1982

An experimental approach to the assessment of respiration for patients with neuromuscular pathologies.

Karen J. Aune
The University of Montana

AN EXPERIMENTAL APPROACH TO THE ASSESSMENT OF RESPIRATION FOR PATIENTS WITH NEUROMUSCULAR PATHOLOGIES

by

Karen J. Aune

B.A., Communication Sciences and Disorders

University of Montana, 1979

A Professional Paper

Submitted in partial fulfillment of the requirements for the degree of

Masters of Communication Sciences and Disorders

UNIVERSITY OF MONTANA

1982

Approved by:

Chairman, Board of Examiners

Dean, Graduate School

4-5-82

Date

ACKNOWLEDGMENTS

I wish to express my appreciation to Dr. David Beukelman and Dr. Kathryn Yorkston for their advice and assistance throughout this project. A special thanks is extended to Ms. Karen Stanton and Ms. Patricia Waugh for their support and supervision during my externship. I would like to thank the members of my externship committee, Dr. Charles Parker, Ms. Fran Tucker, Dr. Barbara Bain, and Dr. Robert Chaney. And finally, I thank Ms. Becky Bingea for all her help and encouragement.

And to those who read this, I hope you are always able to maintain a steady state, have good timing, and be flexible!!

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

FIGURE | Page

Chapter I

INTRODUCTION

The importance of the respiratory process in speech production has long been acknowledged. For example, Hixon (1973) states: "Since respiratory forces provide the basic energy source for all speech, the events of speech respiration are of fundamental importance in any account of oral communication" (p. 98). The effect of abnormal respiratory function on the speech of patients with neuromuscular pathologies has also been well documented (Darley, Aronson, & Brown, 1975). A review of the Darley et al. (1975) descriptions of the perceptual speech characteristics which can result from a disturbed respiratory process indicates that speech can be affected by the following: 1) decreased power for speech; 2) impaired control of respiratory muscle activity; 3) impaired coordination of respiratory muscle activity with the other motor systems of speech production; 4) inefficient motor processes at higher levels of the speech meachanism which overly tax the respiratory system; and 5) disturbances of higher level motor processes which result from a disturbed respiratory system.

A review of the literature regarding the evaluation of respiratory function reveals at least two basic evaluation approaches. One approach is to evaluate respiratory variables in isolation from the articulatory, phonatory, and resonatory processes of speech. This type of evaluation yields information about specific characteristics of respiratory function, independent from the other motor processes. Examples of techniques for studying respiration in this manner include: pneumography, used to record external thoracic movements (Kaplan, 1971); spirometry, for studying partitions of lung volumes (Darley et al., 1975); ink-recording respirometry, for analyzing respiratory rate, amplitude, inspiratory-expiratory rations, etc. (Kaplan, 1971); plythsmography, for assessing chest-wall movements and subsequent changes in lung volumes (Hunker, Bless, & Weismer, 1981); and electromography, for studying action potentials of the respiratory muscles (Kaplan, 1971).

The second approach evaluates respiratory variables during speech; i.e., during interaction with the other motor processes of speech. This approach diverts attention from the isolated phenomenon of the respiratory process and yields information about respiratory function during its interaction with the articulatory, phonatory, and resonatory processes of speech. Examples of techniques for this type of evaluation include: measures of air flow during articulation (Klatt & Stevens, 1968); studies of the relationship between voice intensity to subglottal pressure, airflow rate, and/or glottal resistance (Isshiki, 1964); and evaluation of respiratory function based on the loudness characteristics of connected speech (Rosenbek & LaPointe, 1978).

Unfortunately, the techniques used in both of these approaches are largely limited to laboratory undertakings. Thus, a means of evaluating respiration clinically appears to be lacking. As a result, respiratory function has been frequently overlooked during the clinical evaluation process, despite its important role in normal speech production (Darley et al., 1975; Emerick & Hatten, 1979; Hunker et al., 1981).

The purpose of this paper is to describe an approach for evaluating respiratory function during speech production. It is particularly applicable to patients demonstrating neuromuscular pathologies. It is an initial step in the development of respiratory-evaluation procedures and techniques designed to encompass the following features:

1. Accessibility and feasibility for clinical use.
2. Efficiency in terms of time and cost.
3. Generation of objective and valid data which can be used not only during the evaluation process, but also in monitoring change and improvement in response to treatment.
4. Direction regarding candidacy for therapeutic intervention and for the course of therapy.

The remaining chapters will present a review of normal respiration (Chaper II), the respiratory evaluation (Chapter III), and two case studies to illustrate the application of the assessment approach and some treatment implications (Chapters IV and V). The validity of the proposed perceptual judgments is determined by comparing the results with data obtained from physiological measurements (Case Study #1, Chapter IV). In the final chapter (VI), conclusions are drawn regarding the potential utility of the assessment approach in clinical situations.

Chapter II

NORMAL RESPIRATORY FUNCTION

Vegetative Function

Normal respiratory function has been described by a number of authors (e.g., Darley et al., 1975; Hixon, 1973; Kaplan, 1971; Lieberman, 1977). Its purpose is to move air in and out of the lungs rhythmically so that oxygen can be absorbed from the blood and carbon dioxide discharged into the bloodstream. This process is controlled by the respiratory center of the medulla, which in turn is regulated by afferent impulses from the chest, carbon dioxide content of the blood, and higher regulatory forces originating in the pons and hypothalmus. Darley et al. (1975) described the muscle activity involved in this process as follows: Inspiration, which occurs with an increase in the dimensions of the thoracic cavity, is accomplished by the action of three inspiratory muscles, the diaphragm, the external intercostals, and the accessory muscles. When the diaphragm contracts, it moves downward and enlarges the thoracic cavity. The external intercostals, upon contraction, elevate the ribs and enlarge the thoracic cavity. Accessory muscles (muscles of the neck and shoulder girdle which are attached to the thoracic cage) can further elevate the cage, particularly when a deep inhalation is required.

The second phase of the process, the exhalatory phase, occurs with a decrease in the size of the thoracic cavity. Cavity size reduction is largely a passive process resulting from the elasticity of the lungs and thoracic cage when the inspiratory muscles stop contracting. During physical activity, the exhalatory muscles - the abdominal muscles and external intercostals - become more involved. Upon contraction, the abdominal muscles produce pressure beneath the diaphragm, forcing it upward into the thoracic cavity. The external intercostals pull the ribs downward and further reduce the size of the thoracic cavity.

Respiration for Speech

During speech, there are certain modifications of this respiratory process. The inspiratory phase becomes quicker (approximately 1/6 rather than 1/2 of the cycle) and the expiratory phase becomes more prolonged and controlled (Darley et al., 1975). Lieberman (1977) described the muscle activity involved: The external intercostals, normally inspiratory muscles, function to restrain the high elastic recoil forces of the lungs and thoracic cage. This results in the slow and steady release of pulmonary pressure that is necessary for speech. As the recoil forces decrease and become less than what is needed to drive the vocal cords, the external intercostals stop working and the internal intercostals gradually come into play. As the internal intercostals become involved, a steady pulmonary pressure is maintained, despite the decreasing revoil forces. The average pulmonary pressure which is maintained during speech is approximately 10 cm H_2O (Lieberman, 1977). The ability to maintain 5 cm H_2O for at least 5 seconds is considered to be the minimum requirement level for normal speech (Rosenbek and LaPointe, 1978).

The scheduling of muscle activity varies with utterance length (Lieberman, 1977); i.e., a feedback system is active so that the amount of inspiratory air is proportional to the length of the utterance. Likewise, the length of the expiratory phase can vary (from 300 msec to 40 seconds) depending on utterance length (Lieberman, 1977). The muscle action also allows variation of subglottic pressure for emphatic and stressed utterances (Hixon, 1973). This involves frequent changes in muscle pressure of a brief duration (75-150 msec) and of small magnitude (1-3 cm H_2O). These changes of muscle pressure are thought to be regulated mainly by the thoracic muscles, although the specific muscles involved and the extent of the involvement is not yet known (Hixon, 1973).

These processes of normal speech production allow the demonstration of three basic respiratory skills:

1. Ability to maintain steady peak loudness. During the expiratory phase of normal speech, respiratory muscles function to maintain a relatively steady air pressure. The perceptual correlate of this relatively stable pressure during speech is a relatively stable speech loudness. Difficulty or inability to maintain steady peak loudness can result in one or more of the following: (a) inability of the speaker to maintain adequate loudness; (b) frequent inhalations during speech in an effort to maintain loudness;

(c) increased speech rate, particularly at the end of an utterance, in an effort to complete the utterance before loudness becomes inadequate; and (d) abnormal loudness variations from overdriving the vocal mechanism in the effort to maintain adequate loudness.

2. Adequate timing. For normal speech, the activity of the respiratory system must be temporally coordinated with the phonatory processes so that air is not wasted on exhalation before phonation is initiated. Exhalation normally occurs in a smooth, cyclic pattern immediately after inhalation, and phonation is initiated coincidentally with the initiation of exhalation. Common problems associated with inadequate timing include: (a) wastage of air on exhalation before phonation is initiated; (b) speech during inhalation; and (c) disruption of the normal cyclic pattern between inhalation and exhalation (frequently inserted by the speaker who needs time to coordinate the motor activities of speech).

3. Flexibility. The respiratory system must be flexible enough to allow modifications of the relatively steady state of expired air pressure. Respiratory flexibility is necessary for at least 4 skills, defined within this paper as follows: (a) syllabic stress (e.g., in differentiating the word perfect in the sentences, "It was a perfect day," and "I will try to perfect it"); (b) emphasis (e.g., on the

word _give_ in the response, "Give it to him," when asked, "Should I sell it to him?"); (c) loudness variations (as in the sentence, "The boy yelled, 'Watch out for the car!'"); and (d) phrase-length variations (as in, "She said, 'Yes'" versus "The old woman in the chair said, 'Yes'"). Common problems associated with adequate flexibility include inappropriate stressing, inability to emphasize, inability to make loudness variations, and abnormal phrase-length variations.

Chapter III

RESPIRATORY ASSESSMENT

The schematic used to evaluate the three respiratory skills of steady peak loudness, timing, and flexibility is depicted in Figure 1. Within this assessment technique, the three skills are evaluated with three types of stimuli:

1. Habitual speech: Running speech on given materials without special instructions or cues.
2. Optimal speech: Running speech with special instructions and a model of the desired response, provided by the clinician.
3. Speech-like productions: Isolated syllables or phonemes (prolongations of /a/ and repetitions of /pʌ/.

"Habitual speech" performance provides information regarding the patient's typical skill-level. Performance during "optimal speech" incorporates stimulability, which allows identification of patients who do not demonstrate the skill habitually, but who can demonstrate the skill when given special instructions and a model of the desired response. Evaluation of performance during "speech-like productions" allows identification of patients who can at least demonstrate the skills when the articulatory and linguistic constraints of the speech act are reduced.

	STEADY PEAK LOUDNESS	TIMING	FLEXIBILITY
HABITUAL SPEECH	Oral counting for 3, 5, and 10 seconds.	Oral reading of phrases initiated with a vowel or voiced consonant.	Oral reading of sentences containing a variety of prosodic patterns.
OPTIMAL SPEECH	After a model of the desired response, oral counting for 3, 5, and 10 seconds, with instructions to count as steadily as possible on a single inhalation.	After a model of the desired response, oral reading of the phrases initiated with a vowel or voiced consonant, with instructions to begin the first word immediately the end of inhalation.	After a model of the desired response, oral reading of the sentences containing a variety of prosodic patterns, with instructions to mimic the examiner.
SPEECH-LIKE PRODUCTIONS	Oral productions of the sounds /pʌpʌpʌpʌ/	Oral productions of the sounds /pʌpʌpʌpʌ/ and /a/	Oral repetitions of prosodic patterns which mimic the sentences used in running speech, using the sound /pʌpʌpʌ/.

Figure 1. Schematic for the evaluation of three respiratory skills (steady peak loudness, timing, and flexibility) during habitual speech, optimal speech, and speech-like productions.

This evaluation method thus focuses on the most prominent respiratory skills needed for normal speech. Evaluation results can then be used to direct treatment in that therapy can focus on improving any or all of the respiratory skills found to be deficient. In addition, the evaluation provides information regarding treatment candidacy and the potential for improvement. For example, the therapeutic prognosis assumably would be better for a patient who can demonstrate the skills with special instructions and a model, or when articulatory and linguistic demands are reduced, than a patient who is unable to demonstrate the skills during any of the conditions.

Assessment of Steady Peak Loudness

Because of the relationship between subglottal air pressure and loudness, the ability of the respiratory system to maintain a steady air pressure can be evaluated by assessing a speaker's ability to maintain steady loudness. Within this evaluation approach, steady peak loudness is assessed by evaluating the ability to maintain steady loudness for 3, 5, and 10 seconds. The gradually increasing time spans allow more than a pass/fail differentiation for this skill: three-second trials allow identification of patients who can maintain a steady loudness only for a short duration; five-second trials allow identification of patients who can at least perform at a minimum level of competence; and ten-second trials allow identification of patients who can demonstrate a control above the minimum level.

For evaluation of the skill during habitual and optimal running speech, counting is used. Counting is desirable since, 1) it is automatic and does not require reading; 2) it does not involve any inherent breaks (i.e., syntactic junctures) other than those imposed by the respiratory system; and 3) it does not include any inherent modifications of steady state (i.e., stressing, emphasis, and loudness variations). In addition, the use of counting allows results to be compared to performance during speech-like productions. Prolongations of /a/ for 3, 5, and 10 second trials provides information about the ability to maintain a steady loudness when control is at the laryngeal level. Repetitions of /pʌ/ allow evaluation of ability to maintain a steady loudness during articulation, but with fewer articulatory and linguistic constraints than in running speech.

Data are obtained by counting each of the following for each stimulus condition:

1. Number of inhalations per utterance
2. Number of syllables per utterance
3. Number of syllables per inhalation
4. Number of syllables per second

Also noted is the ability of the patient to maintain vocal loudness throughout each utterance. The specific tasks, instructions, and measurements are contained on Appendix A. Resulting data are recorded on the charts depicted in Figures B1 and B2 of Appendix B.

Assessment of Timing

Timing between the respiratory and phonatory motor systems can be evaluated by assessing a speaker's ability to initiate voicing at the peak of the expiratory cycle. Within this assessment technique, the evaluation of timing during running speech (habitual and optimal speech) takes place during oral reading of the sentences, "Eat some pie," "Beat the team," "At the game," and "Date the girl." These stimuli were chosen because they begin with vowels and voiced consonants, requiring coordination of the respiratory and phonatory processes immediately at the beginning of the phrase. This initial voicing is advantageious in that, 1) evaluation of the skill can focus on the first part of the utterance; and 2) precision of articulatory and velopharyngeal function are less of a factor in assessing possible air wastage. The evaluation of timing during speech-like productions takes place during prolongations of /a/ and repetitions of /pʌ/. This provides information about timing skills when the articulatory and linguistic constraints of the speech act are reduced.

Interpretations of a patient's timing skills are based on the answer to the question, "Was phonation initiated coincidentally with exhalation and in a smooth, cyclic pattern with inhalation?" If the answer is "no," further information is obtained: a) Was air wasted on exhalation before phonation was initiated? b) Was there a time lag between inhalation and exhalation? and c) Was there speech on inhalation? Specific tasks, instructions, and measurements are contained in Appendix A, while data charts are depicted in Figures B3 and B4 of Appendix B.

Assessment of Flexibility

Flexibility of the respiratory system can be evaluated by assessing a speaker's ability to stress, emphasize, and vary loudness and phrase length appropriately. While these suprasegmental aspects of speech are difficult to evaluate, they are of considerable linguistic significance and, therefore, need to be considered. Within this assessment technique, the evaluation of flexibility during running speech (habitual and optimal speech) takes place during oral reading of sentences, some of which are presented in a dialogue format with the examiner. The first six sentences allow evaluation of ability to approxiately stress:

1. It's a perfect day.
2. I'm going to perfect my cooking.
3. I'm worried that my schedule might conflict with yours.
4. I'd hate to have a conflict with you.
5. His license is invalid.
6. He is an invalid.

The next three sentences evaluate the ability to emphasize words:

1. Show Sam some snow. (In response to "Should I show Sam an icycle?")
2. Show Sam some snow. (In response to "Should I show Fred some snow?")
3. Show Sam some snow. (In response to "Should I give Sam some snow?")

The ability to make loudness variations utilizes the following sentences:

1. The boy yellowed, "Watch out!"
2. The woman whispered, "I have to go home now." The man replied loudly, "No, you can't leave yet!"
3. The woman said loudly, "Don't let him eat it!" The girl said quietly, "I won't."

Variation of phrase length is assessed with the following sentences:

1. Oh, you can.
2. Oh, you can go.
3. Oh, you can go too.
4. Oh, you can go with me.
5. Oh, you can go to the store.
6. Oh, you can go to the grocery store.

Flexibility during speech-like productions is assessed during verbal repetitions of the sound /pʌ/, mimicing the prosodic pattern of the stimuli used in running speech.

Data utilizing these stimuli are obtained by, 1) noting if stress, emphasis, and loudness variations were appropriate; and 2) noting whether or not the speaker was able to vary phrase length, then counting the number of total pauses, number of pauses with breaths, and number of pauses without breaths. The specific tasks, instructions, and measurement for evaluating flexibility are presented in Appendix A. Figures B5 through B17 in Appendix B display flexibility data charts.

Chapter IV

MEASUREMENT AND VALIDITY OF ASSESSMENT RESULTS: CASE STUDY #1

The case study described in this chapter is presented to illustrate the use of the respiratory assessment technique discussed in the previous section (Chapter III). Included are a description of the subject, the evaluation procedures, and the evaluation results and their validity for this patient. Physiological measurements were used to assess the validity of the evaluation results. The research question asked was: Can perceptual judgments (made by a clinician listening to tape-recorded speech) be used to validly evaluate the three respiratory skills of steady peak loudness, timing, and flexibility?

Subject

The subject was a 27-year old female with spastic quadriparesis, secondary to anoxic encephelopathy. She evidenced a mixed dysarthria with predominately spastic and ataxic properties. Vocal quality was harsh, secondary to unilateral vocal-cord paralysis. Her speech was characterized by inspiratory stridor, slowed rate (45 wpm), imprecise consonants, and irregular articulatory breakdowns. Single words were 38% intelligible, and sentences were 45% intelligible, as measured on the Assessment of Intelligibility of Dysarthric Speakers (Beukelman and Yorkston, 1981).

Procedures

Perceptual evaluation. Perceptual judgments were made by a clinician listening to the subject's voice, as recorded on a reel-to-reel tape recorder. The speech signal was transduced by a Dual Realistic Hi Volt 2 microphone, which was placed approximately six inches from the subject's mouth. A single judge listened to the tape-recorded speech and evaluated each of the three respiratory skills (steady peak loudness, timing, and flexibility) perceptually. The measurements were then tabulated on the charts as presented in Appendix B.

Perceptual judgments of steady peak loudness included the following: (1) counting number of inhalations per utterance; (2) counting number of syllables per utterance; (3) counting number of syllables per inhalation; (4) counting number of syllables per second and (5) makes a yes/no judgment as to whether or not vocal loudness was maintained throughout the utterance.

Perceptual judgments of timing was accomplished by first making a yes/no judgment as to whether or not phonation was initiated coincidentally with exhalation. If the answer was "no," further yes/no judgments were to be made: Was air wasted on exhalation before phonation? Was there a time lag between exhalation and inhalation? and Was there speech on inhalation?

Flexibility was assessed perceptually by making yes/no judgments regarding appropriate use of stress, emphasis, and loudness/softness variations. In addition, phrased-length variations were evaluated by making yes/no judgments as to whether or not the subject varied phrase length and in addition counting 1) the number of total pauses, 2) the number of pauses with inhalations, and 3) the number of pauses without inhalations.

Physiological evaluation. During the subject's vocal productions, two types of physiological measurements were obtained simultaneously: (1) the intensity of the voice was recorded onto an FM tape-recorder, as transduced by a throat microphone; and (2) chest movements were recorded onto the FM tape-recorder also, via a mercury strain-guage and plethysmograph. The chest movement and vocal intensity recordings were then transferred from the FM tape onto a visacorder for visual display. This enabled objective measurements of the physiological processes.

Physiological steady peak loudness measurements were obtained by viewing the visicorder chest-movement and vocal-intensity displays and counting the number of inhalations per utterance, number of syllables per utterance, number of syllables per inhalation, and number of syllables per second. Assessment of vocal-intensity maintenance throughout an utterance was made by measuring the amplitude (in cm) from the baseline to the peak of the visually displayed intensity of each syllable uttered. The percentages of each syllable's peak amplitude was then calculated, relative to the largest peak amplitude in the production. For the purposes of this study, a difference in peak amplitude of 5% or more between syllables was considered significant. This because it appeared to be a difference which could be consistently perceived.

The physiological measurement of timing was accomplished by measuring the time lag (in seconds) between the peak of inhalation and the initiation of phonation, from the visicorder display.

Flexibility measurements regarding stress, emphasis, and loudness/softness variations were obtained in the same way as were the steady state physiological measurements; i.e., by measuring peak amplitude of each syllable (in cm) and calculating relative percentages. Again, a difference in peak amplitude of 5% or more between syllables was considered significant. The physiological measurement of phrase-length variation was obtained by viewing the chest-movement and vocal-intensity displays and counting total number of pauses, number of pauses with inhalations, and number of pauses without inhalations.

Four examiners were involved in obtaining these measurements: one instructed the subject and presented the stimuli; one stabilized the strain-gauge and plethysmograph; another held the voice microphone the appropriate distance from the subject's mouth; and the final examiner manipulated equipment controls.

Results

Steady Peak Loudness

Perceptual measurements. Results of the perceptual evaluation of the subject's ability to maintain a steady peak loudness can be found in Appendix B, Figure B1. During habitual speech, the subject was judged able to maintain steady loudness for the 3, 5, and 10 second trials. She produced approximately 5 syllables per inhalation at a rate of 1.5 syllables per second.

During optimal speech, when asked to take only one breath at the beginning and speak as steadily as possible, the subject was able to maintain a steady loudness only on the 3-second trial, at which time she produced 4 syllables per inhalation at a rate of 1.67 syllables per second. This was similar to performance during habitual speech. On the 5- and 10-second trials, the subject produced more syllables per inhalation (8 vs. the habitual 5 syllables per inhalation) and maintained approximately the same rate as during habitual speech. As a result, she was unable to maintain steady loudness.

During speech-like productions involving repetions of /pʌ/, the subject was judged as able to maintain a steady loudness on the 3- and 10-second trials, where syllables per inhalation and syllables per second were similar to habitual speech performance. On the 5-second trial, the subject increased to 8 syllables per inhalation and did not maintain steady loudness. During speech-like productions of /a/, the subject was unable to maintain steady loudness, despite frequent inhalations.

These perceptual judgments indicated that the subject was able to maintain steady loudness, with frequent inhalations (approximately 5 syllables per inhalation). Attempts to produce more syllables per inhalation, as demonstrated during optimal speech, resulted in failure to maintain a steady loudness. This same pattern was seen during speech-like productions of repetitions of /pʌ/. Thus, even when articulatory and linguistic demands were decreased, the subject remained unable to maintain a steady loudness without frequent inhalations. The subject's inability to maintain steady loudness during productions of /a/ even with frequent inhalations, was likely due to her paralyzed vocal cord.

The subject therefore compensated for reduced steady peak loudness abilities by taking frequent inhalations. In addition, she compensated for decreased laryngeal control of the airstream by relying heavily on the articulatory motor processes. The results also indicated that the subject was performing close to her maximum skill level, in that improved performance was not seen with special instructions and a model (i.e., during optimal speech), nor when articulatory and linguistic demands were reduced (i.e., during speech-like productions).

Physiological measures. Physiological steady peak loudness results are contained in Appendix B, Figure B2a and B2b. The number of inhalations per utterance, syllables per utterance, syllables per inhalation, and syllables per second were consistent with the perceptual judgments of these same measures. However, the evaluation of intensity maintenance was not consistent with the perceptual evaluation of loudness. A consistent increase of peak intensity was evidenced at the beginning of each production; some utterances then settled into a steady peak intensity, others did not. For example, during the 3-second trial of habitual speech (counting), the intensity amplitudes and relative percentages of each syllable were as follows:

Counting:	"one"	"two"	"three"	"four"	"five"
Amplitude (cm):	3.3	2.5	2.4	2.3	2.4
Relative Percent:	100	76	73	70	73

Therefore, although the perceptual evaluation of loudness maintenance indicated normal performance, intensity measures indicated an initial "burst" prior to eventual intensity maintenance. This suggested that the subject needed time to coordinate the processes involved in maintaining a steady peak loudness.

Timing

Perceptual measures. The results of the perceptual evaluation of the subject's ability to demonstrate adequate timing can be found in Figure B3 of Appendix B. A "yes" judgment was made by the examiner; i.e., the subject was able to initiate phonation coincidentally with the initiation of exhalation. This was accomplished in a smooth, cyclic pattern with inhalation during the three stimulus conditions of habitual speech, optimal speech, and speech-like productions. These results, therefore, indicated adequate timing between the respiratory and phonatory processes.

Physiological measures. The subject's physiological timing data are presented in Figure B4 of Appendix B. These data confirmed the perceptual judgments: no more than a .5-second lag existed between the peak of inhalation and the initiation of phonation on any of the productions.

Flexibility

Perceptual measures. Perceptual evaluation of the subject's flexibility skill (stressing, emphasis, loudness variations, and phrase-length variations) can be found in Appendix B, Figures B5a, B5b, and B5c. During habitual speech, the subject stressed syllables in 5/6 words, marked emphasis on 0/3 words, and made loudness variations on 0/3 sentences. The subject varied phrase length on 3/6 sentences and demonstrated a single strategy to accomplish this: pausing with an inhalation.

The subject's ability to stress, emphasize, and make loudness variations during optimal speech was not significantly different from habitual performance; she marked stressed syllables but was unable to emphasize or make loudness variations. She demonstrated better ability to vary phrase length during optimal speech (5/6 sentences vs. 3/6 sentences during habitual speech). As during habitual speech, the subject accomplished variations of phrase length with a single strategy of pausing with an inhalation.

During speech-like productions, which involved repetitions of /pʌ/ while mimicing the prosodic pattern of the sentences used during habitual and optimal speech, the subject was able to stress on 6/6 trials, emphasize on 3/3 trials, and make loudness variations on 2/2 trials. She varied phrase length on 6/6 trials and demonstrated two strategies to accomplish this: pausing with a breath and pausing without a breath.

These results indicated that the subject's respiratory flexibility was severely reduced. Reduced flexibility resulted in inability to emphasize, make loudness variations, or consistently vary phrase length, except when the articulatory and linguistic constraints of the speech act were significantly reduced. In addition, the subject evidenced only a single strategy of varying phrase length: pausing with an inhalation. She was able to demonstrate two strategies--pausing with an inhalation and pausing without an inhalation--only when the articulatory and linguistic demands of the speech act were reduced.

Physiological measures. Figures B6 through B17 (Appendix B) contain the physiological measures of the subject's flexibility skills. Physiological measures of intensity indicate that in habitual speech, the subject modified loudness in order to stress on 3/6 words, to emphasize on 1/3 words, and to make loudness variations on 0/3 sentences. The subject varied sentence length on 3/6 sentences and demonstrated a single strategy to do so: pausing with inhalation.

Performance during optimal speech did not differ significantly from habitual speech, except that the subject varied phrase length on 5/6 sentences vs. 3/6 during habitual speech.

During speech-like productions, the subject stressed on 6/6 trials, emphasized on 3/3 productions, and made loudness/loudness variations on 2/2 trials. She varied phrase length on 6/6 trials and demonstrated two strategies to accomplish the variations: pausing with an inhalation and pausing without an inhalation.

These results confirm the basic findings of the perceptual evaluation. The flexibility results obtained from both perceptual and physiological measures indicated limited ability to stress, emphasize, and vary sentence length, except when articulatory and linguistic constraints of the speech act were reduced.

Although the data obtained from the two measurement techniques are consistent in basic pattern, specific measurements are frequently different. There are at least two possible explanations for these differences: 1) the perceptual judgments were not always accurate, or 2) the perceptual judgments were accurate but not confirmed physiologically because the parameter used to make the modification was not measured physiologically. For example, the subject may have marked a stressed syllable by increasing the duration of the syllable rather than by increasing intensity. This would have been perceived as accurate but not evidenced by the specific physiological measurement made within this study.

Summary

A case study to illustrate use of a respiratory assessment technique was presented. Results of the evaluation indicated that the subject's steady peak loudness and flexibility skills were severely reduced, while timing skills were adequate. In addition, the subject's inability to demonstrate steady peak loudness and flexibility with special instructions and a model of the desired response indicated limited potential as a treatment candidate. Only when articulatory and linguistic constraints were significantly reduced could the subject demonstrate improved performance and, even then, she was inconsistent.

Physiological measurements were used to test the validity of the perceptual data. A comparison of the data indicated that the perceptual yes/no judgments regarding steady-state loudness maintenance were not entirely verified by the physiological data. An initial intensity burst was not picked up by the listener; stabilization of the utterance after that brief burst is apparently what the listener perceived. Although the specific perceptual and physiological measurements of flexibility in the use of stress and emphasis were not identical, their overall patterns were consistent. This suggests that the perceptual judgments can be useful for this aspect of the evaluation.

The other perceptual results were confirmed by the physiological data. These included the following measures:

1. Number of inhalations per utterance
2. Number of syllables per utterance
3. Number of syllables per inhalation
4. Number of syllables per second
5. Yes/no judgments as to whether or not phonation was initiated coincidentally with exhalation
6. Number of total pauses
7. Number of pauses with inhalations
8. Number of pauses without inhalations
9. Loudness/softness variations

Thus, with minor exceptions, the perceptual and physiological data appeared to corroborate.

Chapter V

TREATMENT IMPLICATIONS:

CASE STUDY #2

The following case study illustrates the treatment implications of the evaluation approach. The focus of the subject's therapy was on improving the flexibility of his respiratory system. Flexibility was defined as one of the three major respiratory skills of normal speech.

Subject

The subject was a 20-year old male, status post-closed head injury (approximately one year post). His speech was mildly dysarthric, characterized by slowed rate and imprecise articulation. The subject evidenced decreased flexibility of the respiratory system, characterized by frequent inhalations during running speech, and only a single strategy for varying phrase length (pausing with an inhalation).

Summary of Treatment

Goals. The goals of therapy were: (1) to decrease the number of inhalations during oral reading; and (2) to use a second strategy for varying phrase length: pausing without an inhalation.

Procedures. During therapy, the subject orally read selected sentences and paragraphs, while following written cues provided by the clinician. The written cues instructed the subject when to inhale and when to pause without an inhalation. These cues were gradually faded, while the subject was expected to maintain at least 90% accuracy in the use of inhalations and pauses without inhalations. Acoustic feedback was provided frequently to the subject by playing tape-recordings of his oral readings. In addition, the clinician provided verbal feedback, and encouraged the subject to evaluate his own performance.

Measurements. In order to monitor progress, baseline and monthly post-treatment measures were taken of the frequency and duration of the total number of pauses, number of pauses with an inhalation, and number of pauses without an inhalation. These data were taken from audio tape-recordings, which were displayed on a visicorder, while the subject read "The Mount Rainier Passage" orally (see Appendix C).

Results of Treatment

Baseline and the two post-treatment measurements are shown in Figure 2 and Figure 3. Figure 2 displays the frequency of occurrence of the total number of pauses, pauses with an inhalation, and pauses without an inhalation, as compared to a normal speaker. Figure 3 displays the duration (in sec) of these measures, also comparing them to results of a normal speaker.

The results indicated that both of the therapy goals were achieved. That is, the subject was able to decrease the frequency and duration of the total pauses with an inhalation, and to increase the frequency and duration of the total pauses without an inhalation. The

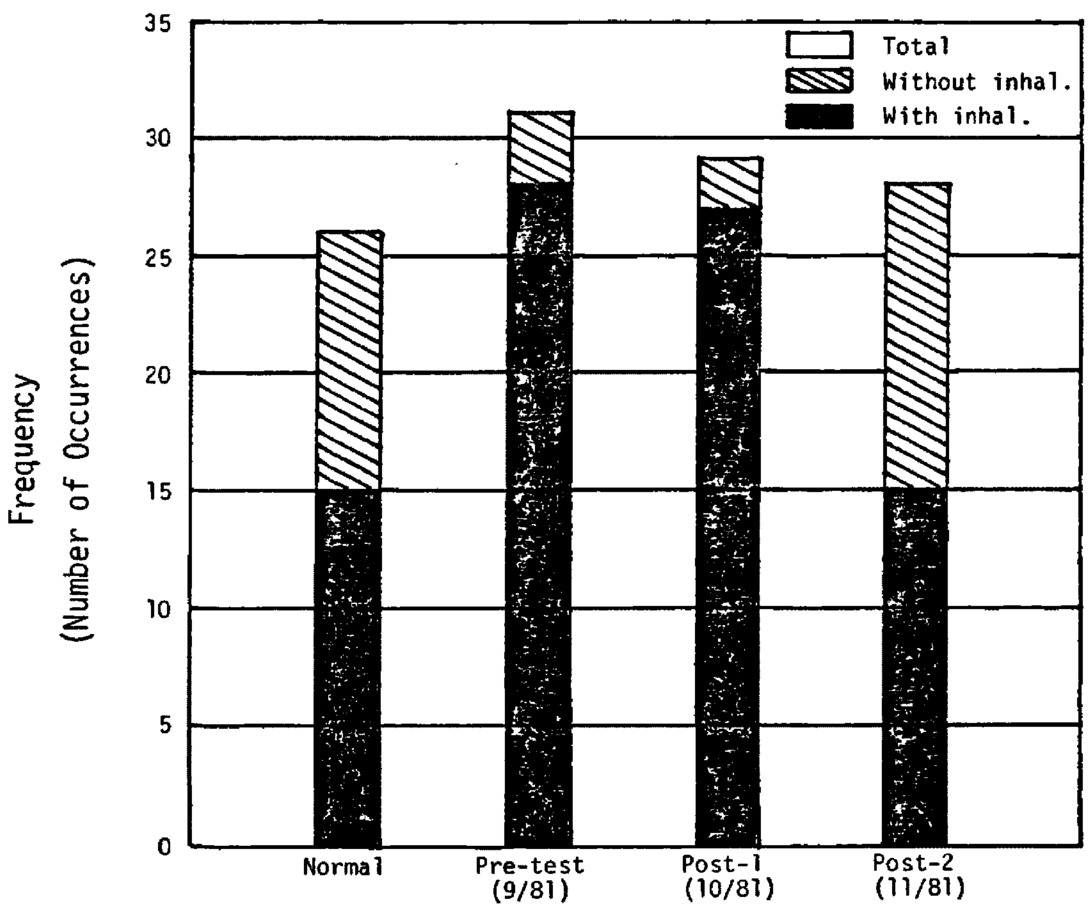

FIGURE 2. Baseline and post-treatment measurement of the frequency of occurrence of total number of pauses, number of pauses with an inhalation, and number of pauses without an inhalation during oral reading, as compared to a normal speaker.

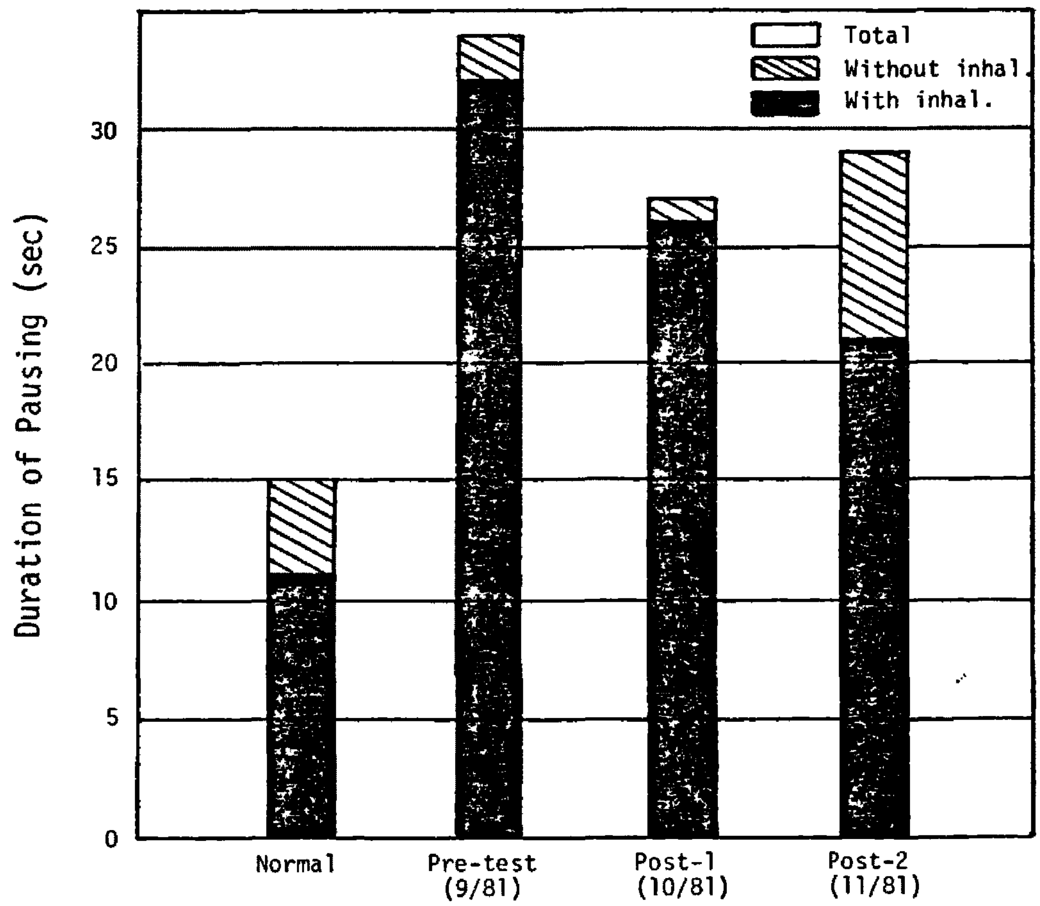

FIGURE 3. Baseline and post-treatment measurement of duration of pausing for total number of pauses, number of pauses with inhalation, and number of pauses without inhalation during oral reading, as compared to a normal speaker.

proportion of pauses without an inhalation to those with an inhalation became more like that of a normal speaker (both in frequency and duration). As a result, the subject was able to demonstrate a more normal speech pattern, at least during oral reading. Thus, with the accomplishment of the therapy goals, the subject was able to increase the flexibility of his respiratory system.

Implications

As evidenced in this case study, an evaluation which focuses on the respiratory skills needed for normal speech not only can direct the course of treatment, but also can objectively demonstrate therapeutic progress.

Chapter VI

SUMMARY AND CONCLUSIONS

A review of the literature regarding respiration in speech production indicated that although it has been established that respiratory function is crucial to speech production, its evaluation is largely confined to laboratory studies. The purpose of this paper was to present an approach for evaluating respiration which has potential clinical applicability. A method of assessing the respiratory skills of steady peak loudness, timing, and flexibility was developed, and use of the approach was demonstrated.

A research question considered was: Could the respiratory skills be evaluated without elaborate equipment which is not usually accessible to the majority of practicing clinicians? To begin to answer this question, the validity of perceptual judgments regarding the respiratory skill level of one subject was investigated. The results indicated that the majority of the perceptual judgments used in this investigation were corroborated by the physiological measures. Now, further testing on a larger population is needed to confirm this finding and to test the reliability of the perceptual judgments.

Until normative data are obtained for the tasks used with this evaluational approach, results can only be interpreted in a limited manner. For example, it is necessary to know the pausing strategies of normal speakers before definite conclusions can be drawn regarding a speaker's ability or inability to vary phrase length. In addition, there is a need to refine the tasks and measurements. In this study, only one strategy of stressing (increasing intensity on a stressed syllable) was evaluated physiologically. Frequency and durational changes (which may have been made by the subject and perceived by the judge) were not measured. Further studies of this evaluation approach should attempt to include these variables. Also, a 5% difference in peak intensity was arbitrarily defined as significant. Further investigation of the relationship between these subjective judgments and physiological changes are necessary.

The present study, therefore, represents an initial step in the development of a means of evaluating respiration clinically. More research and refinement of measures are needed. However, until more data are available, the assessment approach presented can be clinically useful in that 1) it yields objective results which can be used not only during the evaluation process but also to monitor change and response to treatment and 2) its focus on the most prominent respiratory skills necessary for normal speech gives information regarding treatment candidacy and course of therapy.

REFERENCES

DARLEY, F. L., ARONSON, A. E., & BROWN, J. R. Motor speech disorders. Philadelphia: W.B. Saunders Company, 1975.

EMERICK, L. L., & HATTEN, J. T. Diagnosis and evaluation in speech pathology. Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1979.

HIXON, T. Respiratory function in speech. In F. Minifie, T. J. Hixon, & F. Williams (Eds.), Normal aspects of speech, hearing, and language. Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1973.

HUNKER, C. J., BLESS, D. M., & Weismer, G. Respiratory inductive plethysmography: A clinical technique for assessing respiratory function for speech. Paper presented at the Convention of the American Speech-Language-Hearing Association, Los Angeles, 1981.

ISSHIKI, N. Regulatory mechanisms of voice intensity variation. Journal of Speech and Hearing Research, 1964, 7, 17-29.

KAPLAN, J. Anatomy and physiology of speech. New York: McGraw-Hill Book Company, 1971.

KLATT, D. H., & STEVENS, K. N. Studies of articulatory activity and air flow during speech. In Bouhuys (Ed.), New York Academy of Science 155, 1968.

LIEBERMAN, P. Speech physiology and acoustic phonetics: An introduction. New York: Macmillan Publishing Company, 1977.

ROSENBEK, J. C., & LA.POINTE, L. L. The dysarthrias: Description, diagnosis, & treatment. In D. F. Johns (Ed.), Clinical management of neurogenic communication disorders. Boston: Little, Brown, & Company, 1978.

APPENDIX A

TASKS, INSTRUCTIONS, AND MEASUREMENTS

TASKS, INSTRUCTIONS, AND MEASUREMENTS

I. Evaluation of Steady State

A. Habitual Speech

1. Task: Counting normally for 3, 5, and 10 seconds.
2. Instructions: "When I say go, please count normally until I say stop."
3. Measurements: (1) Number of inhalations per utterance (2) Number of syllables per utterance (3) Number of syllables per inhalation (4) Number of syllables per second and (5) Was loudness maintained (Y/N).

B. Optimal Speech

1. Task: After a model of the desired response, counting as steadily as possible, on one inhalation.
2. Instructions: "When I say go, please count until I say stop. This time, count as steadily as you can take only one inhalation at the beginning. First, I will do it that way and then I want you to do it."
3. Measurements: (1) Number of inhalations per utterance (2) Number of syllables per utterance (3) Number of syllables per inhalation (4) Number of syllables per second and (5) Was loudness maintained (Y/N).

C. Speech-like Productions

1. Task: Repeating /pʌ/ and prolonging /a/ for 3, 5, and 10 seconds.

2. Instructions: "When I say go, please repeat the sound /pʌ/ until I say stop. After that, please say the sound /a/ until I say stop."

3. Measurements: (1) Number of inhalations per utterance (2) Number of syllables per utterance (3) Number of syllables per inhalation (4) Number of syllables per second and (5) Was loudness maintained (Y/N).

II. Evaluation of Timing

A. Habitual Speech

1. Task: Reading phrases presented by the examiner.

2. Instructions: "Please read these phrases as I present them."

3. Measurements: Was phonation initiated coincidentally with exhalation and in a smooth, cyclic pattern with inhalation (Y/N).

B. Optimal Speech

1. Task: After a model of the desired response, reading phrases by initiating phonation coincidentally with exhalation.

2. Instructions: "Please read the phrases again as I present them. This time begin to say the first word immediately after your inhalation at the beginning. First, I will do it that way and then I want you to do it."

3. Measurements: Was phonation initiated coincidentally with exhalation and in a smooth, cyclic pattern with inhalation (Y/N).

C. <u>Speech-like Productions</u>

1. Task: Repeating /pʌ/ and prolonging /a/.
2. Instructions: "When I say go, please repeat the sound /pʌ/ until I say stop. After that, please say the sound /a/ until I say stop."
3. Measurements: Was phonation initiated coincidentally with exhalation and in a smooth, cyclic pattern with inhalation (Y/N).

III. <u>Evaluation of Timing</u>

A. <u>Habitual Speech</u>

1. Task: Reading sentences presented by the examiner.
2. Instructions: "Please read the sentences as I present them."
3. Measurements: (1) Was stress appropriate (Y/N) (2) Was emphasis appropriate (Y/N) (3) Was loudness/softness variation appropriate (Y/N) (4) Was phrase length varied (Y/N) (5) Number of pauses (6) Number of pauses with inhalations and (7) Number of pauses without inhalations.

B. <u>Optimal Speech</u>

1. Task: After a model of the desired response, reading sentences presented by the examiner.

2. Instructions: "Please read the sentences again as I present them. But this time, I will read them first and I want you to read them as much as you can like I did."
3. Measurements: (1) Was stress appropriate (Y/N) (2) Was emphasis appropriate (Y/N) (3) Was loudness/softness variation appropriate (Y/N) (4) Was phrase length varied (Y/N) (5) Number of pauses (6) Number of pauses with inhalations and (7) Number of pauses without inhalations.

C. <u>Speech-like Productions</u>

1. Task: Repeating the sound /pʌ/ mimicing the prosodic pattern of the sentences used in habitual and optimal speech.
2. Instructions: "I am going to repeat the sound /pʌ/. Please repeat it after me, saying it as much as you can like I did."
3. Measurements: (1) Was stress appropriate (Y/N) (2) Was emphasis appropriate (Y/N) (3) Was loudness/softness variation appropriate (Y/N) (4) Was phrase length varied (Y/N) (5) Number of pauses (6) Number of pauses with inhalations and (7) Number of pauses without inhalations.

APPENDIX B

DATA CHARTS WITH RAW DATA FOR CASE STUDY #1

	Total # Inhalations	Total # Syllables	Syllables per Inhalation	Syllables per Second	Loudness Maintained? (Y/N)
HABITUAL SPEECH					
3 Seconds	1	5	5.00	1.67	Yes
5 Seconds	2	9	4.50	1.80	Yes
10 Seconds	3	14	4.67	1.40	Yes
OPTIMAL SPEECH					
3 Seconds	1	5	5.00	1.67	Yes
5 Seconds	1	8	8.00	1.60	No
10 Seconds	1	8	8.00	1.33	No
SPEECH-LIKE PRODUCTIONS /pʌ/					
3 Seconds	1	6	6.00	2.00	Yes
5 Seconds	1	8	8.00	1.60	No
10 Seconds	3	13	4.33	1.30	Yes
SPEECH-LIKE PRODUCTIONS /a/					
3 Seconds	2				No
5 Seconds	2				No
10 Seconds	2				No

Figure B1. Perceptual steady peak loudness evaluation results for a 27-year old female with mixed dysarthria.

	Total # Inhalations	Total # Syllables	Syllables per Inhalation	Syllables per Second
HABITUAL SPEECH				
3 Seconds	1	5	5.00	1.67
5 Seconds	2	9	4.50	1.80
10 Seconds	3	14	4.67	1.40
OPTIMAL SPEECH				
3 Seconds	1	5	5.00	1.67
5 Seconds	1	8	8.00	1.60
10 Seconds	1	8	8.00	1.45
SPEECH-LIKE PRODUCTIONS /pʌ/				
3 Seconds	1	5	5.00	1.66
5 Seconds	1	8	8.00	1.60
10 Seconds	3	13	4.33	1.30
SPEECH-LIKE PRODUCTIONS /a/				
3 Seconds	2			
5 Seconds	2			
10 Seconds	3			

Figure B2a. Physiological steady peak loudness evaluation results.

AMPLITUDE AND RELATIVE PERCENTAGES

	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%
HABITUAL SPEECH																								
3 Seconds	3.3	100	2.5	76	2.4	73	2.3	70	2.4	73														
5 Seconds	3.6	100	2.7	75	2.3	64	2.1	58	2.3	64	3.0	83	2.8	78	2.6	72								
10 Seconds	3.0	100	2.9	97	2.5	83	2.3	77	2.8	93	2.4	80	2.8	93	2.3	77	2.8	93	2.6	86	2.9	97		
OPTIMAL SPEECH																								
3 Seconds	3.1	100	2.7	87	2.3	74	2.1	68	2.1	68														
5 Seconds	3.1	100	2.9	94	2.2	71	2.9	94	3.1	100	2.7	87	2.8	90										
10 Seconds	3.0	100	2.4	80	2.5	83	2.2	73	2.5	83	1.5	50	2.4	80										
SPEECH-LIKE PRODUCTIONS /pʌ/																								
3 Seconds	2.3	100	1.9	83	2.2	96	2.0	87	2.0	87	2.2	96												
5 Seconds	2.2	96	2.1	91	1.7	74	1.7	74	2.0	87	2.3	100	1.7	74	2.0	87								
10 Seconds	2.2	85	2.2	85	2.0	77	2.2	85	1.9	73	2.1	81	2.3	88	2.3	88	2.0	77	2.2	85	2.4	92		
SPEECH-LIKE PRODUCTIONS /a/																								
3 Seconds	2.4	92	2.6	100	2.7	75	2.2	61	3.6	100	2.1	58												
5 Seconds	3.0	97	1.9	61	3.1	100	1.9	61																
10 Seconds	3.4	85	1.9	48	3.1	78	2.0	50	4.0	100	2.0	50												

Figure B2b. Physiological steady peak loudness evaluation results.

If no-

	Was phonation initiated coincidentally with exhalation (Y/N)	Was air wasted on expiration before phonation (Y/N)	Was there a time lag between inspiration and expiration (Y/N)	Was there speech on inspiration (Y/N)
Habitual Speech				
Eat some pie.	yes			
Beat the team.	yes			
At the game.	yes			
Date the girl.	yes			
Optimal Speech				
Eat some pie.	yes			
Beat the team.	yes			
At the game.	yes			
Date the game.	yes			
Speech-like Productions				
/pʌ/	yes			
/a/	yes			

Figure B3. Perceptual evaluation results of timing.

If no-

	Time lag between peak of exhalation & initiation of phonation	Was air wasted on expiration before phonation	Was there a time lag between inspiration and expiration	Was there speech on inspiration
Habitual Speech				
Eat some pie.	0			
Beat the team.	.2			
At the game.	.2			
Date the girl.	.5			
Optimal Speech				
Eat some pie.	.1			
Beat the team.	.1			
At the game.	.1			
Date the game.	.2			
Speech-like Productions				
/pʌ/	.2			
/a/	.1			

Figure B4. Physiological evaluation results of timing.

Stimulus Sentences	Stress Appropriate? (Y/N)	Emphasis Appropriate? (Y/N)	Loudness/ Softness Appropriate? (Y/N)	Varied Phrase Length? (Y/N)	Total Number Pauses	# Pauses With Inhalations	# Pauses Without Inhalations
It's a perfect day.	yes						
I'm going to perfect my cooking.	yes						
I'm worried that my schedule will conflict with yours.	no						
I'd hate to have a conflict with you.	yes						
His license is invalid.	yes						
He is an invalid.	yes						
Show Sam some snow.		no					
Show Sam some snow.		no					
Show Sam some snow.		no					
The boy yelled, "Watch out!"			no				
The woman whispered, "I have to go home now." The man replied loudly, "No, you can't leave yet!"			no				
The woman said loudly, "Don't let him eat it!" The girl said quietly, "I won't."			no				
Oh, you can.				no	0	0	0
Oh, you can go.				no	0	0	0
Oh, you can go too.				no	0	0	0
Oh, you can go with me.				yes	1	1	0
Oh, you can go to the store.				yes	1	1	0
Oh, you can go to the grocery store.				yes	2	2	0

Figure B5a. Perceptual evaluation results of habitual flexibility.

Stimulus Sentences	Stress Appropriate? (Y/N)	Emphasis Appropriate? (Y/N)	Loudness/ Softness Appropriate? (Y/N)	Varied Phrase Length? (Y/N)	Total Number Pauses	# Pauses With Inhalations	# Pauses Without Inhalations
It's a perfect day.	no						
I'm going to perfect my cooking.	yes						
I'm worried that my schedule will conflict with yours.	yes						
I'd hate to have a conflict with you.	yes						
His license is invalid.	yes						
He is an invalid.	yes						
Show Sam some snow.		no					
Show Sam some snow.		no					
Show Sam some snow.		no					
The boy yelled, "Watch out!"			yes				
The woman whispered, "I have to go home now." The man replied loudly, "No, you can't leave yet!"			no				
The woman said loudly, "Don't let him eat it!" The girl said quietly, "I won't."			no				
Oh, you can.				no	0	0	0
Oh, you can go.				yes	1	1	0
Oh, you can go too.				yes	1	1	0
Oh, you can go with me.				yes	1	1	0
Oh, you can go to the store.				yes	1	1	0
Oh, you can go to the grocery store.				yes	1	1	0

Figure B5b. Perceptual evaluation results of optimal flexibility.

Stimulus Sentences	Stress Appropriate? (Y/N)	Emphasis Appropriate? (Y/N)	Loudness/ Softness Appropriate? (Y/N)	Varied Phrase Length? (Y/N)	Total Number Pauses	# Pauses With Inhalations	# Pauses Without Inhalations
/pʌpʌ/	yes						
/pʌpʌ/	yes						
/pʌpʌ/	yes						
/pʌpʌ/	yes						
/pʌpʌpʌ/	yes						
/pʌpʌpʌ/	yes						
/pʌpʌpʌpʌ/		yes					
/pʌpʌpʌpʌ/		yes					
/pʌpʌpʌpʌ/		yes					
/pʌpʌpʌpʌpʌpʌ/			yes				
/pʌpʌpʌpʌpʌpʌ/			yes				
/pʌ pʌpʌ/				yes	1	0	1
/pʌ pʌpʌpʌ/				yes	1	0	1
/pʌ pʌpʌpʌpʌ/				yes	1	1	0
/pʌ pʌpʌpʌpʌpʌ/				yes	1	1	0
/pʌ pʌpʌpʌpʌpʌpʌ/				yes	1	1	0
/pʌ pʌpʌpʌpʌpʌpʌpʌ/				yes	1	1	0

Figure B5c. Perceptual evaluation results of flexibility in speech-like productions.

Stimulus Sentences	Amplitudes and Relative Percentages					
	cm	%	cm	%	cm	%
1. It is a perfect day.	2.8	100	2.5	89		
2. I'm going to perfect my cooking.	2.7	96	2.8	100		
3. I'm worried that my schedule might conflict with yours.	2.8	100	2.6	93		
4. I'd hate to have a conflict with you.	3.2	100	2.4	75		
5. His license is invalid.	2.5	100	2.2	88	1.8	72
6. He is an invalid.	2.7	100	2.2	89	1.8	96

Figure B6. Physiological data of habitual flexibility: Peak amplitude (cm) and relative percentages for stressed and unstressed syllables.

Stimulus Sentences	Amplitudes and Relative Percentages					
	cm	%	cm	%	cm	%
1. It is a perfect day.	2.9	100	2.3	79		
2. I'm going to perfect my cooking.	2.8	97	2.9	100		
3. I'm worried that my schedule might conflict with yours.	1.9	100	1.9	93		
4. I'd hate to have a conflict with you.	2.2	100	2.0	91		
5. His license is invalid.	2.3	100	2.2	96	1.9	83
6. He is an invalid.	2.8	100	1.8	64	1.7	61

Figure B7. Physiological data of optimal flexibility: Peak amplitude (cm) and relative percentages for stressed and unstressed syllables.

Stimulus Sentences	Amplitudes and Relative Percentages					
	cm	%	cm	%	cm	%
1. /pʌpʌ/	2.5	76	3.3	100		
2. /pʌpʌ/	3.0	100	2.9	73		
3. /pʌpʌ/	3.3	100	2.2	67		
4. /pʌpʌ/	2.2	65	3.4	100		
5. /pʌpʌpʌ/	3.7	100	2.6	70	1.9	51
6. /pʌpʌpʌ/	3.7	100	1.8	64	1.7	61

Figure B8. Physiological data of speech-like flexibility: Peak amplitude (cm) and relative percentages for stressed and unstressed syllables.

Stimulus Sentences	Amplitudes and Relative Percentages							
	cm	%	cm	%	cm	%	cm	%
Show Sam some snow.	3.2	100	3.0	94	2.5	78	2.6	81
Show Sam some snow.	2.5	78	3.2	100	2.5	78	2.6	81
Show Sam some snow.	2.9	88	2.9	88	2.6	79	3.3	100

Figure B9. Physiological data of habitual flexibility: Peak amplitude (cm) and relative percentages for emphasized and unemphasized words.

Stimulus Sentences	Amplitudes and Relative Percentages							
	cm	%	cm	%	cm	%	cm	%
Show Sam some snow.	2.7	84	3.2	100	2.7	84	2.9	91
Show Sam some snow.	2.5	64	2.9	74	2.9	74	3.9	100
Show Sam some snow.	3.2	100	2.7	84	2.1	66	3.2	100

Figure B10. Physiological data of optimal flexibility: Peak amplitude (cm) and relative percentages for emphasized and unemphasized words.

Stimulus Sentences	Amplitudes and Relative Percentages							
	cm	%	cm	%	cm	%	cm	%
/pʌ pʌ pʌ pʌ/	2.2	73	2.2	73	2.0	67	3.0	100
/pʌ pʌ pʌ pʌ/	3.7	93	4.0	100	2.5	63	2.5	63
/pʌ pʌ pʌ pʌ/	3.9	100	2.0	51	2.1	54	2.2	56

Figure B11. Physiological data of flexibilityfor speech-like productions: Peak amplitude (cm) and relative percentages for emphasized and unemphasized syllables.

Stimulus Sentences	Amplitude and Relative Percentages											
	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%
1. The boy yelled, "Watch out!"	2.7	90	2.8	93	2.8	93	3.0	100	2.8	93		
2. The woman whispered, I have to	3.9	100	2.8	72	3.8	90	2.8	72	2.6	67	2.5	64
go home now." The man replied	2.6	67	2.3	59	2.3	59	2.8	72	2.9	74	2.4	61
loudly, "No, you can't leave yet!"	2.9	74	3.6	92	1.8	46	3.6	92	2.5	64	2.3	59
3. The woman said loudly, "Don't let	3.2	91	2.5	71	2.9	83	2.4	68	3.5	100	3.4	97
him eat it!" The girl said	2.6	74	2.3	66	2.1	60	2.5	71	3.4	97	2.5	71
quietly, "I won't."	3.5	100	3.4	97	2.3	66						

Figure B12. Physiological data of habitual flexibility: Peak amplitude (cm) and relative percentages for loud and soft words.

Stimulus Sentences	Amplitude and Relative Percentages											
	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%
1. The boy yelled, "Watch out!"	2.6	53	3.4	69	2.0	41	4.9	100	3.6	73		
2. The woman whispered, I have to	3.0	77	2.8	72	2.4	62	2.4	62	2.5	64	2.3	59
go home now." The man replied	1.9	49	3.9	100	1.6	41	3.1	79	3.0	77	3.5	90
loudly, "No, you can't leave yet!"	3.1	79	3.1	79	2.5	64	2.5	64	3.0	77	3.1	79
3. The woman said loudly, "Don't let	3.1	78	3.4	85	2.6	65	3.4	85	2.7	79	4.0	100
him eat it!" The girl said	3.0	75	2.7	68	2.5	63	2.9	73	2.8	70	2.5	63
quietly, "I won't."	2.8	70	2.9	73	2.3	58						

Figure B13. Physiological data of optimal flexibility: Peak amplitude (cm) and relative percentages for loud and soft words.

Stimulus Sentences	Amplitude and Relative Percentages											
	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%
1. /pʌpʌpʌ pʌpʌ/	2.6	74	2.1	60	1.9	54	3.3	94	3.5	100		
2. /pʌpʌpʌpʌ pʌpʌ/	3.3	100	2.5	76	2.8	85	2.1	64	1.9	58	2.3	70

Figure B14. Physiological data of speech-like flexibility: Peak amplitude (cm) and relative percentages for loud and soft syllables.

Phrase Variations

Stimulus Sentences	Pause at Syntactic Juncture (Y/N)	Total # Pauses	Total # Pauses With Inhalations	Total Pauses Without Inhalations
1. Oh, you can.	No	0	0	0
2. Oh, you can go.	No	0	0	0
3. Oh, you can go too.	No	0	0	0
4. Oh, you can go with me.	Yes	1	1	0
5. Oh, you can go to the store.	Yes	1	1	0
6. Oh, you can go to the grocery store.	Yes	2	2	0

Figure B15. Physiological data of habitual flexibility: Ability to vary phrase length.

Stimulus Sentences	Pause at Syntactic Juncture (Y/N)	Phrase Variations Total # Pauses	Total # Pauses With Inhalations	Total Pauses Without Inhalations
1. Oh, you can.	No	0	0	0
2. Oh, you can go.	Yes	1	1	0
3. Oh, you can go too.	Yes	1	1	0
4. Oh, you can go with me.	Yes	1	1	0
5. Oh, you can go to the store.	Yes	1	1	0
6. Oh, you can go to the grocery store.	Yes	1	1	0

Figure B16. Physiological data of optimal flexibility: Ability to vary phrase length.

Phrase Variations

Stimulus Sentences	Pause at Syntactic Juncture (Y/N)	Total # Pauses	Total # Pauses With Inhalations	Total Pauses Without Inhalations
1. /pʌ pʌpʌ/	Yes	1	0	1
2. /pʌ pʌpʌpʌ/	Yes	1	0	1
3. /pʌ pʌpʌpʌpʌ/	Yes	1	1	0
4. /pʌ pʌpʌpʌpʌpʌ/	Yes	1	1	0
5. /pʌ pʌpʌpʌpʌpʌpʌ/	Yes	1	1	0
6. /pʌ pʌpʌpʌpʌpʌpʌpʌ/	Yes	1	1	0

Figure B17. Physiological data of speech-like flexibility: Ability to vary phrase length.

APPENDIX C

THE MOUNT RAINIER PASSAGE

I think that the study of nature can be a wonderfully exciting experience for a child. My children are content to hike regularly. I attribute this to the need to rebel against the city and its content. One day we were hiking on Mount Rainier. It was a perfect day! One attribute of my oldest daughter is her desire to perfect her younger brother's knowledge of the outdoors. Notwanting to be a rebel, she asked her mother, "Can I show Sam an icicle?" Her mother said, "Show Sam some snow." My daughter said, "Can I give Sam some snow?" Her mother replied, "Show Sam some snow." After watching his sister for a while, Sam grabbed a handful of snow. His sister said, "Mother, should he do that?" My wife answered loudly, "No, don't let him eat it!" My daughter said quietly, "I won't."

(Beukelman & Yorkston, 1980)