (MFR)

The velocity of air flow through the glottis is directly related to the subglottal pressure and glottal resistance (Isshiki and von Leden, 1964). Based on this assumption, several investigators have selected the rate of air flow -- the average rate of air that is coming out of the mouth -- as a critical measurement of vocal function. Isshiki and von Leden (1964) state that measurements of air flow rate provide information regarding how efficiently the available air is used. For example, an increase in glottal resistance accounts for the lower flow rates frequently reported in cases of hoarse voice-quality. A decrease in glottal resistance, such as when the vocal folds cannot approximate completely, results in higher flow rates so long as the pressure remains constant. Iwata, von Leden, and Williams (1972) stated that higher mean air flow rates reflect a laryngeal hypotensive status as in unilateral laryngeal paralysis; lower mean air flow rates are suggestive of hypertensive conditions found in constricted strident voices.

Phonation Volume (PV)

Phonation volume is defined as the total amount of air consumed for maximum sustained phonation at given levels of pitch and loudness. Phonation volume has been found to vary between 2500 cc and 4500 cc for males and between 1000 cc and 3000 cc for females (Yanagihara and Koike, 1967). Yanagihara and Koike (1967) reported a significantly positive correlation between phonation volume and vital capacity. They also found that the maximum duration of phonation varied systematically with the phonation volume as well as with the flow rate.

Phonation Volume/Vital Capacity Ratio

The ratio of phonation volume to vital capacity in normal speakers falls in a narrow range (Yanagihara and von Leden, 1967). The range reported by Yanagihara and Koike (1967) and Yanahihara and von Leden (1967) was from 50 to 80 per cent for male speakers and 45 to 75 per cent for female speakers. Yanagihara and von Leden (1967) have suggested that the phonation volume/vital capacity ratio may be useful in the evaluation of air consumption and that any phonation volume/vital capacity ratio falling outside the suggested range may be considered abnormal.

Vocal Velocity Index (VVI)

The vocal velocity index is the ratio of mean flow rate to vital capacity. Koike and Hirano (1968) suggested using this index of air consumption in clinical diagnosis because it does not differ according to sex. Based on the reported data, the critical region of the VVI in normal speaking adults is 14.3 to 44.0 sec^{-1} (expressed in pro-mille which is 1000 times the true value of the number). The authors concluded that the small range exhibited by normal speakers compared to the large range exhibited by speakers with a vocal pathology was suggestive of a possible application of the index for use in the evaluation of laryngeal vocal function and dysfunction.

Phonation Quotient (PQ)

Phonation quotient is defined as the ratio of vital capacity to maximum phonation time (Hirano et al., 1968). This measure is an indicator of air consumption similar to the mean air flow rate. It is considered to be useful if direct measurements of air flow during phonation are not feasible. Values of 145 cc/sec for males and 137 cc/sec for females are considered normal (Hirano et al., 1968). While the phonation quotient has been shown to provide valuable clinical information on laryngeal dysfunction, it is considered to be a less sensitive indicator than the mean air flow (Iwata and von Leden, 1970b).

S/Z Ratio

Boone (1971) suggested that the clinical evaluation of vocal fold function should measure not only maximum phonation time but be contrasted with a sustained expiration without phonation. The subject is asked to sustain an [s] as long as possible, and then asked to prolong a [z]. The [s] is a measure of expiratory control, whereas [z] is a measure of sustained phonation. The [s] value is divided by the [z] measure, producing the s/z ratio. Typical s/z ratios of normal speaking subjects approximate 1.0 indicating that voiceless expiration time closely matches maximum phonation time. Eckel and Boone (1981) looked at the use of the s/z ratio as an indicator of laryngeal pathology. Subjects with laryngeal pathology had lower duration times for [z] (s/z ratios in excess of 1.4) than normal speaking subjects and dysphonic subjects without laryngeal pathology. The authors concluded that the s/z ratio measure is an excellent indicator of poor laryngeal function as a result of glottal margin lesions. They also suggested the usefulness of the s/z ratio as one indicator of voice treatment effectiveness.

Children

An estimated 6 to 9 percent of school age children are found to have voice problems, especially hoarse voices (Baynes, 1966; James and Cooper, 1966; Pont, 1965; Senturia and Wilson, 1968; Silverman and Zimmer, 1975; Warr-Leeper, McShea, and Leeper, 1979; Wilson, 1971; and Yairi, Horton Currin and Bulian, 1974). Even though the potential usefulness of vocal function measures for the voice clinician has been demonstrated, little attention has been devoted to aerodynamic measures during phonation in children. The child's larynx is not a miniature model of the adult larynx; it differs in shape, relative size, and position (Zemlin, 1980).

Information that is available was obtained for either small numbers of children with large differences in age or for children aged 7 to 9 years. The mean values for vocal function measures of the available studies are presented in Table 3. Maximum phonation time was either the most

Table 3

Mean values on 7 vocal function measures
for normal children as reported in selected studies.

Authors	N	Age	VC (cc)	PV (cc)	MPT (sec)	MFR (cc/sec)	VVI (sec^{-1})
Olson et al. (1975)	28	5-10			13	105	
Leeper (1971)	10	7-14			13.6	95	53.7
Beckett et al. (1971)	M 10	7	1548	1310	14.2	95.9	
	F 10	7	1345	1069	15.4	71.6	
Bless (1971)	M 10	9	2500	2400	16	132	52
	F 10	9	2100	1800	19	97	55
Platt et al. (1975)	52	5-10	1744	1398	13.4	113.6	

frequent measure or the only measure assessed. Table 4 presents MPT for subjects aged 9 to 17 years old.

Olsen, Perez, Burk, and Platt (1969) investigated maximum phonation time and air flow rate in children. They reported a mean phonation time of 12.8 seconds and a mean air flow rate of 105 ml per second for 28 normal speaking children who varied in age from 5 to 10 years old (mean = seven years six months). Their measures are similiar to those found by Leeper (1971) in children ranging in age from 7 to 14 years (MPT 13.6 sec; MFR 95 cc/sec). Launer (1971) and Finnegan (1985) separated MPT data according to the age and sex of their subjects aged 9 through 17 years. Phonation time increased with age, and boys had longer sustained phonation times than girls did. Bless (1971) obtained 8 measures of vocal function of 20 children (10 boys and 10 girls) aged 8 and 9 years. Her measures of maximum phonation time (girls 19 sec and boys 16 sec) and mean air flow (girls 97 cc/sec; boys 132 cc/sec) were substantially higher than any of the previous reported studies. In contrast to Launer, Bless found that females had longer phonation times. Female subjects also had lower flow rates and lower lung volumes than male subjects, but these differences were not statistically significant. Beckett, Thoelke and Cowan (1971) also reported a smaller phonation time and a greater air flow rate for their seven year old male subjects. However, the Pratt, Harris, Burk, Perez and Grizzel (1975) study of normal speaking and

Table 4

Mean and standard deviations of sustained phonations measured in seconds for children and adolescents.

Age	Launer (1971)*			Finnegan (1985)**		
	N	Mean	SD	N	Mean	SD
9	M 5	11.4	5.9	M 10	16.83	6.07
	F 8	8.8	3.6	F 10	14.47	3.78
10	M 7	10.4	4.2	M 10	22.20	4.74
	F 7	9.4	2.8	F 10	15.88	5.99
11	M 8	12.8	7.2	M 10	19.85	3.79
	F 8	11.5	2.7	F 10	14.76	2.06
12	M 13	12.2	5.3	M 9	20.23	5.72
	F 9	12.2	3.7	F 10	15.16	3.87
13	M 15	12.3	4.4	M 10	22.34	8.19
	F 11	11.0	3.5	F 10	19.24	4.58
14	M 11	17.6	7.2	M 10	22.34	6.89
	F 12	13.3	6.2	F 10	18.85	5.15
15	M 10	18.9	6.0	M 10	20.74	5.32
	F 20	12.4	5.2	F 10	19.53	4.66
16	M 6	17.8	4.5	M 10	21.04	4.40
	F 10	12.9	2.9	F 10	21.85	4.47
17	M 9	16.9	8.0	M 10	28.70	7.08
	F 10	13.5	2.9	F 10	21.99	6.30

* Averaged phonation time for [a], [i], and [u]
** Mean of three longest sustained phonations

dysphonic 7 year olds did not substantiate these findings. In addition, the 7 year olds in their study yielded slightly shorter mean MPT measures than did the Beckett et al. subjects. Pratt et al. concluded that normal children in the 7 year old range should be able to sustain voicing for 12-15 sec with a mean air flow rate of 100-120 cc/sec.

In addition to normal speaking children, 31 children with vocal nodules were included in the Pratt et al. study. Differences were found between the vocal nodule subjects and the normal speaking subjects in terms of MPT and MFR. Children with vocal nodules had a greater MFR (more than half again as large) and a shorter MPT (2/3 of MPT for the normals) than the normal speaking children. Olson et al. (1969), in addition to their normal speaking children, included the mean flow rates for six children with voice problems. They recorded the mean air flow rate and maximum phonation time for these dysphonic children prior to, during, and following a voice therapy program. Prior to the initiation of voice therapy their mean flow rate was 192 cc per sec and their average maximum phonation time was 10.1 sec. A decrease in air flow rate and an increase in phonation time were observed to correspond to therapeutic progress. The investigators concluded that measurements of the mean rate of flow would aid the voice clinician in assessing a child's progress. These findings are consistent with previous research with adults having laryngeal pathologies.

The differences in findings, especially with maximum phonation time, in these measures of vocal function cannot be readily explained. Methodological differences such as different instrumentation, number of subjects used, number of trial performances on the tasks, reinforcements used to increase task performance, etc. may account for some of the differences. Another explanation might be related to the variability of children's speech motor control. Kent (1976) indicated that the maturation of motor skills in speech is not complete until the child enters puberty.

In a normative study of [s] and [z] duration, children ages five, seven, and nine were found to produce s/z ratios close to 1.0 with the duration of [z] being slightly longer than [s] (Tait, Michel, and Carpenter, 1980). The s/z ratio, however, has not been found to be a sensitive measure of vocal nodules in children (Rastatter and Hyman, 1982).

Statement of the Problem

Missing from the literature are sufficient and adequate studies of aerodynamic parameters of adolescent children. This is surprising since it is during the period of adolescence that boys and girls undergo voice change. While the mutational change may go unnoticed in females, boys may experience what has been called a "stormy" mutation which includes pitch fluctuations, pitch breaks, and a husky-hoarse quality as well as an octave drop in fundamental frequency (Aronson, 1980; Boone, 1983; Case, 1984; Curry, 1949; Greene, 1980; Weiss, 1950). In fact, it has been suggested that many of the voice disorders in adults have their origin in the period of adolescence and are outgrowths of the voice problems of this period (Brodnitz, 1962; Brodnitz, 1971; Cooper, 1973; Ellis, 1959; Harrington, 1950; Kallen, 1959; Moses, 1940; White, 1946). Normative vocal function measures of the adolescent male population would not only provide a frame of reference for assessing pathological phonation in adolescent male children but may also provide some additional information relative to pubertal voice change in males.

It was the intent of the present study to investigate maximum phonation time, phonation volume, vital capacity, air flow rate, and s/z ratio during phonation of adolescent boys. Specifically, the following questions were asked:

1. How do male adolescents aged 11, 13, and 15 years perform on tests of vocal function?

2. Are there differences in performances on tests of vocal function between these male adolescent groups?

3. How do the performances on vocal function of adolescent males compare with previously reported norms of adults and younger children?

4. Are the indices of phonation volume/vital capacity, vocal velocity index, and phonation quotient less variable measures of vocal function than the direct measures of maximum phonation time, mean air flow, and phonation volume?

5. What is the relationship between measures of vocal function and the adolescent's self-rating of voice change characteristics?

CHAPTER II

REVIEW OF LITERATURE

Aristotle (1910), in his writings, De Animabilus Historiae, suggested that "... when the male reaches the age of twice seven years ... the voice begins to alter, getting harsher and more uneven, neither shrill as formerly, nor deeper as afterward, nor yet of any even tone, but like an instrument whose strings are frayed and out of tune" (Book VII, 581 a.). This phenomenon of voice change or mutation has long been the subject of speculation among psychologists, physicians, voice teachers, and speech-language pathologists. Yet it is surprising to find so little systematic research on the subject. Instead, writers have often been satisfied with casual observations and with repeating what someone else has written. Much of the existing information regarding the changing voice is based on general or clinical observations or on personal and sometimes subjective theories regarding what happens as the process of voice change or mutation affects the speaking and/or singing ability. Many of these observations and opinions, such as length of time to compete vocal change and length of vocal folds at various ages, are repeatedly quoted and apparently are accepted as factual. For many of these facts it is impossible to trace the source or the methodology, if any, used to establish them. It has only

been since the turn of the century that professionals of medicine, education, music, and speech-language pathology have attempted to understand the phenomenon of vocal change in adolescent males through scientific investigations. A substantial amount of information on fundamental frequency and pitch variability of the adolescent voice is available (Curry, 1946; Hollien and Malcik, 1962, 1967; Kent, 1976; Tosi, Postan, and Bianculli, 1974), but there is little in the form of acoustical and aerodynamic studies relating to vocal function. In addition, only fragmentary data exist on the associated anatomical changes in the larynx during this period.

Anatomy and Physiology of the Developing Larynx

The infant's larynx differs from its adult counterpart not only in size but in consistency of tissues, positon in the neck, and shape (Wilson, 1953). The cartilages of the larynx are not only smaller in infants; but post-mortem examinations conducted by Wilson of 50 larynges of full-term infants also found all of the laryngeal tissues, including the cartilaginous framework, the musculature, and the mucous and submucous tissues to be softer than in the adult. The cartilages not only were softer but also more pliable, and the submucous tissues were looser and less fibrous (Wilson, 1953; Zemlin, 1981). The soft cartilages of the neonatal larynx and lax supporting tissues predispose the infant's larynx to collapse if negative air pressures become execssive (Aronson, 1980).

As a consequence of vertical growth of the pharynx and cervical vertebral column, the larynx becomes positioned more caudally in the neck (Noback, 1923; Roche and Barkal, 1965). In infancy the larynx is located at a level between the first and second cervical vertebrae and descends during childhood through puberty to assume its adult position. In adulthood the lower border of the cricoid cartilage coincides with the lower border of the 6th cervical vertebrae (Negus, 1949; Kahane, 1982) or the 7th cervical vertebrae (Nobach, 1923; Arnonson, 1980).

Ossification of the hyoid bone is said to begin by age 2 (Aronson, 1980). The thyroid and cricoid cartilages ossify between ages 20 and 23; and the arytenoid cartilages ossify in the late 30's. By age 65, all the laryngeal cartilages except the cuneiforms and corniculates have ossified (Aronson, 1980).

At birth, the hyoid bone and the thyroid cartilage are close together. The laryngeal skeleton then separates in a cranio-caudal direction (Aronson, 1980; Bosma, 1975; Kahane, 1982; Roche and Barkal, 1965). The configuration of the laminae of the thyroid cartilage changes from a rounded shield during fetal life to the angle of about 110 degrees in the male and 120 degrees in the female at birth (Aronson, 1980; Negus, 1949). It has been widely accepted that during puberty the angle in the male thyroid laminae narrows to 90 degrees (Aronson, 1980; Negus, 1949), whereas in the female larynx, the angle remains approximately 120 degrees. It is this acute male angle that is frequently stated to be responsible for the more noticeable "Adam's Apple." However, recent studies (Kahane, 1975; Malinowski, 1967) have shown that there is little difference between the angular relationship of the thyroid laminae in female and male larynxes. These studies show that the male larynx has an angle which is only slightly more acute than the female larynx.

The glottal opening is small in infancy with the vocal processes assuming a proportionally larger share of the glottis than in the adult larynx. During the first years of life, the opening into the larynx widens and changes to a more rounded or oval shape (Aronson, 1980; Bosma, 1975). Glottal width dimensions continue to increase with age.

The shape of the infra-glottal region of the infant's and child's larynx is also different from that of the adult (Negus, 1949; Wilson, 1953). Negus (1949) states that in the infant and the young child the infra-glottal area is funnel-shaped and the cricoid lamina is tilted posteriorly functioning as an expansion of the trachea to assist in respiration. The funnel shape becomes reduced by mid-childhood and disappears by adulthood when the shape of the infra-glottal region is tubular.

In infancy and in childhood the membraneous portion of the vocal folds is short and thickened causing the length of the vibrating mass to be reduced (Bosma, 1975). During the first 3 years of life the larynx undergoes rapid and

significant amounts of growth. There then is a period of slow, steady growth until puberty when development is once again accelerated (Negus, 1949). There are no significant morphologic differences between male and female prepubertal larynges; however, clear sexual dimorphism is manifested in laryngeal structures at puberty (Kahane, 1982).

Vocal fold length measurements reported by Negus in 1949 are well accepted (Aronson, 1980; Greene, 1972; Zemlin, 1981). At birth the vocal folds are only about three millimeters in length. The rate of growth is very rapid during the first years as the folds almost double in length. Throughout childhood the rate of growth is gradual. The vocal folds are 5.5 mm long at the end of the first year, 7.5 mm at the end of the fifth year, 8.0 mm at the end of the sixth year; and at fifteen years, they are about 9.5 mm in length. Postpubertal vocal folds are from 17 to 24 mm for the male and from 12.5 to 17 mm in length for the female. During puberty the male vocal folds grow about 11 mm, thicken, and cause the lower range of the voice to drop a full octave. Vocal fold length and thickness grow independently. Data support the possibility that thickness continues to increase after length has reached adult dimensions (Kahane, 1982).

Much of the recent knowledge of pubertal larynx growth comes from Kahane's (1978, 1982) investigations of pre and post pubertal cadaveric larynges and adult larynges. During the pubertal growth period the larynx increases in cartilage size but maintains its shape. With the exception of anteroposterior dimensions of the thyroid cartilage, intracartilage proportions for the arytenoid, cricoid and thyroid cartilages retain their basic shape from prepuberty to adulthood for both sexes. Laryngeal arytenoid growth during the pubertal growth period occurs through appositional (external addition) and interstitial (internal expansion) (Kahane, 1982). One of the striking developmental changes in post natal laryngeal morphology is the growth of the anteroposterior dimension in the male. In the male from prepuberty to adulthood this dimension undergoes 3 times more growth than in the female. The mean increase from anterior to posterior is 15.04 mm for males and 4.47 mm for females. Increases in the size of the male laryngeal cartilages are accompanied by significant increases in cartilage weight. Approximately one half of the total weight increase occurs from prepuberty to puberty. Prepubertal female laryngeal dimensions are closer to adult size and weight than male counterparts, suggesting that the female larynx requires less growth per time unit to reach maturity.

Phonational Frequency Range

Phonational frequency range or the physiological range is the difference between the lowest sustainable tone in the modal register and the highest falsetto (Aronson, 1980; Hollien, 1977). Information of the frequency (pitch) ranges across all age levels are incomplete. In addition, interpretations of these studies are complicated due to mixed purposes and methodologies; some designed for musical information and others for physiological data. Since musicians differentiate between what they call the singing range which is comprised of artistically usable tones [having musical quality] and the physiological range that encompasses all the tones that can be produced with effort regardless of musical quality, interpretation of data is difficult unless it is known what system is being used.

The early investigations of the 1900s into the frequency range of the voice of the growing child were based strictly upon musical criteria (van Oordt & Drost, 1963). Additionally, some notions regarding the singing range stemmed from an analysis of church music and the music of composers such as Bach, Bizet and Wagner who made use of children's voices in church choirs. Misconceptions regarding the characteristics and capabilities of the child's voice arose, i.e. the boy's voice was equivalent to the mature woman's voice. The demands of this music far exceeded the natural range of children (van Oordt & Drost, 1963).

Conflicting opinions regarding the frequency range are reported in the literature. Gutzmann (1911) cited by van Oordt and Drost (1963) holds the view that the frequency range of the voice develops gradually from birth onward. The first cries of the newborn baby lie around 440 Hz, after which the frequency range expands gradually where it reaches an octave and a half increase just before the voice change. According to Hartlieb (1957), the complete range of at least 3 octaves is reached during the first years of life and remains so until the voice changes.

Since the place occupied by the speaking voice in the voice range had received minimal investigation, van Oordt and Drost (1963) studied both the musical and physiological vocal ranges of children. Their subjects were divided into two groups: 45 children aged birth through five years of age and 81 children six through 16 years of age. In the first group, tape recordings of crying were used to determine the lowest tone, the highest "pure" tone and the highest "impure" tone. These children had a range of 2 and one half to 3 octaves. No child in the group had a physiological frequency range of less than one octave. For the older children both singing and speaking voice ranges were explored. The children were instructed to sing from an arbitrary tone up to the highest they could reach, the highest registered musical tone and the highest registered physiological tone, and then down to the lowest, the lowest musical tone and lowest physiological tone. Twenty-three percent had a physiological voice range wider than three octaves. Thus, the physiological frequency range increased with age but only minimally. For the most part from ages six to sixteen the physiological frequency range was found to remain constant at about 2 and 1/2 octaves, whereas the musical voice expanded. For the older group the frequency range of the reading voice and the speaking voice was also determined using reading and conversational tasks. The results suggested that during development the frequency of the speaking voice and the lowest reachable musical tone do not run parallel. The child under 11 years had a speaking voice below the musical voice range. The frequency of the speaking voice was found to parallel that of the lowest reachable physiological tone by an average of 4.3 half-tone intervals.

Hollien (1977) discussed findings from his unpublished investigation and that of Doherty regarding the phonational frequency range of male adolescents. In the Hollien study 48 males nearly 10 years old were examined every two months for 6 years on numerous variables including the phonational frequency range. Although no raw data were reported, Hollien concluded, based on the combined findings of the two investigations, that subjects within any of the three subgroups -- pre-adolescent, neo-adolescent, and post-adolescent -- have a phonational frequency range at least one-half octave larger than that noted for young adults. Pre-adolescents had the narrowest range. These data are contrary to the commonly held opinion that individuals experiencing voice change exhibit reduced phonation frequency ranges. The reverse opinion probably stemmed from music observations and research of the music range of adolescent male singers. Additionally, the singing voice requires, as a rule, a year or two longer to develop than the speaking voice (Brodnitz, 1971). Most of our knowledge appears to be based more on personal opinion and observation of music teachers rather than on scientific investigations. Music teachers have proposed that the ranges of boys' changing voices varied from a few notes to as much as two octaves (Cooper, 1964). Naidr et al. (1965) observed that boys beginning vocal change first experience a loss of high notes and later a restriction of the singing range. Joseph (1966) reported that the range limits of boys between the ages of 11 and 18 years extended from one isolated tone to 42 consecutive semitones or 3.25 octaves, with the largest percentage (11.22%) exhibiting a range of one octave. While the physiological voice range may be unchanged during the mutational voice period, the singing range apparently is not only restricted but is variable depending upon the stage of vocal development. Cooper (Collins, 1982; Cooper, 1964) identified four stages of boys' voices which exist during grades 4 through 12: (1) Treble (unchanged), (2) Cambiata (first phase of change), (3) Baritone (second phase of change), and (4) Bass (changed). These stages which refer to the comfortable singing range overlap one another and encompass an octave or an octave and one-half. Contrary to the advice of many speech-language pathologists and to the prevailing practice in European countries, Cooper advocated that boys can sing completely throughout vocal mutation without any detriment to the voice as long as they sing music written in accordance with the range and limitation of the voice. In other words, the voice should not be made to fit the music; the music should be made to fit the voice.

Phonational frequency range for adult males and females was reported by Hollien, Dew, and Philips (1971). They found a mean frequency range in excess of three octaves for the 332 male and 202 female subjects (ages 18-36). The mean values for the lowest fundamental was 78 Hz for males and 139 Hz for females. The mean values for highest fundamental are 698 Hz for males and 1,108 Hz for females. Their data would also suggest that change of the phonational frequency range from puberty to adulthood is minimal.

Developmental Changes in Mean Fundamental Frequency

The first use of the larynx as a sound generator usually is at birth with the infant cry. Regardless of the sex, the frequency of the cry is essentially equal and is around 400 Hz (Lieberman, Harris, Woolff and Russell, 1971). The pitch level of the male child is known to descend over a wide interval from infancy to adulthood. The developmental course of mean fundamental frequency, based on data from several different studies, would suggest that there are substantial drops in fundamental frequency between 1 and 4 months and between 1 and 3 years, little change between 3 and 6 years, a gradual decline from age 6 through 11 or 12 years, and another sharp decline for male speakers during the pubertal voice change. Existing investigations of fundamental frequency permit a somewhat complete plot of the changes in pitch level as a function of age.

Early prepubertal fundamental frequency studies of males (Fairbanks, Wiley & Lassman, 1949) found mean pitch levels of 15 seven year olds and 15 eight year olds respectively to be 294 and 297 Hz or approximately D#4 on the musical scale. For this study fundamental frequency was calculated from a phonograph recording of an oral reading passage by means of an oscillographic device specifically designed for the study. These values are similiar to those for ten-year-olds (mean = 270 Hz) found by Curry (1940). Similiar cross-sectional studies conducted over 20 years later (Eguchi & Hirsh, 1969; Hasek, Singh & Murry, 1980; Horii, 1983; Vuorenkoski, Lenko, Tjernlund, Vuorenkoski, and Perheentupa, 1978) found somewhat lower mean fundamental frequency values for males. In a recent longitudinal study of boys and girls 8 through age 12 years, Bennett (1982; 1983) found the mean fundamental frequency of the males to be 234 Hz [8 years], 226 Hz [9 years], 224 Hz [10 years], 216 Hz [11 years], and 220 Hz [12 years]. There were no significant sexual differences in mean fundamental frequency at any of the age levels studied by Bennett. The findings of this study indicated that age-related changes in mean fundamental frequency occurred during the 4 year period. These changes were small but significant decreases across all four 12 month periods. The group mean declined about 10 Hz between 8 and 9 years and then declined another 7 Hz between 10 and 11 years. The group means did not change significantly between 9 and 10 and 11 and 12 years. Despite high variability of fundamental frequency findings for individual subjects for the growing periods reported, all of the subjects evidenced some decline in fundamental frequency. Prepubertal fundamental frequency studies suggest that there is a gradual decline in mean fundamental frequency until the onset of puberty. However, the substantial drop in fundamental frequency for males, the well-known adolescent voice change, has not occurred by age 12. A gender difference is also not apparent until at least age 13 (Bennett, 1982, 1983, Kent, 1976).

Studies of mean fundamental frequency during the period of pubertal change have been related to chronological age (usually 13 to 17 years), mental age, skeletal age, or pubic hair (PH) development. Curry (1940) conducted one of the earliest quantitative acoustic studies of the fundamental frequency of adolescent males. His 6 adolescent subjects of 14 years had a mean fundamental frequency of 233 Hz (approximately C#4 on the musical scale). Investigations 20 years later found somewhat lower values. Hollien and Malcik's (1962) study of southern Negro males replicated the Curry study. Their 14 year old males' mean fundamental frequency of 158 Hz was 3.42 tones lower than Curry's 14 year olds. Initially these results were felt to be a racial factor, i.e. southern Negro boys mature physiologically at a somewhat earlier age; however, an investigation of southern white males (Hollien, Malcik and Hollien, 1965) did not support that conclusion. The 14 year old southern white males had a mean fundamental frequency of 185 Hz. The differences between the mean fundamental frequencies for the two southern groups was not statistically significant. A parallel study of northern white males (Hollien & Malcik, 1967) found a mean fundamental frequency of 184 Hz. The difference between fundamental frequency values of these studies and that of Curry may be explained with respect to the onset of adolescent voice change. Curry's subjects had not begun the process of vocal change. These investigators and others (Greene, 1972; Kent, 1976) suggested that adolescent voice change occurs earlier in males than it did in previous decades. Adolescent voice change in males today commences before 14 years.

Hollien & Jackson (1973) carried out a normative investigation of the speaking fundamental frequency on a population of 157 males from 17.9 to 25.9 years of age. A mean reading fundamental frequency of 129.4 Hz and a mean extemporaneous speaking fundamental frequency of 123.3 Hz was found. These values fall within the range of similiar data reported for previous research. In studies of 18 year olds Curry (1940) found a mean level of 133 Hz (close to C#3); Hollien and Malcik 121.9 Hz (1962) and 115.9 Hz (1965) respectively for two groups of 18 year olds. By age 18 subjects had a mean fundamental frequency within the adult range. The male voice had dropped about one octave from its characteristic prepubescent level. Other comparable data from 20 to 30 year olds have been provided by Pronovost

(1942), who observed a fundamental frequency level of 132 Hz, and Hollien and Shipp (1972), who observed a fundamental frequency level of 119 Hz.

Other Vocal Characteristics of Pubertal Voice Change

The phenomenon of voice change in adolescent males is more than merely a lowering of fundamental frequency. It has been described as a normal loss of control and general instability of the voice which is usually evidenced by instantaneous, unpredicted, and involuntary changes of pitch (Curry, 1946; Greene, 1921; Jerome, 1937). Reported to accompany this loss of control of the voice are a hoarse-husky quality, double resonance, restricted range of pitch, and the appearance of a tremolo (Curry, 1949; Greene, 1972; Jerome, 1937; Naidr, Zboril and Seveik, 1965; Weiss, 1950). Whether these characteristics are concomitant with or actually precede the change has not been demonstrated.

The phenomenon that has received the most attention has been that of the "break of the voice" or the sudden, involuntary, and uncontrollable changes from the characteristic pitch of the individual (Pedrey, 1946). This sudden drop or rise of the voice, changing momentarily from the childish treble to that of the adult male or vice versa is said to be so conspicious that it has been considered the main characteristic of the pubertal voice change. At one time widespread belief held that the break occurs in all or at least in the majority of cases of mutation of the boys' voices. Presently most sources state that it is a minority which suffer from this symptom.

This change of opinion may have started with the investigation of Curry (1940). Voice "breaks" were counted in a wave to wave analysis of the reading performances of his three groups of males, 6 at each of the ages of 10, 14, and 18 years. Twenty measureable voice "breaks" occurred in the reading performances of the 10 year old subjects, 25 at the 14 year old level, and none among the 18 year old subjects. These voice breaks were essentially different from the common inflectional changes of speech in that they showed an abrupt upward or downward change in fundamental frequency from wave to wave. The typical location of the voice breaks was found to be between the medial pitch and a point one octave below with the extent of breaks being approximately one octave. Since the pre-adolescent group presented almost as many voice breaks as the mid-adolescent boys the question of whether the voice breaks at age 10 were advanced signs of pubertal change or just typical phenomenon in the voices of pre-adolescent males was raised. Fairbanks et al. (1949) found voice breaks in boys ages 7 and 8 similiar to Curry's older boys in number, extent, and location. These studies would suggest that the symptoms of voice breaks cannot be attributed exclusively to adolescence.

A number of writers have suggested that most adolescent boys are unduly self-conscious or embarrassed when their voice suddenly breaks into a squeaky falsetto. Pedrey

(1945) made a survey, both observational and retrospective, of the number of boys who experienced breaks and the effects of the voice breaks on the boys' behaviors. He counted only 4 voice breaks during the course of listening to 1,014 boys aged 11 to 16 years read for an average of 5 minutes. Thus, fewer breaks were observed than earlier research or tradition had suggested. However, as Pedrey stated, reading may not be an appropriate technique for observing breaks in a boy's voice since the boys themselves recalled having experienced such breaks. Although such recollections occurred at all of the age levels, there was a gradual increase in the boys reporting voice breaks: 12% in the 11 year old group to 51% in the 15 year old group. Memories of one or more breaks were reported by 5.52% of the boys whose voices had not begun to change, 34% of the boys whose voices were in the process of changing, and by 49% of the boys whose voices had completed the change. It should be mentioned that the stage of voice change assigned to each subject was based exclusively upon the perceptual judgment of the investigator. Of the boys who reported having experienced breaks, 47% remembered some feelings of embarrassment. Only 6 reported extreme embarrassment. Undue embarrassment as recalled by these subjects cannot be considered a frequent concomitant of voice breaks.

Weiss (1950) suggested that writers made the mistake of considering the most conspicuous symptom to be the most frequent. He reported questioning "scores" of boys who just pass

Dran

reca

reco

fel

a c

Wei

tha

of

th

e

v

r

c

Th

cre

and

recal

thoroug

occur

Pre

passed their mutational period and 200 students of the Dramatic Workshop in New York City regarding what they recalled about their change of voice. A majority had no recollections and only a few recalled voice breaks. Weiss felt that this was proof that real breaking of the voice was a characteristic symptom in a minority of cases only. While Weiss' interpretation may be correct, it is also possible that recollections of voice breaks diminish after completion of vocal mutation or that voice breaks may go unnoticed by the speaker. Case (1984) is of the opinion that most boys experience some embarrassment about their rapidly changing voice but that it is only a momentary concern for most. He feels that pitch breaks and other voice adjustment problems will have a significant effect only on the boys with a poor self-image or who are shy and insecure in peer relationships. Murphy (1964) discussed the individual's changing self-concept relative to the new physical changes. Thus, the psychosocial influence the voice break has may create an increased auditory awareness, self-consciousness, and anxiety about recurrence which are more apt to be recalled after voice change.

The phenomenon of voice breaks needs to be more thoroughly investigated not only in their frequency of occurrence but also in terms of when they occur and what precipitates that occurrence. Although there have been no systematic investigations, writers have reported that voice breaks are more likely to occur during anger, fear, excitement, laughter (especially if uncontrolled), sudden intensity changes, threatening speaking situations, and nervousness and tension (Case, 1984; Greene, 1972; Van Riper & Emerick, 1984; Weiss, 1950). Control of pitch during pubertal development can vary widely from day to day and within the same day with less control early in the morning than later in the day (Van Riper & Emerick, 1984). Voice breaks may occur during only a portion of the voice change period. Joseph (1967) took monthly measurements of 200 boys 11 years to 16 years over a 10 month period. One of the interesting observations of his study was the discovery of voice breaks during the charting of one month's data where they did not appear in either the previous or the following month's measures.

The cause of the breaking of the voice is attributed to the rapid growth of the laryngeal cartilages and muscles and to disturbances in the fine co-ordination of the vocal mechanism (Greene, 1972; Murphy, 1964; Weiss, 1950). A change from the child voice to tenor requires less time and demands less adjustment than the change from the child voice to bass. The deeper the voice drops presumably the greater the difficulties in muscular adaptations (Greene, 1972) and the more voice breaks (Weiss, 1950). West (1935) hypothesized that voice breaks were due mainly to an acoustical adjustment to the resonatory tube. The pubertal boy must learn to make adjustments because of the change in both his larynx and pharynx. In his attempt he tends to slide from one octave to the next similiar to the learner on the trombone. Both, according to West, can learn more quickly to control the key than to control the register. Van Riper and Emerick (1984) suggested that a possible cause of voice breaks may be the greater air pressure that suddenly becomes available because of the rapid increase in the length and circumference of the chest.

Change of Vocal Quality

The pubertal voice is not only subject to pitch breaks but may also be accompanied by chronic laryngitis or a certain huskiness or hoarseness. Such observations were described frequently by early 1900 writers (cited by Curry, 1946; Curry, 1949; Weiss, 1950) but less frequently by current writers (Aronson, 1984; Boone, 1983; Greene, 1972; Murphy, 1964). The huskiness, according to Weiss (1950), may be highly variable, even during the same day. Curry (1949) investigated the question of hoarseness that early writers alleged to precede male voice mutation. He examined 40 boys aged 10 years and 40 boys aged 14 years. Three speech correctionists, acting as judges, agreed that 55% of the ten-year-olds and 80% of the 14-year-olds were 'hoarse husky.' His data confirmed the earlier observational reports that hoarseness is more prevalent in the mutation period.

The pubertal change in vocal quality has been attributed to strain or abuse resulting from shouting or loud singing (Aronson, 1980; Greene, 1972; Weiss, 1950).

Fournier (cited by Weiss, 1950) described in 1866 an openness of the posterior part of the glottis called a "mutational triangle." This incomplete closure of the glottis was considered a functional sign of mutation and the main cause of the huskiness of the voice. Fournier referred to this form of the glottis as being very frequent; however, later writers claim that such cases are rare (Greene, 1972; Weiss, 1950).

Other writers, such as Paulsen in 1895 (cited by Weiss, 1950), have described a "redness of the vocal lips." The redness was considered to be a "physiological inflammation due to the dominance of the thyroid gland at the time of puberty." Greene (1921) suggested that a slight hyperemia is responsible for the raucity of the voice.

Whatever the cause of the hoarse-husky vocal quality during puberty, it is considered transient and not pathological.

Correlates of Vocal Change

At puberty the boy experiences a rapid change in somatic growth and skeletal development as well as secondary sexual development. These changes are the result of a series of alterations that take place as a result of endocrinological hormone secretions of the hypothalamic-pituitary-gonadal-adrenal mechanism (Wilkins, 1965).

Voice change is but one of the pubertal bodily changes. It also occupies only a portion of the pubertal development period. Vocal change is said to take 3 to 6 months on the average (Aronson, 1980; Van Riper & Emerick, 1984; Weiss, 1950). Individual variations have been reported that suggest a sudden rapid change (Greene, 1972; Van Riper & Emerick, 1984) or a gradual change lasting up to one year (Aronson, 1980). Beyond a year the mutation is considered to be pathological (Weiss, 1950). However, Pedrey (1946) suggested that, on the average, the time might extend over several years. Like much of the available data on pubertal voice change, these data also appear to be based on observation rather than controlled investigations. No longitudinal study has yet been conducted to determine the length of time it takes for a boy's voice to change.

Investigators have sought not only to understand the normal pubertal process of vocal change but also to identify any pathological deviations. Additionally, if singing or abuses are possible detriments to appropriate development of the voice, it is important to be able to readily identify when the boy has entered pubescence and thus to prevent future vocal disorders. Researchers have attempted to identify the relationships of various mutational processes to the voice change.

The relationships between pubescence, voice, and genital organs have long been evident by lay persons as well as by professionals in music and medicine. Literature makes frequent mention and observation of the unnaturalness of the voice of eunuchs. During the 18th centry castration of boys was practiced in order to hinder the natural development of the adult voice. The castrated boys were carefully trained vocally so that when they were older, they comprised the adult soprano singers in church choirs of Rome. Pedrey (1945), investigating the relationship of stages of vocal change to pubic hair development, found a correlation of 0.68. The simplistic pubic hair development criteria utilized by Pedrey has been replaced by the more sophisticated stages based upon changes in the genitalia and pubic hair development devised by Marshall and Tanner (1970). Pubic hair and other simultaneous appearing symptoms of sexual puberty such as hair in the armpit, ejaculation, growth of the penis, and hair on the upper lip are of interest because they reflect the androgenic action that also determines pubertal voice change. Marshall and Tanner (1970) found the following mean ages to be related to their descriptive standards for pubic hair development (PH): Stage I, Pre-adolescent; Stage II, mean age = 13.44 years; Stage III, mean age = 13.90; Stage IV, mean age = 14.36; and Stage V, (Adult) mean age = 15.18. In essence they suggested that boys aged 13 and 14 could be at any stage of sexual development. Two investigations have attempted to relate vocal change with these stages of pubic hair development. Vuorenkoski et al. (1978) found that parallel to pubic hair development was a gradual decrease of speaking fundamental frequency and lowest frequency. Boys found to be in PH II had a mean age of 13.7 years and a fundamental frequency of 216 Hz; PH III had a mean age of 13.9 years and a fundamental frequency of 174 Hz; PH IV had a mean age of 14.0 years and a fundamental frequency of 137 Hz. The boys who were experiencing vocal change were in the PH development stages of III and IV. Tosi, Postan, and Bianculli (1976) attempted to determine the reationship between endocrinologic changes and fundamental frequency in a group of 33 Argentine prepubertal and pubertal males aged 9-18 years. The subjects were followed longitudinally for a period of 18 months. Spectrographic recordings, pediatric examinations, and hormonal studies were made at 4.5 month intervals so that vocal and physiological changes could be related directly. The authors found that significant changes in fundamental frequency coincided with maximal rates of change in percentage of plasma testosterone and urinary 17-ketosteroids, increased growth in body height and weight, and an increased size of the genitalia. Maximal rates of change occurred for subjects evolving from Stage III to Stage IV. They concluded that the "turning point" toward adulthood for Argentine adolescents was the PH development stage III as defined by Marshall and Tanner (1970), with a mean age of 13.3 years.

Growth of the larynx cannot be viewed independently of growth of the entire body. The growth of the larynx is under hormonal influences similiar to those which govern general somatic growth. While the general relationship between somatic growth and vocal change is accepted, much of the basis of that relationship comes from observations of specific subjects rather than controlled group investigations. Few studies were found that explored that relationship. The few studies that are available rely more on descriptive analysis rather than on statistically calculated confidence limits of the relationships. These studies also fail to report sufficient information regarding methodology for obtaining growth measurements and data obtained.

One of the first investigations was conducted by Jerome (1937) who looked at the relationship between change of voice and three criteria of age: chronological age, mental age, and skeletal age. Skeletal age was determined by x-rays of the epiphyses of the knee, wrist, and hand. Twelve boys who were reported to be undergoing change of voice were evaluated. Statistical measures of range, mid-score, quartile points, quartile deviation, standard deviation, and correlation co-efficiences were used. Skeletal age was found to be more closely correlated with change of voice than the other criteria of age. Mental age was the least consistent measure. Change of voice was established as a growth phenomenon and, therefore, would be expected to vary to a large extent with either chronological age or mental age.

Other investigations have looked at indices of somatic growth which are more easily obtained. Height and weight are probably the most frequent of those measures. Naidr et al. (1965) conducted a five-year study of 100 school boys relating changes in the singing and speaking voice with anatomical changes in the size of the larynx and height and weight. Methodological and qualitative analysis descriptions were not provided. The authors found that boys 12-13 years experienced a loss of high notes corresponding with height of the larynx and increase in body weight. Between 13-14 years when the singing range became restricted, the thyroid cartilage became prominent and there was considerable increase in body weight. By 14 to 15 years when the voice had reached its full depth, maximal growth of the larynx, body weight, and height were also attained.

Taranger and Hagg (1980) investigated growth events, specifically peak height velocity (PHV) in a longitudinal study of Swedish boys aged 10-18 years. One aspect of their study looked at PHV in relation to voice change. Subjects were assessed annually using three stages of voice change: pre-pubertal, pubertal, and male voice. Assessment of the voice was described as "clinical." The authors concluded that if a boy had a prepubertal voice, it was probable that PHV had not been reached. In 14% of the boys studied, the voice change began in the first annual interval after PHV. If the voice change had begun, the boy was in his most intensive period of growth during puberty. When the voice acquired adult characteristics, the growth rate had begun to decelerate. These findings are similiar to the study of Tosi et al. (1976) where a significant drop in fundamental fre

jud
con
dev
pro
cha
des
obt
cro
loc
of
of
On
a
(p
an
15
Fo
(b
in
th
J
w
ma
c
J

frequency was related to increased body height and weight.

In an effort to provide music educators criteria for judging adolescent vocal change, Joseph (1965, 1966, 1967) conducted several investigations charting growth developments. While these studies have potential for providing fruitful data regarding growth correlates of voice change, they are limited by an analysis that is more descriptive than statistical and an absence of much of the obtained data. Joseph's first study (1966) was a cross-sectional study of 917 boys ages 11 to 18 years. He looked at data from school records and obtained measurements of height, weight, hip and shoulder breadth, biotype, number of teeth, appearance of facial growth, and a singing task. Only the following results were reported: For subjects with a Lower Terminal Pitch between Middle C and the octave below (prepubertal boys), the average height was under 65.5 inches and over 60 inches, the average shoulder breadth was under 15 inches, and the average chronological age was 13.8 years. For subjects with a Lower Terminal Pitch in the lower octave (below 130 Hz), the average height was in excess of 65 inches, the average shoulder breadth was over 15 inches, and the average chronological age was 15.4 years. In general, Joseph found that boys with the deepest low terminal pitches were taller and had broader shoulders than their peers. The more muscular boys (mesomorph body type) had a wider range of pitches than less muscular types. In a follow-up study, Joseph (1967) looked specifically at boys aged 12-15 years over the course of a school year. He took anthropometric measures of age, height, weight, hip breadth, shoulder breadth, number of teeth, and musical measures of fundamental frequency and the upper and lower limits of voice range. Data that were reported tended to substantiate the 1966 findings that the most critical time in the development of the male voice was around 12-15 years.

CHAPTER III

METHOD

The present study was conducted to investigate (1) how male adolescents aged 11, 13, and 15 years performed on tests of vocal function -- vital capacity, phonation volume, maximum phonation time, air flow rate, and s/z ratio; (2) what differences in vocal function performances, if any, existed among these adolescent age groups; and (3) how the obtained measurements compared with previously reported norms of adults and younger children. Additionally, the study sought to examine whether the indices of vocal velocity index, phonation quotient, and the ratio of phonation volume to vital capacity were less variable measures of vocal function than the direct measures of maximum phonation time, mean air flow rate, and phonation volumes. Lastly, comparisons baetween these vocal function performances and the adolescents' self-ratings of voice change characteristics were performed.

Subjects

The subjects for the present study were 30 adolescent males from the Lansing, Michigan, area. The boys ranged in age from eleven years to fifteen years. Subjects were divided into three groups of ten boys each: a) Group I - 11;3-11;9 years old [mean = 11;5 years], b) Group II - 13;6-13;9 years old [mean =13;4 years], and c) Group III -

15;3-15;9 years old [mean = 15;5 years]. These specific age groups were selected because of their possible relationship to stages of vocal change. All subjects included in the study met the following selection criteria: (1) normal voice and articulation based on perceptual judgments by two certified speech-language pathologists during an interview with the subject and/or an audiorecording of a short reading passage; (2) no anatomical structural defects such as cleft palate or a physical-based control problem as in cerebral palsy, vocal fold paralysis or other neurological disorders; (3) bilateral hearing within normal limits at all speech frequencies as determined by pure tone audiometric screening at 25 db HL; (4) no reported cold, cough, sore throat, or shortness of breath at the time of testing; (5) height within limits for their age level as assessed by developmental growth charts (Goodhart and Shils, 1980, p. 1257); and (6) plus or minus 3 months in age relative to their age group membership.

Instrumentation

For the collection of respiratory and phonatory data, a recording respirometer (Collins, Model P-900) and an audio tape recorder (Ampex, Model 601) were used. Inspection of all aspects of the instrumentation was conducted prior to the collection of any data to insure proper operation. The respirometer was fitted with a face mask that was used to trap the air flow. Fit of the face mask to the subject's face was inspected by the investigator during the data collection to assure an air-tight seal. Inspiratory and expiratory air flow was directed through the outlet of the mask to the respirometer. The movement of the cylinder of the respirometer was automatically traced on a sheet of paper wrapped around a vertically positioned drum turned by a motor which was set at 120 mm per min. The paper was calibrated to show volume on the vertical axis and time on the horizontal axis. Measures taken with the respirometer have been shown to be equivalent and reliable when compared to those reported for the pneumotachograph (Beckett, 1971; Isshiki et al., 1967). The respirometer is reported to be useful as a clinical tool in the evaluation of laryngeal pathologies (Beckett, 1971; Isshiki et al., 1967) and therapeutic and surgical effectiveness (Amerman & Williams, 1979).

A tape recorder (Ampex, Model 601) with an omnidirectional microphone (Electro-Voice, Model 635 A) served to record an oral reading speech sample and the phonation tasks produced by each subject. The mircophone of the tape recorder was placed within three inches of the subject's mouth to obtain voice recordings of the subjects.

In order to obtain fundamental frequency readings, the oral reading speech sample audio-recording was played on a tape recorder that was coupled to a Kay Elemetrics Visi-Pitch (Model 6087). With the Visi-pitch the fundamental frequency is extracted on a cycle-to-cycle basis from the input speech signal and displayed to a Tektronix scope video screen. A numeric digital display indicates the average fundamental frequency. A time display of 8 sec and a pitch band of 50-300 HZ or 135-535 Hz was used.

Procedure

The experimental tasks were carried out in the speech pathology laboratory at Michigan State University. Individual subjects were seated and instructed regarding the nature and purpose of the experiment. One practice trial of each task was provided in order to familiarize the subjects with the experimental procedures and instrumentation and to allow for stable productions of phonation during the task. The experimenter instructed the subjects prior to each task to be performed and demonstrated each phonation task, using an abbreviated duration model. Instructions to subjects are provided in Appendix A. Order of presentation of the four measures was counter-balanced across subjects. The vocal scale was administered between the first two tasks and the last two tasks. Each subject was required to complete each task three times, with a rest between each trial. The longest or greatest value obtained was defined as the value for that task. A five minute rest break was held between each of the tasks.

Respiratory Task

Vital Capacity (VC). With the face mask held tightly in place, the subject was instructed to inhale as much as he could and then to exhale all of his air. The actual trials of vital capacity were obtained following a practice trial with the greatest of the three trials being defined as the vital capacity for that subject.

Phonation tasks

Maximum Phonation Duration of Sustained [ɑ]. Each subject was masked and requested (1) to take as deep a breath as possible (inhale maximally); (2) to begin to phonate the vowel [ɑ] at the easiest, most comfortable level of pitch and loudness; and (3) to continue phonation until the sound could no longer be sustained. One practice trial was allowed to familiarize the subject with the task; then with the mask in place an actual performance was obtained. Three actual trials were obtained with the longest duration being defined as the maximum duration time.

Maximum Phonation Duration of Sustained [s] and [z]. The subject was asked to take a deep breath and to sustain [z] and then [s] as long as he possibly could at the easiest, most comfortable pitch and loudness level. Order of presentation of [s] and [z] was counter-balanced across subjects. Each subject was given three trials for each phoneme with the longest duration per phoneme taken as the subject's score. The three experimental trials for each phoneme were tape recorded at 3 3/4 ips for later measurements. Simultaneously, each trial prolongation was timed with a hand-held stop watch; timing of each task was initiated when the investigator heard the phoneme and terminated when the phoneme could no longer be heard. Values to the nearest 0.1 sec were recorded. If the investigator determined that a maximum effort for any of the phoneme duration measures had not been exerted, the trial was repeated. Criteria used by the experimenter to judge inadequate performance were shallow inspiration, premature termination of phonation (less than six seconds), and failure to maintain normal vocal pitch and loudness.

Finnegan (1984) and Tait et al. (1980) found no significant differences between measurement values obtained by the use of a stop watch and a graphic level recorder. In order to establish the reliability of the stop watch timings 25% of the [s] and [z] trials from each of the three age groups were timed by an independent judge. The timings made by the investigator and the independent judge were then compared. The percentage of agreement ranged from 93.9 to 100%, with a mean of 96% across subjects.

Speech Sample

Prior to completing the experimental tasks each subject was asked to read aloud a short passage. The first paragraph of "The Rainbow Passage" (Fairbanks, 1960) was selected for the oral reading. Unfamiliar words, if any, were explained and their pronunciations were demonstrated by the experimenter. Most subjects, however, did not have any problem with the passage. After familiarization through a practice reading, the subject was instructed to read the passage at a comfortable vocal intensity level. The voice was then recorded via the tape recorder at 3 3/4 ips.

Voice Change Scale

In addition to the respiration and phonation measures, each subject was asked to complete a vocal change scale. The scale contained 11 statements relating to observable factors reported in the literature to be associated with voice change in adolescent males. The voice change scale is found in Appendix B. Each subject was asked to rate each statement on a 5 point scale in relation to voice change characteristics he was exhibiting at the time of the study. The purpose of the voice scale was to investigate what relationship might exist between the obtained vocal function measures of the age groups and the specific variables of voice change.

Measurements

Respiration and Phonation

The measures for these dimensions included calculations obtained directly from the respirometer chart paper (vital capacity, phonation volume, and maximum phonation duration) and the phonation durations of [s] and [z]. The following additional measures were derived from the direct respirometer measures: mean air flow rate, vocal velocity index, phonation quotient, and the ratio of phonation volume to vital capacity.

Vital Capacity (VC) : Vital capacity was determined from the peak value of the first high peak to the second low trough or the sum of inspiratory reserve volume, expiratory reserve volume, and tidal volume.

Phonation Volume (PV) : Phonation volume is the total volume of air used during a maximum phonation. This value was determined from the peak value of maximum inspiration and the end of the phonation. The following formula was used:

PV = maximum inspiration volume - maximum expiratory volume

Maximum Phonation Time (MPT) : The duration of the acoustic signal was used as a measure of total phonation time. The distance from the onset to the cessation of phonation was measured in millimeters. The distance measures were converted to time in seconds. The maximum phonation time utilized was always the value that was obtained from the same trial of the largest phonation volume value.

S/Z Ratio : The maximum phonation duration value of [s] was divided by the [z] MPD measure, producing the s/z ratio.

Mean Airflow Rate (MFR) : The mean airflow rate was determined by dividing the phonation volume by the maximum phonation time. The units are in cc/sec.

MFR = phonation volume /maximum phonation time

Volume Velocity Index (VVI) : Air ratio of the mean air flow to vital capacity during sustained phonation was used to calculate the vocal velocity index using the following formula:

VVI = Vital Capacity/Mean Flow Rate

Phonation Quotient (PQ) : Phonation quotient was determined by dividing the vital capacity by the phonation time.

PQ = vital capacity/phonation time

Phonation Volume/Vital Capacity Ratio : The PV/VC ratio was calculated by forming a ratio between phonation volume and vital capacity.

Fundamental Frequency Analysis

The second sentence ["The rainbow is a division of white light into many beautiful colors."] of the reading passage was selected for fundamental frequency analysis. This sentence was chosen in order to avoid possible initial or final sentence effects and also to limit the sample to a sentence with a sufficient but manageable length of duration. Additionally, Horii (1975) has established that, for average fundamental frequency data, a mean fundamental frequency for this second-sentence would be an accurate estimate of the entire paragraph within plus or minus 3.0 Hz two-thirds of the time.

The fundamental frequency was obtained by moving the horizontal cursor of the Visi-Pitch to the approximate center of the displayed pitch curve. The numerical digital readout display of that selected point along the stored pitch curve was taken as the value of the fundamental frequency for each subject. Fundamental frequencies of all subjects were determined by an additional judge working independently. Reliabilities between the two judges were within 10 Hz for all subjects. Discrepancies were resolved based on a mutual review by the judges of the subjects' pitch curves.

CHAPTER IV

RESULTS

Respiration and phonation measures

The results of the respiration and phonation measures obtained in the present study are presented in the order of mean vital capacity, mean phonation volume, mean maximum phonation time, mean air flow rate, mean phonation volume/vital capacity, mean vocal velocity index, mean phonation quotient, and mean s/z phonation ratio. The group means of individual values, standard deviations, and ranges for each respiration and phonation condition are presented for all measures obtained. The data obtained for individual subjects for each measured variable are presented in Appendix C.

A one-way analysis of variance was used to evaluate the significance of differences in performance between the adolescent male speakers in each of the three age groups during each measured task. A subsequent multiple comparison test (Scheffé) was used to further evaluate the task differences following significant F-ratios obtained within each analysis of variance. A critical level of $p < .05$ was used for all tests of significance. All statistical analyses were performed using SPSS-X 2.1 at the University of South Dakota.

Vital Capacity (VC)

Table 5 is a summary of the measured vital capacity in terms of mean, range, and standard deviation for each of the subjects. The vital capacity for each subject was in accordance with established norms of vital capacity measures for children with specified heights.

As was anticipated given the differences in height of the adolescent male subjects, the vital capacities increased with the age and height of the subjects. To test for significant differences in mean vital capacity between the age groups, a one-way analysis of variance was used. Results of the analysis are summarized in Table 6. The differences in mean vital capacity were significant ($F(2,27) = 29.13$, $p < .0001$). To determine which inter-group comparisons contributed to this significance, Scheffé tests were applied among the three groups. The mean performance between all groups was found to be significantly different ($p < .05$).

Phonation Volume

The phonation volume means, ranges, and standard deviations presented in Table 7 represent the total amount of air used for phonation for each subject during the maximum phonation task. A one-way ANOVA (summarized in Table 8) revealed significant differences ($F(2,27) = 14.32$, $p < .0001$). Using the Scheffé test, it was found that there were no significant differences between the 11 year old and 13 year old males; however, significant differences ($p < .05$)

TABLE 5

Mean, range, and standard deviation values of vital capacity (cc).

Subject Group	Mean	Range	Standard Deviation
Group I	2388	1680-3000	400.09
Group II	2934	2250-3425	370.29
Group III	3953.5	2900-4825	595.33

TABLE 6

Summary of Analysis of Variance to evaluate differences between 11, 13, 15 year-old males on the measures of Vital Capacity.

Source of Variance	df	MS	F	P<
Between Groups	2	6328060.83	29.13	.0000
Within Groups	27	217205.65		
Total	29			

TABLE 7

Mean, range, and standard deviation values of phonation volume (cc).

Subject Group	Mean	Range	Standard Deviation
Group I	2106	1450-2750	342.07
Group II	2497	1480-3245	583.68
Group III	3417	2150-4350	700.75

TABLE 8

Summary of Analysis of Variance to evaluate differences in mean phonation volume between 11, 13, and 15 year-old adolescent males.

Source of Variation	df	MS	F	P
Between Groups	2	4530003.33	14.32	.0001
Within Groups	27	316248.51		
Total	29			

were found between the 15 year old and the 13 year old males and between the 15 year old and the 11 year old males.

Phonation volumes, like vital capacities, were found to increase with the age and height of the subjects. The greatest increase, almost twice the amount seen in the other age groups, was found in the 15 year old group. There was also considerable overlap of individual values between the groups. While there was only one individual (Subject 11-5) who had a recorded phonation volume higher than the mean volume of the next higher age group, every group had individual scores that were lower than the mean value of the previous lower age group.

Maximum Phonation Time (MPT)

The means, standard deviations, and ranges of the maximum phonation times for the males in each of the three age groups are presented in Table 9. To test for significant differences in mean maximum phonation times between the age groups, a one-way ANOVA (summarized in Table 10) was used. The differences in maximum phonation time between the three age groups were not significant.

Although differences were not statistically significant, the thirteen year old adolescents sustained phonation longer than did either the 11 or 15 year old males. However, the 13 year old MPT value was only 1.10 seconds longer than that recorded for the 15 year old males and 3.13 seconds longer than that for 11 year old males. The longest individual phonation times for all the groups

TABLE 9

Mean, range, and standard deviation values of maximum phonation time (in seconds).

Subject Group	Mean	Range	Standard Deviation
Group I	18.52	12.0-22.5	3.46
Group II	21.65	14.5-31.0	5.19
Group III	20.55	14.0-25.0	3.45

TABLE 10

Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on the measurements of maximum phonation time.

Source of Variation	df	MS	F	P
Between Groups	2	25.13	1.48	.2447
Within Groups	27	16.94		
Total	29			

were 31 seconds and 27.5 seconds which were recorded for subjects in the 13 year old group. At the opposite end of the scale, the shortest phonation time was 12 seconds for an 11 year old individual. However, the next shortest time of 14 seconds was recorded for individuals in each of the age groups. As seen in Table 9, the variability of maximum phonation time within the three groups was high. Standard deviation was highest for the 13 year olds with the 11 and 15 year olds having not only lower but also comparable standard deviations. The extent of the difference in MPT between the longest and shortest measures was 19 seconds.

Mean Flow Rate (MFR)

The phonation volume/maximum phonation time ratio (PV/MPT) is a simple direct measure of mean air flow and was used for the air flow rate analyses. The means, ranges, and standard deviations for the phonation volume/maximum phonation time (mean rate of flow) are shown in Table 11.

To test for significant differences in mean flow rate between the age groups, a one-way ANOVA (summarized in Table 12) was used. The differences in mean rate of air flow among the adolescent age groups were not found to be statistically significant.

Mean air flow rates tended to increase with the age of the subjects. The most obvious difference in the means was that the 15 year old adolescents showed higher air flow rates than did the other age groups. High individual variation between subjects of the different age groups and

TABLE 11

Means, ranges, and standard deviation of flow rates during sustained phonation (cc/sec).

Subject Group	Mean	Range	Standard Deviation
Group I	118.05	73.42-174.17	31.49
Group II	123.93	61.67-223.79	49.15
Group III	164.02	66.18-254.28	53.91

TABLE 12

Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on the measures of mean air flow rate.

Source of Variation	df	MS	F	P
Between Groups	2	6258.43	2.97	.0680
Within Groups	27	2104.48		
Total	29			

within the same age grouping was obtained. For example, the differences in values from the highest air flow rate to the lowest air flow rate was 188.10 cc/sec in the 15 year old group, 162.12 cc/sec in the 13 year olds, and 100.75 cc/sec in the 11 year olds. The highest air flow rate for an individual (254.28 cc/sec) was for a 15 year old, whereas the lowest reported mean air flow rate (61.67 cc/sec) was for a 13 year old.

Phonation Volume/Vital Capacity Ratio (PV/VC)

Table 13 contains the means, ranges, and standard deviations obtained for the PV/VC ratio. A one-way analysis of variance applied to the data (see Table 14) revealed no significant differences among the age groups for the means of PV/VC ratio measurements.

Comparison of the means of the 3 adolescent male age groups showed that all group ratios were within the 80 percent range. The 11 year olds' PV/VC ratios were 4-5% higher than the other two age groups. The lowest mean ratio fell in the 13 year old group.

While group PV/VC ratio means were comparable, ranges -- as seen in Table 13 -- were not. The 11 year old and 15 year old groups with the highest mean ratios had the narrowest ranges (differences were 27% and 26% respectively), whereas the range for the 13 year old group was broader; differences in PV/VC ratio was 39% The highest individual score (.955) was recorded for an 11 year old adolescent; the lowest (.556) for a 13 year old adolescent.

TABLE 13

Mean, range, and standard deviation values of phonation volume/vital capacity ratio (percent).

Subject Group	Mean	Range	Standard Deviation
Group I	.8859	.725-.995	.0788
Group II	.8292	.556-.947	.1192
Group III	.8441	.695-.957	.0870

TABLE 14

Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on the phonation volume/vital capacity ratio.

Source of Variance	df	MS	F	P
Between Groups	2	.0086	.9261	.4083
Within Groups	27	.0093		
Total	29			

Vocal Velocity Index (VVI)

A ratio of the mean air flow rate to vital capacity during sustained vowel phonation was used to calculate the vocal velocity index. VVI is expressed in pro mille. The means, ranges, and standard deviations of the three adolescent male age groups on measurements of vocal velocity index are presented in Table 15. The one-way analysis of variance applied to the data (see Table 16) revealed no significant differences among the adolescent male age groups for the means of vocal velocity index measurements.

While VVI mean values for all three age groups tended to fall in the 20 sec^{-1} range, comparison of means and ranges of the 13 year old and 15 year old groups showed only a 1 sec^{-1} difference. Only 5-6 sec^{-1} differentiated the average VVI of those two groups from the average VVI of the 11 year old group. The VVI range for the 11 year old group was also not as wide as the ranges of the other two age groups.

Phonation Quotient (PQ)

The ratio of vital capacity to maximum phonation time was used to calculate the phonation quotient. Table 17 shows the mean values, the ranges, and the standard deviations of the phonation quotient. To test for significant differences in mean phonation quotient among the three groups of adolescent males, a one-way ANOVA was used. Results are summarized in Table 18. The differences in phonation quotient were significant $(F\ 2,\ 27) = 7.09$,

TABLE 15

Mean, range, and standard deviation values of Vocal Velocity Index (sec^{-1} in promille)

Subject Group	Mean	Range	Standard deviation
Group I	21.09	14.07-27.92	4.62
Group II	27.03	15.30-43.13	8.98
Group III	26.38	14.75-43.82	7.94

TABLE 16

Summary of Analysis of Variance on the Vocal Velocity Index (MFR/VC) of 11, 13, and 15 year-old males.

Source of Variation	df	MS	F	P
Between Groups	2	106.21	1.93	.1645
Within Groups	27	55.01		
Total	29			

TABLE 17

Mean, range, and standard deviation values of the Phonation Quotient (cc/sec).

Subject Group	Mean	Range	Standard Deviation
Group I	133.75	85.06-204.17	35.87
Group II	146.47	81.82-236.21	44.84
Group III	196.40	150.68-267.86	36.66

TABLE 18

Summary of Analysis of Variance on the Phonation Quotient (MPT/VC) of 11, 13, and 15 year-old males.

Source of Variation	df	MS	F	P
Between Groups	2	10969.76	7.09	.0034
Within Groups	27	1547.32		
Total	29			

p <.0034. To determine which group means contributed to this significance, Scheffé tests were applied among the three age groups of adolescent males. There were no significant differences between the 11 year olds and the 13 year olds. However, significant differences (p <.05) were found between the 15 year olds and the other two age groups.

There were noticeable differences between the means of the 3 age groups. Mean PQ values increased with the age of the subjects; however, the values for the 15 year olds were higher than the other two age groups. There was about a 50 cc/sec difference between the 13 year old and the 15 year old mean PQ values as compared to only a 13 cc/sec difference between 13 year olds and 11 year olds.

S/Z Ratio

The maximum sustained duration values of the sounds of [s] and [z] were obtained without the constraints of the face mask. The means, ranges, and standard deviations of [s], [z], and the ratio of s/z are presented in Table 19. While the maximum phonation times increased slightly with age increase, a one-way ANOVA showed no significant differences among the means of maximum duration of [s] and [z]. Results are summarized in Table 20. When the three age groups were compared as to their respective mean s/z ratios, utilizing a one-way ANOVA, significant differences were not found.

The mean phonation times for both [s] and [z] increased slightly (2-4 seconds) with age increase. Increments,

TABLE 19

Mean, range, and standard deviation values
of [s], [z], and s/z ratios.

Subject Group	Mean	Range	Standard deviation
Group I			
[s]	21.50	15.32-28.48	4.82
[z]	24.81	19.82-28.32	3.10
s/z	.87	.56- 1.16	.16
Group II			
[s]	23.36	13.69-36.67	7.48
[z]	24.64	14.44-34.74	6.43
s/z	.96	.71- 1.30	.22
Group III			
[s]	26.04	15.64-36.77	7.38
[z]	28.16	20.77-39.21	6.23
s/z	.92	.71- 1.30	.20

TABLE 20

Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on the S/Z ratio.

Source of Variation	df	MS	F	P
Between Groups	2	.0199	.5326	.5931
Within Groups	27	.0374		
Total	29			

although quite small, were largest for the 15 year old adolescents. Mean [s] and [z] values for the three groups were similiar; however, individual scores exhibited more variability. [z] values were longer than [s] values in 24 of the 30 subjects. However, several subjects displayed markedly longer [z] than [s] values with these differences sometimes as great as 6-12 seconds longer.

Visual inspection of the s/z ratios showed that 80% of all subjects regardless of their age groupings had ratios approximating 1.0. Subjects with s/z ratios above 1.0 were found in all age groups. Half of the individuals above a 1.0 ratio were in the 13 year old group as was the subject with the largest s/z ratio (1.42).

Fundamental Frequency

The fundamental frequency for each subject was obtained from a recorded reading of a segment of "The Rainbow Passage." The means, ranges, and standard deviations of the fundamental frequency for the adolescent males in each of the three age groups are presented in Table 21.

To test for significant differences in fundamental frequency among the age groups, a one-way analysis of variance was used. Results are summarized in Table 22. The differences in mean fundamental frequency were significant $(F\ 2, 27) = 42.02$, $p = <.0001$). To determine which inter-group comparisons contributed to this significance, Scheffé tests were applied. The mean comparison between all groups was found to be significant ($p <. 05$). The mean

TABLE 21

Mean, range, and standard deviation of the Fundamental Frequency (Hz).

Subject Group	Mean	Range	Standard Deviation
Group I	221.00	204-238	10.51
Group II	187.80	146-238	30.64
Group III	125.80	82-160	24.85

TABLE 22

Summary of Analysis of Variance to evaluate differences between Fundamental Frequencies of 11, 13, and 15 year-old males.

Source of Variation	df	MS	F	P
Between Groups	2	23348.80	42.02	>.0001
Within Groups	27	555.60		

fundamental frequencies of the three groups of adolescent males were different from each other.

The mean fundamental frequency showed a substantial decline as the adolescent males increased in age. Thirteen year olds' mean fundamental frequency of 188 Hz was about 45 Hz (or 2 musical notes) below the 11 year olds' mean fundamental frequency of 221 Hz, whereas the 15 year olds' mean fundamental frequency of 125 Hz was an additional 52 Hz (or 3 musical notes) below the 13 year olds. Intersubject variability was high, especially for the 13 and 15 year olds. Variability was highest for the 13 year old adolescent males.

Voice Change Scale

In addition to the phonation and respiration measures, each subject completed a voice change scale. This scale was a subjective assessment by the subjects of specific factors that have been established as correlates of vocal change in males. The scale was constructed so that an affirmative response regarding the specified correlate received a rating of 1 or 2 and a negative response a 4 or 5 rating. A rating of 3 was selected if the subject did not know. The individual responses to the 11 questions of the Voice Change Scale from each subject are presented in Appendix C.

The numerical rating for each of the 11 scale questions was tabulated for a total scale score. Ideally, subjects who might be in the process of vocal change would have a total scale score that was lower than those obtained by adolescent males who either felt that they had not started or had completed vocal change.

Voice Change Scale Totals

Table 23 is a summary of the total ratings of the voice change scale in terms of means, ranges, and standard deviations for the males in each of the three age groups. To test for significant differences in the mean voice change scale total score among the three age groups, a one-way ANOVA (summarized in Table 24) was used. The differences in the mean total scores among the adolescent age groups were not statistically significant.

The mean total scores obtained by the three age groups were, however, in the anticipated direction. The mean total score for the 13 year old adolescent males was lower than the total score for both the 11 year and the 15 year old adolescents. However, these mean differences represented only a few points. Variability within and between groups (see Table 23) was high. The 11 and 15 year old males showed similiar standard deviations (8-9 points) as compared to 4 points for the 13 year old males. Ranges of scores for the three groups also differed. The widest ranges were reported for the 11 year olds; the smallest were for the 13 year olds. It is interesting to note that the lowest total scores on the Voice Change Scale for individual subjects (17 and 19) were obtained by a 15 and a 11 year old respectively.

TABLE 23

Mean, range, and standard deviation values of the Voice Change Scale total scores.

Subject Group	Mean	Range	Standard Deviation
Group I	34.60	19-45	8.82
Group II	28.20	24-36	3.76
Group III	30.10	17-41	8.32

TABLE 24

Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on Voice Change Scale Total Scores.

Source of Variation	df	MS	F	P
Between Groups	2	108.03	2.01	.1535
Within Groups	27	53.74		
Total	29			

Averaged Voice Change Scale Score

Since a ranking of 3 or "I don't know" tended to skew the Voice Change Scale total scores obtained by individual subjects, an averaged Voice Change Scale score was calculated. This averaged score was obtained by totaling all numerical ratings for each of the 11 scale questions after all 3 ratings had been omitted and dividing by the number of the remaining responses. The means, standard deviations, and ranges of the averaged Voice Change Scale scores for the males in each of the 3 age groups are presented in Table 25.

A one-way ANOVA reavealed significant differences ($F(2,27) = 3.59$, $p < .0414$). Results of the analysis are summarized in Table 26. Using the Scheffé test, it was found that there were no significant differences between the 13 year old and the 15 year old males or between the 11 year old and the 15 year old males. Significant differences ($p < .05$) were found between the 13 year old and the 11 year old males.

A ranking of "I dont' know" was most frequently marked by the 13 year old adolescents (29/110 or 26%), whereas 11 year old adolescents chose I don't know 19% (21/110) and 15 year old adolescents 12% (13/110). The most frequent times "3" was marked by an individual subject -- 7 times -- occurred in the 13 year old group. Fifteen year olds and 11 year olds were more decisive as 4 and 3 subjects respectively never chose the ranking of 3, or "I don't

TABLE 25

Mean, range, and standard deviation values of the averaged Voice Scale score.

Subject Group	Mean	Range	Standard Deviation
Group I	3.25	1.73-4.22	.960
Group II	2.27	1.57-3.30	.519
Group III	2.71	1.40-3.89	.925

TABLE 26

Summary of Analysis of Variance to evaluate differences between 11, 13, and 15 year-old males on averaged Voice Scale scores.

Source of Variance	df	MS	F	P
Between Groups	2	2,4497	3.59	.0414
Within Groups	27	.6819		
Total	29			

know."

<u>Individual Voice Change Scale Responses</u>

Individual responses within the adolescent male age groups presented the following findings:

Questions 1 - 4 asked the adolescent subjects to relate conditions specifically related to their voices. The questions asked whether there was an awareness that the voice was changing, was there an occurrence of pitch breaks or a hoarse-husky vocal quality, and was the voice lower than it had previously been. Affirming that they were aware that their voice was changing were 4 (or 40%) of both 11 and 15 year old boys, whereas 5 (or 50%) of the 13 year olds felt that their voices were changing. Another 5 or 50% of the the 13 year olds indicated that they didn't know whether their voice was changing. Two (20%) 11 year olds and 4 (40%) 15 year olds responded that they did not think their voices were changing. Responding positively that their voices were lower were 3 (30%) 11 year olds, 7 (70%) 13 year olds, and 4 (40%) 15 year olds. The phenomenon of pitch breaks were reported by nearly half (13/30) of all the adolescent males. Most of these subjects also noted that their voices were changing. Hoarseness was not as frequently reported. The hoarse-husky quality was most frequently reported by the 13 and 15 year olds (4 or 40% in each group). Subjects who reported hoarseness also usually related that their voices were either changing or was lower.

Questions 6 and 7 asked the adolescent subjects whether they were experiencing difficulty singing high notes and/or singing in general. Half of all the adolescent males responded affirmatively to the statement that they could no longer sing high notes. Thirteen year old males responded "yes" more frequently (70%) than did the 11 year olds (40%) or 15 year olds (50%). Singing in general was infrequently reported by subjects, regardless of age grouping, as being difficult.

The final questions (5,8,9,10,11) asked the adolescent males about physical bodily changes they were experiencing. These included gains in height and weight, increased bodily hair and genital size, and general increased muscular development. An increase in weight, which is indicated as being a later developing physical change in males of these ages, was affirmed by only a few of the subjects. Increase in height, on the other hand, was reported by almost all of the adolescent subjects -- 50% for 11 year olds, 90% for 13 year olds, and 80% for 15 year olds. The questions related to an increase in bodily hair (especially pubic hair) and in genital size frequently drew the response of I don't know. However, most subjects (73%) who did respond indicated they were developing more hair on their bodies. In agreement to the statement that genital size had increased were 60% of the 15 year olds as compared to the 11 year olds (20%) and 13 year olds (40%) Nearly all adolescent male subjects felt their bodies had become more muscular. No subjects replied with a definite negation of this statement.

Relationship to Measures of Vocal Function

Pearson product-moment correlation coefficients were calculated to determine the relationship between the respiration and phonation measures obtained in this study and the averaged Voice Change Scale score for the subjects within each of the 3 age groupings. Summaries of the Pearson correlation coefficients for each of the age groups are presented in Tables 27, 28, and 29. While most vocal function measures yielded low non-significant correlation coefficients, there were some scattered significant correlation coefficients within each of the three groups. The 15 year old group had the highest number (4) of significant correlations; the 13 year old group the lowest (1). Significant correlations for the 11 year olds included MPT ($r = .640$) and VVI ($r = .724$); 13 year olds PV/VC ($r = .486$); 15 year olds MPT ($r = .656$), S ($r = .588$), Z ($r = .582$), and PQ ($r = -.592$). The only common vocal function/ averaged Scale score significant correlation -- maximum phonation time -- was shared by 11 and 15 year olds.

TABLE 27

Correlation of Averaged Voice Change Scale Score to Measurements of Vocal Function. (11 year old adolescent males)

Vocal Function Measure	Averaged Vocal Change Scale Score
Vital Capacity	.2389
Phonation Volume	.0475
MPT	.6404*
MFR	-.5178
PQ	-.4229
PV/VC Ratio	-.3204
VVI	.7240*
S	-.1194
Z	.1910
S/Z Ratio	-.2309

*Significant at the .05 level of confidence

TABLE 28

Correlation of Averaged Voice Change Scale Score
to Measurements of Vocal Function.
(13 year old adolescent males)

Vocal Function Measure	Averaged Vocal Change Scale Score
Vital Capacity	.1603
Phonation Volume	.3607
MPT	-.1185
MFR	.2027
PQ	.1003
PV/VC	.4857*
VVI	-.3889
S	-.4599
Z	-.1658
S/Z	-.5298

*Significant at the .05 level of confidence

Table 29

Correlations of Averaged Voice Change Scale Score to Measurements of Vocal Function. (15 year old adolescent males)

Vocal Function Measure	Averaged Vocal Change Scale Score
Vital Capacity	.0708
Phonation Volume	-.0695
MPT	.6558*
MFR	-.3232
PQ	-.5916*
PV/VC Ratio	.0105
VVI	.1278
S	.5883*
Z	.5821*
S/Z Ratio	.2539

*Significant at the .05 level of confidence

CHAPTER V

DISCUSSION AND CONCLUSIONS

The importance of respiratory and phonatory measures such as air flow rate, phonation air volume, phonation time, and vital capacity has been related to the act of speech and, more specifically, to the study of normal and dysphonic voices. Most of the investigations have dealt with adult subjects (Hirano et al., 1968; Isshiki, 1965; Isshiki et al., 1969; Yanagihara and von Leden, 1968; Yanagihara et al., 1968) or, to a lesser extent, young children (Beckett et al., 1971; Bless, 1971; Leeper, 1971; Olson et al..1969; Platt et al., 1975). The present study sought to extend this research to adolescents, especially adolescent males during voice mutation.

The scope of the present investigation should be considered exploratory in nature. The need remains for additional measures of vocal function to be obtained from females as well as larger samples of male adolescents. Within the sample size and performance variability limitations of the present study, however, the measures obtained for the 30 adolescent males provided some interesting results.

Several general statements can be made at the onset. Significant differences were found between the three age levels of adolescents in terms of mean age, height, vital

capacity, and fundamental frequency. While these findings established that the adolescent males did indeed represent three distinct populations, the variability of the subjects and the lack of significant differences across the other variables suggested that the three groups were heterogeneous as well as homogeneous.

Secondly, some vocal function performances appeared to be a function of age although statistical significance was not obtained on any group differences with the exceptions of the measures of phonation volume and phonation quotient in the 15 year old group. Subject variability could have obscured potential systematic differences as there were large intersubject variability observed on all measures.

Thirdly, the obtained measurements of the adolescent males in the present study were in many ways different from those that have been reported for adults and younger children and may be a reflection of the voice mutation taking place. The various phonatory and respiratory measures for adolescent males displayed both a wide range of values and large standard deviations. In most cases, however, the male adolescents in this study performed as consistently as adult and young child speakers on the various vocal function tasks.

With these general findings in mind, the following sections will discuss the results for some of the individual measures. The simplest of the measures and the most frequently applied diagnostic measure is the maximum phonation time, the first to be discussed.

Maximum Phonation Time

The maximum phonation times obtained for adolescent males in this study support the conclusion of previous research that maximum phonation time tends to increase with age. Values obtained for adolescent males lie, as expected, between measures reported for young children and for adults. Adolescents in the present study had mean MPT scores between 18-21 seconds, whereas phonation times are reported for boys 7 years old of 14 sec (Beckett et al., 1971; Finnegan, 1984) and 9 years old of 16 sec (Bless, 1971; Finnegan, 1984). Launer (1971) found somewhat lower values for all ages. Adult male mean values were reported to be from 25-35 sec. Adolescent males, especially 13 and 15 year olds, have MPT values comparable with adult female speakers.

Although MPT tended to increase with age, this trend was neither linear nor monotonic. The mean MPT for 13 year olds was longer, although not statistically significant, than for 15 year olds. Finnegan (1984) reported similiar findings. In addition, Finnegan and the present study found standard deviations to be larger for the 13 year olds. Subject variability has always been considered a serious limitation in interpretation of MPT and has been attributed to such factors as differences in body height and weight, competiveness, motivation, and degree of maximum effort exerted. Since these variability sources can certainly be associated with all age groups, the question arises as to why 13 year old male adolescents displayed more variability than 11 year olds or 15 year olds. The explanation for such differences is not immediately apparent. Could the larger variability be a reflection of uncontrolled expiratory effort associated with vocal change? This supposition may have some support in lieu of the fact that this pattern of variability was not exhibited by 13 year old female adolescents in the Finnegan study.

Another possibility, which may have significance as the other vocal function measures are discussed, is that the 15 year old adolescent boys had reduced phonation times. Since MPT is directly related to vital capacity, the 15 year olds with their larger vital capacities should have exhibited longer phonation times.

Mean Flow Rate

Higher mean flow rates were found as the adolescent males advanced in age. While these differences were not found to be statistically significant, their mean flow rates were considerably higher than rates reported for either adults or young children.

Direct comparison of the flow rates of the present subjects with those reported in previous studies of young children (Leeper, 1971; Olsen et al., 1969; Platt et al., 1975) was impossible since these data were not analyzed for either sex or age differences. These studies of boys and girls 5-14 years of age, as did Beckett et al. (1971) for 7 year olds, reported mean flow rates from 95-113 ml/sec.

Bless' data from 9 year old males [MFR = 132 cc/sec] were substantially higher than all other reported flow rates and make explanation of the adolescent mean values somewhat tenuous. Bless' boys had flow rates that were higher than those reported for adults. In adult subjects the average values of the MFR during maximally sustained phonation were 110 cc/sec in males [SD = 30] and 100 cc/sec in females [SD = 23]. The range was reported to be from 70-164 cc/sec (Yanagihara et al., 1966).

The present data suggest that 11-13 year old adolescents have mean air flow rates that correspond with established adult norms. Fifteen year old adolescent males, on the other hand, displayed MFR mean values higher than the mean for normal adult subjects and were outside the MFR adult range.

In an investigation of vocal function in patients with different diseases of the larynx, the mean flow rate varied in a wide range from 20 to 1000 cc/sec (Yanagihara and von Leden, 1967). The degree of vocal dysfunction varied with the nature and severity of the pathology in the larynx. Patients with laryngeal tumors or vocal cord paralyses exhibited the most severe dysfunction [MFR = 442 cc/sec], whereas patients with vocal nodules, minor inflammatory changes, and chronic laryngitis [MFR = 133-154 cc/sec] demonstrated moderate to slight degrees of dysfunction (Iwata et al., 1972; Yanaghara et al., 1967).

From the data in the present study it is apparent that

the adolescent males, especially the 15 year olds, exhibited irregularities of air flow during phonation that were similiar to those reported for dysphonias of minor inflammatory changes and chronic laryngitis. Since glottal condition is said to be directly reflected by the air flow rate during phonation, older adolescent males appear to be demonstrating mild functional disturbances. However, the actual values of the mean flow rate varied widely from subject to subject, even within the same age grouping. This spread or standard deviation of the mean flow rates is summarized in Table 12. Subjects displayed the extremes in MFR, i.e. lower than normal flow values as well as higher than normal values. Low mean flow rates reportedly reflect increased glottal resistance i.e., hypertensive condition in the larynx rather than a reduction in the expiratory effort (Isshiki and von Leden, 1964). High mean flow rates, on the other hand, result from the reduction of the laryngeal resistance created by an incomplete approximation of the vocal cords with the extent of the elevation correlating with the degree of laryngeal dysfunction. While the values of mean flow rate reflect the overall function or dysfunction of the larynx, these measures are more appropriately interpretated in relation to other measures of vocal function. For this reason, further explanation of the MFR found in adolescent males will be reserved for the final discussion of all vocal function variables.

Phonation Volume

The whole quantity of vital capacity is never utilized for longest phonation. Thus, the amount of air during sustained phonation varies in accordance with the amount of vital capacity (Yanagihara et al., 1966). This was true for the adolescent males in the present study. As shown in Table 8, none of the subjects utilized their whole amount of vital capacity for his longest phonation.

While the phonation volumes -- like the vital capacities -- increased with age, these differences were only significant between the 15 year olds and the other two age levels. Fifteen year olds not only utilized more air but this air volume proportionally was also more than that used by 11 and 13 year olds. The greater air consumption would suggest more air wastage. This was consistent with the 15 year old's higher air flow rates and their lower (than the 13 year olds) MPT. Studies comparing the three age groups relative to voice initiation and termination would provide some explanations for this greater air consumption by the 15 year old adolescent males.

Phonation Volume/Vital Capacity Ratio

The mean percentage of the air volume expired to vital capacity (PV/VC) during the longest phonation was highest for the 11 year olds (88%) and decreased as the subjects increased in age (13 year olds 83%; 15 year olds 84%). The standard deviations, especially for the 15 year olds were quite large, thus illustrating the differences among subjects.

The mean values of the PV/VC ratios were higher than those reported for adults. Yanagihara and von Leden (1976) found mean values of 67% in males and 59% in female subjects with corresponding deviations of 6.5 and 7.5 and normal ranges of 50-80% (males) and 45-75% (females). Adolescent mean PV/VC ratios fell slightly above the upper limits of the male adult range. Bless (1971) presented the only available data for young children. She found mean values of 100% for 9 year old boys and 93% for girls. Young children and adolescent males appeared to use more of the air available to them than did the adult subjects reported in previous studies (Isshiki et al., 1969; Yanagihara and Koike, 1968).

An interesting question is raised. What accounts for the larger use of available air for sustained phonation by young children and adolescents? These observations would suggest that children have a more efficient mechanism for sustained phonation than do adults, as adults displayed a larger degree of air wastage.

The discrepancy between phonation volume and vital capacity has been attributed to many factors. First, types or patterns of voice initiation and termination, e.g. air expelled prior to vocalization and/or air cost associated with types of voice onset and cessation, will cause air wastage. Secondly, since vital capacity and phonation volume are derived from two separate tasks, normal respiratory dynamics associated with a maximum exhalation will force out more air creating the larger vital capacity value.

Investigators of aerodynamic parameters during phonation, however, have postulated additional explanations for the different air volume during maximum exhalation and longest phonation. Gutman (cited by Yanagihara et al., 1966) attributed the difference to the level of Co_2 in the blood. He speculated that the Co_2 level might rise during long sustained phonation; the termination of phonation was then inevitable because of the intolerably high level of Co_2. This theory was not substantiated by other investigators (Isshiki et al, 1969; Yanagihara et al. 1966).

Isshiki et al. (1969) attributed the differences in the amount of air available for phonation and the amount used for phonation by adults to more distension of the subglottal system by a higher subglottal pressure during phonation.

> At the end of longest phonation, however, an additional force that distends the lung and subglottal cavity is exerted by the subglottal pressure. The subglottal pressure during exhalation is very low compared with that during loud phonation. Actually, distension of the trachea during loud phonation, which results from the increased subglottal pressure, can be visualized by fluoroscopy. Consequently, more air is reserved in the subglottal system at the end of longest phonation than at the end of maximum exhalation.
>
> Immediately after termination of longest phonation, emission of air at an increased flow rate without voicing is frequently noted. This phenomenon, presumably resulting from a sudden and wide opening of the glottis, is considered to support our explanation. Furthermore, Dohne stated that the expired air volume during longest phonation approaches the vital capacity value in

> case of aphonia where the glottal resistance is very small. This statement also appears consistent without explanation. (Isshiki, Okamura, and Morimoto, 1969, p. 1002.)

Yanagihara et al. (1966) attributed the discrepancy to a decreased expiratory force. They suggested that "when the phonation volume is completely utilized, the expiratory force may decrease to such an extent that the remaining expiratory power is too weak to overcome the laryngeal resistance" (p. 336).

The explanations for the discrepancy between vital capacity and phonation volume that have been presented, however, relate only to investigations utilizing adult subjects and may offer limited information relative to the higher PV/VC ratios exhibited by young children and adolescent males. Since measurements of glottal resistance, fluoroscopic pictures of the trachea, and subglottal air pressure were not included in the present study, explanations based on adult subjects cannot be evaluated. Bless (1971) also offered no explanations for her findings of high PV/VC ratios with young children.

High air flow rate with high PV/VC ratios was frequently observed in association with organic laryngeal diseases or functional voice disorders (Yanagihara and von Leden, 1967). The high PV/VC ratio of adolescents in this study are similiar to Yanagihara and von Leden's findings for patients with small vocal nodules and minor inflammatory conditions. The investigators concluded that while the expiratory air supply of these dysphonic patients was adequate, their expiratory effort was greater than in normal persons. "An increase in the PV/VC ratio would suggest the consumption of excessive air volume for the entire period of phonation; this excess may be attributed mainly to an abnormally high expiratory effort, or in other words, subglottic power" (p. 163). By contrast, a decrease in PV/VC ratio would suggest that the subject is unable to supply the necessary amounts of air for the production of sustained voice; the result of high glottal resistance or weakness in the expiratory effort.

The adolescent males in this study usually exhibited PV/VC ratios higher than adults. This high PV/VC ratio coupled with their higher flow rate suggests decreased glottal resistance with a high expiratory effort. Glottal resistance of this nature is associated with an inconsistent closure of the vocal folds during phonation. Measurements of glottal resistance, however, are difficult to discuss without measurement of subglottic pressure. Subglottal pressure measurements seem crucial to a complete understanding of the forces that maintain and regulate flow during air consumption.

Vocal Velocity Index

Since the mean Vocal Velocity Indices were similiar for all of the adolescent males in all the age groups, the total range of group means was used as the basis for comparison to the critical region suggested by Koike and Hirano (1968) for normal adults and dysphonic patients. The significance of the VVI ratio for adults was the small range [14.3 to 44.0 per mille] and the establishment of a single standard applicable to both sexes. The sex difference is not as critical for young children since vocal function measures reported in previous studies (Beckett et al., 1971; Bless, 1971; Leeper, 1971; Pratt et al., 1975) have not shown significant differences between the sexes.

The use of VVI with young children was reported by Bless (1971). She reported mean values of 53 per mille with a range of 15 to 99 for both male and female 9 year olds. Leeper (1971) found similiar values. The mean VVI index for young children appeared to be outside the normal limits for adults as suggested by Koike and Hirano (1968). This was not true for the adolescent males in the present study. The adolescent males' performances, as measured by VVI, were much closer to adult standards than to standards of younger children.

Iwata and von Leden (1970) demonstrated that the range of the VVI in adult patients with laryngeal disease was far greater than in normal subjects. The distribution varied with the different pathologic groups. While chronic laryngitis patients had a mean value of VVI of 41.6 per mille which was significantly higher than that for normal, the investigators found the increase in the VVI to be directly proportional to the degree of the inflammatory findings. Leeper (1971) has demonstrated that VVI ratios of dysphonic children generally fall into the upper range of abnormality as reported by Koike and Hirano (1968).

The Vocal Velocity Index of the adolescent males did not reflect the laryngeal inefficiency pattern that is suggested by the other measures of the laryngeal or expiratory functions involved in sustained phonation. Another explanation for the lack of abnormal measurements is that the Vocal Velocity Index simply was not a sensititive indicator of the type and/or degree of laryngeal dysfunction displayed by these adolescent males.

Phonation Quotient

Phonation Quotient or VC/MPT has been used as a substitute for air flow rate when direct measures of air consumption are not feasible. An evaluation of the relationship between PQ and air flow demonstrated that PQ values are always larger than mean air flow rates (Iwata and von Leden, 1970).

The PQ of the adolescents in the present study increased with age paralleling the increment pattern of the air flow rate. As was found for air flow mean values, the 15 year old adolescent phonation quotient measures were considerably higher than those of 11 and 13 year olds. However, unlike air flow means, the differences found between the phonation quotients of 15 year olds and the other ages were statistically significant. Fifteen year olds, based on PQ calculations, demonstrated significantly increased atypical air consumption during sustained phonation.

No studies have looked at the phonation quotient in younger children; however, since PQ is the ratio of VC/MPT, it is reasonable to assume that the PQ of younger children would be consistent with their smaller vital capacity and maximum phonation time. Therefore, PQ of young children would be less than that observed for adolescents. The mean PQ for adult males, established by Hirano et al. (1968), was 145 cc/sec. Mean phonation quotient for 11 year old and 13 year old adolescents were in close agreement with that mean. In comparison, 15 year old subjects demonstrated an unusually high PQ. They fall close to the upper limit of the normal adult range [101 to 207 cc/sec] but well within the established critical region [69-307 cc/sec]. Thus, the PQ for adolescents, using the adult standards, would be considered higher than average, but not abnormal. However, since PQ data were lacking for younger children, it might be reasonable to consider the 13 year old scores as also being somewhat elevated.

In order to determine whether the phonation quotient is a reasonable clinical substitute of the mean flow rate, the correlation between the two should be examined (Hirano et al., 1968). A significant positive correlation coefficient of 0.92 was obtained. This suggested that the phonation quotient can be considered an indicator of air consumption and can serve as a fairly accurate substitute for MFR.

Hirano et al. (1968) and Iwata and von Leden (1970), investigating air usage during phonation of dysphonic patients of various laryngeal pathologies, found mean PQ values similiar to those exhibited by the 15 year old adolescent males in the present study. The types of dysphonia exhibiting the comparable PQ were chronic laryngitis [194.5 cc/sec] and some inflammatory benign tumors of the larynx [225 cc/sec]. The values for patients with chronic laryngitis were said to exhibit values proportional to the degree of inflammatory changes.

Thus, the indirect measure of VC/MPT or the phonation quotient was consistent with other vocal function measures. Adolescent males, especially 15 year olds, exhibited greater air consumption during sustained phonation, a finding which suggests that males this age may be exhibiting difficulties with laryngeal adjustments (glottal resistance) and/or greater expiratory force.

S/Z Ratio

The mean expiratory air flow times and mean sustained phonation times employing [s] values and [z] values showed as was the case with the phonation time of the vowel [ɑ], a gradual increase with age (see Table 19). Although there were differences separating the values of [s] and [z] between age levels, none were statistically significant. The mean values for the adolescent males fit into a linear increment pattern established for 5, 7, and 9 year olds by Tait et al. (1980). Five year old boys had reported [s] values of 7.9 sec and [z] of 8.6 sec. Seven and nine year old boys had values of 9.3 sec and 13.2 sec and 16.7 sec and

18.1 sec respectively.

The ratio of [s] to [z] did not vary across the three age groups. S/Z ratios of the adolescent males in all three age groups were close to 1.0. The data generally support Boone's observation (1971) that voiceless expiration time closely matches maximum phonation time in that a normal subject will be able to produce [s] and [z] for approximately the same length of time.

All populations performed the maximum phonation task of [s] and [z] in the same manner, disregarding mean durational values. The duration of [z] was usually found to be longer than [s], as was reported in previous studies (Eckel and Boone, 1981; Rastatter and Hyman, 1982; Tait et al., 1980). Tait et al. (1980) attributed the longer production of [z] to a conservation of air flow created by laryngeal valving.

Mean [z] values for the adolescent males were higher than for their duration of [ɑ]. This might be accounted for by several factors. First, the increased articulatory contriction of [z] will cause more impedance of the air flow, and, hence, a longer expiration. Secondly, the face mask can have definite effects on speech production. A slight resistance to air flow may be created by the mask which in turn increases intraoral pressure and, consequently, a shorter phonation time. The face mask can also alter the effort required to produce the sustained phonation causing the subject to hyper-value the glottal mechanism, or it may create a potential Lombard effect whereby the subject increases his phonatory effort in order to achieve what he perceives to be his "natural voice." Maximum phonation attempts with and without a face mask cannot appropriately be compared.

Interestly, the maximum phonation times of [s] and [z] of the 13 year old subjects were not longer than those of 15 year olds as had been the finding for the MPT vowel measurement. However, intersubject variability of [s] and [z] scores was still high, especially among the 13 and 15 year olds.

The S/Z ratios obtained in the present study do not support the implications from the other vocal function results that adolescent males have difficulty using the available air supply when sustaining phonation.

Voice Change Scale

Although the averaged scores on the Voice Change Scale were in the anticipated direction, the differences between the scores were not sufficient to differentiate the three groups. The statistically significant difference obtained between the averaged scores of the 11 year and 13 year olds would suggest that the 11 year old boys, as a group, had not begun the process of voice change, whereas the 13 year old boys were in pubertal voice change. The non-significant differences between the 13 and 15 year olds and the 11 and 15 year olds might suggest that the 15 year old adolescent boys were not homogeneous in terms of voice change. Some of the 15 year olds were apparently still in vocal change,

whereas others may have completed the change. The fundamental frequency readings would support this conclusion. The fundamental frequency readings suggested that voice change was in process for a few 11 year olds, nearly all 13 year olds, and half of the 15 year olds.

Several factors may account for the lack of differences across all adolescent ages on the Voice Change Scale. First, despite the significant differences in fundamental frequencies across age levels, variability was large, especially for 13 and 15 year olds, suggesting that subjects within each age group were not homogeneous in terms of vocal change. Additionally, there was no way to ascertain, if a subject was in the process of vocal change, what stage he might be experiencing. Subjects within the same age grouping may have been in vocal change, but each may have been at a stage different from the others.

Secondly, one might question whether all adolescent male subjects truly understood the questions and whether they could formulate an appropriate reply to the 6 months time frame asked by the questions. For example, question 6 asked whether the subjects were able to sing the high notes in songs like they had 6 months ago. Since loss of high notes in singing has been reported to be one of the early signs of pubertal voice change, 11 year olds and 13 year olds should have responded affirmatively most often. Most subjects, regardless of age grouping, responded yes. If the subjects interpretated this question to mean can you sing as high as you once did, their responses are understandable.

Thirdly, adolescent males of these age groupings may not be totally aware of the physiological and maturational changes they are experiencing, especially those very subtle changes such as gradual growth of genitals and pubic hair. These changes may not have been consciously perceptible by these subjects.

Additionally, some replies may have been influenced as much by comments of others or what they thought adolescents should be experiencing as well as their own actual awareness. For example, while fundamental frequency readings suggested that almost all 13 year olds were probably experiencing vocal change, only half were sure that their voices were changing; the other half did not know. Lastly, some responses, especially those asking about pubic hair and genital development, may have been embarrassing to the subjects. Those questions drew more "I don't know" responses than all other questions.

While most replies to the Voice Change Scale offer limited information relative to pubertal vocal change, there were several interesting observations. Pitch breaks and/or a hoarse-husky vocal quality were reported with about the same frequency that is reported in the literature. This continued to support the prevalent notion that pitch breaks occur during pubertal voice change, but they do not occur in all subjects nor do they represent the predominate characteristic of voice change. Responses to the increased height question were affirmative with the same frequency as the questions about voice change. These responses confirmed that increased height, like voice change, is a phenomenon that continues from pre to post pubertal development. An increase in weight, on the other hand, received infrequent positive replies suggesting that it does not occur throughout pubertal development. All adolescent males seemed to feel that they were becoming more muscular.

The Voice Change Scale did not completely differentiate adolescent males undergoing voice change from those who had completed voice change. It was able to identify pre-pubertal voice change subjects from pubertal voice change subjects. However, such distinctions were only possible after removing all "I don't know" responses, a finding which may provide relevant information relative to the adolescents' self-perceptions during this stage of development. Responses on the Voice Change Scale, for the most part, probably just reflected differing degrees of pubertal maturation. The development of a completely valid Voice Change Scale may be impossible because of individual variation and the interrelationship of various events within the pubertal developmental maturation sequence.

Relationship to Vocal Function Measurements

Several significant correlations were found between the averaged score from the Voice Change Scale and the vocal function measurements. Any interpretation regarding relationships between the Scale averaged score and the vocal function measurements must be made with extreme caution. Interpretations must take into account the small sample size and the exclusion of selected data in order to derive the averaged Scale score. Some correlations were significant that were derived from other vocal function measures that were not found to be significant. Additionally, although significant, correlation coefficients were only moderately high. The highest was $r = .724$.

Considering the above precautions, it would appear that maximum phonation tasks had moderate positive relationships with the averaged Scale scores for 11 year and 15 year olds. The averaged Scale score of 13 year olds had weak relationships with the vocal function parameters measured in this study.

Conclusions

The establishment of normative values on the vocal function measures obtained in this study has been complicated by the lack of sufficient data on certain measures from young children. However, based on the values that have been reported, adolescent males appeared to perform closer to the adult norms. On some measures, their scores matched female adult norms which are never as large as those obtained from adult males. The findings for adolescent males on these vocal function measures certainly were to be expected given the increased heights and vital capacities of adolescent males.

However, there were some findings that did not fall into the developmental pattern associated with increased skeletal structure and muscular development. Some of the values of vocal function were found to not only be above the adult norms, but they also closely resembled values found in certain dysphonic subjects. Yangihara and von Leden (1976) stressed that an abnormal value in one or several vocal function variables indicated a disturbance in the laryngeal or expiratory function involved in sustained phonation. Thus, adolescent males, especially 15 year olds and some 13 year olds, displayed manifestations of a mild vocal dysfunction. Subjects who might be judged on the basis of their fundamental frequency reading to be in the process of vocal change exhibited the most dramatic indications.

Adolescents presented air flow rates that were higher than normal adults; however, in some cases the deviations were not outside the adult range. Coupled with this high air flow rate was a PV/VC ratio raised beyond the normal limits and a somewhat shortened phonation time (or an MPT within the normal range). These conditions are indicative of a hypo-tensive mode of phonation with reduced glottal resistance and/or a greater expiratory effort. While intersubject variability of values reflecting this laryngeal inefficiency was large, several subjects presented excellent examples. Subject 15-7 with a vital capacity of 3750 cc and a phonation volume of 3560 cc presented a MFR of 254 cc/sec,

a PV/VC ratio of 95% and an MPT of 14 sec (although [z] was 20 sec). His fundamental frequency of 144 Hz would suggest that voice change was taking place. Another 15 year old, Subject 15-5, exhibited somewhat smaller values. His MFR was 214 cc/sec with a MPT of 19 sec and a PV/VC ratio of 78%. He displayed an S/Z ratio higher than 1.0 (1.19). His fundamental frequency was 138 HZ. One 13 year old also demonstrated an excellent example of dysfunction. Subject 13-7 with a fundamental frequency of 158 Hz had a MFR of 223 cc/sec, MPT of 14.5 sec, and PV/VC of 95%. His vital capacity (3425 cc) was the largest of the 13 year olds although he was not the tallest. Unlike other subjects, he displayed an abnormal S/Z ratio (Eckel and Boone, 1981) of 1.42 ([s] = 20.5 sec; [z] = 14.5 sec).

These findings resembled Yangihara and von Leden's (1968) vocal function measures from subjects with small vocal nodules, chronic laryngitis, and minor inflammatory conditions or an incomplete glottal closure. Interestingly, early investigators of pubertal voice change (Curry, 1946, 1949; Weiss, 1950) described, in addition to a lowering of pitch, an accompanying hoarse-husky vocal quality. This change in vocal quality was attributed to hyperemia, inflammation, or a "mutational triangle" -- an incomplete closure of the posterior part of the glottis. The vocal function measures obtained in this study are consistent with those observations. However, traditional clinical examination, synchron-stroboscopy, and high speed cinematographic observations coupled with measurements of aerodynamic activity are needed to verify that adolescent males experiencing vocal change exhibit an incomplete closure of the glottis. Since it is difficult to ascertain whether the vocal dysfunction is the result of the presumed incomplete glottal closure causing low glottal resistance or of a greater expiratory force in order to compensate for the glottal opening, a study of the sub-glottic power in the production of the voice is also indicated.

The vocal function disturbance seen in these adolescent males is apparently extremely slight because acoustical perceptual parameters were not affected. However, changes in laryngeal function are not always detected by audible means. Additionally, sustained vocalization may present entirely different results from those obtained from studies which concentrate on phonation conditions approximating conversational levels and effort, with data being obtained over several trials on different days. While the vocal function measures obtained on these adolescent males may appear to be pathological, they are considered to be normal for these ages and to be related to laryngeal readjustments associated with a stage of pubertal voice change.

What, perhaps, is most surprising is why 15 year old adolescents displayed more significant differences than the other adolescents. It is more perplexing when we consider that it is the 13 year old who is usually felt to be in the process of vocal change (fundamental frequency measurements obtained in this study are consistent with this notion), whereas 15 year olds are considered to have completed or nearly completed voice change. Some of the 15 year olds displayed fundamental frequencies lower than adult means and, therefore, might be considered to have completed voice change. However, a low fundamental frequency, even within the adult range, may not be sufficient, in itself, to signify the completion of voice change. This might suggest that pubertal voice change may take longer than the 3-6 months that is frequently reported in the literature. Additionally, it may mean that laryngeal efficiency, in terms of control and stability, lags behind the establishment of the lowered pitch.

Recommendations for Future Research

In light of the preceding findings and conclusions, future research might include the following:

1. Expand the exploration of aerodynamic measures of adolescent males not only to a larger population but also to a wider age range of adolescent males.
2. Investigate vocal function parameters of the adolescent female. Since the female adolescent's voice is thought to develop rather than to undergo the physiological change characteristic of the male adolescent, a comparative investigation may help support the above findings and conclusions. However, an investigation of

the female adolescent voice may be interesting in itself since choral music directors (Huff-Gackle, 1985) have suggested that females also undergo laryngeal readjustments during pubertal development.

3. Explore air flow characteristics during vocal initiation and termination of phonation in adolescent males. Such a study would provide additional information regarding male adolescent vocal function in terms of voice onset, type of vocal attack, and air flow and air volume changes.
4. Obtain laryngoscopic examinations, stroboscopic observations, and/or high speed cinematographic recordings coupled with measurements of aerodynamic activity to ascertain the nature of the physiological and anatomical changes experienced by males undergoing pubertal voice change.
5. Evaluate sub-glottic air pressure of adolescent males in order to have a more complete understanding of the forces that maintain and regulate flow during air consumption.

APPENDIX A

APPENDIX A

INSTRUCTIONS

As you have previously been told, the purpose of this study is to obtain from normal boys of your age measures that show how much air you can inhale into your lungs and how well you can control that air stream when you breathe out and produce sounds. Four measures of vocal function will be taken. For two of the measures this instrument, a respirometer, will be used; the other two will be measured with a stop-watch and will be recorded. In order to capture your air flow a face mask like this will be used. Let's try it now to show you how it fits and to make sure that the mask does not allow air leakage. [Face mask will be tried for fit and comfort.]

Before each task I will explain and demonstrate what you are to do. You will have one practice of each task. You will rest between each task trial and you will have a five minute break between each task. When the first two tasks have been completed, you will complete a scale asking you to identify associated vocal change characteristics that you are presently exhibiting. O.K. Unless you have some questions, we'll start the tasks.

[Order of presentation of the tasks was counter-balanced across subjects.]

Vital Capacity : In this task, called vital capacity, I want to see what is the maximum amount of air that you can take into your lungs and breathe out again. You will take as deep a breath as possible and then blow the air all out. This will be measured with the respirometer.

Let's try it. Take as deep a breath as possible and then blow it all out. Like this. [Experimenter demonstrates for subject.] Now you try it. [With all tasks, if the subject was successful, the experimenter moved on to the next instructions. If the subject had any difficulty with the task, the experimenter continued working with the subject using these instructions until the subject could successfully perform the task.] That was easy, wasn't it? Now let's take the measurements. You will have three trials with a rest between each trial. Let's put the mask in place. [Experimenter assured an appropriate fit.] O.K. First just relax and get used to the mask. Now when you are ready take as deep a breath as possible and then blow all the air out. That's right, all of the air out. Good. Let's rest and then try that again. O.K. Are you ready? Remember take in as much air as you possibly can. Now blow all the air out. Very good! Now we'll do that one more time. O.K.

Ready? Take in all the air you can; now blow it all out. Great!

Maximum Phonation of [ɑ] : In this task I want to see how long you can produce the vowel [ɑ] on one exhalation. This task will be measured with the respirometer. You must take as deep a breath as possible and then immediately produce [ɑ] for as long as possible.

Let's try it. Take as deep a breath as possible. As you breathe out, produce [ɑ] for as long as you can. When you say [ɑ], use your normal voice -- that is a comfortable and natural pitch and loudness level. Here is how I want you to do it. [Experimeter demonstrates.] Now you try it. O.K. Now let's take the measurements. You will have three trials with a rest between each trial. Let's put the mask in place. Okay. Take as deep a breath as possible. As you breathe out say [ɑ] for as long as possible. Remember I want you to use your normal natural voice. Good. Let's rest and then try again. Okay, ready? Breathe deeply and say [ɑ] as long as you possibly can. Excellent. Now the last trial. Take in all the air you can and say [ɑ] for as long as possible. Nice job!

[After the first two tasks the vocal change scale was administered.]

Maximum Phonation of [s] : In this task I want to see how long you can sustain [s] on one exhalation. The respirometer will not be used for this task. You are to take as deep a breath as possible and then immediately produce [s] for as long as possible.

Let's try it. Take as deep a breath as possible. When you produce [s], use your normal voice -- that is a comfortable and natural pitch and loudness level. As you breathe out, produce [s] for as long as you can. Like this. [Experimenter demonstrates.] Now you try it. O.K. Now we'll take the measurements. You will have three trials with a rest between each trial. Ready? Take a deep breath and produce [s] for as long as possible. Remember to use your normal natural voice. That was good. Rest and then try again. Okay. Ready? Breathe deeply and produce [s] as long as you possibly can. Great. Now let's do the last trial. Take in all the air you can; say [s] for as long as possible. Terrific!

Maximum Phonation of [z] : The instructions used for maximum phonation of [s] were used for [z].

APPENDIX B

APPENDIX B

VOICE CHANGE SCALE

Subject______________________________ Age_______________

Answer the following statements as they pertain to you today. Select one of the following five choices.

1 - I strongly agree
2 - I sort of agree
3 - I don't know
4 - I sort of disagree
5 - I strongly disagree

Sample Question

I can run faster now than I could 6 months ago.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

The statement asks you to think about your speed in running today and to compare it with your rate of running over the past 6 months. If you feel that you are faster today than you were within the past 6 months circle 1. If you think you may be faster but you are not sure circle 2. If you do not know whether you can run faster, circle 3. If you don't think you are faster, but you are not sure circle 4. If you know that there is no change in your running speed, circle 5.

Do you understand what you are to do? Do you have any questions? Mark your answer to the sample question.

Now read or follow along as the examiner reads the following statements. Circle the appropriate answer. Remember that you are to answer as it relates to you today. If you do not know a word or do not understand what the statement means be sure to ask the examiner.

1. I am aware that my voice within the past 6 months has been changing.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

2. I have sometimes experienced pitch breaks in my voice [cracking, squeaking sounds, or abrupt changes in pitch or voice] within the past 6 months.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

3. My voice has a hoarse-husky quality that it did not have 6 months ago.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

4. My voice is lower than it was 6 months ago.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

5. I have more hair on my body [especially pubic hair] than I did 6 months ago.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

6. I am no longer able to sing high notes in songs like I used to 6 months ago.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

7. Singing, in general, is more difficult than it was 6 months ago.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

8. Within the past 6 months, I have experienced a sharp or rapid increase in weight.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

9. Within the past 6 months, I have experienced a sharp or rapid increase in height.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

10. Within the past 6 months, I have experienced a increase in the size of my genitals [penis and testicles].

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

11. My body has become more muscular within the past 6 months.

1	2	3	4	5
strongly agree	sort of agree	don't know	sort of disagree	strongly disagree

APPENDIX C

VOICE CHANGE SCALE - 11 YEAR OLD MALES

	Voice Change Scale Questions												
Subject	1	2	3	4	5	6	7	8	9	10	11	Total	Mean
11-1	2	1	5	2	1	1	5	1	5	1	2	26	2.36
11-2	3	5	5	5	2	4	5	5	4	5	2	45	4.20
11-3	3	3	5	2	1	2	1	1	2	3	1	24	1.88
11-4	1	1	2	5	2	1	1	1	2	2	1	19	1.73
11-5	2	2	5	2	5	5	5	5	1	5	1	38	3.45
11-6	3	5	5	5	2	5	5	5	1	3	1	40	4.00
11-7	2	2	4	3	3	2	5	3	3	4	2	33	3.00
11-8	4	2	4	3	5	4	3	5	4	5	5	44	4.22
11-9	3	4	5	3	2	4	5	4	3	3	2	38	3.71
11-10	5	5	3	5	5	3	3	3	2	3	2	39	4.00

VOICE CHANGE SCALE - 13 YEAR OLD MALES

Subject	Voice Change Scale Questions											Total	Mean
	1	2	3	4	5	6	7	8	9	10	11		
13-1	3	2	2	3	1	2	3	3	1	2	3	25	1.66
13-2	2	1	5	1	3	1	2	5	2	3	2	27	2.33
13-3	3	4	2	1	2	1	5	5	2	3	2	30	2.67
13-4	3	4	2	3	2	1	2	5	4	3	1	30	2.62
13-5	2	5	4	2	2	5	5	5	1	2	3	36	3.30
13-6	1	1	2	1	2	5	4	5	2	3	1	27	2.40
13-7	2	1	3	1	2	1	1	5	2	3	3	24	1.88
13-8	2	3	3	2	2	1	5	2	2	2	1	25	2.11
13-9	3	3	3	3	2	3	3	5	2	3	2	32	1.57
13-10	3	4	3	2	1	2	3	2	2	2	2	26	2.13

VOICE CHANGE SCALE - 15 YEAR OLD MALES

	Voice Change Scale Questions												
Subject	1	2	3	4	5	6	7	8	9	10	11	Total	Mean
15-1	5	4	5	5	1	5	5	2	2	2	1	38	3.45
15-2	3	1	3	2	2	3	5	2	2	3	3	29	2.33
15-3	2	1	2	2	2	5	5	5	1	4	4	33	3.00
15-4	4	4	4	4	4	2	2	3	2	4	4	37	3.40
15-5	1	1	1	2	3	1	1	2	1	2	2	17	1.40
15-6	5	5	5	4	1	2	2	5	4	2	1	36	3.73
15-7	1	3	4	1	1	1	3	2	1	1	1	19	1.44
15-8	1	2	2	2	1	2	5	5	4	2	2	28	2.54
15-9	1	4	1	1	1	3	3	5	1	2	2	23	1.89
15-10	4	5	4	5	4	3	3	5	1	5	1	41	3.89

VOCAL FUNCTION MEASURES - 11 YEAR OLD MALES

Subject	Age	HT	VC	PV	MPT	MFR	PV/VC
11-1	11.8	59.5	2175	2000	14.00	142.86	.919
11-2	11.6	61.5	3000	2175	20.00	108.75	.725
11-3	11.7	57.0	2300	2085	18.00	115.83	.906
11-4	11.3	58.75	2450	2090	12.00	174.17	.853
11-5	11.3	59.0	2850	2750	20.50	134.39	.965
11-6	11.5	60.0	2650	2475	16.50	150.00	.934
11-7	11.4	57.5	2075	2065	22.50	91.78	.995
11-8	11.9	61.5	2600	2095	22.50	93.11	.806
11-9	11.5	54.5	1680	1450	19.75	73.42	.863
11-10	11.3	57.0	2100	1875	19.50	96.16	.893
Mean	11.5	58.6	2388	2106	18.52	118.05	.8859
SD	.22	2.2	400.1	342.1	3.46	31.49	.0788

11 YEAR OLD MALES (Cont)

Subject	PQ	VVI	S	Z	S/Z	f_o
11-1	155.36	15.22	28.48	24.64	1.16	204
11-2	150.00	27.58	15.32	27.40	.56	218
11-3	127.78	19.86	23.68	27.80	.85	216
11-4	204.17	14.07	15.72	20.06	.78	224
11-5	139.02	21.21	25.30	25.64	.99	212
11-6	160.61	17.67	21.71	22.32	.97	214
11-7	92.22	22.61	23.17	26.72	.87	224
11-8	115.56	27.92	26.62	28.32	.95	236
11-9	85.06	22.88	15.33	19.82	.77	238
11-10	107.69	21.84	19.71	25.42	.78	224
Mean	133.75	21.09	21.50	24.81	.87	221
SD	35.87	4.62	4.82	3.10	.16	10.5

VOCAL FUNCTION MEASURES - 13 YEAR OLD MALES

Subject	Age	HT	VC	PV	MPT	MFR	PV/VC
13-1	13.5	64.00	3195	2875	22.00	130.68	.905
13-2	13.7	66.00	3275	2750	18.00	152.78	.840
13-3	13.3	64.00	2800	2450	18.00	136.11	.875
13-4	13.3	64.00	2810	2350	16.00	146.87	.836
13-5	13.6	62.00	3275	3100	21.50	144.19	.946
13-6	13.4	62.00	3300	2900	31.00	93.55	.879
13-7	13.5	64.00	3425	3245	14.50	223.79	.947
13-8	13.4	64.00	2850	2025	24.00	84.37	.710
13-9	13.3	63.00	2660	1480	24.00	61.67	.556
13-10	13.3	62.00	2250	1795	27.50	65.27	.798
Mean	13.4	63.50	2934	2497	21.65	123.93	.829
SD	.14	1.27	370.3	583.7	5.19	49.15	.119

13 YEAR OLD MALES (Cont)

Subject	PQ	VVI	S	Z	S/Z	f_o
13-1	145.23	24.45	23.05	24.30	.95	210
13-2	181.94	21.44	13.69	19.19	.71	178
13-3	155.56	20.57	18.22	22.68	.80	148
13-4	175.62	19.13	17.47	23.07	.76	146
13-5	152.32	22.71	17.90	19.53	.92	186
13-6	106.45	35.28	23.94	30.53	.78	198
13-7	236.21	15.30	20.51	14.44	1.42	158
13-8	118.75	33.78	33.76	34.74	.97	238
13-9	110.83	43.13	28.36	24.96	1.14	198
13-10	81.82	34.47	36.67	32.96	1.11	218
Mean	146.47	27.03	23.36	24.64	.96	187.8
SD	44.84	8.98	7.48	6.43	.22	30.6

VOCAL FUNCTION MEASURES - 15 YEAR OLD MALES

Subject	Age	HT	VC	PV	MPT	MFR	PV/VC
15-1	15.3	70.5	4600	3750	24.00	156.25	.815
15-2	15.6	70.0	3920	3750	21.50	174.42	.957
15-3	15.7	69.0	3315	2305	22.00	104.77	.695
15-4	15.6	67.0	4025	3430	23.00	149.13	.852
15-5	15.4	72.0	4550	4075	19.00	214.47	.775
15-6	15.3	68.0	4075	3525	25.00	141.00	.865
15-7	15.3	67.0	3750	3560	14.00	254.28	.949
15-8	15.6	71.5	4825	4350	22.00	197.73	.901
15-9	15.3	68.0	2900	2150	17.00	66.18	.741
15-10	15.6	68.0	3675	3275	18.00	181.94	.891
Mean	15.5	69.1	3954	3417	20.55	164.02	.844
SD	.16	1.80	595.3	700.8	3.45	53.91	.087

15 YEAR OLD MALES (Cont)

Subject	PQ	VVI	S	Z	S/Z	f_o
15-1	191.67	29.41	28.00	39.21	.71	100
15-2	182.32	22.47	24.27	29.70	.82	112
15-3	150.68	31.64	28.78	26.69	.97	120
15-4	175.00	26.99	36.77	37.87	.97	82
15-5	239.47	21.22	29.74	25.00	1.18	138
15-6	163.00	28.90	36.40	27.96	1.30	126
15-7	267.86	14.75	15.64	20.77	.75	144
15-8	219.32	24.40	19.15	24.66	.78	118
15-9	170.59	43.82	16.95	21.75	.78	158
15-10	204.17	20.20	24.66	25.00	.99	160
Mean	196.40	26.38	26.04	28.16	.92	125.8
SD	36.66	7.94	7.38	6.23	.20	24.9

LIST OF REFERENCES

LIST OF REFERENCES

Amerman, J. & Williams, D. (1979). Implications of respirometric evaluation for diagnosis and management of vocal fold pathologies. British Journal of Disorders of Communication, 14, 153-160.

Aristotle, (1910). De Animabilus Historiae, Book VII. 581a (D. Thompson, Trans.) In J. Smith and W. Ross (Eds.), The Works of Aristotle. Oxford: Clarendon Press.

Aronson, A. (1980). Clinical Voice Disorders, New York: Thieme-Stratton.

Arnold, G. (1955). Vocal rehabilitation of paralytic dysphonia. Archives of Otolaryngology, 62, 593-601.

Baynes, R. (1966). An incident study of chronic hoarseness with voice disorders. Journal of Speech and Hearing Disorders, 31, 172-176.

Beckett, R. (1971). The respirometer as a diagnostic and clinical tool in the speech clinic. Journal of Speech and Hearing Disorders, 36, 235-241.

Beckett, R., Thoeleke, W., & Cowan, L. (1971). A normative study of airflow in children. British Journal of Disorders of Communication, 6, 13-16.

Bennett, S. (1983). A 3 year longitudinal study of school-aged children's fundamental frequencies. Journal of Speech and Hearing Research, 26, 137-142.

Bennett, S. (1982). A four-year longitudinal study of school-aged children's fundamental frequencies. Paper presented at the American Speech and Hearing Association Annual Convention - Toronto.

Bless. D. (1971). Maximum phonation time, air flow rate, and air volume during phonation: Normative information on third grade children. Unpublished doctoral dissertation, University of Wisconsin - Madison.

Boone, D. (1971). The Voice and Voice Therapy (1st ed.). Englewood Cliffs, NJ: Prentice Hall.

Boone, D. (1983). The Voice and Voice Therapy (3rd ed.). Englewood Cliffs, NJ: Prentice Hall.

Bosma, J. (1975). Anatomic and physiologic development of the speech apparatus. In D. Tower (Ed.), The Nervous System. Volume 3: Human Communication and Its Disorders (pp. 469-499). New York: Raven Press.

Brodnitz, F. (1962). The voice of the speaker and singer. In N. Levin (Ed.), Voice and Speech Disorders: Medical Aspects (pp. 429-452). Springfield, IL: Charles C. Thomas.

Brodnitz, F. (1971). Vocal Rehabilitation, Rochester, MN: American Academy of Ophthalmology and Otolaryngology.

Case, J. (1984). Clinical Management of Voice Disorders, Rochville, MD: Aspen Systems Corporation.

Cavagna, G. & Margaria, R. (1968). Airflow rates and efficiency changes during phonation. Annuals of the New York Academy of Sciences, 55, 152-163.

Collins, D. (1982). The cambiata concept-more than just about changing voices. Choral Journal, 23 , 5-9.

Cook, C., Helliesen, P., & Agathon, S. (1958). Relation between mechanics of respiration, lung size and body size from birth to young adulthood. Journal of Applied Physiology, 13, 349-352.

Cooper, I. (1964). A study of boys' changing voices in Great Britian. Music Educators Journal, 51, 118-120.

Cooper, M. (1973). Modern Techniques of Vocal Rehabilitation. Springfield, IL: Charles C. Thomas.

Curry, E. (1940). The pitch characteristics of the adolescent male voice. Speech Monographs, 7, 48-62.

Curry, E. (1946). Voice changes in male adolescents. The Laryngoscope, 56, 795-805.

Curry, E. (1949). Hoarseness and voice change in male adolescents. Journal of Speech and Hearing Disorders, 14, 23-25.

Eckel, F. & Boone, D. (1981). The s/z ratio as an indicator of laryngeal pathology. Journal of Speech and Hearing Disorders, 46, 147-149.

Eguchi, S. & Hirsh, I. (1969). Development of speech sounds in children. Acta Otolaryngologica, Supplement 257.

Ellis, M. (1959). Remarks on dysphonia. Journal of Laryngology and Otology, 73, 99-103.

Fairbanks, G. (1960). Voice and Articulation Drillbook (2nd ed.). New York: Harper and Brothers.

Fairbanks, G., Wiley, J. & Lassman, F. (1949). An acoustical study of vocal pitch in seven-and eight-year-old boys. Child Development, 20, 63-69.

Finnegan, D. (1984). Maximum phonation time for children with normal voices. Journal of Communication Disorders, 19, 309-317.

Goodhart, R. & Shils, M. (1980). Modern Nutrition in Health and Disease, (6th ed.). Philadelphia: Lea & Febiger.

Gould, W. (1975). Quantitative assessment of voice function in microlaryngology. Folia Phoniatricia, 27, 190-200.

Greene, J. (1921). The falsetto voice in the male-with a demonstration of four cured cases. Laryngoscope, 31, 33-41.

Greene, M. (1972). The Voice and its Disorders, 3rd ed.). Philadelphia: Lippincott.

Greene, M. (1980). The Voice and its Disorders, (4th ed.). Philadelphia: Lippincott.

Hartlieb, K. (1957). Der Umfang der Jugendstimme. Folia Phoniatricia, 9, 225-232.

Harrington, R. (1950). Children with voice disorders. In W. Johnson (Ed.), Speech Problems of Children (pp. 190-203). New York: Grune and Stratton.

Hasek, C., Singh, S., & Murry, T. (1980). Acoustic attributes of preadolescent voices. Journal of the Acoustical Society of America, 68, 1262-1265.

Hirano, M., Koike, Y. & von Leden, H. (1968). Maximum phonation time and air usage during phonation. Folia Phoniatricia, 20, 185-201.

Hollien, H. (1977). The registers and ranges of the voice. in Cooper M. & Cooper, M. (Eds.), Approaches to Vocal Rehabiliation (pp. 76-121). Springfield, IL: Charles C. Thomas.

Hollien, H., Dew, D., & Phillips, P. (1971). Phonational frequency ranges of adults. Journal of Speech and Hearing Research, 14, 755-760.

Hollien, H. & Jackson, B. (1973). Normative data on the speaking fundamental frequency characteristics of young adult males. Journal of Phonetics, 1, 117-120.

Hollien, H. & Malcik, E. (1962). Adolescent voice change in southern negro males. Speech Monographs, 29, 53-58.

Hollien, H. & Malcik, E. (1967). Evaluation of cross-sectional studies of adolescent voice change in males. Speech Monographs, 34, 80-84.

Hollien, H., Malcik, E. & Hollien, B. (1965). Adolescent voice change in southern white males. Speech Monographs, 32, 87-90.

Hollien, H. & Shipp, T. (1972). Speaking fundamental frequency and chronologic age in males. Journal of Speech and Hearing Research, 15, 155-159.

Horii, Y. (1983). Some acoustic characteristics of oral reading by ten-to twelve-year old children. Journal of Communication Disorders, 16, 257-267.

Horii, Y. (1975). Some statistical characteristics of voice fundamental frequency. Journal of Speech and Hearing Research, 18, 192-201.

Huff-Gackle, L. (1985). The young adolescent female voice (ages 11-15): Classification, placement, and development of tone. Choral Journal, 25, 15-18.

Isshiki, N. (1964). Regulatory mechanism of voice intensity variation. Journal of Speech and Hearing Research, 7, 17-29.

Isshiki, N. (1965). Vocal intensity and air flow rate. Folia Phoniatricia, 17, 92-104.

Isshiki, N., Okamura, H., & Morimoto, M. (1969). Maximum phonation time and airflow rate during phonation: Some clinical tests for vocal function. Annals of Otology, Rhinology and Laryngology, 76, 998-1008.

Isshiki, N. & von Leden, H. (1964). Hoarseness: Aerodynamic studies. Archives of Otolaryngology, 80, 206-213.

Isshiki, N., Yanagihara, N. & Morimoto, M. (1966). Approach to the objective diagnosis of hoarseness. Folia Phoniatricia, 18, 393-400.

Iwata, S. & von Leden, H. (1970a). Clinical evaluation of vocal velocity index in laryngeal disease. Annals of Otology, Rhinology and Laryngology, 79, 259-268.

Iwata, S. & von Leden, H. (1970b). Phonation quotient in patients with laryngeal diseases. Folia Phoniatricia, 22, 117-128.

Iwata, S. von Leden, H., & Williams, D. (1972). Air flow measurement during phonation. Journal of Communication Disorders, 5, 67-79.

James H. & Cooper, C. (1966). Accuracy of teacher referrals of speech handicapped chidren. Exceptional Child, 33, 29-33.

Jerome, E. (1937). Change of voice in male adolescents. Quarterly Journal of Speech, 23, 648-653.

Joseph, W. (1965). A summation of the research pertaining to vocal growth. Journal of Research in Music Education, 13, 93-100.

Joseph, W. (1966). Vocal growth in the human adolescent and the total growth process. Journal of Research in Music Education, 14, 135-141.

Joseph, W. (1977). Vocal growth measurement in male adolescents, Journal of Research in Music Education, 15, 423-426.

Kahane, J. (1978). A morphological study of the human prepubertal and pubertal larynx. American Journal of Anatomy, 151, 11-20.

Kahane, J. (1982). Anatomy and physiology of the organs of the peripheral speech mechanism. In Lass, N., McReynolds, L., Northern, J. & Yoder, D. (Eds.), Speech, Language, and Hearing, Volume 1: Normal Processes (109-155). Philadelphia: W.B. Saunders.

Kahane, J. (1982). Growth of the human prepubertal and pubertal larynx. Journal of Speech and Hearing Research, 25, 446-455.

Kallen, L. (1959). What is "optimal" for the human voice?. Logos, 2, 40-48.

Kelman, A., Gordon, M., Morton, F. & Simpson, I. (1981). Comparison of methods for assessing vocal function. Folia Phoniatricia, 33, 51-65.

Kent, R. (1976). Anatomical and neuromuscular maturation of the speech mechanism: Evidence from acoustical studies. Journal of Speech and Hearing Research, 19, 421-447.

Koike, Y. & Hirano, M. (1968). Significance of vocal velocity index. Folia Phoniatricia, 20, 285-296.

Koike, Y., Hirano, M., & von Leden, H. (1967). Vocal initiation: Acoustic and aerodynamic investigations of normal subjects. Folia Phoniatricia, 19, 172-182.

Koike, Y. & von Leden, H. (1967). Respiration and phonation: The functional examination of laryngeal disease. Folia Phoniatricia, 19, 153-166.

Launer, P. (1971). Maximum phonation time in children. Unpublished master's thesis, State University of New York at Buffalo.

Leeper, H. (1971). A clinical evaluation of laryngeal efficiency measures of children with vocal dysfunction. Paper presented at the American Speech and Hearing Association Annual Convention - Chicago.

Lieberman, P., Harris, K., Woolff, P., & Russell, L. (1971). Newborn infant cry and nonhuman primate vocalization. Journal of Speech and Hearing Research, 14, 718-727.

Luchsinger, R. & Arnold, G. (1965). Voice-Speech-Language. Belmont: Wadsworth Publishing Co.

Malinowski, A. (1967). Shape, dimensions, and process of calcification of the cartilagious framework of the larynx in relation to age and sex in the polish population. Folia Morphologica, 26 ,118-128.

Marshall, W. & Tanner, J. (1970). Variations in the pattern of pubertal changes of boys. Archives of Disease in Childhood, 45 ,13-23.

Moses, P. (1940). Is medical phonetics an essential part of otorhinolaryngology? Archives of Otolaryngology, 31, 444-450.

Murphy, A. (1964). Functional Voice Disorders, Englewood Cliffs, NJ: Prentice-Hall.

Naidr, V., Zboril, M. & Sevcik, K. (1965). Die pubertalen veranderungen der stimme bei jungen im verlauf van 5 jahren. Folia Phoniatricia, 17, 15-18.

Negus, V. (1949). The Comparative Anatomy and Physiology of the Larynx. London: W. S. Cowell.

Noback, G. (1923). The developmental topography of the larynx, trachea and lungs in the fetus, new-born, infant and child. American Journal of Diseases of Children, 26, 515-533.

Olsen, B., Perez, D., Burk, K., & Platt, J. (1969). Respiratory-phonatory study of children with and without vocal nodules. Paper presented at the American Speech and Hearing Association Annual Convention - Chicago.

Pedrey, C. (1945). A study of voice change in boys between the ages of eleven and sixteen. Speech Monographs, 12, 30-36.

Platt, L., Harris, T., Burk, K., Perez, D. & Grizzel, B. (1975). Maximum phonation time and mean air flow rate of children with and without vocal nodules. The Journal Kansas Speech and Hearing Association, 15, 49-55.

Pont, C. (1965). Hoarseness in children. Western Michigan University Journal of Speech Therapy, 2, 6-8.

Pronovost, W. (1942). An experimental study of methods for determining natural and habitual pitch. Speech Monographs, 9, 111-123.

Ptacek, P. & Sander, E. (1963a). Maximum duration of phonation. Journal of Speech and Hearing Disorders, 28, 171-182.

Ptacek, P. & Sander, E. (1963b). Breathiness and phonation length. Journal of Speech and Hearing Disorders, 28, 267-27

Rastatter, M. & Hyman, M. (1982). Maximum phoneme duration of [s] and [z]. Language, Speech, and Hearing Services in Schools, 13, 197-199.

Roche, A. & Barkla, D. (1965). The level of the larynx during childhood. Annals of Otology, Rhinology, and Laryngology, 74, 646-654.

Silverman, S. & Wilson, F. (1975). Incidence of chronic hoarseness among school-age children. Journal of Speech and Hearing Disorders, 40, 211-215.

Senturia, B. & Wilson, F. (1968). Otorhinolaryngologic findings in children with voice deviations: Preliminary report. Annals of Otology, Rhinology, and Laryngology, 77, 1027-1042.

Tait, N., Michel, J., & Carpenter, M. (1980). Maximum duration of sustained [s] and [z] in children. Journal of Speech and Hearing Disorders, 45, 239-246.

Taranger, J. & Hagg, U. (1980). Clinical evaluation of the occurrence of the various periods of adolescent growth by means of maturity indicators. In E. Cacciari, & A. Prader. (Eds). Pathophysiology of Puberty. New York: Academic Press.

Tosi, O., Postan, D., & Bianculli, C. (1974). Longitudinal study of children's voice at puberty. XVIth International Congress of Logepedics and Phoniatrics. Interlaken, 486-490.

van Doordt, H. & Drost, H. (1963). Development of the frequency range of the voice in children. Folia Phoniatricia, 15, 289-298.

Van Riper, C. (1954). Speech correction, principles and methods (3rd ed). Englewood Cliffs: Prentice-Hall.

Van Riper, C. (1972). Speech correction, principles and methods (5th ed). Englewood Cliffs: Prentice-Hall.

Van Riper, C. & Emerick, L. (1984). Speech correction: An introduction to speech pathology and audiology. Englewood Cliffs: Prentice-Hall.

Vuorenkoski, V., Lenko, H., Tjernlund, P., Vuorenkoski, L. & Perheentupa, J. (1978). Fundamental voice frequency during normal and abnormal growth, and after androgen treatment. Archives of Disease in Childhood, 53, 201-209.

Warr-Leeper, G., McShea, R., & Leeper, H. (1979). The incidence of voice and speech deviations in a middle school population. Language, Speech, and Hearing Services in Schools, 4, 14-22.

Weiss, D. (1950). The pubertal change of the human voice. Folia Phoniatricia, 2, 126-159.

West, R. (1927). The nature of the laryngeal vibration. Archives of Otolaryngology, 5, 385-393.

White, F. (1946). Some causes of hoarseness in children. Annals of Otology, Rhinology, Laryngology, 55, 537-542.

Wilkins, L. (1965). The Diagnosis and Treatment of Endocrine Disorders in Childhood and Adolescence. Springfield, IL: Charles C. Thomas.

Wilson, D. (1971). Emotional stress may cause voice anomalies in kids. Journal of American Medical Association, 216, 2085.

Wilson, D. (1979). Voice Problems of Children. Baltimore: Williams & Wilkins.

Wilson, T. (1953). Some observations on the anatomy of the infantile larynx. Acta Otolaryngologica, 43, 95-99.

Yairi, E., Horton Currin, L., Bulian, N., & Yairi, J. (1974). Incidence of hoarseness in school children over a 1 year period. Journal of Communication Disorders, 7, 321-328.

Yanagihara, N. & Koike, Y. (1967). The regulation of sustained phonation. Folia Phoniatricia, 19, 1-18.

Yanagihara, N., Koike, Y., & von Leden, H. (1966). Phonation and respiration: Function study in normal subjects. Folia Phoniatricia, 18, 323-340.

Yanagihara, N. & von Leden, H. (1967). Respiration and phonation: The functional examination of laryngeal disease. Folia Phoniatrica, 19, 153-166.

Zemlin, W. (1981). Speech and Hearing Science (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.