7-11-1977

Mercury Strain Gauge Assessment of Lung Volume Partitions During Speech

Michael Susca

THE UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO 87131

Policy on Use of Theses and Dissertations

Unpublished theses and dissertations accepted for master's and doctor's degrees and deposited in the University of New Mexico Library are open to the public for inspection and reference work. *They are to be used only with due regard to the rights of the authors.* The work of other authors should always be given full credit. Avoid quoting in amounts, over and beyond scholarly needs, such as might impair or destroy the property rights and financial benefits of another author.

To afford reasonable safeguards to authors, and consistent with the above principles, anyone quoting from theses and dissertations must observe the following conditions:

1. Direct quotations during the first two years after completion may be made only with the written permission of the author.

2. After a lapse of two years, theses and dissertations may be quoted without specific prior permission in works of original scholarship provided appropriate credit is given in the case of each quotation.

3. Quotations that are complete units in themselves (e.g., complete chapters or sections) in whatever form they may be reproduced and quotations of whatever length presented as primary material for their own sake (as in anthologies or books of readings) ALWAYS require consent of the authors.

4. The quoting author is responsible for determining "fair use" of material he uses.

This thesis/dissertation by Michael Susca has been used by the following persons whose signatures attest their acceptance of the above conditions. (A library which borrows this thesis/dissertation for use by its patrons is expected to secure the signature of each user.)

NAME AND ADDRESS DATE

NAME AND ADDRESS	DATE

7/76-500

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of The University of New Mexico in partial fulfillment of the requirements for the degree of

Master of Science

MERCURY STRAIN GAUGE ASSESSMENT OF
LUNG VOLUME PARTITIONS
DURING SPEECH

Title

Michael Susca

Candidate

Communicative Disorders

Department

David T. Benedetti

Dean

July 11, 1977

Date

Committee

Wayne E. Swisher

Chairman

John I. Dybalt

Fred M. Chreist, Sr.

MERCURY STRAIN GAUGE ASSESSMENT OF LUNG VOLUME PARTITIONS DURING SPEECH

BY
MICHAEL SUSCA
B.A., University of California at Santa Barbara, 1975

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in
Communicative Disorders
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico

August, 1977

To

Lisa Lynn

whose love is patient, is kind. . . .

ACKNOWLEDGMENTS

I wish to thank Dr. Wayne E. Swisher, whose support, enthusiasm, and patience while directing this thesis was greatly appreciated. The experience of learning from him during the past two years has made my graduate studies worthwhile.

I wish also to thank Dr. John T. Lybolt and Dr. Fred M. Chreist, Sr., for serving on my committee. Their time and comments were appreciated.

Special thanks go to my family, especially my mother and father. Without my parents' selfless emotional and financial support, my graduate studies would not have been possible.

Lastly, I would like to thank each of the men who served as subjects in this study.

MERCURY STRAIN GAUGE ASSESSMENT OF
LUNG VOLUME PARTITIONS
DURING SPEECH

BY
Michael Susca

ABSTRACT OF THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in
Communicative Disorders
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico

August, 1977

MERCURY STRAIN GAUGE ASSESSMENT OF
LUNG VOLUME PARTITIONS
DURING SPEECH

Michael Susca, M.S.
Department of Communicative Disorders
The University of New Mexico, 1977

The primary purpose of this study was to see if the mercury strain gauge could be used to assess lung volume partitions from chest wall motions. The air supply within any given lung volume provides the basic foundation upon which speech respiratory events rest. By assessing lung volumes in speech, the speech clinician is aided in the diagnosis and treatment of inappropriate uses of speech respiration.

Although lung volumes have been assessed by a variety of instrumentation, only the respirometer has been widely used in speech physiology research. The major disadvantages of the respirometer over the mercury strain gauge are: 1) reduced measurement accuracy from the mechanical impedance between airflow and the kymograph, 2) oxygen consumption, 3) back-pressure against the airstream, 4) finite time use, and 5) high initial cost.

A six inch mercury strain gauge was placed on the chest wall of each of seven healthy adult males. Each subject calibrated body surface displacements measured by

the strain gauge to five 20 percent partitions of lung volume simultaneously monitored by a respirometer. The recording of body surface displacements was stored on a model 5103N Tektronix two channel storage oscilloscope and photographed with a polaroid camera. After the calibration procedure, the respirometer was removed and each subject did the following experimental tasks:

1. Three vital capacity maneuvers.

2. Quiet tidal breathing.

3. Prolongation of the vowel /a/ from total lung volume to residual volume on three repeated trials.

4. Repetition of the syllable /tʌ/ from total lung volume to residual volume on three repeated trials.

5. Repetition of the syllable /sʌ/ from total lung volume to residual volume on three repeated trials.

6. Oral reading of the first five sentences of "The Rainbow Passage."

Test-retest reliability measurements were conducted on three subjects on two separate days. Quantitative measurements of lung volume partitions were made from the photographs of the calibration and experimental tasks.

The body surface displacements for each 20 percent partition of lung volume were similar across all subjects. The mean percentage of lung volume used during a) quiet tidal breathing was 13 percent, b) prolongation of the vowel /a/ was 100 percent, and c) reading was 26 percent.

The mean differences in the time to repeat the syllables /tʌ/ and /sʌ/ was 6.88 seconds.

The mean values for seven calculations related to airflow were 27.02 increments for vital capacity, 27.19 increments for phonation volume, 25.93 seconds for phonation time, 1.18 increments per second for mean flow rate, .04 increments squared per second for vocal velocity index, .18 for maximum predicted phonation time, and 153.34 for the ratio of phonation time to maximum predicted phonation time.

The means of the inter- and intra-subject reliability coefficients were at or above .80 for all assessments made from the calibration and experimental tasks.

This study concludes that the mercury strain gauge can be used to assess lung volume partitions from chest wall motions during speech. The mercury strain gauge is inexpensive, reliable, easy to use, and overcomes many drawbacks of the respirometer when used for speech research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLE PAGE

CHAPTER I

INTRODUCTION

Since his beginning, man has relied on his respiratory processes to sustain life. This basic physiological need has been augmented with a unique ability--the ability to communicate with his fellow man via speech. Little was known, however, about the mechanics of speech respiration until the present century.

Speech physiologists have measured lung volume partitions via an assortment of apparatuses. These apparatuses have included respirometers (Beckett, 1971; Hoshiko, 1965), flowmeters (Hardy & Edmonds, 1968), body plethysmographs (Bouhuys, Proctor, & Mead, 1966; Draper, Ladefoged, & Whitteridge, 1959), linear differential transducers (Konno & Mead, 1967), and electromagnetic transducers (Hixon, Goldman, & Mead, 1973). In many cases, the researchers have provided data on the reliability and validity as well as the advantages, disadvantages, and range of applications of their equipment. Only the respirometer (Beckett, 1971) has been assessed for its clinical applicability.

In 1965, Shapiro and Cohen noted the practicability of using mercury capillary length gauges on the chest and abdomen to determine the volume of respired air in human subjects. Although the gauges were used to assess respiration for breathing, their use to assess respiration for various speech events is plausible. Since the mercury strain gauges are less obtrusive, less expensive, and may prove to be just as reliable as a respirometer, their implementation with individuals in the speech clinic is also plausible.

CHAPTER II

REVIEW OF THE LITERATURE

In a study to observe volume and pressure events in experienced and trained, experienced and untrained, and untrained singers, Bouhuys et al. (1966) measured lung volume displacement by means of a body plethysmograph. They found that a) volume changes in singing were related to vital capacity, b) soft tones sung at high lung volume required the ribcage to be held in a more inspiratory position (expanded more) than in quiet breathing, c) a larger proportion of vital capacity was used at higher intensities in speech, and d) lung volumes in spontaneous speech were often below functional residual capacity. In the Bouhuys et al. study, as in others which use body plethysmography to measure lung volumes, the validity of their measurements strongly rests on an adequate seal around the subject's body. Draper et al. (1959), in their electromyographic study of respiratory muscles used during speech, also used a body plethysmograph. A spirometer was attached to the body plethysmograph so simultaneous recordings of the displaced air (when subjects inhaled) could be made on a kymograph. A significant advantage of their technique was that a face mask was not used and, therefore, the subject's vocal processes were not obstructed.

Hoshiko (1965) used a respirometer to measure the percentage of vital capacity used by thirty males and thirty females at the onset of phonation. All subjects phonated in the standing position. He found that both sexes began phonating /a/ at approximately half of their vital capacities. He also noted that his values approximate end-inspiratory volumes in quiet breathing. Beckett (1971) reported on the clinically reliable use of respirometric measurements. He noted that timed phonation measures were more helpful indices to assessment of laryngeal pathology in adults than vital capacity measures alone. Beckett also reported that the respirometer is limited to measurements of large volumes and elongated time segments of speech in the speech clinic. These limitations are imposed by the various mechanical devices such as chains, drums, and ink pens on the respirometer which are subjected to inertia and frictional resistance and, therefore, reduce measurement accuracy.

Hardy and Edmonds (1968) discussed the disadvantages of using a respirometer. These disadvantages included 1) resistance to breathing, 2) mechanical impedance between a fast changing airflow (in some speech tasks) and the write-out system, 3) dead space (or air volumes not used), 4) a sloping write-out trace from oxygen consumption, and

5) finite time use. To overcome these disadvantages, Hardy and Edmonds discuss the use of an electronic integrator which is used with an airflow meter (such as a pneumotachograph). They discussed how volume measurements could be computed if airflow rate over a unit of time is known. Although their system could measure volume and airflow simultaneously with greater reliability than a respirometer, their system was subjected to various sources of error including 1) a small deviation in linearity of the pneumotachograph (resulting, they noted, in a larger error in volume calculation), 2) problems of electronic drift, and 3) reduced oral movements from a face mask.

In an effort to measure lung volume change by recording ribcage and abdominal displacement, Konno and Mead (1967) used linear differential transducers to measure anterior-posterior surface movement of the chest wall. These researchers found that the chest wall moved in two parts and that the ribcage moved more as a unit than the abdomen in all subjects. They also noted that if the total volume change and volume change of one part is known, then the contribution of the other volume part could be determined by subtraction. Using the theory established by Konno and Mead, Hixon et al. (1973) used the magnetometers to measure the contributions of the ribcage and abdomen to changes in lung volume during speech. Lung volumes were derived during conversation, reading, and singing tasks in both an upright and supine posture. The basic point of Hixon's study was the discovery of a "posture" from a relaxed wall configuration. From this "posture," subjects made minor chest wall distortions to "provide the rapid compressional volume change (pressure fluctuations) needed to drive the larynx and upper airway" (p. 113) during speech. Other findings by Hixon et al. during speech tasks included: 1) that lung volume is mostly restricted to the midrange of vital capacity in both postures, 2) expired volume usually constituted 10-20 percent of vital capacity between expiratory and inspiratory limbs, 3) the ribcage plays a lesser role in supine than upright position, 4) subjects used higher volumes at higher intensities, 5) both mechanical and linguistic factors influence lung volume, 6) relative contributions of the ribcage and abdomen vary between subjects and speech tasks, and 7) for sustained vowels and syllable repetition at the same volume, the abdomen diminished and the ribcage increased in size with faster and louder utterances. Although the information from Konno and Mead (1967) and Hixon et al. (1973) provided data needed from the laboratory, their respective instrumentations do not readily lend themselves to clinical use because of cost, availability, and the restriction of movement imposed on the subjects from the beginning to end of the measurements.

From a series of studies requiring a reliable method of monitoring amplitudes and rates of thoracic and abdominal breathing during sleep, dreaming, and psychiatric interviews, Shapiro and Cohen (1965) had a need for an unobtrusive device which could be fastened to (but light enough not to indent or displace) the skin of the chest or abdomen for calculation of volume of respired air. They presented a theory and mathematical model with the conclusion that:

> The volume of air moved by ribs and diaphragm together is proportional to a weighted average of the simultaneous changes in the squares of the circumference of chest and abdomen at fixed levels (p. 638).

To measure such changes in the circumference of the chest and abdomen, they presented a theory behind the use of mercury capillary length gauges. Further, they applied the gauges around the entire chest and abdomen of psychiatric patients to study the patients' breathing patterns. They concluded that the volume of respired air could be computed from the change in electrical resistance of the mercury capillary length gauges placed on the chest and abdomen. The change in electrical resistance of the mercury capillary length gauges was passed through a potentiometer, which was adjusted to give readings in liters. This electrical computing bridge was referred to as an "analog." In the Shapiro and Cohen (1965) study, they found a high agreement between spirometer readings and analog readings when measuring respired air in two subjects. Their measurements were taken "on plateaus" to minimize error from the inertia of the spirometer. They found the analog and spirometer readings agreed over a wide range of inspired air volumes. As noted above, they used mercury strain gauges which completely encircled the subject. The possibility of using smaller sized mercury strain gauges which do not encircle the subject remains unknown.

It should be noted that different terms have been used in the literature to denote various lung volumes and capacities. Therefore, a need arises to agree on the definitions used in this study concerning the subdivisions of lung volumes into partitions. This study will use the same terminology as used by Hixon, in Minifie et al. (1973). His terminology is illustrated in Appendix A and outlined as follows:

<u>Inspiratory reserve volume</u>: The amount of air that can be maximally inhaled from the end-inspiratory level.

<u>Expiratory reserve volume</u>: The largest volume of air that can be further expired from the resting expiratory level.

<u>Residual volume</u>: The directly unmeasurable amount of air remaining in the airways at the end of maximum expiration.

Inspiratory capacity: The maximum volume of air that can be inhaled from the resting expiratory level.

Vital capacity: The largest amount of air that can be expired from maximum inspiration.

Functional residual capacity: The amount of air remaining in the airways from the resting expiratory level.

Total lung capacity: The volume of air within the airways at the end of maximum inspiration.

This terminology is used to add consistency to the study as well as encourage use of contemporary definitions for the different amounts of air used in the respiratory system.

Summary

From the literature reviewed, it is apparent that a variety of equipment has been used in the laboratory to assess speech respiration. Only the respirometer has been reported for clinical application. Body plethysmographs require an adequate seal to prevent air from escaping, and have been found to be cumbersome and time consuming to use. Linear differential transducers and magnetometers require the subject to remain in a fixed position over long periods of time, are difficult to acquire, and are expensive. Flowmeters and respirometers require a face mask which impedes oro-facial movement required for speech production. The disadvantages of the respirometer include reduced measurement accuracy from mechanical impedance between airflow and the kymograph, oxygen consumption, back-pressure against the airstream, and finite time use. The need for instrumentations which are not obtrusive, not expensive, reliable, and can be used as a clinical tool was demonstrated.

The Problem

In comparison to past instrumentation used, the mercury strain gauge is relatively inexpensive, available, and unobtrusive. However, its use to monitor breathing patterns and lung volume contributions during speech has not been studied. If it can be shown that measurements of lung volume partitions by mercury strain gauge plethysmography is valid and reliable, then its diagnostic and therapeutic application would allow for its use with individuals who have respiratory problems associated with stuttering, voice misuse, cleft palate, cerebral palsy, dysarthria, and other disorders affecting speech production.

Purpose

The major purpose of this study was to observe if changes in chest wall surface displacements during speech as measured by a mercury strain gauge are as accurate as lung volume partitions as measured by a respirometer.

If it can be shown that changes in the distance between two points on the chest wall are related to lung volume partitions, then the reliability and validity of mercury strain gauge measurements of lung volume contributions in quiet and speech respiration will be indicated.

Specifically, this study proposed to answer the following questions:

1. Can lung volume partitions during speech be assessed from chest wall motions as measured by the mercury strain gauge?

2. On what portion of the human chest wall do recordings from a mercury strain gauge show linear response characteristics?

3. Can the mercury strain gauge be used to calculate the following: a) vital capacity, b) phonation volume, c) phonation time, d) mean flow rate, e) vocal velocity index, f) maximum predicted phonation time, and g) the ratio of phonation time to maximum predicted phonation time?

4. Can the mercury strain gauge register lung volume partitions during an oral reading task?

Instead of at least two mercury strain gauges completely wrapping around the body (as was done previously for nonspeech tasks), this investigation used only one mercury strain gauge placed on some portion of the chest wall. The particular combination of chest wall placement and mercury strain gauge size was consistent across all subjects on all experimental tasks.

CHAPTER III

METHODOLOGY

Instrumentation

In this study, three sizes of silastic mercury strain gauges with an outside diameter of .040 inches were used. One size had an unstretched length of four inches, another six inches, and another eight inches. A model 270 Parks Electronic plethysmograph conveyed the signal from the mercury strain gauge to a model 5103N Tektronix two channel storage oscilloscope. The gain control was manipulated to accommodate the extremes of the vertical response from the mercury strain gauge. A polaroid camera, mounted on the oscilloscope face, was used to take pictures of the electron trace after completion of each of the calibration and experimental tasks. A Collins seven liter respirometer was used to record lung volumes. A special kymograph was used in which percentages of air used could be readily determined from any lung volume up to six liters. An example of this kymograph is illustrated in Appendix B.

Subjects

Seven healthy, nonsmoking adult males, with no current or past history of respiratory problems, served as subjects in this study. Each was a native English speaker with no known anatomical or physiological abnormalities of the speech apparatus. Subjects were seated in an upright posture during calibration and experimental tasks.

Calibration of the Mercury Strain Gauge

The response characteristics of each length of mercury strain gauge was determined by placing the gauge at its unstretched length parallel to a standard ruler. One end of the strain gauge was taped to the corresponding end of the ruler. The other end was pulled one-quarter inch and the corresponding number of inches of electron beam excursion on the oscilloscope face was recorded. This procedure of pulling the strain gauge by one-quarter inch increments was repeated and continued until the mercury strain gauge had reached its maximum stretch.

After the equal stretch increments were completed, a photograph of the oscilloscopic trace was taken. A graph plotting quarter inch of stretch pulled (on the abscissa) to inches of electron beam excursion (on the ordinate) was drawn. The response of each mercury strain gauge from its unstretched position to its most stretched position was drawn by connecting the corresponding points. This graph indicated the linearity of the response characteristics for any given number of inches that the mercury strain gauge was stretched. Each graph is presented in Appendix C.

Calibrations to the Chest Wall

The mercury strain gauge was stretched to a section of its length which displayed a linear response characteristic across equal amounts of stretch, as determined by the above calibration procedure. The gauge was then placed on the chest wall of one subject in one of 13 arbitrary positions (Appendix D). The ends of the strain gauge were secured to the body with medical adhesive tape. The oscilloscope was set at a sweep speed of five seconds per one-half inch. The face mask for the respirometer was securely placed over the subject's mouth and nose. The subject was allowed to breathe room air through the face mask until he was relaxed and comfortable with the simultaneous respirometric and mercury strain gauge placements. After the subject had sat and breathed quietly for three minutes, the stop-cock adjacent to the face mask was closed so that the subject began breathing into the respirometer. The subject did three vital capacity maneuvers which were averaged. The recording pen was then positioned on the kymograph at the lowest point of the subject's averaged vital capacity (Appendix B). After inhaling to the highest point (100 percent) of the averaged vital capacity, the subject exhaled into the respirometer until the recording pen reached the equivalent of 80 percent of his vital capacity. The subject held his breath at this lung volume until the oscilloscope had recorded a stable horizontal trace. This procedure was continued for each 20 percent decrement of lung volume until the subject expelled all of his air down to residual volume. The image of this stair-step vital capacity maneuver was photographed as stored on the oscilloscope. Appropriate identification notations were written on the photograph. The complete procedure was done at each position on the chest wall with each strain gauge size.

Three sets of tables were generated which related percentage of body surface displacement measured by a mercury strain gauge to five 20 percent partitions of lung volume measured by a respirometer. From these tables, one strain gauge size on one chest wall position was chosen to be used across all subjects. Such a choice was based on:

1. The ease of strain gauge application to the chest wall.

2. The ease of placing and/or finding the trace on the oscilloscope.

3. The least amount of influence by posture and muscular artifacts (such as heartbeat, leg and/or arm movements, or other bodily movements).

4. The relative influence of the chest and abdomen on each 20 percent partition of lung volume.

5. The similarity of response across the three strain gauge sizes on each chest wall position.

6. The ease of readability and interpretation of each trace.

7. The limited range of strain gauge responses across each 20 percent partition of lung volume.

8. The smallest standard deviation and variance of response for each combination of strain gauge size and chest wall position.

9. The closest agreement of mean and mode across the 20 percent partitions for each chest wall position.

Experimental Tasks

From all of the nine criteria listed above, one strain gauge size placed on one position of the chest wall was chosen to be used across all subjects. After the average of three vital capacity maneuvers was determined with the respirometer, each subject calibrated the percentage of body surface displacement to the 20 percent partitions of lung volume by the stair-step vital capacity maneuver described previously. After the oscilloscopic trace of body surface displacements for each 20 percent partition of lung volume were photographed, the subject was ready for the experimental tasks. The respirometer was removed and was not used during the experimental tasks. Therefore, all experimental measurements were made with the mercury strain gauge. Three subjects completed the calibration and experimental tasks on two separate days to establish test-retest reliability. A photograph was taken of the stored oscilloscopic trace after each of the following tasks:

1. The subject breathed at quiet tidal volume until a stable sinusoidal wave was repeatedly generated for 50 seconds on the oscilloscope. "Stable" is defined as equal distance from peak to peak on the horizontal axis.

2. The subject did a one-stage vital capacity maneuver, breathed quietly for 7 to 10 seconds, did another one-stage vital capacity maneuver, breathed quietly for 7 to 10 seconds, and repeated a one-stage vital capacity maneuver once more.

3. The subject sustained a vowel after the instructions: "Take a deep breath and sustain the vowel /a/ for as long as you can." This task was done three times.

4a. The subject repeated the syllable /tʌ/ after the instructions: "Take a deep breath and repeat the syllable /tʌ/ at your normal pitch, rate, and loudness for as long as you can." This task was done three times.

4b. The subject repeated the syllable /sʌ/ after the instructions: "Take a deep breath and repeat the syllable /sʌ/ at your normal pitch, rate, and loudness for as long as you can." This task was done three times.

5. The subject was given a typed page of the first five sentences of "The Rainbow Passage" (Fairbanks, 1960) and was instructed: "Read these sentences at your normal pitch, rate, and loudness."

Data Reduction

All measurements were made from the photographs by counting the number of increments[1] from the midpoint of the electron trace thickness from the beginning to the end of each task. During the calibration task, the midpoint was defined at the horizontal trace or as the central position between the change in a sloping trace at each lung volume partition.

---

[1]The graticule of the oscilloscope was divided into one-half inch squares. Each one-half inch square was further divided into five, one-tenth inch divisions. The author had the option of reporting all results which referred to the graticule markings as one-tenth inches, inches, units of strain gauge stretch, units of displacement, markings, or increments. For the sake of simplicity and consistency, all values which refer to the one-tenth inches on the graticule will be reported as "increments." Therefore, one-tenth inch equals one increment.

The following airflow measurements were computed: 1) Vital Capacity (the average of three), 2) Phonation Volume (the average of sustaining /a/ three times), 3) Phonation Time (the average of sustaining /a/ three times), 4) Mean Flow Rate (the phonation volume divided by phonation time), 5) Vocal Velocity Index (the mean flow rate divided by the vital capacity), 6) Maximum Predicted Phonation Time (the vital capacity divided by 100 and multiplied by 0.67), and 7) the ratio of Phonation Time to Maximum Predicted Phonation Time (with a ratio of under 0.70 indicating abnormality). Further analysis of the percentage of lung volume used 1) for tidal volume respiration, 2) in the average of sustaining /a/ three times, and 3) during the reading task were computed. The average differences in phonation time between the three /tʌ/ and three /sʌ/ repetitions were also analyzed.

CHAPTER IV

RESULTS AND DISCUSSION

The data from this study are presented in the following order: 1) the calibration of three strain gauges to lung volumes, 2) the relationship between body surface displacements measured by one strain gauge on one chest wall position and lung volume partitions measured by a respirometer, 3) lung volume partitions used in various speech and nonspeech respiratory events, and 4) inter- and intra-subject reliability. Subjective observations made in connection with this study are also reported.

During the discussion of reliability measurements, the term "good" will be used to indicate a reliability coefficient of .70 or better. Each of the photographs of the calibration tasks was measured on two separate days to assess measurement reliability. The coefficients of the measurement reliability ranged from .91 to 1.00 with a mean of .98.

Preliminary Calibration

The relationships between the percentage of body surface displacement measured with a given strain gauge size on a given chest wall position and the percentage of lung volume measured with a respirometer were used to calibrate the body surface displacements for the assessment of lung volumes during speech.

The data in Appendix E indicate that the amount each strain gauge stretches with each 20 percent partition of lung volume differs with the strain gauge position on the chest wall. For example, when a six inch strain gauge was placed on the number eight position, the percentage of strain gauge stretch was nearly equal to each 20 percent partition of lung volume across the subject's vital capacity. However, the six inch strain gauge placed on the number three position stretched by different amounts with each 20 percent partition of lung volume. Since each of the nine criteria listed in the "Calibrations to the Chest Wall" section could be applied to the six inch gauge placed on the number 11 position, that combination of strain gauge size and chest wall position was chosen to be used with each subject during the following calibration and experimental tasks.

Lung Volume Partitions during Calibration

Figure 1 illustrates a typical oscilloscopic trace of the percentage of body surface displacement measured by the mercury strain gauge. The oscilloscopic

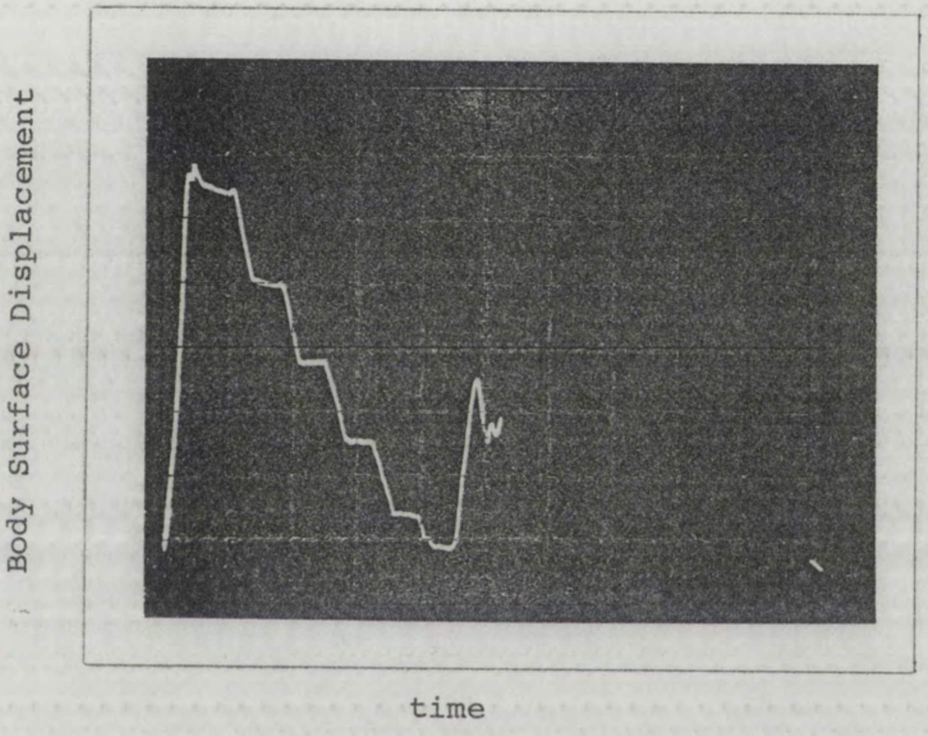


Figure 1. An oscilloscopic trace showing the percentage of body surface displacement measured by a mercury strain gauge for each 20 percent partition of lung volume measured by a respirometer.

trace reveals each partition of the total lung volume at which changes in lung volume occurred. It was possible to determine the percentage of body surface displacement for each 20 percent change in lung volume by dividing the number of increments of displacement from one horizontal trace to the next horizontal trace by the total number of increments of maximum displacement across the oscilloscopic face.

The percentage of body surface displacement for each subject is illustrated in Table 1. The mean percentage and range of percentages for each of the five 20 percent partitions are presented. Across all subjects, the first 80 percent of body surface displacements measured by the strain gauge closely approximated the first 80 percent of lung volume measured by the respirometer. The agreement of the mean body surface displacement with each 20 percent of lung volume was .89 in the 100 percent partition, .90 in the 80 percent partition, .92 in the 60 percent partition, .99 in the 40 percent partition, and .71 in the 20 percent partition.

The strain gauge stretched a mean of 14.9 percent in the 20 percent partition of lung volume. In Appendix E it can be seen that for one subject, 1) the strain gauge

Table 1

Percentage of Body Surface Displacement Measured by a Mercury Strain Gauge for Each 20 Percent Partition of Lung Measured by a Respirometer

Subject	Percent of Lung Volume					
	100%	80%	60%	40%	20%	
MS	18	22	20	16	24	Percent of body surface displacement
EU	19	21	23	26	12	
JM	20	22	20	27	11	
WR	26	18	21	24	11	
BS	26	24	21	21	08	
SF	20	27	21	08	25	
DB	28	21	26	17	09	
Mean:	22.43	22.14	21.71	19.86	14.29	
Range:	10	09	06	19	17	

had stretched 18 percent of its length in the 20 percent partition and 2) each percentage of stretch was a similar amount across all five partitions of lung volume. The group's mean stretch of 14.29 percent is not only lower than the expected 18 percent, but it is also lower than the mean percentage of stretch for each of the other partitions of lung volume. A possible reason for the lower mean percentage of stretch may be that this particular combination of mercury strain gauge size and chest wall position is not as sensitive to changes at lower lung volumes as the combination is to changes at higher lung volumes.

Lung Volume Partitions in Speech and Nonspeech Tasks

Figure 2 illustrates the oscilloscopic trace which typically occurred when a subject prolonged the vowel /a/ across the range of his vital capacity. In most subjects, a slight but sudden change in the direction of the oscilloscopic trace was observed during the sustained vowel task. The change in direction typically occurred within the 80 percent partition of lung volume or at the end of the subject's inspiratory reserve volume (the peak of a tidal volume cycle). A possible explanation for this may be that at that point, the checking action of the chest muscles ceased and the entire chest wall began to contract

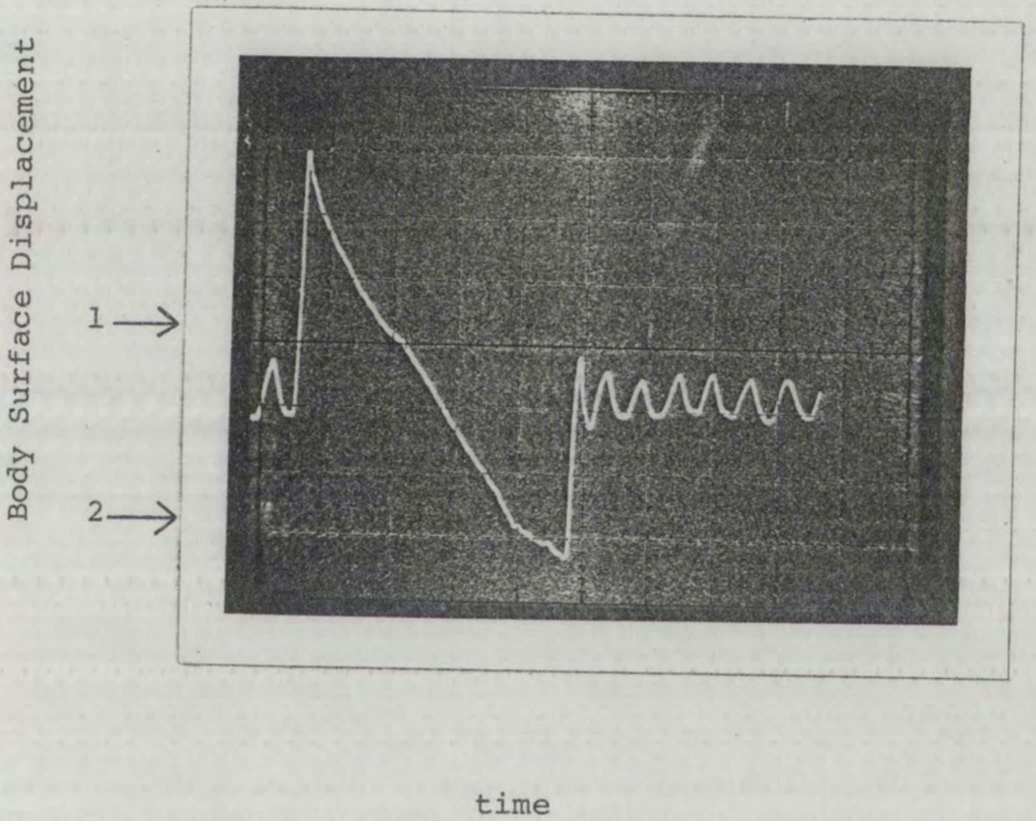


Figure 2. A typical trace produced during the prolongation of the vowel /a/. Note the change in direction of the trace at the level of arrow #1 (where it is hypothesized that the checking action of the chest muscles ceases) and arrow #2 (where the abdominal muscles become the primary force to expel the remaining air).

as a unit. The trace continued uninterrupted until approximately the 20 percent (fifth) partition of lung volume. In the last percentages of lung volume (which varied one to 20 percent from subject to subject), the trace again shifted direction as the contraction of the abdominal muscles became the predominant force for the expulsion of the remaining air. These phenomena which were observed during the vowel prolongation task were also observed during the syllable repetition tasks.

Figure 3 illustrates the oscilloscopic trace produced as a subject read five sentences. In the reading tasks, the mean percentage of lung volume used was 26 percent (range = 14 to 35 percent) of the vital capacity. Five of the subjects read the passage at the middle 60 percent of their vital capacity. The other subjects read the sentences within the 40 percent partition of lung volume. Hixon et al. (1973) also found that the lung volume used in reading took place in the mid-range of vital capacity (the middle 60 percent).

All but one subject used 12 to 15 percent (mean = 13 percent) of their vital capacity during quiet tidal breathing. The quiet tidal breathing was observed to occur at a static level within the 80 percent partition, the 60 percent partition, or the 40 percent partition of lung volume. The differences in the level of quiet tidal breathing may be attributed to inter-subject variability and thus reflect the heterogeneity of this group. Examples of the oscilloscopic trace of quiet tidal breathing may be seen

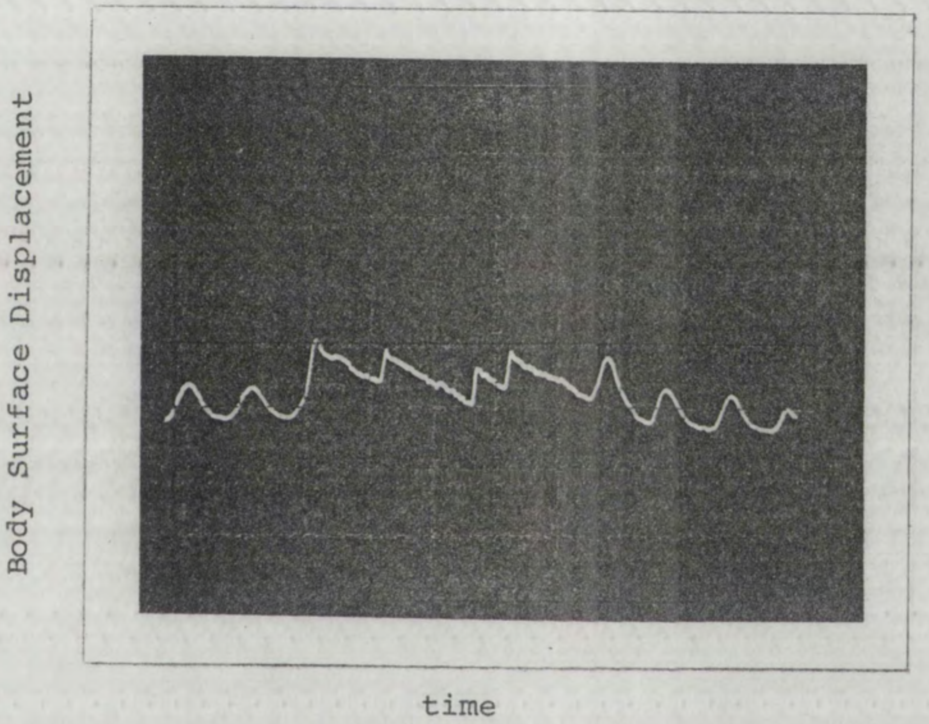


Figure 3. A typical trace produced during oral reading of five sentences. Note the quick inspiration before each unit of speech activity.

between the three vital capacity maneuvers in Figure 4. The percentages of lung volume used during prolongation of the vowel /a/, reading, and quiet tidal breathing are summarized in Table 2.

Figures 5 and 6 illustrate examples of oscilloscopic traces of the repetitions of a string of /tʌ/ syllables and a string of /sʌ/ syllables, respectively, from total lung volume to residual volume in the same subject. In this pair of photographs, the time required to repeat the syllable /tʌ/ clearly exceeded the time required to repeat the syllable /sʌ/. By counting the increments (sweep speed equals one second per increment), it was determined that the string of /tʌ/ syllables required 24.5 seconds to complete and the string of /sʌ/ syllables required 17 seconds to complete. The difference between the two times is 7.5 seconds. Table 3 lists the averaged time to repeat three strings of /tʌ/ syllables and three strings of /sʌ/ syllables for each subject. Also presented are the differences in the pair of each averaged string of syllable repetitions as well as the ratio of the time required to repeat the /tʌ/ syllables to the time required to repeat the /sʌ/ syllables. The differences in the time required to produce the /tʌ/ and /sʌ/ repetitions ranged from 1.67 seconds to 10.83 seconds (or a difference of 9.16 seconds) with a mean of 6.88 seconds. As reported above, the changes in the trace which occurred at different

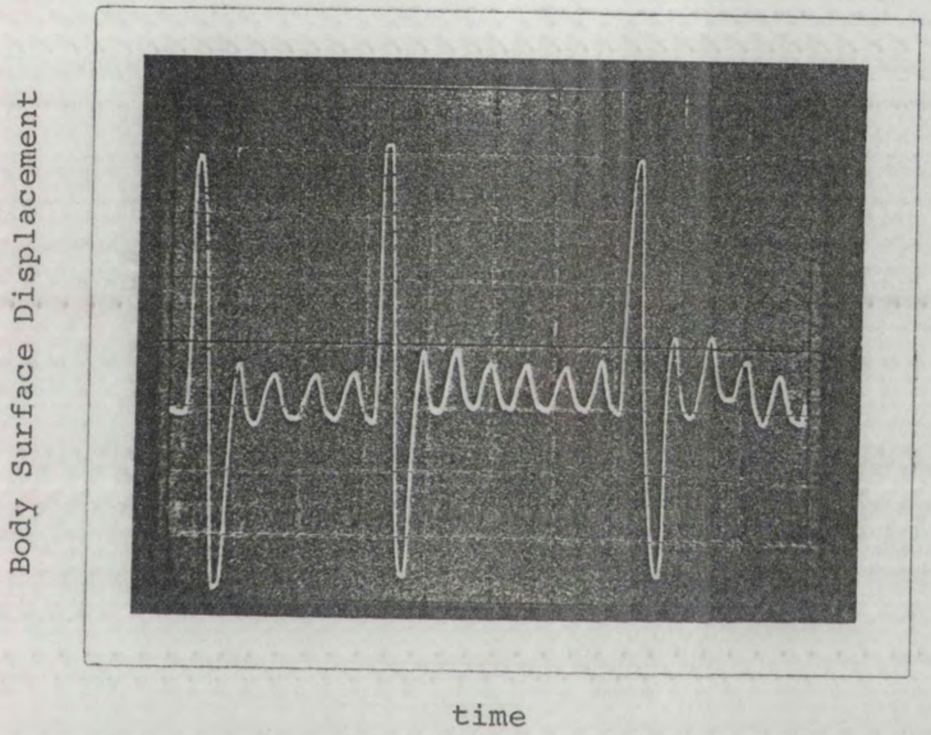


Figure 4. Three vital capacity maneuvers with quiet tidal breathing between each maneuver.

Table 2

Percentage of Lung Volume Used during Quiet Tidal Breathing, Prolongation of the Vowel /a/, and Reading

	Percent of Lung Volume		
Subject	Tidal Breathing	Prolonged /a/*	Reading
MS	12	94	18
EU	13	94	29
JM	13	112	32
WR	13	104	35
BS	15	102	25
SF	14	96	14
DB	08	107	31
Mean:	13	101	31

*The average of three trials.

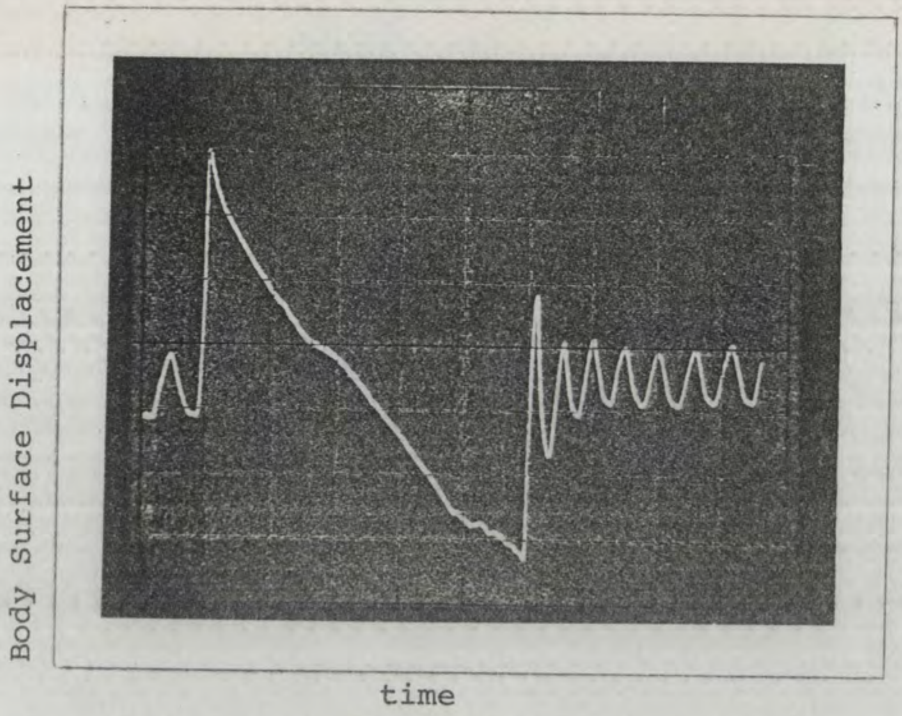


Figure 5. A typical trace produced while the subject repeated the syllable /tʌ/ from total lung volume to residual volume. Elapsed time equaled 24.5 second.

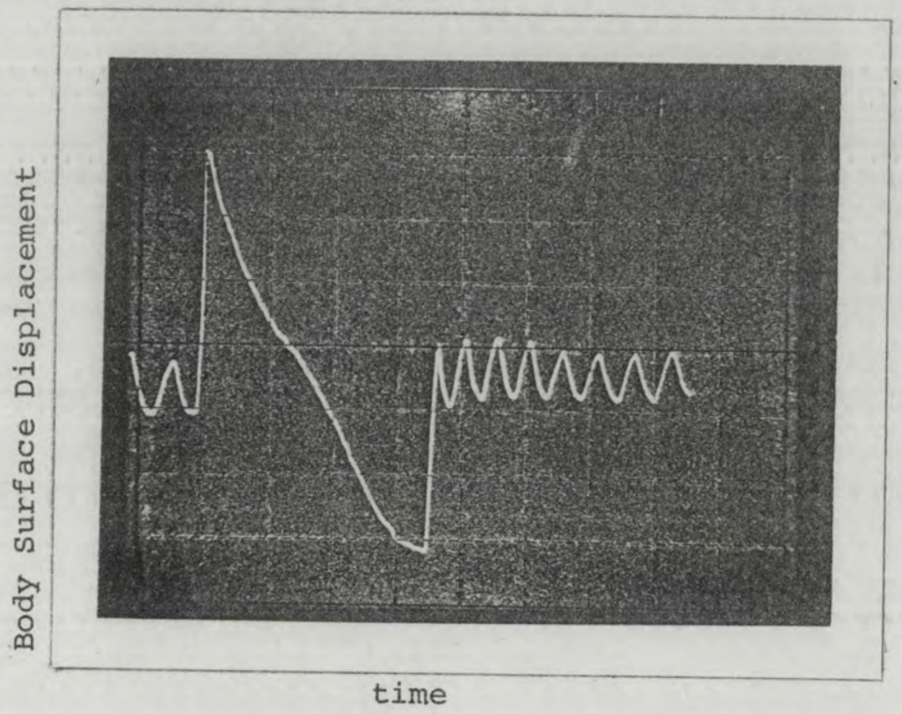


Figure 6. A typical trace produced while the subject repeated to syllable /sʌ/ from total lung volume to residual volume. Elapsed time equaled 17 seconds.

Table 3

Each Subject's Averaged Time Required To Repeat Three Strings of /tʌ/ and Three Strings of /sʌ/ Syllables from Total Lung Volume to Residual Volume

	Time (in seconds)			
Subject	/tʌ/	/sʌ/	Difference	Ratio
MS	23.33	17.17	6.16	.27
EU	15.17	11.17	4.00	.27
JM	17.67	12.00	5.67	.29
WR	29.17	19.33	9.84	.30
BS	31.33	21.33	10.00	.29
SF	21.50	19.83	1.67	.22
DB	28.50	17.67	10.83	.32
Mean:	23.81	16.93	6.88	.28

lung volumes during the prolongation of the vowel /a/ were also observed with the syllable repetition tasks.

Figure 4 illustrates the oscilloscope trace of three vital capacity maneuvers. Each subject's vital capacity, phonation volume, and phonation time was calculated by counting the increments of displacement from peak to valley of the traces derived from three vital capacity maneuvers and three prolongations of the vowel /a/. Each of the three calculations were averaged. Each subject used approximately all of his vital capacity during the prolongation of the vowel /a/. In some subjects, the values for the average of the three vital capacity calculations were smaller than the average of the three phonation volume calculations thereby producing values which slightly exceed 100 percent of the lung volume used for the prolongation of the vowel /a/ in Table 2. A possible explanation for the excessive percentages is that as some subjects forced the last of their air out during the prolongation of the vowel /a/, they may have inadvertently shifted their body position and caused the oscilloscopic trace to drop slightly below the level of the 20 percent partition of lung volume. However, across all subjects the agreement between vital capacity and phonation volume ranged from .89 to .99 with a mean of .95. All calculations of phonation time were within normal limits. The averaged of the three phonation time calculations ranged from 38.67 to 17.00

seconds with a mean of 25.93 seconds. The longest averaged phonation time (38.67 seconds) was by subject BS who had had 15 years of voice training.

Mean flow rate, vocal velocity index, maximum predicted phonation time, and the ratio of phonation time to maximum predicted phonation time may each be calculated using the formulas described by Beckett (1971) once the vital capacity, phonation volume, and phonation time are known. Table 4 shows the airflow calculations which were determined from the body surface displacements recorded in this study. The mean of the calculated values for mean flow rate (phonation volume divided by phonation time) was 1.18 increments per second, for vocal velocity index (mean flow rate divided by vital capacity) was .04 increments squared per second, for maximum predicted phonation time (vital capacity divided by 100 and multiplied by 0.67) was .18, and for the ratio of phonation time to maximum predicted phonation time was 153.34. The calculated values reported here may be considered as standard until further studies are completed. It should be noted, however, that in some instances the values for the ratio of phonation time to maximum predicted phonation time appear to be inflated. A possible reason why these values may be inflated might be because they are secondary calculations of airflow after the primary assessments of body surface displacements have been made.

Table 4

Mercury Strain Gauge Assessment of Seven Airflow Calculations

Subject	VC*	PV*	Pt*	MFR	VVI	MPPt	Pt:MPPt
MS	33.50	31.33	22.00	1.42	.04	.22	100.00
EU	31.17	29.33	17.00	1.73	.06	.21	80.95
JM	27.83	31.17	26.67	1.17	.04	.19	140.37
WR	22.67	23.67	37.50	.63	.03	.15	250.00
BS	20.17	20.50	38.67	.53	.03	.14	276.21
SF	29.33	28.17	17.67	1.59	.05	.20	88.35
DB	24.50	26.17	22.00	1.19	.05	.16	137.34

Key:
VC = vital capacity (the number of increments counted vertically on the oscilloscope face), PV = phonation volume (the number of increments counted vertically on the oscilloscope face), PT = phonation time (in seconds), MFR = mean flow rate (the number of increments per second), VVI = vocal velocity index (the number of increments squared per second), MMPt = maximum predicted phonation time, Pt:MPPt = the ratio of phonation time to maximum predicted phonation time.

*The average of three trials.

Inter-Subject Reliability

Table 5 presents each subject's agreement with the group's mean percentage of body surface displacement for each of the five 20 percent partitions of lung volume. In the first four 20 percent partitions of lung volume, each subject's percentage of body surface displacement measured with the strain gauge was in good agreement with the group's mean percentage of body surface displacement measured with the strain gauge. The only exception was with subject SF in the 40 percent partition of lung volume. Generally, the poorest agreement of individual body surface displacements with the mean percentage of body surface displacement was found in the last 20 percent partition of lung volume. The average of the group's agreements with the mean percentage of body surface displacement was .85 (range = .80 to .89) for the 100 percent partition of lung volume, .92 (range = .81 to .99) for the 80 percent partition of lung volume, .93 (range = .84 to .97) for the 60 percent partition of lung volume, .76 (range = .70 to .95) for the 40 percent partition of lung volume, and .68 (range = .56 to .84) for the 20 percent partition of lung volume. Across all subjects at all lung volumes the averaged agreement with the mean percentage of body surface displacement was .83.

Table 5

Each Subject's Reliability with the Group's Mean Percentage of Body Surface Displacement for Each 20 Percent of Lung Volume (from Table 1)

	Agreement with the Mean				
Subject	100%	80%	60%	40%	20%
MS	.80	.99	.92	.81	.60
EU	.85	.95	.94	.76	.84
JM	.89	.99	.92	.74	.77
WR	.86	.81	.97	.83	.77
BS	.86	.92	.97	.95	.56
SF	.89	.82	.97	.40	.57
DB	.80	.95	.84	.86	.63
Mean agreement with respirometer:	.89	.90	.92	.99	.71

Table 6 presents the individual agreements with the group's mean value for the percentage of lung volume used during quiet tidal breathing. The inter-subject reliability during quiet tidal breathing ranged from .62 to 1.00 with a mean of .91.

Table 6 also presents the individual agreements with the group's mean value for the percentage of lung volume used during the prolongation of the vowel /a/ and during reading. Generally, the inter-subject reliability was good across these two tasks. The reliability coefficients for the percentage of lung volume used during the prolongation of the vowel /a/ ranged from .90 to .99 (mean = .94) and during reading ranged from .45 to 1.00 (mean = .80). The coefficients were low for subject MS (.58) and subject SF (.45) on the reading task. When subjects MS and SF were excluded from the group, the mean of the reliability coefficients in the reading task rose from .80 to .92.

Each subject's agreement with the group's mean on the syllable repetition tasks is presented in Table 7. The average of the group's agreement with the mean was .81 (range = .64 to .98) for the averaged time required to repeat three strings of the syllable /tʌ/ and .84 (range = .66 to .99) for the averaged time required to repeat three strings of the syllable /sʌ/.

Table 6

Each Subject's Reliability with the Group's Mean Percentage of Lung Volume Used during Quiet Tidal Breathing, Prolongation of the Vowel /a/, and Reading (from Table 2)

	Agreement with the Mean		
Subject	Tidal breathing	Prolonged /a/*	Reading
MS	.92	.93	.58
EU	1.00	.93	.94
JM	1.00	.90	.97
WR	1.00	.97	.86
BS	.87	.99	.81
SF	.93	.95	.45
DB	.62	.94	1.00

*Average of three trials.

Table 7

Each Subject's Reliability with the Mean of the Averaged Time Required to Repeat Three Strings of /tʌ/ and Three Strings of /sʌ/ Syllables from Total Lung Volume to Residual Volume (from Table 3)

	Agreement with the Mean			
Subject	/tʌ/	/sʌ/	Difference	Ratio
MS	.98	.99	.90	.96
EU	.64	.66	.58	.96
JM	.74	.71	.82	.97
WR	.82	.88	.70	.93
BS	.76	.79	.69	.97
SF	.90	.85	.24	.79
DB	.84	.96	.64	.88

Each subject's agreement with the mean of the seven airflow calculations is detailed in Table 8. Generally, the inter-subject reliability on the seven calculations was good. Each of the subject's agreements with the mean value on the vital capacity, phonation volume, vocal velocity index, and maximum predicted phonation time calculations were good. On the average, the group agreed with the mean value at .87 for vital capacity, .89 for phonation volume, .82 for the vocal velocity index, and .86 for maximum predicted phonation time. The individual agreement with the mean value on the mean flow rate calculation was good for all subjects except WR (.53) and BS (.45). The averaged group agreement for the mean flow rate calculation was .74 but when WR and BS were excluded from the group, the figure rose to .85. The group's averaged agreements with the mean value on phonation time (.77) and the ratio of phonation time to maximum predicted phonation time (.68) were the lowest of the averaged agreements with the mean values due to the wide range of raw scores on these calculations. The wide range of scores on all timed measurements may reflect the heterogeneity of this group of subjects.

Intra-Subject Reliability

Three of the subjects completed the entire calibration and experimental protocols twice for test-retest

Table 8

Each Subject's Agreement with the Group's Mean of the Seven Airflow Calculations (from Table 4)

Subject	VC*	PV*	Pt*	MFR	VVI	MPPt	Pt:MPPt
MS	.81	.87	.85	.83	1.00	.82	.65
EU	.87	.93	.66	.68	.67	.86	.53
JM	.97	.87	.97	.99	1.00	.95	.92
WR	.84	.87	.69	.53	.75	.83	.61
BS	.75	.75	.67	.45	.75	.78	.56
SF	.92	.97	.68	.74	.80	.90	.58
DB	.91	.96	.85	.99	.80	.89	.90

*Average of three trials.

purposes. The test-retest times were separated by at least 24 hours. The test-retest data are presented in Table 9. The mean test-retest reliability coefficients during the calibration task for the three subjects were .95 for BS, .85 for JM, and .75 for MS. The reliability coefficients were considered very good considering these subjects were untrained on these specific tasks.

Test-retest reliability was high for the assessments of percentages of lung volume used during resting tidal breathing, the prolongation of the vowel /a/, and reading. The coefficients ranged from .83 to 1.00 across these three tasks. The intra-subject reliability was high for the productions of each string of syllable repetitions. The coefficients for each string of /tʌ/ and /sʌ/ syllables were .85 and .97 for MS, .93 and .91 for JM, and .88 and .95 for BS, respectively.

Generally, the intra-subject reliability was good on the seven airflow calculations made in this study. The test-retest reliability across the calculations of vital capacity, phonation volume, mean flow rate, maximum predicted phonation time, and the ratio of phonation time to maximum predicted phonation time was good for all subjects. All three subjects had strong reliability coeff-cients (.93, .89, and .97) on the calculation of phonation time. On the calculation of vocal velocity index, the coefficient was perfect (1.00) for JM and BS and good

Table 9

Test-retest Reliability*

	MS	JM	BS
Calibration Task			
100%	.72	.95	.96
80%	.95	.85	1.00
60%	.74	.95	.95
40%	.94	.70	.95
20%	.42	.79	.89
Range:	.47	.75	.89
Mean	1.00	.99	1.00
Experimental Tasks			
Tidal breathing:	.92	.85	.93
Prolonged /a/:	1.00	.95	.92
Reading:	.95	.94	.83
Repeating /tʌ/:	.85	.93	.88
Repeating /sʌ/:	.97	.91	.95
Ratio:	.81	1.00	.93
Airflow Calculations			
VC:	.95	.97	.70
PV:	.96	.91	.65
Pt:	.93	.89	.97
MFR:	.97	.98	.66
VVI:	.80	1.00	1.00
MPPt:	.95	.95	.74
Pt:MPPt:	.98	.94	.76

*All test-retest times were separated by at least 24 hours.

(.80) for MS. The values indicate that the mercury strain gauge is a reliable clinical tool for the indirect assessment of the above seven airflow calculations.

The good intra-subject reliability across all calibration and experimental tasks suggests that either 1) the strain gauge was placed on the same chest wall position or 2) high reliability may be maintained even if only approximate placements are used on test-retest dates.

Subjective Observations

Appendix E displays the percentage of body surface displacement measured by each of the three mercury strain gauge sizes placed on the 13 different chest wall positions for each 20 percent of lung volume measured by the respirometer. The six inch strain gauge placed on the number 11 position was the gauge size and chest wall position chosen for this study. Other combinations of gauge size and chest wall position which met most of the nine criteria listed under the "Calibrations to the Chest Wall" section were the number 2, number 5, number 11, and number 13 positions with the four inch gauge, the number 5, number 8, number 12, and number 13 positions with the six inch gauge, and the number 1, number 2, number 6, and number 11 positions with the eight inch gauge. Any one of these other combinations could have also been used in this study.

Each subject required four to ten practice trials of calibrating body surface displacements measured by a mercury strain gauge to lung volumes measured by a respirometer before he was comfortable doing the calibration procedure. Once he was comfortable with the calibration procedure, each subject was able to calibrate the percentage of body surface displacement to each 20 percent of lung volume.

Hardy and Edmonds (1968), in a comparison of the tracings made by a respirometer and an electronic integrator, stressed that the subject's consumption of oxygen from the canister in the respirometer caused the baseline of the respirometer trace to rise. The rising trace did not occur when the electronic integrator was used. A stable baseline trace was also found when the mercury strain gauge was used to assess quiet tidal breathing since the subject breathed room air. A subject's posture or bodily readjustments (movements), however, may affect the stability of the trace during baseline or other measurements when a six inch gauge is placed on the number 11 chest wall position. Therefore, when a six inch strain gauge is placed on the number 11 chest wall position, posture should be controlled to make easier comparisons across a series of traces.

The ease of reading and interpreting a trace may be affected by the position of the mercury strain gauge on the chest wall. For example, during the calibration procedure with the most lean subject (DB), the recording trace actually rose (as if he were inhaling) in the 20 percent partition of lung volume. The effect occurred as the subject exhaled the end of his air supply by contracting the abdomen. The abdominal contraction increased the distance between the two stationary points of the strain gauge thereby causing the rise in the oscilloscopic trace. The rise in the trace made the 20 percent partition of lung volume occur within the same level as the 40 percent partition of lung volume. In other words, the mercury strain gauge diminished in length from total lung volume throughout the 100, 80, 60, and 40 percent partitions but increased in length as the subject approached residual volume through the 20 percent partition. This observation is similar to Konno and Mead's (1967) finding that "the ratio of linear motion of points at the surface to the volumes displaced by the surface tends to be smallest when the surface is most nearly flat and to increase as the surface becomes more highly curved" (pp. 415). For subject DB, another position on the chest wall, not affected by such an artifact, may have been more appropriate for measuring lung volumes.

Another interesting observation was that subject DB, the oldest of the group (48), used only 8 percent of his vital capacity during quiet tidal breathing. He generated a tidal volume cycle at approximately four second intervals instead of in the continuous sinusoidal curve which was observed in the other subjects. This observation may be a factor of age, of excellent physical condition, or of both age and physical condition combined.

All subjects repeated the syllable /tʌ/ from total lung volume to residual volume over a longer time period than they were able to repeat the syllable /sʌ/ in the same lung volume range. As reported above, the difference between the time used to repeat the syllables /tʌ/ and /sʌ/ ranged 9.16 seconds. To make the time differences more meaningful and comparable across subjects, a ratio of the time required to repeat the syllable /tʌ/ to the time required to repeat the syllable /sʌ/ was devised. It was reasoned that if /t/ required 50 milliseconds to produce and /s/ required 250 milliseconds to produce, then the ratio of /t/:/s/ would be .20. Assuming that the vowel /ʌ/ would be of nearly equal duration in each syllabic context, and assuming that each string of syllable repetitions was performed at the subject's "normal pitch, rate, and loudness," then the ratio of the two strings of syllable repetitions should approximate .20. This is illustrated by the following formula:

$$\frac{\text{time required to repeat /t}\text{ʌ/ X 50}}{\text{time required to repeat /s}\text{ʌ/ X 250}} = \text{ratio}$$

The data collected generated ratios from .22 to .32 with a mean of .28. This closely approximates the expected ratio and implies that the mercury strain gauge may be sensitive enough to delineate time factors in various speech events. Each subject's agreement with the mean ratio of .28 ranged from .79 to .97 with a mean of .92. For each of the three subjects who completed the protocol twice, the test-retest reliability coefficients for the ratio measure were good (.81, 1.00, and .93). It is believed that smaller speech segments may be assessed by the mercury strain gauge if the sweep speed of the recording device is increased and if greater controls are placed on the speech stimuli.

Each strain gauge size presented its own advantages and disadvantages. For example, the major advantage of the four inch gauge was its ease of application to the chest wall. Its size could also be considered a disadvantage if the points on the chest wall to which it was attached expanded beyond the upper limit of the gauge, making it impossible to record changes at greater lung volumes. This disadvantage could occur on large chest wall surfaces since the four inch strain gauge stretches to twice its unstretched length. On the other hand, the six and eight inch strain gauges stretched to more than three times their unstretched length. The longer the gauge, however, the harder it was to place at a defined position on the chest wall. For example, in order to get a reliable oscilloscopic trace, the six and eight inch gauges had to be extended beyond the level of the nipples and the umbilicus in all vertical positions. In positions number seven and nine, the attachments were from the crest of the ilium to a point just posterior to the armpit. Any arm movements or change in posture would cause a change in the oscilloscopic trace independent of respiration. The good response characteristics of the eight inch gauge in the number six position is probably because the attachments were actually off the scapula and onto the latero-posterior sections of the ribcage.

An important point with respect to all three mercury strain gauges is that each had to be stretched to a length that would accurately register both extremes of lung volume. If a strain gauge was not stretched enough, the electron trace would level off at the bottom of the oscilloscope and the lower lung volumes would not be registered. If a strain gauge was stretched too much, the electron trace would again level off (but at the top of the oscilloscope) and the upper lung volumes would not be registered.

Another problem occurred when a strain gauge was placed on the number three chest wall position. On the number three position, each strain gauge tended to roll over the expanding and contracting flesh of the abdomen. To minimize the rolling action, a small piece of tape was rolled into a tube about a quarter of an inch in diameter and with the adhesive side turned outward. The tube of tape was then placed at the level of the umbilicus and the strain gauge passed through it. This arrangement prevented the strain gauge from sliding over the flesh.

In future studies, investigators might explore various uses of the four inch gauge placed on the number two or number five position or the six inch gauge placed on the number five position of the chest wall. The advantage of the number five position over the number four position is that the artifact of the heartbeat is greatly reduced, making the readout trace easier to interpret. Appendix F provides general steps for the application of a strain gauge to the chest wall.

Briefly, the results of the present study may be summarized as follows:

1. The mercury strain gauge has a linear response characteristic from its unstretched length to its fully stretched length.

2. The mercury strain gauge can assess lung volume partitions from chest wall motions during speech.

3. The response characteristics of a mercury strain gauge may vary with the portion of the chest wall on which it is placed. Each mercury strain gauge size, whether it is placed at similar or different positions on the chest wall, may be affected to various degrees by

posture, muscular artifacts (such as heartbeat, leg and/or arm movements) and/or the relative influence of the chest and abdomen.

4. The mercury strain gauge may be used to make calculations related to airflow. These calculations include vital capacity, phonation volume, phonation time, mean flow rate, vocal velocity index, maximum predicted phonation time, and the ratio of phonation time to maximum predicted phonation time.

5. The mercury strain gauge is a reliable tool for the assessment of percentages of lung volumes used in various speech (reading aloud) and nonspeech tasks.

The mercury strain gauge appears to be a viable instrument for the assessment of lung volumes and airflow calculations from body surface displacements. The present results, however, have been inspected only with respect to a six inch strain gauge placed in the number 11 position on the chest wall. The reliability and validity of using other strain gauge sizes on other chest wall positions remains unknown but is implied.

CHAPTER V

SUMMARY

The primary purpose of this study was to see if the mercury strain gauge could be used to assess lung volume partitions from chest wall motions. The air supply within any given lung volume provides the basic foundation upon which speech respiratory events rest. By assessing lung volumes in speech, the speech clinician is aided in the diagnosis and treatment of inappropriate uses of speech respiration.

Although lung volumes have been assessed by a variety of instrumentation, only the respirometer has been widely used in speech physiology research. The major disadvantages of the respirometer over the mercury strain gauge are 1) reduced measurement accuracy from the mechanical impedance between airflow and the kymograph, 2) oxygen consumption, 3) back-pressure against the airstream, 4) finite time use, and 5) high initial cost.

In this study, a subject monitored lung volumes with a respirometer while changes in displacement on one chest wall position measured by one mercury strain gauge were simultaneously stored on an oscilloscope. Using this procedure, the subject was able to calibrate the mercury strain gauge response to five 20 percent partitions of lung volume in his vital capacity. The calibration procedure was completed with three strain gauge sizes on 13 different chest wall positions. One strain gauge size placed on one chest wall position was chosen on the basis of:

1. The ease of strain gauge application to the chest wall.

2. The ease of placing and/or finding the trace on the oscilloscope.

3. The least amount of influence by posture and muscular artifacts.

4. The relative influence of chest and abdomen on each 20 percent partition of lung volume.

5. The similarity of response across the three strain gauge sizes on each chest wall position.

6. The ease of readability and interpretation of each trace.

7. The limited range of strain gauge response across each 20 percent partition of lung volume.

8. The smallest standard deviation and variance of response for each combination of strain gauge size and chest wall position.

9. The closest agreement of mean and mode across each 20 percent partition at each chest wall position.

The six inch strain gauge placed on the number 11 position adequately met each of these nine criteria.

Seven subjects did the calibration procedure using the six inch strain gauge on the number 11 chest wall position. After the calibration, the respirometer was removed and each subject performed the following experimental tasks:

1. Three vital capacity maneuvers.

2. Quiet tidal breathing for 50 seconds.

3. Prolongation of the vowel /a/ from total lung volume to residual volume on three repeated trials.

4. Repetition of the syllable /tʌ/ from total lung volume to residual volume on three repeated trials.

5. Repetition of the syllable /sʌ/ from total lung volume to residual volume on three repeated trials.

6. Oral reading of the first five sentences of "The Rainbow Passage." The stored oscilloscopic trace of the mercury strain gauge response was photographed after the completion of each of these tasks. Three subjects completed the entire calibration and experimental tasks twice for test-retest reliability measurements.

On the basis of the experimental tasks, quantitative assessments were made of 1) the percentage of lung volume used in quiet tidal breathing, the prolongation of the vowel /a/, and reading, 2) the averaged time required to repeat the syllable /tʌ/ and the syllable /sʌ/, each from total lung volume to residual volume, 3) seven airflow calculations, 4) inter-subject reliability, and 5) intra-subject (test-retest) reliability.

The data from the present study indicate that the mercury strain gauge can be used to assess the percentage of lung volume used in quiet tidal breathing, vowel prolongation, and reading. The mercury strain gauge is a very sensitive instrument for assessing time factors associated with speech respiration as well as for determining the relationships between timed segments of different speech stimuli. Since the mercury strain gauge had never been used to assess physiological measures related to speech, the assessments of the seven airflow calculations (which were derived from the lung volume measurements) are unique to this study.

The inter-subject agreement on each of the five 20 percent partitions of lung volume measured by the mercury strain gauge ranged from .68 to .93 with a mean of .83. The mean inter-subject reliability coefficients were good for the percentage of lung volume used during quiet tidal breathing (.91), prolongation of the vowel /a/ (.94), and reading (.80). The mean inter-subject reliability was also good on the averaged time required to repeat the syllable /t^/ (.81) and the syllable /s^/ (.84). The reliability coefficients on timed measures were excellent considering the heterogeneity of the group.

The mean inter-subject reliability on each airflow calculation was good. The mean of the reliability coefficients were .87 for vital capacity, .89 for phonation volume, .77 for phonation time, .74 for mean flow rate, .82 for vocal velocity index, .86 for maximum predicted phonation time, and .68 for the ratio of phonation time to maximum predicted phonation time. These values were considered very good considering that they are secondary calculations derived from the averages of lung volume measures.

The mean intra-subject (test-retest) reliability was good on the calibration tasks for the three subjects (.75, .85, .95). The reliability coefficients for the percentage of lung volume used during quiet tidal breathing, prolongation of the vowel /a/, and reading ranged from .83 to 1.00. The mean intra-subject reliability coefficients for the averaged syllable repetitions was .89 for /tʌ/ and .94 for /sʌ/. The mean intra-subject reliability coefficients on the airflow calculations were .87 for vital capacity, .84 for phonation volume, .93 for phonation time, .87 for mean flow rate, .93 for vocal velocity index, .88 for maximum predicted phonation time, and .89 for the ratio of phonation time to maximum predicted phonation time.

The findings indicate that the mercury strain gauge can be used in place of the respirometer in the speech clinic. The high inter- and intra-subject reliabilities indicate that the mercury strain gauge may be applicable for the assessment of lung volume partitions in clinical populations which use aberrant speech and non-speech respiratory patterns. The mercury strain gauge overcomes each of the disadvantages of the respirometer listed above. In addition, it is an unobtrusive device and does not use a face mask which requires an airtight seal. The strain gauge is easy to use and readily applicable to children and adults. Lastly, the mercury strain gauge also appears to be useful as a biofeedback device in the speech clinic.

The results of the study were summarized as follows:

1. The mercury strain gauge has a linear response characteristic from its unstretched length to its fully stretched length.

2. The mercury strain gauge can assess lung volume partitions from chest wall motions during speech.

3. The response characteristics of a mercury strain gauge may vary with the portion of the chest wall on which it is placed. Each mercury strain gauge size, whether it is placed at similar or different positions on the chest wall, may be affected to various degrees by posture, muscular artifacts (such as heartbeat, leg and/or arm movements), and/or the relative influence of the chest and abdomen.

4. The mercury strain gauge may be used to make calculations related to airflow. These calculations include vital capacity, phonation volume, phonation time, mean flow rate, vocal velocity index, maximum predicted phonation time, and the ratio of phonation time to maximum predicted phonation time.

5. The mercury strain gauge is a reliable tool for the assessment of the percentage of lung volume used in various speech and nonspeech tasks.

Suggestions for Future Research

1. Compare the lung volumes used for speech in a normal population with the lung volumes used for speech in any clinical population that uses aberrant speech respiratory patterns.

2. Investigate the clinical applicability of the mercury strain gauge as a biofeedback device.

3. Investigate the appropriateness and reliability of different strain gauge sizes on different chest wall positions in females and children.

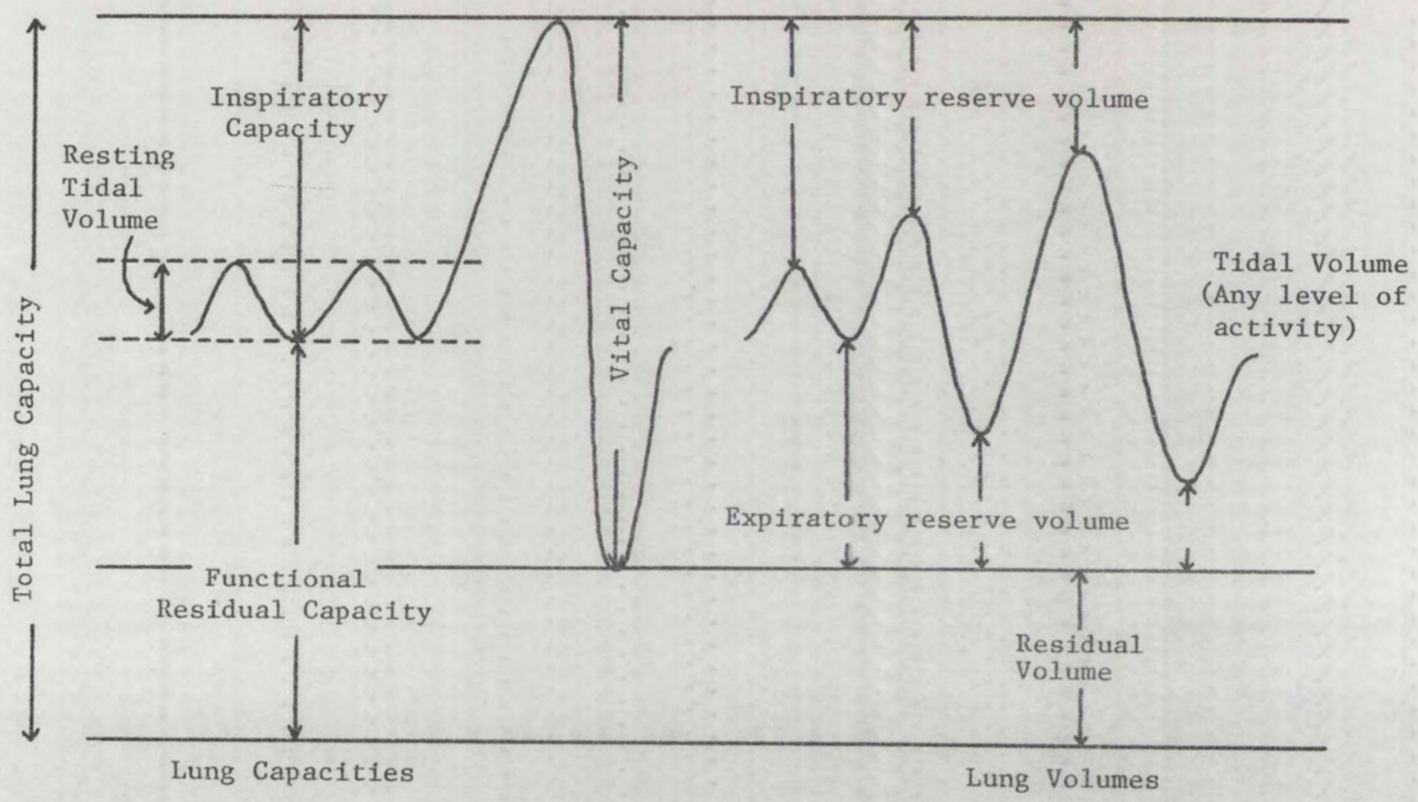
4. Replication of this study.

APPENDIX

APPENDIX A

Illustrations of Lung Capacities and
Lung Volumes Used in Speech Respiration

APPENDIX A



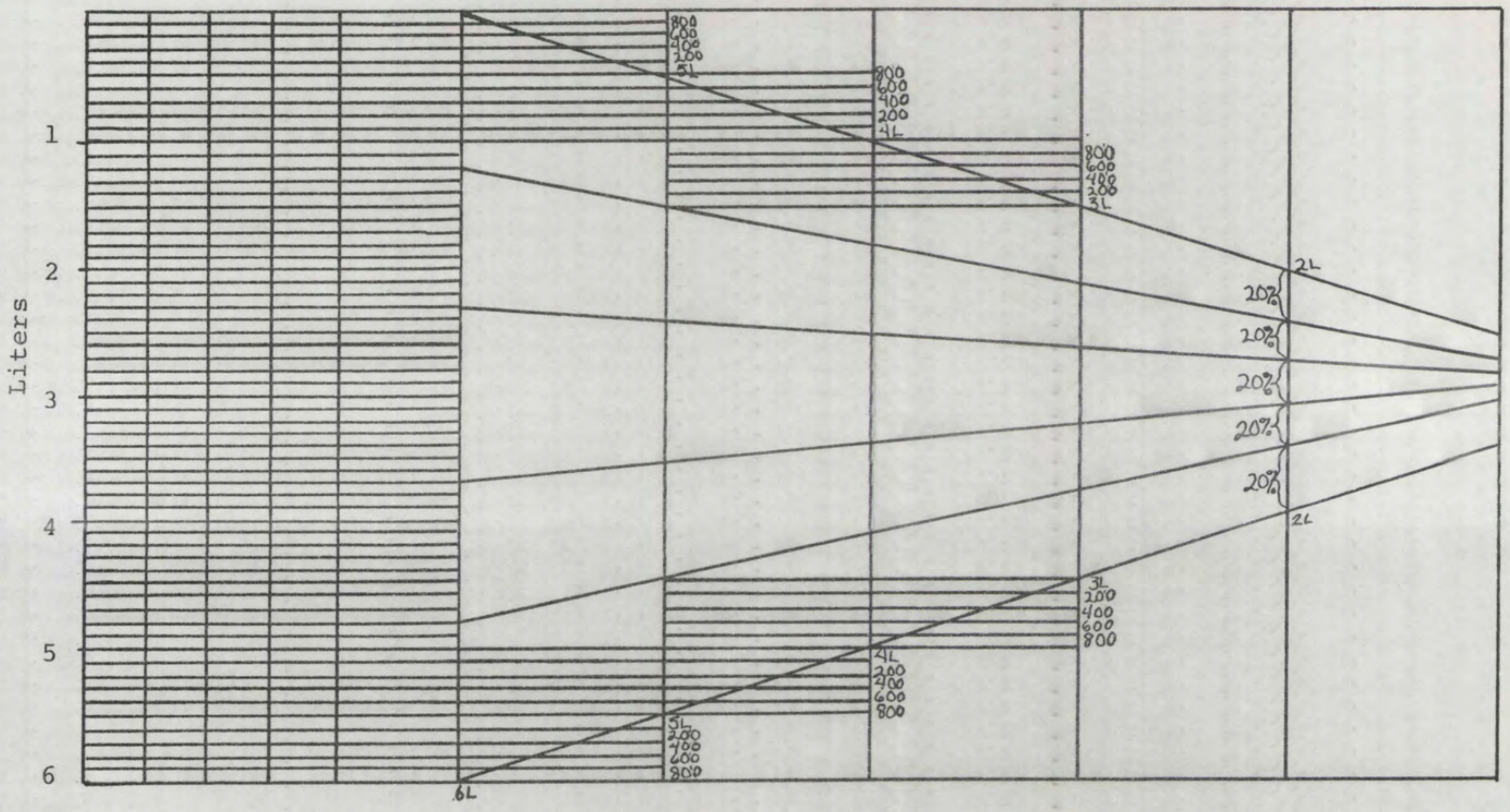
Source: T. J. Hixon, Respiratory function in speech. In F. D. Minifie, T. J. Hixon and F. Williams (Eds.), Normal aspects of speech, hearing, and language (Englewood Cliffs, N.J.: Prentice-Hall, 1973), p. 95.

APPENDIX B

Example of Kymograph Used

APPENDIX B

Example of Kymograph Used

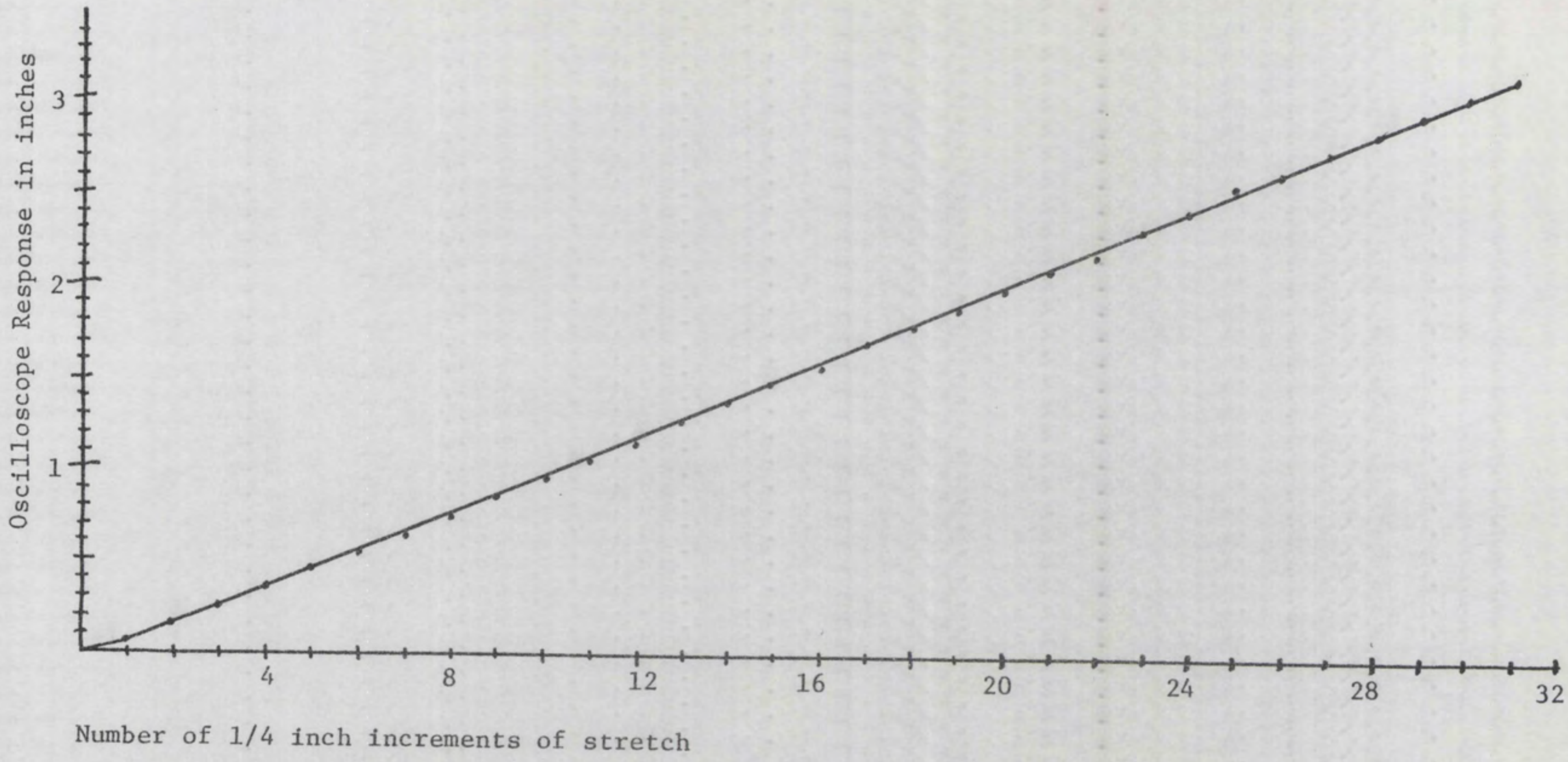


APPENDIX C

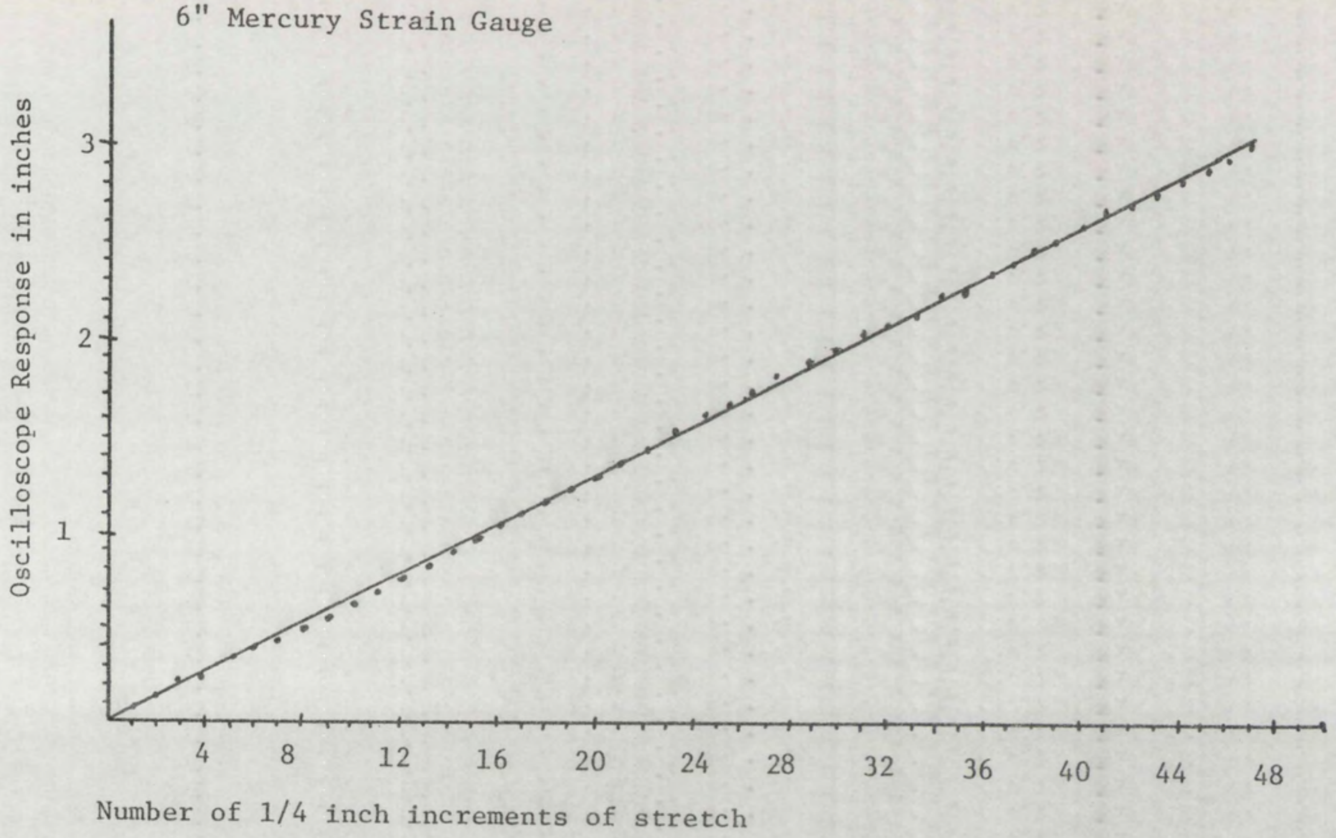
The Response Characteristics of the
Four Inch, Six Inch, and Eight Inch
Mercury Strain Gauges

APPENDIX C

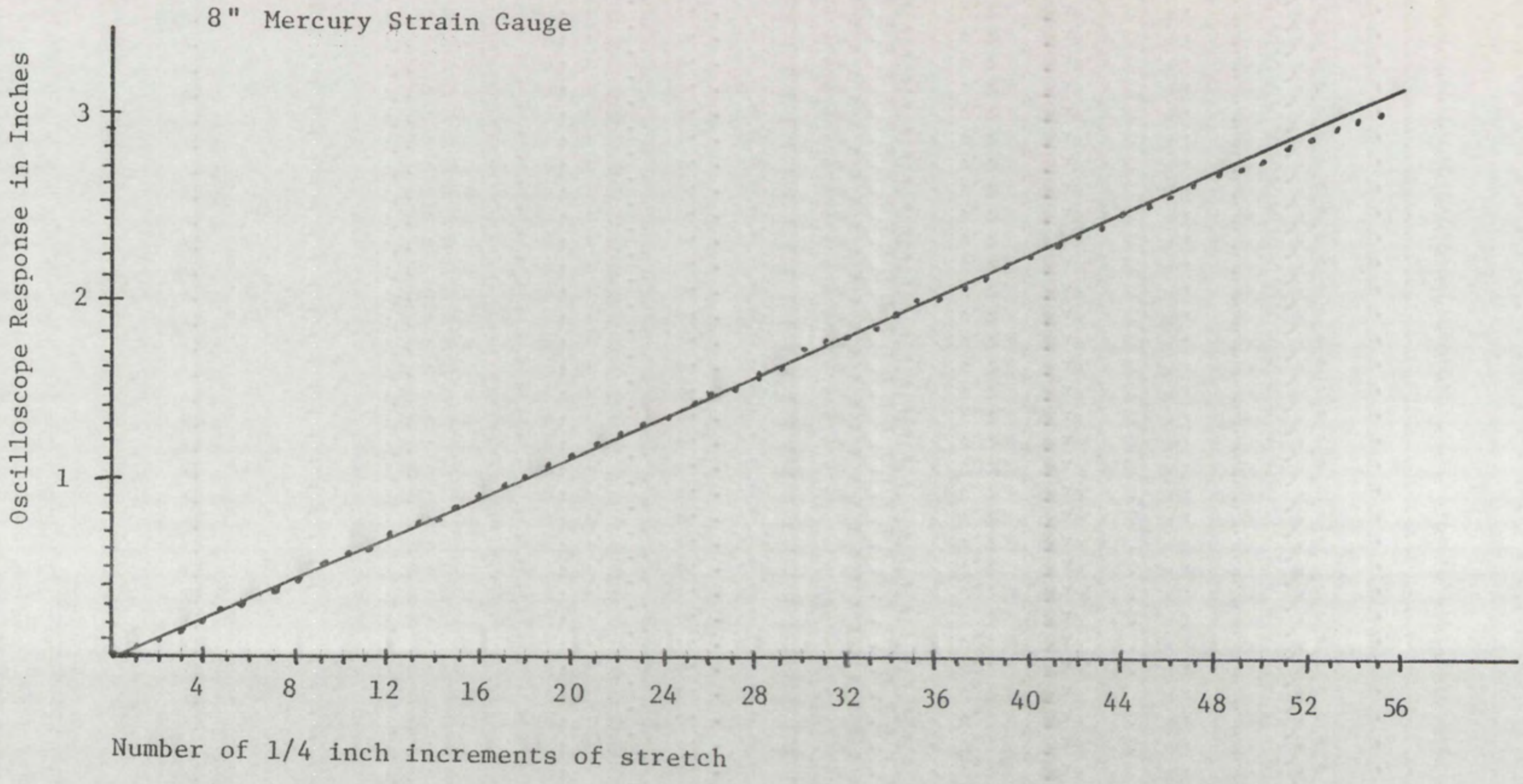
4" Mercury Strain Gauge



APPENDIX C (continued)



APPENDIX C (continued)

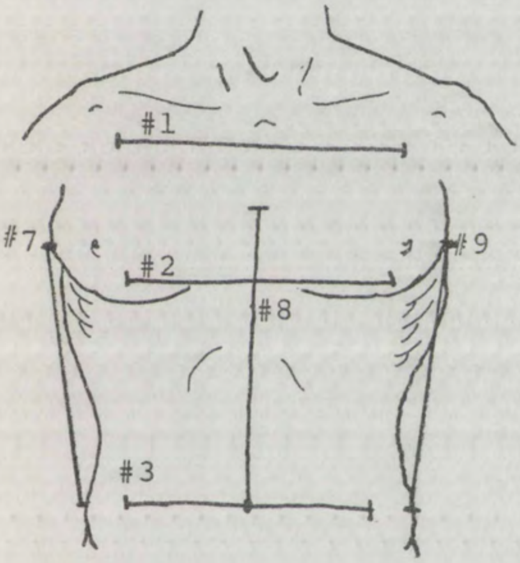


APPENDIX D

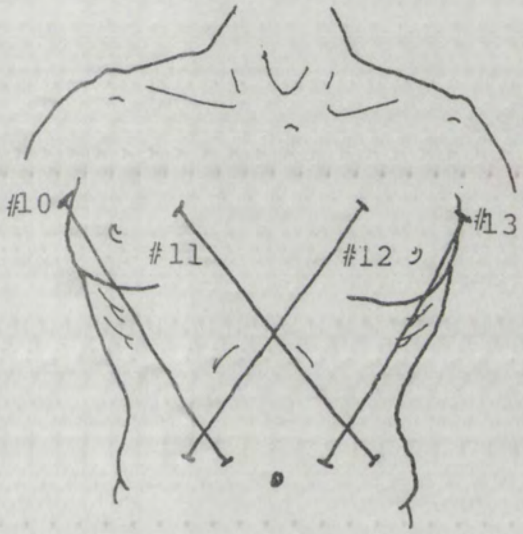
Chest Wall Positions

APPENDIX D

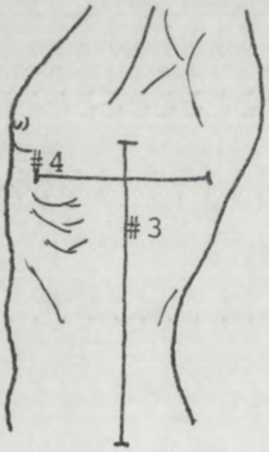
Thirteen chest wall positions on which three mercury strain gauges were placed for "Calibrations to Chest Wall."



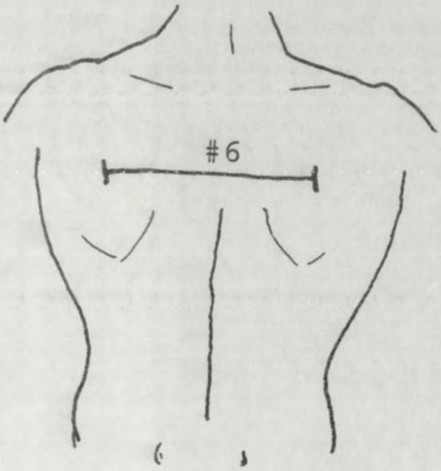
Anterior Chest Wall



Anterior Chest Wall



Lateral Chest Wall



Posterior Chest Wall

APPENDIX D (continued)

Key to Positions:

Horizontal:

1. Two inches above the nipples.
2. Two inches below the nipples
3. Level of the umbilicus (the umbilicus devides the strain gauge in half).
4. Level of rib six or seven, left side.
5. Level of rib six or seven, right side (not shown).
6. Central Plate portion of scapula.

Vertical:

7. Right lateral wall, level of nipple to level of umbilicus.
8. Anterior midline, level of nipple to level of umbilicus.
9. Left lateral wall, level of nipple to level of umbilicus.

Oblique:

10. Right lateral wall at level of nipple to one inch lateral of umbilicus ipsilaterally.
11. One inch medial of right nipple to three inches lateral of umbilicus contralaterally.
12. Left lateral wall at level of nipple to one inch lateral of umbilicus ipsilaterally.
13. One inch medial of left nipple to three inches lateral of umbilicus contralaterally.

APPENDIX E

Percentage of Mercury Strain Gauge Response to Five 20 Percent Partitions of Lung Volume as Measured with a Respirometer

APPENDIX E

Percentage of Mercury Strain Gauge Response to Five 20 Percent Partitions of Lung Volume as Measured with a Respirometer

	Per- cent	Four inch strain gauge: 1	2	3	4	5	6	Positions 7	8	9	10	11	12	13
respirometer	20	18	17	14	19	20	15	14	23	13	21	23	17	24
	20	18	21	23	19	18	19	25	25	19	19	21	17	20
	20	24	17	23	14	16	31	31	27	13	11	19	11	16
	20	26	23	29	32	20	27	22	18	31	28	23	20	22
	20	13	23	11	17	27	08	08	07	25	21	15	35	16
range		13	06	18	18	11	23	23	20	18	17	08	21	08
mean		19.80	20.20	20	20.20	20.20	20	20	20	20.20	20	20.20	20	19.60
mode		18	17,23	23	19	20	all	all	all	13	21	23	17	16
(s.d.) σ		4.67	2.71	6.42	6.18	3.71	8.25	8.12	7.16	6.70	5.44	2.99	8.05	3.20
(Var.) σ^2		21.77	7.36	41.20	38.16	13.76	68.00	66.00	51.20	48.96	29.60	8.96	64.80	10.24

	Per- cent	Six inch strain gauge: 1	2	3	4	5	6	7	8	9	10	11	12	13
respirometer	20	14	14	14	16	20	17	31	20	10	16	21	18	23
	20	14	17	17	20	20	19	29	20	14	20	20	20	19
	20	23	17	10	18	22	29	20	20	19	13	20	18	21
	20	27	28	12	28	25	31	10	21	14	30	21	20	16
	20	21	25	45	18	14	05	10	20	43	22	18	24	21
range		13	14	35	12	11	26	21	01	33	17	03	06	07
mean		19.80	20.20	20.20	20	20.20	20.20	20	20.20	20	20.20	20	20	20
mode		14	17	all	18	20	all	10	20	14	all	20,21	18,20	21
(s.d.) σ		5.11	5.34	12.92	4.20	3.60	9.35	8.97	.40	11.85	5.81	1.10	2.20	2.37
(Var.) σ^2		26.16	28.56	167.00	17.60	12.96	87.36	80.40	.16	140.40	33.76	1.20	4.80	5.60

APPENDIX E (continued)

	Per-cent	Eight inch strain gauge: Positions 1	2	3	4	5	6	7	8	9	10	11	12	13
respirometer	20	20	15	05	16	19	21	07	19	13	14	26	17	27
	20	20	18	16	16	19	17	12	19	15	16	21	17	18
	20	22	20	15	16	21	22	31	25	13	18	17	17	22
	20	22	24	29	22	28	24	26	28	26	27	21	21	20
	20	16	24	35	29	14	16	24	09	34	25	15	29	13
range		06	09	30	13	14	08	24	19	21	13	09	12	14
mean		20	20.20	20	19.80	20.20	20	20	20	20.20	20	20	20.20	20
mode		20,22	24	all	16	19	all	all	19	13	all	21	17	all
(s.d.) σ		2.20	3.49	10.70	5.15	4.53	3.03	9.01	6.51	8.42	5.10	3.79	4.66	4.60
(Var.) σ^2		4.80	12.16	114.40	26.56	20.56	9.20	81.20	42.40	70.96	26.00	14.40	21.76	21.20

APPENDIX F

General Steps for the Application of a Mercury Strain Gauge to the Chest Wall

APPENDIX F

General steps for the application of a mercury strain gauge to the chest wall.

1. Tape one end of the strain gauge to one portion of the chest wall.

2. Let the subject exhale to residual volume and hold that volume.

3. While the subject holds his lung volume at residual volume, stretch the strain gauge and observe the trace on your readout system. Tape the free end of the strain gauge to the chest wall at a stretched point beyond the first response on the readout system (to ensure the strain gauge response does not level off at residual volume). Allow the subject to breate normally.

4. Have the subject do a vital capacity maneuver and observe the readout trace. If the readout trace responds evenly from total lung volume to residual volume, then you are ready for lung volume measurements. If the trace levels off or changes irregularly across the subject's vital capacity, then

   a) stretch or reduce the stretch of the strain gauge and/or

   b) adjust the gain and calibration controls on the readout device and/or

   c) adjust the coarse and fine balance controls on the plethysmograph.

APPENDIX G

Subjects' Age, Height, and Weight

APPENDIX G

Subjects' Age, Height, and Weight

Subject	Age	Height	Weight (lbs.)
MS	23	5'6"	130
EU	24	6'0"	165
JM	26	5'10"	155
WR	23	5'8"	145
BS	29	5'8"	140
SF	24	5'11"	150
DB	48	5'11"	130

APPENDIX H

Release Form

APPENDIX H

RELEASE FORM

I, ____________________________, do hereby knowingly
(Name)

and willingly participate in an experimental study conducted by Michael Susca and supervised by Wayne E. Swisher, Ph.D. I understand that I will breathe into a seven-liter Collins respirometer and have a mercury strain gauge attached to me by medical adhesive. I also authorize the use of my initials if the study is published.

____
Signature

____
Date

REFERENCES

Beckett, R. L. The respirometer as a diagnostic and clinical tool in the speech clinic. Journal of Speech and Hearing Disorders, 1971, 36(2), 235-241.

Bouhuys, A., Proctor, D. F., & Mead, J. Kinetic aspects of singing. Journal of Applied Physiology, 1966, 21, 483-496.

Draper, M. H., Ladefoged, P., & Whitteridge, D. Respiratory muscles in speech. Journal of Speech and Hearing Research, 1959, 2(1), 16-27.

Fairbanks, G. Voice and articulation drillbook (2nd ed.). New York: Harper & Row, 1960.

Geddes, L. A., & Baker, L. E. Principles of applied biomedical instrumentation (2nd ed.). New York: John Wiley & Sons, 1968.

Hardy, J. C., & Edmonds, T. D. Electronic integrator for measurement of partitions of the lung volume. Journal of Speech and Hearing Research, 1968, 11(4), 777-786.

Hixon, T. J. Respiratory function in speech. In F. D. Minifie, T. J. Hixon and F. Williams (Eds.), Normal aspects of speech, hearing, and language. Englewood Cliffs, N. J.: Prentice-Hall, 1973.

Hixon, T. J., Goldman, D., & Mead, J. Kinematics of the chest wall during speech production: Volume displacements of rib cage, abdomen, and lung. Journal of Speech and Hearing Research, 1973, 16(1), 78-115.

Hoshiko, M. S. Lung volume for initiation of phonation. Journal of Applied Physiology, 1965, 20(3), 480-482.

Konno, K., & Mead, J. Measurement of the separate volume changes of rib cage and abdomen during breathing. Journal of Applied Physiology, 1967, 22(3), 407-422.

Shapiro, A., & Cohen, H. D. The use of mercury capillary length gauges for the measurement of the volume of thoracic and diaphragmatic components of human respiration: A theoretical analysis and a practical method. Transactions of the New York Academy of Sciences, Series II, 1965, 27(6), 634-649.

Shapiro, A., Cohen, H. D., Maher, E., & McAveney, W. J. On-line analog computation of volume of respired air in human subjects and its partition into costal and diaphragmatic components. Proceedings of the 1964 17th Annual Conference on Engineering in Medicine and Biology, 1964, 6, 13.

Shapiro, A., Cohen, H. D., Nathanson, M., & McAveney, W. J. Continuous monitoring of thoracic and abdominal respiration, theoretical and practical considerations. Proceedings of the 16th Annual Conference on Engineering in Medicine and Biology, 1963, 5, 108-109.

Wade, O. L. Movements of the thoracic cage and diaphragm in respiration. Journal of Physiology, 1954, 124, 193-212.

Zemlin, W. R. Speech and hearing science anatomy and physiology. Englewood Cliffs, N. J.: Prentice-Hall, 1968.