*Journal of Speech and Hearing Research*, Volume 30, 351–366, September 1987

# AGE AND SPEECH BREATHING

JEANNETTE D. HOIT THOMAS J. HIXON
*University of Arizona, Tucson*

Thirty healthy men representing three widely different age groups (25, 50, and 75 years) were studied with respect to general respiratory function and speech breathing. Subdivisions of the lung volume were found to differ with age and most markedly so for measures of vital capacity and residual volume. Speech breathing also was found to differ with age and was characterized by differences in lung volume excursion, rib cage volume initiation, number of syllables per breath group, and lung volume expended per syllable. Age-related differences in general respiratory function and speech breathing are discussed in relation to possible underlying mechanisms. In addition, implications are drawn regarding the evaluation and management of individuals with speech breathing disorders.

Most of what is known about normal speech breathing has come from the study of young men (Hixon, 1987). It is uncertain whether or not knowledge obtained from such study can be generalized to older individuals. If it cannot, current theory regarding normal speech breathing and current clinical practice related to the evaluation and management of individuals with speech breathing disorders will need revision. As has been pointed out by Kahane (1981), there is a compelling need to know if speech breathing changes with age and, if so, to understand how it changes.

There is reason to believe that speech breathing may be different in young and older adults. This belief stems from the fact that substantial age-related changes are known to occur in general respiratory function, some of the most important of which are listed in Table 1. Although general respiratory function and speech breathing are different behaviors, they take advantage of the same physical apparatus and share certain nervous system innervation, which suggests that speech breathing also may be subject to age-related influences. However, it is difficult to speculate as to how age-related changes in general respiratory function might impact on speech breathing, both because such changes are so numerous and because they may have complex interacting effects.

This investigation was designed to address the need to understand the possible link between age and speech breathing by way of a large exploratory study. It was anticipated that from this endeavor would come an understanding of the salient relations between age and normal speech breathing that would lay groundwork for hypothesis testing and large-scale normative data collection. In addition, it was anticipated that knowledge gained would be useful in the clinical evaluation and management of individuals with speech breathing disorders.

## METHOD

### SUBJECT SELECTION

Subject selection was made from three widely different age groups—25, 50, and 75 years (all within 3 years). Groups were chosen to represent young adulthood (when general respiratory function is at its peak), middle age (midway along the age continuum selected), and senescence (when general respiratory function has undergone significant change from its peak).

The selection process was designed to control subject characteristics that are known to influence general respiratory function, speech breathing, or both. These included sex (Altman, 1986; Cotes, 1979; Miller, 1986a), race (Cotes, 1979; Miller, 1986a), respiratory health (Gibson, 1984), general health (Johnson, 1985; Ramig & Ringel, 1983; Ringel 1986a), body type (Hoit & Hixon, 1986), spoken-language characteristics (Hixon, 1987), and hearing (Forner & Hixon, 1977; Whitehead, 1980). Individuals selected as subjects were Caucasian men who were in good respiratory health, in good general health, of average body type, had both homogeneous and normal spoken-language characteristics, and had adequate hearing sensitivity.

Good respiratory health was ascertained from responses to a questionnaire, portions of which were based on the published report of the Epidemiology Standardization Project (Ferris, 1978), and from performances on selected respiratory function screening tests. To be included as a subject, responses to the questionnaire had to indicate that the candidate was free of symptoms suggestive of respiratory disease, without skeletal disease or abnormality affecting the chest wall, free of arthritis of the chest wall, without history of major surgery or injury involving the breathing apparatus (including laryngeal and upper airway components), without history of having smoked for at least 5 years, and without history of prolonged exposure to high levels of dust or toxic agents. In addition, a subject was required to be free of allergies or respiratory infections at the time of testing. Respiratory function tests used to screen potential subjects were the forced vital capacity (FVC) and the forced expiratory volume in 1 s ($FEV_1$), tests that are employed routinely as indicators of respiratory health (Miller, 1986b). To obtain measures of FVC and $FEV_1$, each subject candidate (wearing a noseclip) inspired fully and expired fully and as forcefully as possible into a Collins 9-liter respirom-

  0022-4685/87/3003-0351$01.00/0

TABLE 1. Some of the most important age-related changes in general respiratory function.

| |
|---|
| Changes in structure |
| alveolar duct size increases and alveolar surface area decreases |
| alveolar tissue resting length increases |
| elastin in the pleurae, septae, bronchi, and vessels increases |
| cross-linking of elastic tissue in the lung decreases |
| anteroposterior diameter of the lung increases |
| anteroposterior diameter of the thorax increases and thorax length decreases |
| calcification of costal cartilages increases |
| intervertebral spaces decrease |
| connective tissue and fat cells increase and skeletal muscle cytoplasm decreases |
| Changes in subdivisions of the lung volume |
| vital capacity decreases |
| inspiratory reserve volume decreases |
| inspiratory capacity decreases |
| functional residual capacity may increase slightly |
| expiratory reserve volume decreases |
| residual volume increases |
| Changes in mechanics |
| pulmonary recoil pressure decreases |
| pulmonary compliance increases |
| chest wall compliance decreases |
| maximal inspiratory and expiratory pressures decrease |
| forced expiratory flow decreases |
| closing volumes and capacities increase |
| Changes in ventilation, perfusion, and gas exchange |
| alveolar ventilation becomes less uniform |
| pulmonary diffusing capacity decreases |
| arterial oxygen tension decreases |
| maximal oxygen uptake decreases |
| Changes in nervous system |
| peripheral nerve fibers degenerate |
| number of cell bodies in the central nervous system decreases |
| number of motor units decreases |
| dendrites are lost |
| neurotransmitter levels are altered |
| ventilatory responses to hypoxia and hypercapnia decrease |
| sensory perception and discrimination decrease |
| reaction time increases |

eter. The volume expired was taken as FVC, and the volume expired in the first second was taken as $FEV_1$. To be included as a subject, an individual had to generate an FVC and $FEV_1$ that were at least 80% of the predicted values (Miller, 1986b) for healthy men of corresponding age and height (Knudson, Lebowitz, Holberg, & Burrows, 1983).

Each subject was required to meet a criterion of good general health as determined from responses to items on a questionnaire and from his status on selected objective indicators. With respect to the questionnaire, each subject had to deny the presence of heart disease, high blood pressure, bone disease, neurological problems, and the use of sedative and stimulant medications or drugs and had to affirm that he was in good general health. The objective indicators of general health used were measures of blood pressure and heart rate. These measures are considered to be good indicators of general health (Ringel, 1986b) and are obtained easily and through noninvasive means. Blood pressure was measured using standard sphygmomanometry on the right arm (Chobanian, 1976), and heart rate was determined by counting the number of pulses detected from the right wrist for 1 min while the subject candidate sat quietly. To be included as a subject, each candidate had to have systolic and diastolic blood pressures that fell within the normal range for healthy men of corresponding age (Altman & Dittmer, 1964) and did not exceed 160/95 (Kannel, 1985). Individuals whose blood pressure was controlled with medication were not excluded from the study. With respect to heart rate, a subject had to be within the normal range for healthy men of corresponding age (Altman & Dittmer, 1964).

Only individuals of average body type were included as subjects. Average body type was defined as being within one standard deviation of the mean rating of body type for men provided in a large-scale investigation of Caucasian adults (Bailey, Carter, & Mirwald, 1982). Body type was determined through use of the Heath-Carter Somatotype Method (Carter, 1980). This method provides a standardized description of physical morphology and composition in the form of a three-numeral rating, each numeral being derived from a relatively independent physical component. Components include endomorphy (relative fatness), mesomorphy (relative musculoskeletal development), and ectomorphy (relative linearity). Ratings on these components are obtained from a variety of physical measurements, which include height, weight, bone diameters, muscle girths, and skinfold thicknesses. To be included in the investigation, candidates had to have component ratings within the ranges of 2 1/2 to 5 1/2 for endomorphy, 4 to 5 1/2 for mesomorphy, and 1 to 3 for ectomorphy.

Subjects were selected to be both homogeneous and normal in spoken-language characteristics. Homogeneity was achieved by including only subjects who were first-language American English speakers without professional training or experience in public speaking, acting, or singing. Normality of spoken language was determined through perceptual judgments made by two clinically certified speech-language pathologists. Judgments were based on the candidate's spontaneous conversational discourse, his reading aloud of a standard declarative paragraph, and his ability to follow complex verbal instructions for the performance of various breathing maneuvers.

Only individuals who demonstrated adequate hearing sensitivity were included as subjects. Adequate was defined as the ability to pass an audiometric screening test for pure tones of 500, 1000, and 2000 Hz at 25 dB HL in at least one ear.

Based on the selection process just described, 30 men were chosen to participate as paid volunteers. Ten were included in the 25-year-old group, 10 in the 50-year-old group, and 10 in the 75-year-old group.

## GENERAL RESPIRATORY FUNCTION

For the present investigation, the study of general respiratory function was considered critical to determination of the extent, if any, to which possible age-related differences in speech breathing are influenced by age-related differences in general respiratory function. Two types of general respiratory function observations were made: static and dynamic.

### *Static Observations*

Static observations involved measures of subdivisions of the lung volume. These measures were chosen because (a) they are used routinely in general respiratory function testing (Agostoni & Hyatt, 1986), (b) they tend to change with age (see Table 1), and (c) many of the biomechanical events of speech breathing are lung volume-dependent (Hixon, 1987).

The following subdivisions of the lung volume were determined with subjects seated upright in a chair: (a) total lung capacity (TLC), the volume of air contained in the lungs and airways at the end of a maximum inspiration; (b) vital capacity (VC), the largest volume of air that can be expired after a maximum inspiration; (c) inspiratory capacity (IC), the largest volume of air that can be inspired from the resting expiratory level; (d) functional residual capacity (FRC), the volume of air contained in the lungs and airways at the resting expiratory level; (e) expiratory reserve volume (ERV), the largest volume of air that can be expired from the resting expiratory level; and (f) residual volume (RV), the volume of air remaining in the lungs and airways at the end of a maximum expiration.

To obtain measures of the subdivisions of the lung volume indicated, a combination of indirect, direct, and derived procedures was employed. To begin, an indirect procedure, helium dilution (Meneely & Kaltreider, 1949), was used to measure FRC. Helium dilution is a gas-mixing procedure in which a known quantity of a marker gas is mixed with an unknown volume of air. The unknown volume of air, in this case FRC, can be calculated from measurements of the concentration of the marker gas taken both before and after gas mixing. Helium dilution was performed three times for each subject using a closed respirometric system and according to standard pulmonary laboratory protocol (Beeler, 1978).

To determine each subject's VC and IC, a direct measurement procedure was used. For this procedure, the subject performed a vital capacity maneuver immediately following each helium dilution trial. That is, the subject, still coupled to the respirometric system, inspired fully from his resting expiratory level and then expired fully.

To obtain a measure of each subject's TLC, ERV, and RV, a set of derived procedures was used. These subdivisions of the lung volume were determined by adding or subtracting specific combinations of other subdivision measures, as explained subsequently.

### *Dynamic Observations*

Dynamic observations involved measures of resting tidal breathing. These measures were chosen for the following reasons: (a) they are used routinely in general respiratory function testing (Rodarte & Rehder, 1986), and (b) they provide information regarding the most common of all respiratory behaviors.

Although measures of resting tidal breathing could have been obtained during the helium dilution procedure, certain measures of resting tidal breathing, such as tidal volume and breathing rate, are influenced by the use of a mouthpiece and noseclip (Gilbert, Auchincloss, Brodsky, & Boden, 1972). Therefore, resting tidal breathing data were collected without equipment at the airway opening as the subject breathed quietly through his nose for 5 min. Observations of resting tidal breathing were of the type applied to the study of speech breathing and are described in the next section.

## SPEECH BREATHING

### *Equipment*

Observations of speech breathing and resting tidal breathing involved surface motions of the rib cage and abdomen. These were recorded following the general procedure of Hixon, Goldman, and Mead (1973). Specifically, anteroposterior diameter changes of the rib cage and abdomen were sensed with linearized magnetometers (GMG Scientific Inc., 1980) incorporating two generator-sensor coil pairs, one for the rib cage and one for the abdomen. The generator coil in each pair was attached to the front of the torso at the midline, that for the rib cage at sternal midlength, and that for the abdomen just above the umbilicus. The sensor coil in each pair was attached to the back of the torso at the midline at the same axial level as its generator mate. Output signals from the two sensors were processed electronically and recorded on FM tape for playback into a storage oscilloscope where they were displayed and traced onto translucent paper. The resulting records were measured using a Houston Instrument TR-1011 digitizing pad interfaced with an IBM personal computer.

The speech audio signal was sensed by an air microphone, amplified, and recorded on a direct-record channel of the FM tape system. This signal provided a record of the subject's speech and a means of synchronizing speech output and breathing behavior.

On occasions requiring the direct measurement of changes in lung volume, a Collins 9-liter respirometer was used. All such measurements were made with the subject wearing a noseclip and coupled to the device through a mouthpiece.

### *Performance Tasks*

Recordings were made with the subject seated upright in a chair. The back of the chair was covered with a thick polyurethane pad which had a rectangular indentation running vertically at the midline to provide a space within which the magnetometer coils on the subject's back were free to move. Once positioned comfortably, the subject was instructed to maintain a constant posture throughout the recording session.

Performance tasks were of two types. The first type included chest wall maneuvers that provided information necessary for measurement calibration of data obtained during speech breathing and resting tidal breathing. The second type of performance task was related to speech production.

*Chest wall maneuvers.* Chest wall maneuvers included isovolume maneuvers, vital capacity maneuvers, rib cage capacity maneuvers, abdominal capacity maneuvers, and relaxation maneuvers. These are a combination of previously described maneuvers (Hixon, 1987) and maneuvers that were developed specifically for this investigation.

Isovolume maneuvers were performed to establish the functional relationships between the relative motion of the two chest wall parts from which volume-motion relationships could be determined. To perform an isovolume maneuver, the subject closed his larynx at the resting expiratory level and slowly displaced volume back and forth between the abdomen and rib cage. Several isovolume maneuvers were performed at the beginning and end of each recording session.

Vital capacity maneuvers defined the subject's manipulable range of lung volumes and were used to normalize lung volumes across subjects. For these maneuvers, the subject, wearing a noseclip and coupled to the respirometer, inspired fully from the resting expiratory level and then expired fully. The largest volume expired over three trials was taken to be the subject's vital capacity.

Rib cage capacity maneuvers defined each subject's range of rib cage volumes and were used to normalize rib cage volumes across subjects. Such normalization made it possible to express the rib cage volume data as percentages of the subjects' ranges of rib cage volumes. This is believed to be the first study of respiratory function in which rib cage volumes have been normalized. For most subjects, the smallest achievable rib cage volume could be generated by displacing the abdomen outward maximally near RV, and the largest achievable rib cage volume could be generated by displacing the abdomen inward maximally near TLC. However, such maneuvers proved too strenuous to be of practical use. A convenient substitute was the vital capacity maneuver. This maneuver was performed easily and reliably by all subjects and elicited a range of rib cage volumes that was acceptably similar to those generated during the more strenuous maneuvers just described. Therefore, the minimum and maximum rib cage volume for each subject was defined by the range of rib cage volumes generated during the vital capacity maneuver. This range of rib cage volumes defined the rib cage capacity.

Abdominal capacity maneuvers defined the range of abdominal volumes for each subject and were used to normalize abdominal volumes across subjects. As with rib cage capacity maneuvers, this is believed to be the first study of respiratory function in which abdominal volumes have been normalized. Because abdominal volume extremes are lung volume-dependent, and differently so for different subjects, maximal inward and outward displacements of the abdomen would have to be performed at several lung volumes to determine the full range of abdominal volumes for a particular subject. During pilot study, it was determined that maximal inward and outward displacements of the abdomen performed at the resting expiratory level elicited a range of abdominal volumes that closely approximated the full range of abdominal volumes. This maneuver was performed quickly, easily, and reliably by all subjects. For these reasons, it was used to determine each subject's abdominal capacity. In practice, an abdominal capacity maneuver was performed in two stages. To begin, the subject displaced his abdomen inward maximally while holding his breath at his resting expiratory level. Next, he displaced his abdomen outward maximally while holding his breath again at the same lung volume level. The maximum inward displacement of the abdomen and the maximum outward displacement of the abdomen defined the subject's maximum range of abdominal volumes, or abdominal capacity.

Relaxation maneuvers were included so that, when examined in relation to other kinematic data generated by the same subject, inferences could be made regarding muscular forces acting on the breathing apparatus. For these maneuvers, the subject was instructed to close his larynx at the resting expiratory level and completely relax the chest wall musculature. Relaxation maneuvers were performed prior to each speech breathing trial and before resting tidal breathing.

*Speech breathing activities.* Speech breathing activities included extemporaneous speaking and reading aloud a paragraph, both of which were performed three times by each subject. Each trial of each activity was preceded by a sequence of stable resting tidal breathing, a relaxation maneuver, and additional stable resting tidal breathing. In this way, the resting expiratory level and the relaxation configuration could be used as references throughout the recording session.

For extemporaneous speaking, the subject talked about a preselected topic of his choice with minimal interruption from the interacting investigator. After the subject produced 10 to 20 breath groups, the trial was terminated.

For reading, the subject read aloud a paragraph that he had practiced before the recording session. This paragraph consisted of 12 sentences ranging in length from 7 to 53 syllables and was designed to elicit a large number of breath groups (usually 15 to 25) that varied in syllable number (see Appendix A).

## Measurements

### General Respiratory Function

*Static observations.* Criterion values for the subdivisions of the lung volume studied were obtained as follows. For FRC, calculations were made from each of the three helium dilution trials. Each subject's criterion measure of FRC was

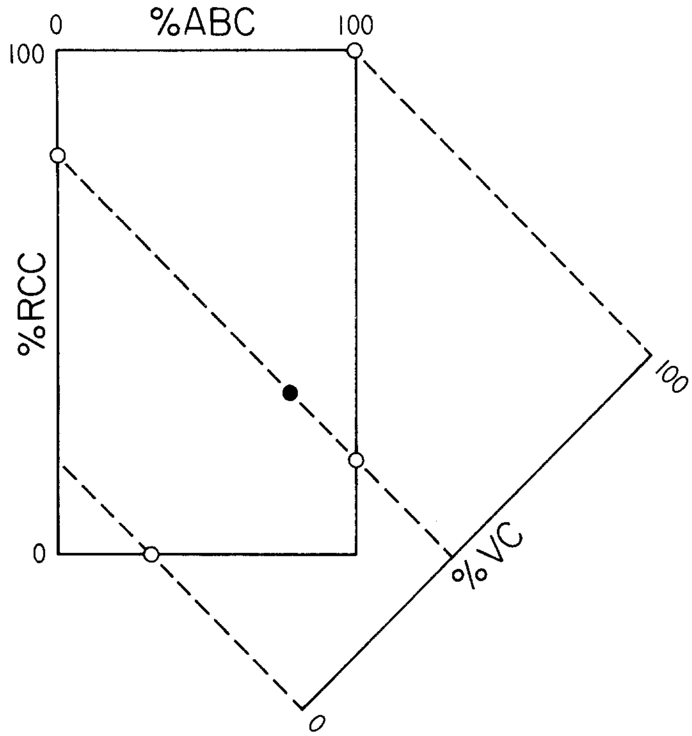


FIGURE 1. Data chart used in the measurement of speech breathing and resting tidal breathing.

determined by averaging the two or three FRC measures that were within 10% of one another. For VC, the largest volume expired by the subject during a VC maneuver was used as the criterion measure. For the remaining four subdivisions of the lung volume (IC, RV, TLC, and ERV), criterion measures were obtained from the two or three trials used to derive FRC. The criterion measure of IC was obtained by averaging the individual IC measurements from the trials. The criterion measure of TLC for each subject was determined by adding IC to FRC for each trial and obtaining an average. The criterion measure of RV was calculated by subtracting the criterion measure of VC from the criterion measure of TLC. The criterion measure of ERV was determined by subtracting the criterion measure of RV from the criterion measure of FRC.

The five subdivisions of the lung volume contained within TLC also were calculated in percentages of TLC values (%TLC). That is, VC, IC, FRC, ERV, and RV each were divided by TLC to obtain a percentage value. In this way, subdivisions of the lung volume were normalized across all subjects so as to express the data independently of absolute differences in TLC.

*Dynamic observations.* Dynamic observations were made on 10 consecutive cycles taken from a stable period of each subject's resting tidal breathing. Measurements and criterion measures were:

1. tidal volume (in liters, L), obtained by multiplying lung volume excursion (in percentage of vital capacity, %VC) for each cycle by the subject's VC (in L) and calculating an average for the 10 cycles;
2. breathing rate (in breaths per minute, BPM), determined by counting the number of cycles occurring in a 3-min period and dividing by 3;
3. minute volume (in liters per minute, LPM), calculated by multiplying the tidal volume by the breathing rate;
4. relative volume contribution of the rib cage (in percentage of rib cage, %RC), determined for each cycle using the same calculation procedure described in the following section and obtaining an average for the 10 cycles.

### *Speech Breathing*

Measurements of speech breathing were made from data obtained during extemporaneous speaking and reading aloud. For extemporaneous speaking, measurements were made from the first 10 breath groups produced by the subject. For reading, measurements were made from all breath groups produced by the subject.

From recordings of the chest wall maneuvers, a data chart, such as the one shown in Figure 1, was traced for each subject. In the chart, the percentage of rib cage capacity (%RCC) is shown on the vertical axis, increasing upward, with 0 and 100 representing the smallest and largest rib cage volumes, respectively. The percentage of abdominal capacity (%ABC) is shown on the horizontal axis, increasing rightward, with 0 and 100 representing the smallest and largest abdominal volumes, respectively. The percentage of vital capacity (%VC) is indicated on the diagonal axis, increasing upward and rightward, with 0 and 100 representing the smallest and largest voluntarily attainable lung volumes, respectively. The filled circle on the chart represents the relaxation configuration of the chest wall at the resting expiratory level. The diagonal line passing through the filled circle represents the resting expiratory level on the lung volume (%VC) axis and indicates the continuum of chest wall shapes that are possible at that lung volume level. This isovolume line is adjusted to a slope of $-1$ to represent equal volume changes for recorded diameter changes of the rib cage and abdomen.

Tracings were made of the expiratory portion of individual speech breathing cycles. Measurements were made from each tracing using the digitizing pad along with special software that made it possible to digitize the limits of the three axes on the subject's data chart (lung volume, rib cage volume, and abdominal volume) and then digitize the initiation and termination points of each breath group tracing along those three axes. From the digitized points, initiation and termination values were obtained for lung volume, rib cage volume, and abdominal volume and were stored on disk for subsequent statistical manipulation.

Nineteen measures were obtained from each breath-group tracing: 15 related to volume, 1 related to relative volume contribution, and 3 related to syllable production. Nine of the volume measures had to do with initiations, terminations, and excursions in relation to the 0% limit on each of the three axes (lung volume, rib cage volume, and abdominal volume). Specifically, these measures were:

1. lung volume initiation (LVI, in %VC);
2. lung volume termination (LVT, in %VC);
3. lung volume excursion (LVE, in %VC);
4. rib cage volume initiation (RCVI, in %RCC);
5. rib cage volume termination (RCVT, in %RCC);
6. rib cage volume excursion (RCVE, in %RCC);
7. abdominal volume initiation (ABVI, in %ABC);
8. abdominal volume termination (ABVT, in %ABC);
9. abdominal volume excursion (ABVE, in %ABC).

The remaining six volume measures were volume initiations and terminations in relation to volumes associated with the relaxation configuration of the chest wall at the resting expiratory level. This relaxation configuration was selected as a reference because it specifies the equilibrium configuration of the overall breathing apparatus. This configuration, as represented by the position of a point on the data chart, was not significantly different across the three subject groups [for lung volume: $F(29) = 2.504$, $p = .101$; for rib cage volume: $F(29) = 2.424$, $p = .108$; for abdominal volume: $F(29) = 0.271$, $p = .765$]. Volume measures obtained in relation to these relaxation references were:

1. lung volume initiation in relation to the reference lung volume (LVI-R, in %VC);
2. lung volume termination in relation to the reference lung volume (LVT-R, in %VC);
3. rib cage volume initiation in relation to the reference rib cage volume (RCVI-R, in %RCC);
4. rib cage volume termination in relation to the reference rib cage volume (RCVT-R, in %RCC);
5. abdominal volume initiation in relation to the reference abdominal volume (ABVI-R, in %ABC);
6. abdominal volume termination in relation to the reference abdominal volume (ABVT-R, in %ABC).

These measures were expressed as positive or negative values, depending on whether they were larger or smaller than the reference volume, respectively.

Measures of relative volume contribution were determined by using the formula:

$$\frac{\dfrac{(\mathrm{RCVI} - \mathrm{RCVT}) \times \mathrm{RC/AB}}{(\mathrm{ABVI} - \mathrm{ABVT})}}{\dfrac{(\mathrm{RCVI} - \mathrm{RCVT}) \times \mathrm{RC/AB}}{(\mathrm{ABVI} - \mathrm{ABVT})} + 1} \times 100$$

where: RCVI = rib cage volume initiation (in %RCC)
RCVT = rib cage volume termination (in %RCC)
ABVI = abdominal volume initiation (in %ABC)
ABVT = abdominal volume termination (in %ABC)
RC/AB = rib cage capacity/abdominal capacity

This formula provided a measure of the relative volume contribution of the rib cage (in %RC) over the entire breath group.

Measures related to syllable production included counts of the number of syllables produced per breath group and calculation of the average lung volume expended per syllable. Syllable counts for each breath group were tabulated from transcripts of the speech audio recordings and expressed in syllables/breath group. The average lung volume expended per syllable was determined by dividing the lung volume excursion of a breath group by the number of syllables uttered in that breath group. Average lung volume expended per syllable was expressed in both absolute values (cc/syllable) and normalized values (%VC/syllable).

Criterion scores for the 19 measures mentioned were determined as follows. To begin, average values were calculated for each of the three trials of the two speech breathing activities. When these average values were inspected, it was apparent that they were highly similar across trials. Computation of eta values indicated that trial number was not a significant source of variability on any of the 19 measures considered (eta values ranged from 0.02 to 0.31). Therefore, all corresponding measures obtained from the three trials of a speech breathing activity were combined, and a grand mean was calculated. These grand means were the criterion scores employed in analysis of variance procedures used in testing for differences among the age groups.

## RESULTS

Data analyses were carried out using standard statistical software (Statistical Package for the Social Sciences—X, [SPSSX INC., 1983]) programmed into a Cyber 175 computer. A significance level of .01 was used for all statistical tests. This level was selected because of the moderate number of subjects in each group.

TABLE 2. Group means and standard deviations of subdivisions of the lung volume in liters (L) and a summary of statistical tests performed on the data.

| Measure | 25 M | 25 (SD) | 50 M | 50 (SD) | 75 M | 75 (SD) |
|---|---|---|---|---|---|---|
| TLC | 6.74 | (0.58) | 7.05 | (1.07) | 6.63 | (0.66) |
| VC | 5.35 | (0.52) | 5.09 | (0.80) | 4.47 | (0.67) |
| IC | 3.62 | (0.53) | 3.59 | (0.62) | 3.19 | (0.49) |
| FRC | 3.12 | (0.40) | 3.46 | (0.64) | 3.44 | (0.47) |
| ERV | 1.73 | (0.25) | 1.50 | (0.44) | 1.28 | (0.51) |
| RV | 1.39 | (0.26) | 1.97 | (0.41) | 2.16 | (0.36) |
| | *F* | | *df* | | *p* | |
| TLC | 0.754 | | 29 | | .480 | |
| VC | 4.525 | | 29 | | .020 | |
| IC | 1.914 | | 29 | | .167 | |
| FRC | 1.423 | | 29 | | .259 | |
| ERV | 2.941 | | 29 | | .070 | |
| RV | 12.881 | | 29 | | .000* | |
| | *t* | | *df* | | *p* | |
| RV | | | | | | |
| 25–50 | 3.656 | | 27 | | .001* | |
| 25–75 | 4.877 | | 27 | | .000* | |
| 50–75 | 1.221 | | 27 | | .233 | |

*$p \leq .01$

*Note.* TLC = total lung capacity
VC = vital capacity
IC = inspiratory capacity
FRC = functional residual capacity
ERV = expiratory reserve volume
RV = residual volume
25 = 25-year-old group
50 = 50-year-old group
75 = 75-year-old group

TABLE 3. Group means and standard deviations of subdivisions of the lung volume in percentage of total lung capacity (% TLC) and a summary of statistical tests performed on the data.

| Measure | 25 M | 25 (SD) | 50 M | 50 (SD) | 75 M | 75 (SD) |
|---|---|---|---|---|---|---|
| VC/TLC | 79.37 | (3.35) | 72.16 | (3.49) | 67.27 | (5.71) |
| IC/TLC | 53.68 | (5.13) | 50.92 | (4.20) | 48.13 | (5.37) |
| FRC/TLC | 46.32 | (5.13) | 49.08 | (4.20) | 51.88 | (5.37) |
| ERV/TLC | 25.69 | (3.73) | 21.24 | (4.66) | 19.15 | (7.09) |
| RV/TLC | 20.63 | (3.35) | 27.84 | (3.49) | 32.73 | (5.71) |
| | *F* | | *df* | | *p* | |
| VC/TLC | 19.846 | | 29 | | .000* | |
| IC/TLC | 3.182 | | 29 | | .057 | |
| FRC/TLC | 3.182 | | 29 | | .057 | |
| ERV/TLC | 3.900 | | 29 | | .033 | |
| RV/TLC | 19.846 | | 29 | | .000* | |
| | *t* | | *df* | | *p* | |
| VC/TLC | | | | | | |
| 25–50 | 3.734 | | 27 | | .001* | |
| 25–75 | 6.262 | | 27 | | .000* | |
| 50–75 | 2.528 | | 27 | | .018 | |
| RV/TLC | | | | | | |
| 25–50 | 3.734 | | 27 | | .001* | |
| 25–75 | 6.262 | | 27 | | .000* | |
| 50–75 | 2.528 | | 27 | | .018 | |

*$p \leq .01$

*Note.* VC/TLC = vital capacity/total lung capacity
IC/TLC = inspiratory capacity/total lung capacity
FRC/TLC = functional residual capacity/total lung capacity
ERV/TLC = expiratory reserve volume/total lung capacity
RV/TLC = residual volume/total lung capacity

## GENERAL RESPIRATORY FUNCTION

### *Static Observations*

Information regarding measures of subdivisions of the lung volume (in L) is provided in Table 2. Mean TLCs for the three age groups ranged from about 6.6 to 7.1 L. Group means ranged approximately from 4.5 to 5.4 L for VC, 3.2 to 3.6 L for IC, 3.1 to 3.5 L for FRC, 1.3 to 1.7 L for ERV, and 1.4 to 2.2 L for RV. Analysis of variance indicated that group differences were significant for RV only. Two-treatment contrasts revealed that differences were significant for the 25–50 and 25–75 group pairings. These differences were characterized by a smaller mean RV in the 25-year-old group than in the older subject groups.

Results pertaining to measures of subdivisions of the lung volume in normalized form (in %TLC) are given in Table 3. Group means ranged approximately from 67.3 to 79.4 %TLC for VC/TLC, 48.1 to 53.7 %TLC for IC/TLC, 46.3 to 51.9 %TLC for FRC/TLC, 19.2 to 25.7 %TLC for ERV/TLC, and 20.6 to 32.7 %TLC for RV/TLC. Inferential statistical analysis indicated significant group differences for VC/TLC and RV/TLC. Two-treatment contrasts revealed that differences were significant for the 25–50 and 25–75 group pairings. These differences were characterized by a larger mean VC/TLC and a smaller mean RV/TLC in the young subject group than in the older subject groups.

### *Dynamic Observations*

Table 4 provides information regarding measures of resting tidal breathing. Group means ranged approximately from 0.5 to 0.7 L for tidal volume, 13.7 to 15.6 BPM for breathing rate, 7.4 to 8.7 LPM for minute volume, and 80.6 to 85.0 %RC for relative volume contribution. Inferential statistical analysis indicated that group differences on these measures were not significant.

## SPEECH BREATHING

### *Extemporaneous Speaking*

Given in Table 5 are findings related to measures of volume as referenced to the 0% limit in lung volume, rib cage volume, and abdominal volume. For lung volume events, group means ranged approximately from 44.1 to

TABLE 4. Group means and standard deviations of resting tidal breathing measures and a summary of statistical tests performed on the data. Measures included tidal volume (in L), breathing rate (in breaths per minute, BPM), minute volume (in liters per minute, LPM), and relative volume contribution (in percentage of rib cage, %RC).

| | 25 | | 50 | | 75 | |
|---|---|---|---|---|---|---|
| *Measure* | M | (SD) | M | (SD) | M | (SD) |
| Tidal volume | 0.56 | (0.13) | 0.71 | (0.26) | 0.53 | (0.11) |
| Breathing rate | 13.66 | (3.42) | 13.69 | (4.67) | 15.57 | (2.26) |
| Minute volume | 7.36 | (1.66) | 8.72 | (1.94) | 8.24 | (1.89) |
| Relative volume contribution | 80.95 | (7.87) | 80.59 | (6.36) | 85.02 | (6.52) |
| | *F* | | *df* | | *p* | |
| Tidal volume | 2.845 | | 29 | | .076 | |
| Breathing rate | 0.932 | | 29 | | .406 | |
| Minute volume | 1.398 | | 29 | | .264 | |
| Relative volume contribution | 1.252 | | 29 | | .302 | |

49.5 %VC for LVI, 27.5 to 30.0 %VC for LVT, and 15.3 to 20.6 %VC for LVE. For rib cage volume events, group means ranged approximately from 48.1 to 54.6 %RCC for RCVI, 27.6 to 33.9 %RCC for RCVT, and 17.0 to 21.6 %RCC for RCVE. For abdominal volume events, group means ranged approximately from 68.0 to 76.7 %ABC for ABVI, 59.3 to 69.2 %ABC for ABVT, and 7.6 to 8.7 %ABC for ABVE. Analysis of variance revealed group differences for LVE only. Two-treatment contrasts indicated that differences were significant for the 25–75 group pairing. These differences were characterized by a smaller mean excursion for the 25-year-old group than for the 75-year-old group.

Information pertinent to measures of volume referenced to volumes associated with the relaxation chest wall configuration is provided in Table 6. For lung volume events, group means ranged approximately from 11.0 to 20.6 %VC for LVI-R, and −4.3 to 0.0 %VC for LVT-R. For rib cage volume events, group means ranged approximately from 16.1 to 26.8 %RCC for RCVI-R, and −0.9 to 5.2 %RCC for RCVT-R. For abdominal volume events, group means ranged approximately from −10.2 to −3.9 %ABC for ABVI-R, and −18.8 to −11.4 %ABC for ABVT-R. Statistical analysis revealed that group differences were significant for RCVI-R only. Two-treatment contrasts indicated significant between-group differences for the 25–50 and 25–75 group pairings. Group differences for RCVI-R were characterized by a smaller mean initiation volume for the 25-year-old group than for older subject groups.

For measures of relative volume contribution during extemporaneous speaking, group means were 84.46 ($SD$ = 4.42), 82.27 ($SD$ = 8.86), and 86.53 ($SD$ = 5.08) %RC for the 25-, 50-, and 75-year-old groups, respectively. Analysis of variance indicated that these means were not significantly different [$F(29) = 1.099$, $p = .348$].

Results of measures related to syllable production are given in Table 7. Group means for these measures ranged approximately from 12.5 to 18.2 syllables/breath group, 64.8 to 91.6 cc/syllable, and 1.2 to 2.2 %VC/syllable. Analysis of variance indicated significant differences for syllables/breath group and %VC/syllable. Two-treatment contrasts revealed significant between-group differences for the 25–75 group pairing for both syllables/breath group and %VC/syllable. For syllables/breath group, group differences were in the form of a larger mean for the 25-year-old group than for the 75-year-old group. For %VC/syllable, group differences were characterized by a smaller mean value for the 25-year-old group than for the 75-year-old group.

TABLE 5. Group means and standard deviations of volume measures referenced to the 0% limit for extemporaneous speaking and a summary of statistical tests performed on the data.

| | 25 | | 50 | | 75 | |
|---|---|---|---|---|---|---|
| *Measure* | M | (SD) | M | (SD) | M | (SD) |
| LVI | 44.10 | (8.97) | 49.54 | (8.30) | 48.14 | (10.50) |
| LVT | 28.83 | (8.83) | 29.97 | (8.31) | 27.50 | (8.92) |
| LVE | 15.27 | (1.58) | 19.57 | (4.46) | 20.63 | (4.30) |
| RCVI | 48.07 | (7.62) | 54.62 | (8.76) | 49.21 | (12.25) |
| RCVT | 31.07 | (8.58) | 33.91 | (10.82) | 27.63 | (10.56) |
| RCVE | 17.00 | (2.66) | 20.71 | (4.82) | 21.58 | (3.76) |
| ABVI | 71.03 | (14.09) | 67.96 | (9.84) | 76.69 | (11.84) |
| ABVT | 62.30 | (15.80) | 59.34 | (10.16) | 69.23 | (11.64) |
| ABVE | 8.73 | (3.42) | 8.67 | (3.27) | 7.55 | (3.66) |
| | *F* | | *df* | | *p* | |
| LVI | 0.921 | | 29 | | .410 | |
| LVT | 0.202 | | 29 | | .818 | |
| LVE | 5.915 | | 29 | | .007* | |
| RCVI | 1.291 | | 29 | | .292 | |
| RCVT | 0.981 | | 29 | | .388 | |
| RCVE | 3.985 | | 29 | | .030 | |
| ABVI | 1.352 | | 29 | | .276 | |
| ABVT | 1.584 | | 29 | | .224 | |
| ABVE | 0.370 | | 29 | | .694 | |
| | *t* | | *df* | | *p* | |
| LVE | | | | | | |
| 25–50 | 2.875 | | 11.2 | | .015 | |
| 25–75 | 3.698 | | 11.4 | | .003* | |
| 50–75 | 0.543 | | 18.0 | | .594 | |

*$p \le .01$

*Note.* LVI = lung volume initiation referenced to the 0% limit of vital capacity (in percentage of vital capacity, %VC)
LVT = lung volume termination referenced to the 0% limit of vital capacity (in %VC)
LVE = lung volume excursion referenced to the 0% limit of vital capacity (in %VC)
RCVI = rib cage volume initiation referenced to the 0% limit of rib cage capacity (in percentage of rib cage capacity, %RCC)
RCVT = rib cage volume termination referenced to the 0% limit of rib cage capacity (in %RCC)
RCVE = rib cage volume excursion referenced to the 0% limit of rib cage capacity (in %RCC)
ABVI = abdominal volume initiation referenced to the 0% limit of abdominal capacity (in percentage of abdominal capacity, %ABC)
ABVT = abdominal volume termination referenced to the 0% limit of abdominal capacity (in %ABC)
ABVE = abdominal volume excursion referenced to the 0% limit of abdominal capacity (in %ABC)

TABLE 6. Group means and standard deviations of volume measures referenced to volumes associated with the relaxation configuration of the chest wall for extemporaneous speaking and a summary of statistical tests performed on the data.

| *Measure* | 25 M | 25 (SD) | 50 M | 50 (SD) | 75 M | 75 (SD) |
|---|---|---|---|---|---|---|
| LVI-R | 10.95 | (7.14) | 16.04 | (6.80) | 20.60 | (7.76) |
| LVT-R | −4.32 | (6.96) | −3.53 | (7.42) | −0.04 | (5.09) |
| RCVI-R | 16.11 | (5.51) | 25.07 | (9.24) | 26.81 | (5.28) |
| RCVT-R | −0.89 | (6.59) | 4.36 | (9.74) | 5.23 | (5.45) |
| ABVI-R | −8.12 | (10.66) | −10.22 | (7.14) | −3.93 | (6.44) |
| ABVT-R | −16.85 | (12.04) | −18.84 | (6.63) | −11.39 | (6.55) |

| | *F* | *df* | *p* |
|---|---|---|---|
| LVI-R | 4.436 | 29 | .022 |
| LVT-R | 1.203 | 29 | .316 |
| RCVI-R | 6.896 | 29 | .004* |
| RCVT-R | 1.960 | 29 | .160 |
| ABVI-R | 1.496 | 29 | .242 |
| ABVT-R | 1.928 | 29 | .165 |

| | *t* | *df* | *p* |
|---|---|---|---|
| RCVI-R | | | |
| 25–50 | 2.898 | 27 | .007* |
| 25–75 | 3.460 | 27 | .002* |
| 50–75 | 0.562 | 27 | .578 |

$^*p \le .01$

*Note.* LVI-R = lung volume initiation referenced to the relaxation lung volume (in %VC)
LVT-R = lung volume termination referenced to the relaxation lung volume (in %VC)
RCVI-R = rib cage volume initiation referenced to the relaxation rib cage volume (in %RCC)
RCVT-R = rib cage volume termination referenced to the relaxation rib cage volume (in %RCC)
ABVI-R = abdominal volume initiation referenced to the relaxation abdominal volume (in %ABC)
ABVT-R = abdominal volume termination referenced to the relaxation abdominal volume (in %ABC)

TABLE 7. Group means and standard deviations of measures related to syllable production for extemporaneous speaking and a summary of statistical tests performed on the data.

| *Measure* | 25 M | 25 (SD) | 50 M | 50 (SD) | 75 M | 75 (SD) |
|---|---|---|---|---|---|---|
| Syllables/breath group | 16.55 | (2.94) | 18.20 | (5.68) | 12.54 | (2.41) |
| cc/syllable | 64.83 | (22.55) | 68.62 | (26.78) | 91.57 | (31.43) |
| %VC/syllable | 1.23 | (0.32) | 1.42 | (0.50) | 2.24 | (0.79) |

| | *F* | *df* | *p* |
|---|---|---|---|
| Syllables/breath group | 5.429 | 29 | .010* |
| cc/syllable | 2.838 | 29 | .076 |
| %VC/syllable | 8.927 | 29 | .001* |

| | *t* | *df* | *p* |
|---|---|---|---|
| Syllables/breath group | | | |
| 25–50 | 0.814 | 13.5 | .430 |
| 25–75 | 3.330 | 17.3 | .004* |
| 50–75 | 2.898 | 12.1 | .013 |
| %VC/syllable | | | |
| 25–50 | 1.057 | 15.3 | .307 |
| 25–75 | 3.765 | 11.9 | .003* |
| 50–75 | 2.770 | 15.1 | .014 |

$^*p \le .01$

## Reading

Table 8 contains information on measures of volume as referenced to the 0% limit in lung volume, rib cage volume, and abdominal volume. For lung volume events, group means ranged approximately from 40.7 to 46.9 %VC for LVI, 22.5 to 26.7 %VC for LVT, and 14.2 to 20.3 %VC for LVE. For rib cage volume events, group means ranged approximately from 45.0 to 51.9 %RCC for RCVI, 24.2 to 30.2 %RCC for RCVT, and 16.8 to 21.7 %RCC for RVCE. For abdominal volume events, group means ranged approximately from 66.2 to 70.3 %ABC for ABVI, 56.6 to 60.9 %ABC for ABVT, and 8.1 to 9.7 %ABC for ABVE. Analysis of variance indicated no significant group differences.

Findings associated with volumetric measures referenced to volumes associated with the relaxation configuration of the chest wall are provided in Table 9. For lung volume events, group means ranged approximately from 7.6 to 14.5 %VC for LVI-R, and −6.9 to −5.1 %VC for LVT-R. For rib cage volume events, group means ranged approximately from 13.5 to 22.6 %RCC for RCVI-R, and −3.3 to 1.8 %RCC for RCVT-R. For abdominal volume events, group means ranged approximately from −12.9 to −10.3 %ABC for ABVI-R, and −21.5 to −19.7 %ABC for ABVT-R. Analysis of variance revealed no significant differences.

For measures of relative volume contribution, group means were 85.27 (*SD* = 6.06), 82.44 (*SD* = 8.13), and 83.94 (*SD* = 9.50) %RC for the 25-, 50-, and 75-year-old groups, respectively. Statistical analysis revealed no significant differences [$F(29) = 0.311$, $p = .735$].

Information regarding measures related to syllable pro-

TABLE 8. Group means and standard deviations of volume measures referenced to the 0% limit for reading and a summary of statistical tests performed on the data.

| *Measure* | 25 M | 25 (SD) | 50 M | 50 (SD) | 75 M | 75 (SD) |
|---|---|---|---|---|---|---|
| LVI | 40.68 | (9.33) | 46.91 | (6.63) | 42.01 | (14.09) |
| LVT | 26.46 | (9.45) | 26.65 | (5.58) | 22.48 | (8.40) |
| LVE | 14.22 | (2.26) | 20.26 | (6.07) | 19.53 | (7.75) |
| RCVI | 45.46 | (8.57) | 51.86 | (7.70) | 45.00 | (14.87) |
| RCVT | 28.67 | (10.04) | 30.16 | (6.35) | 24.15 | (9.36) |
| RCVE | 16.79 | (3.10) | 21.71 | (4.15) | 20.85 | (7.16) |
| ABVI | 66.20 | (14.91) | 66.25 | (8.31) | 70.34 | (12.90) |
| ABVT | 58.31 | (17.13) | 56.64 | (7.25) | 60.90 | (11.36) |
| ABVE | 8.13 | (3.41) | 9.71 | (4.87) | 9.64 | (5.91) |

| | *F* | *df* | *p* |
|---|---|---|---|
| LVI | 0.975 | 29 | .390 |
| LVT | 0.870 | 29 | .430 |
| LVE | 3.166 | 29 | .058 |
| RCVI | 1.247 | 29 | .303 |
| RCVT | 1.281 | 29 | .294 |
| RCVE | 2.644 | 29 | .089 |
| ABVI | 0.360 | 29 | .701 |
| ABVT | 0.292 | 29 | .749 |
| ABVE | 0.339 | 29 | .716 |

TABLE 9. Group means and standard deviations of volume measures referenced to volumes associated with the relaxation configuration of the chest wall for reading and a summary of statistical tests performed on the data.

| | 25 | | 50 | | 75 | |
|---|---|---|---|---|---|---|
| *Measure* | M | (SD) | M | (SD) | M | (SD) |
| LVI-R | 7.56 | (7.07) | 13.41 | (5.29) | 14.47 | (10.16) |
| LVT-R | −6.69 | (7.20) | −6.85 | (4.84) | −5.06 | (5.97) |
| RCVI-R | 13.50 | (6.51) | 22.31 | (6.52) | 22.60 | (9.74) |
| RCVT-R | −3.29 | (8.66) | 0.61 | (8.46) | 1.75 | (7.68) |
| ABVI-R | −12.85 | (11.69) | −11.93 | (6.69) | −10.28 | (8.31) |
| ABVT-R | −20.84 | (13.30) | −21.54 | (5.96) | −19.72 | (8.86) |
| | *F* | | *df* | | *p* | |
| LVI-R | 2.296 | | 29 | | .120 | |
| LVT-R | 0.266 | | 29 | | .768 | |
| RCVI-R | 4.464 | | 29 | | .021 | |
| RCVT-R | 1.020 | | 29 | | .374 | |
| ABVI-R | 0.202 | | 29 | | .819 | |
| ABVT-R | 0.087 | | 29 | | .917 | |

TABLE 10. Group means and standard deviations of measures related to syllable production for reading and a summary of statistical tests performed on the data.

| | 25 | | 50 | | 75 | |
|---|---|---|---|---|---|---|
| *Measure* | M | (SD) | M | (SD) | M | (SD) |
| Syllables/breath group | 20.77 | (4.89) | 22.01 | (6.17) | 16.26 | (4.22) |
| cc/syllable | 39.17 | (10.83) | 48.34 | (11.95) | 54.69 | (12.50) |
| %VC/syllable | 0.74 | (0.15) | 1.00 | (0.19) | 1.36 | (0.42) |
| | *F* | | *df* | | *p* | |
| Syllables/breath group | 3.450 | | 29 | | .046 | |
| cc/syllable | 4.386 | | 29 | | .022 | |
| %VC/syllable | 12.557 | | 29 | | .001* | |
| | *t* | | *df* | | *p* | |
| %VC/syllable | | | | | | |
| 25–50 | 3.338 | | 17.0 | | .004* | |
| 25–75 | 4.424 | | 11.2 | | .001* | |
| 50–75 | 2.529 | | 12.5 | | .026 | |

$^*p \leq .01$

duction is given in Table 10. Group means for these measures ranged approximately from 16.3 to 22.0 syllables/breath group, 39.2 to 54.7 cc/syllable, and 0.7 to 1.4 %VC/syllable. Statistical analysis indicated significant differences for the %VC/syllable measure only. Two-treatment contrasts revealed significant differences for the 25–50 and 25–75 group pairings. Group differences were characterized by a lower mean %VC/syllable for the 25-year-old group than for the older two groups.

A summary of the overall results is provided in Table 11. In this table, all significant between-group contrasts and the directions of differences are indicated for measures of general respiratory function and speech breathing. Regarding general respiratory function, group differences were found on static observations only. These differences were in RV (in L), VC/TLC (in %TLC), and RV/TLC (in %TLC) and were significant for the 25–50 and 25–75 group contrasts. The pattern of differences was a larger VC/TLC and a smaller RV and RV/TLC for the 25-year-old group than for the 50- and 75-year-old groups. Regarding speech breathing, group differences were found on four measures of extemporaneous speaking and one measure of reading. For extemporaneous speaking, significant group differences were found for LVE, RCVI-R, syllables/breath group, and %VC/syllable. Between-group contrasts revealed significant differences for the 25–75 contrast on all four of these measures along with an additional significant contrast (25–50) for RCVI-R. For three measures (LVE, RCVI-R, and %VC/syllable), the 25-year-old group had the lowest means, and the 75-year-old group had the highest means. For the remaining measure (syllables/breath group), the mean of the 25-year-old group was larger than the mean of the 75-year-old group. With regard to reading, significant differences were found for %VC/syllable only. The pattern of difference was a lower mean value for the 25-year-old group than for the older groups. Considering the overall pattern of differences among the groups, five measures, three related to subdivisions of the lung volume and two related to speech breathing, were found to be different for the 25–50 group pairing. Eight measures, the same five that separated the 25- and 50-year-old groups plus three additional speech breathing measures, were significantly different for the 25–75 group pairing. It should be noted that the 50- and 75-year-old groups were not significantly different on any of the 19 variables studied.

## DISCUSSION

### GENERAL RESPIRATORY FUNCTION

#### *Static Observations*

Subdivisions of the lung volume have been a focus of several modern investigations of general respiratory func-

TABLE 11. Summary of significant between-group differences and direction of differences for measures of general respiratory function (static observations) and speech breathing (extemporaneous speaking and reading).

| *Measure* | *25–50* | *25–75* | *50–75* |
|---|---|---|---|
| General respiratory function | | | |
| Static Observations: | | | |
| RV | < | < | |
| VC/TLC | > | > | |
| RV/TLC | < | < | |
| Speech breathing | | | |
| Extemporaneous speaking: | | | |
| LVE | | < | |
| RCVI-R | < | < | |
| syllables/breath group | | > | |
| %VC/syllable | | < | |
| Reading: | | | |
| %VC/syllable | < | < | |

tion (Boren, Kory, & Syner, 1966; Cohn & Donoso, 1963; Frank, Mead, & Ferris, 1957; Mittman, Edelman, Norris, & Shock, 1965; Muiesan, Sorbini, & Grassi, 1971; Stanescu et al., 1968). When considered in relation to such previous reports, the measures of subdivisions of the lung volume obtained from the present subjects were found to be generally similar in magnitudes and in patterns of relative magnitudes.

In previous studies, TLC, when corrected for height, has been shown to remain relatively constant across adulthood (Boren et al., 1966; Frank et al., 1957; Knudson, Clark, Kennedy, & Knudson, 1977). In agreement with previously reported data, TLC for the present group of subjects was not found to differ significantly with age. Accordingly, it was not deemed necessary to apply a height correction to the data.

Although there is relatively consistent agreement that TLC does not change with age, the case for IC and FRC is not so clear-cut. Some investigators have documented a slight age-related increase in FRC accompanied by a measured or inferred decrease in IC (Cohn & Donoso, 1963; Mittman et al., 1965; Turner, Mead, & Wohl, 1968), whereas other investigators have reported no age-related differences for either IC or FRC (Boren et al., 1966; Permutt & Martin, 1960). In the present investigation, no significant differences were found between the age groups for IC and FRC (or IC/TLC and FRC/TLC). However, group means for IC (and IC/TLC) generally decreased with age, and group means for FRC (and FRC/TLC) generally increased with age, trends that are consistent with previous literature that has shown age-related differences for these two subdivisions.

ERV has been shown in previous investigations to decrease with age (Boren et al., 1966; Chebotarev, Korkushko, & Ivanov, 1974). In the present investigation, ERV and ERV/TLC did not differ significantly across the age groups studied. However, group means for ERV (expressed in both absolute and normalized forms) were highest for the young group and lowest for the senescent group, thereby evidencing the expected pattern of age-related differences.

In the present investigation, two subdivisions of the lung volume were found to differ significantly with age, VC (in normalized form) and RV (in both absolute and normalized forms). Age-related differences in these two subdivisions have been well-documented (Boren et al., 1966; Brody et al., 1974; Chebotarev et al., 1974; Cohn & Donoso, 1963; Cole, 1974; Mittman et al., 1965; Stanescu et al., 1968; Storstein & Voll, 1962) and have been shown to be characterized by a decrease in VC and an increase in RV with age. For the present subjects, group means for VC/TLC and RV (and RV/TLC) exhibited the expected age-related patterns. Between-group differences were significant when the young adult group was contrasted against each of the two older groups. It should be noted that, although the group means for VC expressed in absolute values were not significantly different, they were characterized by clear decrements across age, as would be expected from previous research. Contrasting the youngest and oldest groups on this measure, it can be seen that their group means differed by almost 0.9 L. Furthermore, inspection of the individual criterion measures for these two groups of subjects revealed that the VCs of seven of the 75-year-old subjects were smaller than those of the 25-year-old subjects.

These age-related shifts in subdivisions of the lung volume appear to have mechanical roots. As mentioned earlier, certain mechanical properties of the respiratory apparatus tend to change with age (see Table 1). Of these changes, the most relevant with respect to shifts in subdivisions of the lung volume relates to the reduction in recoil pressure in the lungs and airways that accompanies aging. This loss of pulmonary recoil pressure has been implicated strongly as a mechanism underlying the significant age-related reduction of VC and the concomitant enlargement of RV (Begin, Renzetti, Bigler, & Watanabe, 1975; Bode, Dosman, Martin, Ghezzo, & Macklem, 1976; Colebatch, Greaves, & Ng, 1979; Gibson, Pride, O'Cain, & Quagliato, 1976; Islam, 1980; Knudson et al., 1977; Mead, Turner, Macklem, & Little, 1967; Pierce & Ebert, 1958; Turner et al., 1968). Although it might seem reasonable to assume that the magnitude of VC is limited by the muscular forces available in the chest wall, this notion has not proven adequate for understanding general respiratory function in adults of all ages. Two reasons for its inadequacy can be offered. First, although the ability to exert inspiratory muscular pressure may be somewhat reduced in older people when contrasted to younger people (Black & Hyatt, 1969), this reduction does not influence significantly the magnitude of the upper limit of VC (i.e., TLC). Second, although maximum expiratory muscular force decreases somewhat with aging (Black & Hyatt, 1969), the magnitude of the reduction is too small to explain the substantial reduction in VC. An investigation by Leith and Mead (1967) elucidated the probable mechanisms that set the lower limit on VC (and thereby the upper limit on RV) for different-aged individuals. The mechanisms appear to differ across age, with that for young adults being vested in the chest wall system and that for older adults being vested in the pulmonary system. Specifically, for young adults, the limiting mechanism appears to be the magnitude of the expiratory muscular force available. For older adults, the limiting mechanism appears to stem from both decreased pulmonary recoil pressure and lower airway conductance. In addition, air-trapping also is believed to be an important factor in the smaller VC (and larger RV) found in older subjects (Bode et al., 1976; Islam, 1980; Jones, Overton, Hammerlindl, & Sproule, 1978; Leith & Mead, 1967). Other potentially contributing factors in determining the lower limit of VC in older people may include the ability to sustain an expiratory muscular effort and the ability to delay oxygen replenishment (Knudson, Slatin, Lebowitz, & Burrows, 1976; Leith & Mead, 1967).

To summarize what is known from the present investigation as well as from past research, certain subdivisions of the lung volume tend to remain constant across the adult life span, and others tend to change in a predictable manner. Specifically, TLC does not change with age. IC and FRC may alter slightly over the years, with IC decreasing and FRC increasing, or they may remain unchanged. By contrast, VC and RV clearly change with age, with VC becoming progressively smaller and RV becoming progressively larger. In addition, a decrease in ERV is a typical feature of aging.

Regarding the relative importance of these static observations of general respiratory function on speech breathing performance, it is probably the age-related reduction in VC that carries the greatest impact. For any act requiring volitional expenditure of air, such as speech production, the volume of air available to perform the act is, by definition, the vital capacity. Therefore, it follows that older individuals must operate within a more limited range of volumes for speech production.

### *Dynamic Observations*

Measures of resting tidal breathing obtained from the present subjects were similar to previously reported values for tidal volume (Bergofsky, 1964; Chebotarev et al., 1974; Comroe, Forster, DuBois, Briscoe, & Carlsen, 1962; Mead & Agostoni, 1964; Needham, Rogan, & McDonald, 1954), breathing rate (Comroe et al., 1962; Cotes, 1979; Mead, 1960), minute volume (Chebotarev et al., 1974; Cotes, 1979; Robinson, Dill, Tzankoff, Wagner, & Robinson, 1975), and relative volume contribution (Grimby, Bunn, & Mead, 1968; Hixon et al., 1973; Sharp, Goldberg, Druz, & Danon, 1975). In this investigation, none of the measures of resting tidal breathing were found to be significantly different across the age groups.

In addition to the four measures of resting tidal breathing just mentioned, the present subjects were similar to previously studied subjects in the background chest wall configuration assumed at the resting expiratory level (Hixon et al., 1973; Loring & Mead, 1982). That is, most of the present subjects (25 of the 30) breathed with the chest wall deformed slightly from the configuration assumed during relaxation. This deformation was characterized by an abdominal volume that was relatively smaller and a rib cage volume that was relatively larger than those associated with the relaxation configuration. No age-related trends were observed with regard to this feature of resting tidal breathing.

The relative contributions of the rib cage and abdomen demonstrated by the present subjects indicated an increase in both rib cage and abdominal volumes during the inspiratory phase of the tidal breathing cycle, with the contribution of the rib cage predominating. This continuum of chest wall configurations is consistent with volume-pressure studies showing that lung volume change during inspiration parallels the configurations associated with the relaxation characteristic of the chest wall and is accomplished primarily by the activation of the diaphragm (Goldman, 1974; Goldman & Mead, 1973; Mead, 1974). Presumably, the diaphragm was the prime inspiratory driver for the present subjects as well.

To summarize, the present subjects were similar to previously studied subjects in both static and dynamic measures of general respiratory function. The fact that these subjects are representative of other subjects in such measures can only enhance the generalizability of the speech breathing findings of this investigation.

## Speech Breathing

### *Extemporaneous Speaking and Reading*

Age-related differences were found on selected measures of speech breathing. For extemporaneous speaking, significant group differences were found on 4 of the 19 measures (LVE, RCVI-R, syllables/breath group, and %VC/syllable). These differences were characterized by a smaller mean LVE and %VC/syllable for the 25-year-old group than for the 75-year-old group, a smaller mean RCVI-R for the 25-year-old group than for the two older groups, and a larger syllables/breath group for the 25-year-old group than for the 75-year-old group. For reading, only one measure was significant (%VC/syllable). Differences on this measure were characterized by a smaller mean %VC/syllable for the 25-year-old group than for the two older groups.

When significant group differences for both speaking activities are considered, it is apparent that most of the significant between-group contrasts were for the 25–75 group pairing. In two cases, a 25–50 contrast was significant. Therefore, for the most part, more than a 25-year age differential was required for statistically significant differences to be manifested. It is, of course, possible that significant differences might have been found between age groups separated by fewer than 25 years had additional or different age groups been studied.

When group means are examined without regard for the results of inferential statistical analysis, it is apparent that the age-related trends that characterized the two speaking activities were relatively similar. However, the fact that extemporaneous speaking was associated with a greater number of statistically significant group differences than was reading suggests that extemporaneous speaking was more sensitive than reading in revealing age-related differences.

### *Mechanisms*

For the present subjects, mechanisms underlying age-related differences in speech breathing behavior can be conceptualized under three categories. These include (a) adjustments in linguistic performance, (b) adjustments in downstream valving, and (c) adjustments in the breathing apparatus.

*Adjustments in linguistic performance.* Information about linguistic performance is contained in the syllables/breath group measure. Significant group differences on this measure were found for extemporaneous speaking (wherein the linguistic content and form were determined by the subject), but not for reading (a linguistically constrained activity). Because the oldest group of subjects produced significantly fewer syllables per breath group than did the youngest group of subjects during extemporaneous speaking, one might initially think that the older subjects spoke in shorter sentences. However, examination of transcripts of the spoken-language samples obtained from the present subjects failed to reveal any age-related differences in sentence length. Furthermore, other authors have reported that older subjects use sentences that are either of similar length or longer than those of younger subjects (see reviews by Bayles, Tomoeda, & Boone, 1985; Obler & Albert, 1981). It appears that the older subjects in the present investigation chose to manipulate the phrasing of their spoken utterances by reducing the average number of syllables produced per breath group. Support for this notion is contained in the syllable counts for reading, wherein sentence length was predetermined. Although group differences were not found to be significant on the reading activity, there was a strong tendency for the syllables/breath group measure to decrease with age. This may reflect a linguistic adjustment in response to biomechanical differences among the age groups. The most likely reason for such differences has to do with valving changes downstream of the breathing apparatus.

*Adjustments in downstream valving.* Certain between-group differences in measures of speech breathing are suggestive of age-related adjustments in downstream valving. These are the LVE and %VC/syllable measures, both of which were larger in the oldest group than in the youngest group. Larger lung volume excursions and greater expenditures of %VC per syllable suggest a reduced economy of valving of the airstream by laryngeal or upper airway structures, or both. Further evidence to support a reduced economy of valving is provided in the cc/syllable measure, a measure of absolute lung volume expended per syllable not influenced by the magnitude of VC. Although there was not a significant difference on this measure, there was a strong tendency for the magnitude of the cc/syllable measure to increase with age. It is tempting to speculate that the %VC/syllable measure reached statistical significance, and the cc/syllable measure did not, because %VC/syllable is expressed as a percentage of VC, a subdivision of the lung volume that was smallest in the senescent group. Therefore, a given absolute volume of air represents a relatively larger percentage of an older subject's VC than of a younger subject's VC. Although the valving effect alone (represented in the cc/syllable measure) was not powerful enough to reach statistical significance, when it was combined with the reduced VC effect (as in the %VC/syllable measure), age-related differences reached significance.

The most likely source of differences in downstream valving economy is the larynx, a structure that is positioned strategically at the outlet of the breathing apparatus and is known to undergo substantial age-related changes (see review by Kahane, 1981). Some of these changes include atrophy of laryngeal muscles, thinning of elastic fibers in the vocal ligaments, ossification of laryngeal cartilages, and atrophy of mucous glands. It has been suggested that a potential sequela of these age-related changes in the larynx, particularly atrophy of intrinsic laryngeal muscles, might be a reduction in laryngeal airway resistance (Kahane, 1981). A reduction in laryngeal airway resistance without a concomitant decrease in respiratory driving pressure would result in a higher rate of lung volume expenditure. It seems reasonable that such a mechanism could have been operating in the older subjects of this investigation. This mechanism may lead to linguistic adjustments related to breath-group phrasing, as mentioned earlier, as well as to alterations in breathing behavior.

*Adjustments in the breathing apparatus.* Certain age-related differences in measures of speech breathing offer evidence that older subjects adjust the breathing apparatus to accommodate to changes in downstream valving. These differences are in measures related to lung volume and rib cage volume initiations and excursions.

Significant group differences for RCVI-R and LVE indicated that older subjects, when compared to younger subjects, generally used higher rib cage volume initiations and larger lung volume excursions. A mechanism that may account for these group differences relates to the older subjects' anticipated need for a somewhat larger volume of air to produce the ensuing breath group than would be anticipated by a younger subject. Therefore, to accommodate for the relatively greater loss of lung volume during speech production associated with reduced valving economy, the older subject inspires to a higher lung volume than his younger counterpart. In the present subjects, inspiratory volume change was accomplished primarily with the rib cage. This muscular solution provides the dual advantage of increasing rib cage volume along with lung volume. The advantage of increasing rib cage volume, in contrast to abdominal volume, is that the rib cage is responsible for executing high flow events (Watson & Hixon, 1985). By placing the rib cage at a higher size for utterance initiation, its mechanical advantage for producing high flows would be optimized, thereby increasing its effectiveness in compensating for reduced valving economy. The mechanism proposed above is supported by trends (i.e., group differences that did not reach statistical significance) found in measures of LVI-R and RCVE for extemporaneous speaking and LVE, RCVE, and RCVI-R for reading. Specifically, these trends indicate that the older subject groups had larger lung volume and rib cage volume initiations and larger lung volume and rib cage volume excursions.

The muscular mechanism underlying speech breathing behavior can be inferred from the configuration of the chest wall in relation to its relaxation configuration as well as from changes in configuration (Hixon, 1987). From past research, it can be assumed that the relaxation characteristic of the chest wall passes through the point designating the relaxation configuration at the resting expiratory level on the data chart of each of the present subjects (see Figure 1). The volumetric data that were referenced to this point (see Tables 6 & 9) indicate that speech was produced to the left of the presumed relaxation characteristic. This means that during speech production the abdomen was smaller and the rib cage was larger than they would have been had the subjects relaxed at the prevailing lung volumes. Although there are several combinations of muscular activities that could bring about this departure from the relaxation characteristic, the most plausible is the one determined empirically for other normal subjects (Hixon, Mead, & Goldman, 1976). That is, the configuration associated with speech breathing most likely was the result of continuous positive muscular pressure produced by both the rib cage and the abdomen, but with the latter predominating.

Although the general muscular mechanism just described probably applies to all three age groups studied in this investigation, variations in this mechanism must have occurred to account for the age-related differences found in lung volume and rib cage volume initiations and excursions. For the older subjects, whose breath groups were initiated at generally higher lung volumes and rib cage volumes, the rib cage probably was lifted to a higher position by inspiratory rib cage muscle contraction or contraction of the diaphragm (realized as volume change in the rib cage). These options are preferred over the possibility of the abdomen lifting the rib cage through increased abdominal pressure because there was no evidence of greater inward abdominal displacement in the older subjects.

Several subjects demonstrated a progressively greater deformation from relaxation over the first few breath groups of utterance. The presumed muscular mechanism involved was a progressive increase in abdominal drive over the course of the first few breath groups. Such an increase probably had important consequences for diaphragmatic function. That is, inward displacement of the abdomen would serve to dome the diaphragm, thereby placing it at a greater mechanical advantage for the generation of rapid inspiration.

## Clinical Implications

Findings of the present investigation appear to have implications for the evaluation and management of individuals with speech breathing disorders. First, the clinician should expect slightly different speech breathing behavior from a senescent client than from a young adult client. Specifically, when contrasted to a young adult client, a senescent client might be expected to speech breathe using generally (a) higher lung volume and rib cage volume initiations, (b) larger lung volume and rib cage volume excursions, (c) fewer syllables per breath group, and (d) greater average lung volume expended per syllable. This means that clinicians who have been making clinical judgments using a standard based on data from young adults need to modify their expectations regarding normal target behaviors for older clients. For example, a clinician working with a senescent individual with parkinsonism should not assume that the presence of short breath groups is strictly a disease sign. It could be a manifestation of age, disease, or both.

A second implication is that the rib cage and abdominal capacity maneuvers developed for this investigation appear to be appropriate for clinical use. These maneuvers, which enabled normalization of rib cage and abdominal volumes, were performed quickly, easily, and reliably by all the present subjects. Therefore, it seems reasonable to be optimistic regarding their applicability to clinical evaluation and management of individuals with speech breathing disorders.

A third clinical implication that may be drawn from the present investigation is that extemporaneous speaking may be more effective than reading in elucidating mechanisms underlying speech breathing and possibly speech production in general. This implication stems from the fact that, although the trends in age-related differences in speech breathing behavior were similar for these two speaking tasks, a greater number of age-related differences reached statistical significance for the extemporaneous speaking task. This suggests that age-related differences in speech breathing are more clearly manifested when the subject is free to vary his linguistic content and form so as to use patterns of performance that are best adapted to the mechanical properties of his breathing apparatus and downstream valving function. This implication extends not only to the clinician concerned directly with evaluation and management issues but also to the researcher interested in describing clinical phenomena. For example, the clinician or researcher attempting to describe the speech or speech production signs associated with a particular form of dysarthria should be aware that descriptions of speech output or speech motor characteristics may be conditioned by whether running speech is sampled through extemporaneous speaking or reading.

A great deal remains to be learned about age-related modifications in speech production biomechanics. This investigation is viewed as an initial step toward meeting that need in one subsystem of the speech production mechanism.

## Acknowledgments

We gratefully acknowledge the technical assistance of Mary Ellen Altman, Michele Gertzulin, Wayne Morgan, Joy Roof, and Peter Watson. This research was supported by grant NS-21574 from the National Institute of Neurological and Communicative Disorders and Stroke.

## References

Agostoni, E., & Hyatt, R. (1986). Static behavior of the respiratory system. In A. Fishman, P. Macklem, J. Mead, & S. Geiger (Eds.), *Handbook of physiology: Vol. 3, section 3. The respiratory system* (pp. 113–130). Bethesda, MD: American Physiological Society.

Altman, M. (1986). *Speech breathing kinematics in women.* Unpublished master's thesis, University of Arizona, Tucson.

Altman, P., & Dittmer, D. (1964). Heart rates. Arterial blood pressure. In *Biology data book* (pp. 237–239). Washington DC: Federation of American Societies for Experimental Biology.

Bailey, D., Carter, J., & Mirwald, R. (1982). Somatotypes of

Canadian men and women. *Human Biology, 54*, 813–828.
BAYLES, K., TOMOEDA, C., & BOONE, D. (1985). A view of age-related changes in language function. *Developmental Neuropsychology, 1*, 231–264.
BEELER, E. (1978). *Determination of functional residual capacity by helium dilution.* Procedural manual for Pulmonary Laboratory, Arizona Health Sciences Center, University of Arizona, Tucson.
BEGIN, R., RENZETTI, A., BIGLER, A., & WATANABE, S. (1975). Flow and age dependence of airway closure and dynamic compliance. *Journal of Applied Physiology, 38*, 199–207.
BERGOFSKY, E. (1964). Relative contributions of the rib cage and the diaphragm to ventilation in man. *Journal of Applied Physiology, 19*, 698–706.
BLACK, L., & HYATT, R. (1969). Maximal respiratory pressures: Normal values and relationship to age and sex. *American Review of Respiratory Disease, 99*, 696–702.
BODE, F., DOSMAN, J., MARTIN, R., GHEZZO, H., & MACKLEM, P. (1976). Age and sex differences in lung elasticity, and in closing capacity in nonsmokers. *Journal of Applied Physiology, 41*, 129–135.
BOREN, H., KORY, R., & SYNER, J. (1966). The Veterans Administration-Army cooperative study of pulmonary function. II. The lung volume and its subdivisions in normal men. *American Journal of Medicine, 41*, 96–114.
BRODY, A., JOHNSON, J., TOWNLEY, R., HERRERA, H., SNIDER, D., & CAMPBELL, J. (1974). The residual volume. *American Review of Respiratory Disease, 109*, 98–105.
CARTER, J. (1980). *The Heath-Carter somatotype method* (3rd ed.). San Diego: San Diego State University Press.
CHEBOTAREV, D., KORKUSHKO, O., & IVANOV, L. (1974). Mechanisms of hypoxemia in the elderly. *Journal of Gerontology, 29*, 393–400.
CHOBANIAN, A. (1976). Pathophysiology of systemic hypertension. In H. Levine (Ed.), *Clinical cardiovascular physiology* (pp. 563–596). New York: Grune & Stratton.
COHN, J., & DONOSO, H. (1963). Mechanical properties of lung in normal men over 60 years old. *Journal of Clinical Investigation, 42*, 1406–1410.
COLE, T. (1974). The influence of height on the decline in ventilatory function. *International Journal of Epidemiology, 3*, 145–152.
COLEBATCH, H., GREAVES, I., & NG, C. (1979). Exponential analysis of elastic recoil and aging in healthy males and females. *Journal of Applied Physiology, 47*, 683–691.
COMROE, J., FORSTER, R., DUBOIS, A., BRISCOE, W., & CARLSEN, E. (1962). *The lung.* Chicago: Year Book Medical Publishers.
COTES, J. (1979). *Lung function: Assessment and application in medicine* (4th ed.). Oxford, England: Blackwell Scientific Publications.
FERRIS, B. (1978). Epidemiology standardization project. *American Review of Respiratory Disease, 118*, 1–53.
FORNER, L., & HIXON, T. (1977). Respiratory kinematics in profoundly hearing-impaired speakers. *Journal of Speech and Hearing Research, 20*, 373–408.
FRANK, N., MEAD, J., & FERRIS, B. (1957). The mechanical behavior of the lungs in elderly persons. *Journal of Clinical Investigation, 36*, 1680–1687.
GIBSON, G. (1984). *Clinical tests of respiratory function.* New York: Raven Press.
GIBSON, G., PRIDE, N., O'CAIN, C., & QUAGLIATO, R. (1976). Sex and age differences in pulmonary mechanics in normal nonsmoking subjects. *Journal of Applied Physiology, 41*, 20–25.
GILBERT, R., AUCHINCLOSS, J., BRODSKY, J., & BODEN, W. (1972). Changes in tidal volume, frequency, and ventilation induced by their measurement. *Journal of Applied Physiology, 33*, 252–254.
GMG SCIENTIFIC INC. (1980). *Operation manual for linearized magnetometers.* Burlington, MA: GMG Scientific Inc.
GOLDMAN, M. (1974). The mechanical coupling of the diaphragm and rib cage. In L. Pengelly, A. Rebuck, & E. Campbell (Eds.), *Loaded breathing* (pp. 50–63). London: Churchill-Livingstone.
GOLDMAN, M., & MEAD, J. (1973). Mechanical interaction between the diaphragm and rib cage. *Journal of Applied Physiology, 35*, 197–204.
GRIMBY, G., BUNN, J., & MEAD, J. (1968). Relative contribution of rib cage and abdomen to ventilation during exercise. *Journal of Applied Physiology, 24*, 159–166.
HIXON, T. (1987). *Respiratory function in speech and song.* San Diego: College-Hill Press.
HIXON, T., GOLDMAN, M., & MEAD, J. (1973). Kinematics of the chest wall during speech production: Volume displacements of the rib cage, abdomen, and lung. *Journal of Speech and Hearing Research, 16*, 78–115.
HIXON, T., MEAD, J., & GOLDMAN, M. (1976). Dynamics of the chest wall during speech production: Function of the thorax, rib cage, diaphragm, and abdomen. *Journal of Speech and Hearing Research, 19*, 297–356.
HOIT, J., & HIXON, T. (1986). Body type and speech breathing. *Journal of Speech and Hearing Research, 29*, 313–324.
ISLAM, M. (1980). Mechanism of controlling residual volume and emptying rate of the lung in young and elderly healthy subjects. *Respiration, 40*, 1–8.
JOHNSON, H. (Ed.) (1985). *Relations between normal aging and disease.* New York: Raven Press.
JONES, R., OVERTON, T., HAMMERLINDL, D., & SPROULE, B. (1978). Effects of age on regional residual volume. *Journal of Applied Physiology, 44*, 195–199.
KAHANE, J. (1981). Anatomic and physiologic changes in the aging peripheral speech mechanism. In D. Beasley & G. Davis (Eds.), *Aging: Communication processes and disorders* (pp. 21–45). New York: Grune & Stratton.
KANNEL, W. (1985). Hypertension and aging. In C. Finch & E. Schneider (Eds.), *Handbook of biology of aging* (2nd ed., pp. 859–877). New York: Van Nostrand Reinhold.
KNUDSON, R., CLARK, D., KENNEDY, T., & KNUDSON, D. (1977). Effect of aging alone on mechanical properties of the normal adult human lung. *Journal of Applied Physiology, 43*, 1054–1062.
KNUDSON, R., LEBOWITZ, M., HOLBERG, C., & BURROWS, B. (1983). Changes in the normal maximal expiratory flow-volume curve with growth and aging. *American Review of Respiratory Disease, 127*, 725–734.
KNUDSON, R., SLATIN, R., LEBOWITZ, M., & BURROWS, B. (1976). The maximal expiratory flow-volume curve. *American Review of Respiratory Disease, 113*, 587–600.
LEITH, D., & MEAD, J. (1967). Mechanisms determining residual volume of the lungs in normal subjects. *Journal of Applied Physiology, 23*, 221–227.
LORING, S., & MEAD, J. (1982). Abdominal muscle use during quiet breathing and hyperpnea in uninformed subjects. *Journal of Applied Physiology, 52*, 700–704.
MEAD, J. (1960). Control of respiratory frequency. *Journal of Applied Physiology, 15*, 325–336.
MEAD, J. (1974). Mechanics of the chest wall. In L. Pengelly, A. Rebuck, & E. Campbell (Eds.), *Loaded breathing* (pp. 35–49). London: Churchill-Livingstone.
MEAD, J., & AGOSTONI, E. (1964). Dynamics of breathing. In W. Fenn & H. Rahn (Eds.), *Handbook of physiology: Vol. 1, section 3. Respiration* (pp. 411–427). Washington, DC: American Physiological Society.
MEAD, J., TURNER, J., MACKLEM, P., & LITTLE, J. (1967). Significance of the relationship between lung recoil and maximum expiratory flow. *Journal of Applied Physiology, 22*, 95–108.
MENEELY, G., & KALTREIDER, N. (1949). The volume of the lung determined by helium dilution: Description of the method and comparison with other procedures. *Journal of Clinical Investigation, 28*, 129–139.
MILLER, A. (1986a). Spirometry and maximum expiratory flow-volume curves. In A. Miller (Ed.), *Pulmonary function tests in clinical and occupational lung disease* (pp. 15–51). New York: Grune & Stratton.
MILLER, A. (1986b). Prediction equations and "normal values." In A. Miller (Ed.), *Pulmonary function tests in clinical and*

*occupational lung disease* (pp. 197–213). New York: Grune & Stratton.
MITTMAN, C., EDELMAN, C., NORRIS, A., & SHOCK, N. (1965). Relationship between chest wall and pulmonary compliance and age. *Journal of Applied Physiology, 20,* 1211–1216.
MUIESAN, G., SORBINI, C., & GRASSI, V. (1971). Respiratory function in the aged. *Bulletin de Physio-Pathologie Respiratoire, 7,* 973–1009.
NEEDHAM, C., ROGAN, M., & MCDONALD, I. (1954). Normal standards for lung volumes, intrapulmonary gas-mixing, and maximum breathing capacity. *Thorax, 9,* 313–325.
OBLER, L., & ALBERT, M. (1981). Language and aging: A neurobehavioral analysis. In D. Beasley & G. Davis (Eds.), *Aging: Communication processes and disorders* (pp. 107–121). New York: Grune & Stratton.
PERMUTT, S., & MARTIN, H. (1960). Static pressure-volume characteristics of lungs in normal males. *Journal of Applied Physiology, 15,* 819–825.
PIERCE, J., & EBERT, R. (1958). The elastic properties of the lungs in the aged. *Journal of Laboratory and Clinical Medicine, 51,* 63–71.
RAMIG, L., & RINGEL, R. (1983). Effects of physiological aging on selected acoustic characteristics of voice. *Journal of Speech and Hearing Research, 26,* 22–30.
RINGEL, R. (1986a). *Aging and speech production.* Paper presented at the Third Biennial Clinical Dysarthria Conference, Tucson, AZ.
RINGEL, R. (1986b). *Voice and hearing: The effects of physiological aging.* Research proposal submitted to the National Institute of Aging.
ROBINSON, S., DILL, D., TZANKOFF, S., WAGNER, J., & ROBINSON, R. (1975). Longitudinal studies of aging in 37 men. *Journal of Applied Physiology, 38,* 263–267.
RODARTE, J., & REHDER, K. (1986). Dynamics of respiration. In A. Fishman, P. Macklem, J. Mead, & S. Geiger (Eds.), *Handbook of physiology, Vol. 3, section 3. The respiratory system* (pp. 131–144). Bethesda, MD: American Physiological Society.
SHARP, J., GOLDBERG, N., DRUZ, W., & DANON, J. (1975). Relative contributions of rib cage and abdomen to breathing in normal subjects. *Journal of Applied Physiology, 39,* 608–618.
SPSS, INC. (1983). *Statistical package for the social sciences, X: SPSSX user's guide.* New York: McGraw-Hill.
STANESCU, S., DUTU, S., JIENESCU, Z., HARTIA, L., NICOLESCU, N. & SACERDOTEANU, F. (1968). Investigations into changes in pulmonary function in the aged. *Respiration, 25,* 232–242.
STORSTEIN, O., & VOLL, A. (1962). New prediction formulas for ventilatory measurements: A study of normal individuals in the age group 20–59 years. *Scandinavian Journal of Clinical and Laboratory Investigation, 14,* 633–640.
TURNER, J., MEAD, J., & WOHL, M. (1968). Elasticity of human lungs in relation to age. *Journal of Applied Physiology, 25,* 664–671.
WATSON, P., & HIXON, T. (1985). Respiratory kinematics in classical (opera) singers. *Journal of Speech and Hearing Research, 28,* 104–122.
WHITEHEAD, R. (1980). *Some respiratory and aerodynamic characteristics of the speech of the deaf: Clinical implications.* Paper presented at the International Congress of the Deaf, Hamburg, West Germany.

Received November 14, 1986
Accepted February 16, 1987

Requests for reprints should be sent to Jeannette D. Hoit, Department of Speech and Hearing Sciences, University of Arizona, Tucson, AZ 85721.

## APPENDIX A

### PARAGRAPH READ ALOUD

California is a unique state. It is one of the few states that has all the geographical features found in the rest of the country including deserts, forests, mountain ranges, and beaches. Its beaches draw thousands and thousands of people each year particularly during the summer months when the sun is shining, the skies are blue, and the ocean is warm enough to swim in. Surfers are often in the water by daybreak. Of course there are many other things to do besides surfing such as sailing, swimming, water skiing, kite flying, and sun bathing. In the winter the mountains of California are favorite vacation spots. Here, snow skiing is the sport. There are many places in California to snow ski but the largest and most popular is Mammoth Mountain. Because of its popularity the property surrounding the Mammoth ski resort is extremely expensive. Unfortunately, the threat of earthquakes in this area is very high. In fact, earthquakes are common occurrences in many parts of California. Because of this, there are people who are afraid that someday a large piece of the state will fall into the Pacific Ocean. The possibility of a serious earthquake such as the one that demolished San Francisco in 1906 frightens some people enough that they choose not to visit California just for that reason.