This is to certify that the

dissertation entitled

A QUANTITATIVE INVESTIGATION OF
VELOPHARYNGEAL FUNCTION IN OLDER
ADULTS

presented by

Peter Renwick LaPine

has been accepted towards fulfillment
of the requirements for

Doctoral degree in Audiology and Speech Sciences

Lee V. Beal
Major professor

Date 11-7-83

A QUANTITATIVE INVESTIGATION OF VELOPHARYNGEAL FUNCTION IN OLDER ADULTS

By

Peter Renwick LaPine

A DISSERTATION

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

DOCTOR OF PHILOSOPHY

Department of Audiology and Speech Sciences

1983

ABSTRACT

A QUANTITATIVE INVESTIGATION OF VELOPHARYNGEAL FUNCTION IN OLDER ADULTS

By

Peter Renwick LaPine

In recent years the population of the United States has experienced certain demographic changes. One prominent change in this country has been the increased life expectancy of the average adult. As life expectancy improves, the mortality rate decreases correspondingly. Consequently, the population of older adults has been increasing and will continue to grow. Science, particularly the realm of applied research, needs to identify and describe specific physical changes which occur as chronological age increases. The present study is designed to analyze a select feature of human voice, specifically, the vocal resonance of older adults as measured by objective, bioelectronic instrumentation.

Fifty older adults between the ages of 50 and 75, matched according to gender and age group, participated in two experiments. In the first experiment nasalance ratios

for each subject were determined using TONAR II. In the second experiment the averaged nasal vibration was calculated using a pair of nasal accelerometers.

Resulting data were analyzed via analysis of variance models. Scores derived from each experiment were compared via a Pearson Product Moment correlation coefficient.

Analysis of the data indicated that the vocal resonance of older males and females remained relatively stable as chronological age increased. Nasalance ratios and averaged nasal vibration measurements did not vary systematically according to gender, chronological age, or in combination.

Correlation coefficients comparing TONAR II and the nasal accelerometers revealed a low, positive relationship. Although statistically significant, the relationship was not sufficient to support clinical application of accelerometers as reliable estimates of nasality.

For Spike, Ace, Moon, Boot, Toes, Moe, Punk, Babe, Kid, Hoot, Morocco, Otie, Chet, Smiley, Monroe, Towhead, Snowball, B. B., Chum, Pumpkin, Reb, Toot, Maboota, VanGo, Peach, and Pal:

Four, for, fore, 4.

ACKNOWLEDGMENTS

Recognizing those individuals who, in some special way, contribute to one's education is difficult. In retrospect many individuals deserve mention, but with regard to the present project, five people merit direct acknowledgment. To each individual I extend my personal gratitude.

First, to Dr. Donna Wanous for her natural patience and guidance with my budding statistical background. Next, to Dr. Jerry Higgins for his expertise with the instrumentation and knowledge of the topic. Third, to Dr. Leo Deal for his constant encouragement, direction, and organizational skills which helped shape the project from a passing idea to an attempt at scientific pursuit.

The remaining two individuals are the easiest for me to approach personally, and in different ways they are instrumental in the formation of this document. I would like to thank my older brother, Pat, for "lobbying with a higher authority" on my behalf in the late sixties. He set the early foundation and model for this final goal.

Like many other things, I save the best for last. I sincerely thank my wife, Elaine. What started with a ride along Lake Superior became a reality, primarily because of her unselfishness, flexibility, and persistence; but most of

all, she never once showed the slightest doubt or reservation. I thank her most of all.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

Mueller and Peters (1981) suggested the need for increased attention by speech and language pathology professionals to become actively involved in the clinical and research demands of the geriatric population. These authors contended that additional research is required to enhance the practical skills of those individuals working with older people. The chief undertaking of this study is an attempt to analyze one substrate of speech and language pathology: to assess velopharyngeal functioning in older adults as measured by two quantitative instruments.

Past research supports the prospect that vocal resonance is subject to some degree of audible variation as the human anatomy, particularly the pharynx and soft palate, changes as a function of the aging process. Anatomically, Kiuchi, Sasaki, Arai, and Suzuki (1969) and Zaino and Benventano (1977) agreed that the pharyngeal musculature weakens. Their research also suggested that as chronological age progresses, so does the degree of pharyngeal dilation.

Ferreri (1959) stated that with advancing age sensory innervation to the pharynx decreases, and the mucosal covering of the pharynx becomes thinner.

Several authors (Azzan and Kuehn, 1977; Chaco and Yules, 1969; Croft, Shprintzen, and Daniller, 1978; Pigott, 1969; and Pigott, Benson, and White, 1969) believe the deterioration of uvular muscles leads to decreased velopharyngeal closure. Hutchinson, Robinson, and Nerbonne (1978) furthered the belief in their study of velopharyngeal closure patterns of geriatric speakers.

Given the anatomical evidence put forth by previous research and with regard to the Hutchinson, Robinson, and Nerbonne (1978) study, anatomic changes in velopharyngeal closure in older adults may produce changes in vocal resonance. One facet of this study is to examine that question: Does vocal resonance change as speakers grow older?

Boone (1977) wrote, "the determination of normality or abnormality vis-a-vis resonance, then, is basically a perceptual task, dependent primarily on the subjective judgments of both the speaker and his listeners" (p. 184). Other vocal and linguistic characteristics contribute to the listener's subjective appraisal. Propriety of pitch, articulatory accuracy, and glottal competence can, as Sherman (1954) stated, "contaminate judgments of voice quality." Recognizing the propensity of human error, the need to develop objective resonance measurements has evolved.

Fletcher's (1970) development of TONAR represented an attempt at the bioelectronic measurement of nasality. In short, reliable quantitative measurement of nasality might reduce the impact of subjective judgments on certain resonance characteristics. Thus, a second facet of this study is evidenced: Can the resonance changes of the aging voice be measured using bioelectronic instrumentation?

The result of the TONAR measurement produces a "nasalance" ratio. The ratio is Fletcher's (1970) quantitative measurement of a physical entity, the ratio of sound pressure passing through the nasal cavity divided by the total sound pressure passing through both the oral and nasal cavities. In 1976 Fletcher presented data to support the use of TONAR as a reliable measure of nasalance. Nasalance norms reported in the study were consistent with psychophysical scaling measurements of the nasality -- the perceptual counterpart of nasalance. At this juncture a third element of the present study is identifiable: Is there another form of bioelectronic instrumentation that measures the physical characteristics of nasality? In this study TONAR results are compared to the results of a nasal accelerometer as measures of the physical manifestations of nasality, but more specifically, as measures of velopharyngeal coupling in the speech of older adults.

Purpose of the Study

Recognizing both the anatomical changes of the supralaryngeal resonators and the influence of objective measurements of resonance, the purpose of this study was to answer the following questions:

1. Does vocal resonance change as an individual ages?

2. Does vocal resonance change as the individual ages, and if so, is there a difference between males and females?

3. Does the nasal accelerometer provide a measurement comparable with the TONAR measurement?

In an attempt to answer these questions, the following null hypotheses were established:

1. There is no significant difference in the vocal resonance of five groups of older subjects as indicated by the sound pressure level computation of TONAR II.

2. There is no significant difference in the vocal resonance of five groups of older subjects as indicated by the averaged nasal tissue vibration derived from the nasal accelerometer.

3. There is no significant difference in the vocal resonance of older male and female subjects as indicated by the sound pressure level computation of TONAR II.

4. There is no significant difference in the vocal resonance of older male and female subjects as indicated by the averaged nasal vibration derived from the nasal accelerometer.

5. There is no correlation between the measurement of TONAR II and the measurement of the nasal accelerometer.

Importance of the Study

The primary value of this study was to supplement and enhance the pool of scientific knowledge applicable to the geriatric population. At this chronological point in history the size of the geriatric populace is increasing, and logic suggests that suitable experimental findings should increase accordingly. Understanding the changes of the aging process requires applied research to answer scientific, yet pragmatic, questions regarding the aging process.

In this study the aging process was viewed specifically as one characteristic: velopharyngeal closure, especially the detection of any audible vocal change associated with the voice of older people.

This study is designed to investigate the possibility that qualitative changes occur in the human voice as chronological age increases. In particular, the present study will attempt to analyze a selected vocal feature, examine for similarities or differences between sexes, and explore an area that is not well documented -- the resonance characteristics of the geriatric voice.

Definitions

In this study and in other scientific literature, common terms are encountered. The definitions of the prevalent terms are as follows:

Nasality: In this study "the term nasality is used exclusively to denote the perception of nasal voice quality" (Fletcher, 1978, p. 92).

Nasalance: As defined by Fletcher (1976), the term refers to a "numerical acoustic ratio score, expressed in percent "nasalance" which reflects the relative proportion of sound within a specified frequency band emitted from the mouth and nose during speech" (p. 31). Nasalance, then, can be represented by the following equation:

$$\text{Nasalance} = \frac{\text{N SPL}}{\text{N SPL} + \text{O SPL}}$$

N SPL = Nasal Sound Pressure Level
O SPL = Oral Sound Pressure Level

Averaged Nasal Voltage (ANV): The averaged output voltage of two nasal accelerometers derived from the peak to peak maximum excursion of five paired oscilloscopic tracings.

TONAR: An acronym developed by Fletcher (1970) to refer to the oral-nasal acoustic ratio.

Nasal accelerometer: A miniature vibration transducer with the electronic sensitivity sufficient to analyze vibration of nasal tissue.

Velopharyngeal closure: This term refers to the action of the soft palate and pharynx as structures which effectively separate the nasal and oral cavities. The action of the elevated velum structurally channels air from the hypopharynx into the mouth. The opposite movement, the lowering of the velum, will in turn, channel air through the nasal cavity.

Velopharyngeal incompetence: Velopharyngeal incompetence refers to the "inability to achieve adequate separation of the nasal cavity from the oral cavity by velar and pharyngeal action, although the structures appear normal . . ." (Nicolosi et al., 1978, p. 217).

Velopharyngeal competence: The "ability to separate the nasal cavity from the oral cavity by action of the velum and the pharynx" (Nicolosi, et al., 1978, p. 217).

Resonance: Moore (1971) described resonance as a product of the complex sound wave. As sound passes from the vibratory source at the level of the larynx, the changing shape and volume of the vocal tract selectively emphasize certain portions of the wave while altering and absorbing other segments of the sound wave. Such modifications in the vocal tract couplings contribute not only to the formation of vowels and consonants, but to the augmentation of linguistic factors such as individual or personal voice characteristics.

Sound Pressure Level: A ratio, stated in decibels (dB), derived from measured sound levels compared to a standard reference sound of 0.0002 dyne/CM^2 (Newby, 1972).

Organization of the Study

In chapter I some of the basic concepts to be addressed in the study have been introduced. A brief discussion of the potential value of the present project was presented along with definitions of common conceptual terms.

In chapter II a review of some of the past and current literature pertinent to the topic is presented. In particular, the second chapter will address the concept of nasality and the practical applications of selected instrumentation.

The information regarding the subject selection, experimental instrumentation and methods, and experimental design is provided in Chapter III.

Chapter IV contains the statistical results of the study as compared to the questions put forth in Chapter I. A discussion of the results is included.

In chapter V a summary statement, conclusions based upon the results of the study, and recommendations for additional research is presented.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

Understanding the present study requires more than a formal knowledge of subjective and quantitative measures of nasality. Understanding the concept of nasality, especially defining the abnormal or excessive forms of nasality, is not a simple task. Boone (1977) cautiously warned that accurate appraisal warrants decisions based on observation, objective measurements, and experience. Part of the difficulty in describing nasality is concisely summarized by Counihan (1971) as he stated:

> The problem is not merely defining in an individual experiment what a given group of judges will agree to call nasality, but one of establishing a common set of criteria that will enable investigators to differentiate this quality from other voice qualities that are present within a given sample. The real possibility that the nasality construct embraces a variety of disparate quality disturbances is one that needs to be carefully investigated. More refined perceptual measures may need to be evolved before definitive relationships between acoustic and perceptual dimensions can be derived (p. 192).

Counihan (1971) brought to light certain aspects of nasality that should be discussed prior to further discussion of the "nasality construct." He first related the necessity to "establish a common set of criteria" that assist in the decision and description of resonance differences.

Classification of vocal quality due to perceptual judgments is affected by the interaction of other variables besides the audible signal. Fletcher (1970) supported Counihan's (1971) contentions with his discussion of the relationship of acoustic theory to the supraglottal resonating cavities.

Fletcher (1970) identified three elements of acoustic theory that can distort the perception and objective analysis of nasality. He explained that first, the masking of one audible sound will reduce the audibility of another. Masking, therefore, may lead to bifurcation of the outputs from the nose and mouth during speech. Since the nose and mouth can function as variable filters during speech, it is feasible that the acoustic outputs of each cavity may merge and produce an audible signal with unique masking properties.

The second aspect of acoustic theory which Fletcher (1970) applied to nasality was the potential for signal distortion resulting from a loss of energy. His suggestion that "fragments of acoustic energy may be lost to the nasal cavity at critical junctures of the speech event" can be exemplified if one considers the loss of energy due to the masking of the high frequency components of sibilants -- the consequence of the energy loss is distortion of the audible signal.

The alteration of frequency bands within the total envelope was the third feature of acoustic distortion (Fletcher, 1970). As sounds from the nasal and oral cavities combine, the outcome changes the acoustic spectrum of the total envelope, thus accentuating previously subordinate frequency bands into prominence. The end effect is signal distortion and ultimately distortion of the spoken messsage. Based on these three elements, Fletcher (1970) was in agreement with Counihan's (1971) request for common differential criteria of nasality.

Boone (1977) addressed the qualitative aspects of Counihan's common criteria. In his discussion of resonance, Boone (1977) stated that in order to understand nasality there must be complete knowledge of the relationship between the supralaryngeal resonators and articulation. His discussion, much like Fletcher's (1970), correlated the practical elements of speech sound production as sounds are shaped by the coupling of the resonant cavities. As Fletcher (1970) related the sound distortion of nasality to acoustic theory, Boone (1977) compared nasality disturbances to the productive movements of speech sound articulation.

In each instance, Boone (1977) and Fletcher (1970) seemed to agree that the audible, perceptual feature called nasality was more than a single entity; it was a combination of physical relationships which, when aligned, provided a different, less favorable form of vocal resonance. Given this relationship, it is logical that a common set of qualitative and quantitative criteria be identified in order to consistently ascertain and confirm the presence of nasality.

In an effort to consistently ascertain and confirm the presence of nasality, Counihan (1971) postulated that before the relationship between the acoustic and perceptual characteristics of nasality can be defined, better perceptual measures may need to be developed. Based on the development and research supporting TONAR II, the need for developing objective quantitative measures, according to Fletcher (1972), also was critical to the evaluation and accurate identification of the physical existence of nasality. In his 1972 study, Fletcher generally delineated a variety of nasality measurement techniques ranging from simple nominal classifications, including extensive psychophysical scaling procedures to "qualitative evaluations of the acoustic spectrum." Recognizing the variability of measurement techniques, it is necessary to discuss the assessment of nasality on the bases of two types of measurements: oral and nasal air pressure and oral and nasal sound pressure.

Oral and Nasal Air Pressure Measurements

Counihan (1971) described a number of instruments used to assess oral and nasal air pressures. Certain instruments, such as the U-tube manometer, the oral manometer, "see-scape," or flowmeters, provide a fairly direct method of evaluating the patency of velopharyngeal valving. However, Counihan (1971) listed limitations that affect these instruments:

> they do not permit measurement of air pressure or flow from the nose and mouth simultaneously or continuously; they lack the sensitivity to detect fast variations in flow rates during running speech; they require subjective judgments of dial readings that may affect the precision of measurement; they do not afford a permanent record of the data; and they do not yield direct data concerning the air pressure and flow phenomena that occur during speech (p. 179).

Realizing those limitations, Counihan (1971) mentioned the pneumotachograph and the warm-wire anemometer as potentially useful measures of air pressure and flow. However, since the instrumentation of the present study deals specifically with a measure of nasal airflow, further discussion will relate primarily to the measurement of nasal air pressure and airflow.

Lubker and Moll (1965) stated the assessment of nasal air pressure can be divided into two methods: (1) radiographic studies providing a nearly direct view of the velopharyngeal valving sequence and (2) indirect measures derived from the combined measures of oral and nasal airflow.

Some studies utilized the direct, radiographic type of observation (Bjork, 1961; Carrell, 1952; Moll, 1960; Moll, 1962; and Powers, 1962). The use of radiographic analysis allows the researcher only a two-dimensional view of the interaction between the velum and the pharynx. Because of the limited display capacity of radiographics, greater emphasis has been placed upon the indirect measurement of nasal airflow as an indicator of velar competence (Counihan, 1971).

Additional research studying the impact of nasal airflow on connected speech commonly utilized indirect measurements of nasal airflow (Black, 1950; Carrell, 1952; Hess and McDonald, 1960; Kelleher, Webster, Coffey, and Quigley, 1960; Masland, 1946; Spriestersbach, 1959; and Warren and DuBois, 1964). Although there seem to be methods of measuring the function of the velopharyngeal valve, the relationship of

nasal airflow has not been clearly outlined. Complete agreement on the relationship between velar height, dimension of the velopharyngeal orifice, and speech has not yet been reached.

Oral and Nasal Sound Pressure Measures

As previously stated, nasality is a perceptual label for a concept that lacks consistent identity. Counihan (1971) stated "that attempts to explain nasal speech through perceptive measures alone may be limited" (p. 187). Efforts to analyze nasality as a measurable acoustic phenomenon met with some experimental flaws. Counihan (1971) reported the "variability among speakers and among vowels produced by the same speaker has deterred the identification of a consistent spectrum pattern that defines the presence and degree of nasal speech" (p. 187). In his description Counihan (1971) wrote that although shifts of the formant energies have been better classified, it is the lack of consistency in the acoustic spectra of nasal speech that remains unclear.

A number of electronic and recording devices have been designed in attempts to differentiate normal from nasal speakers. One instrument frequently used during the 1960's was the probe-tube assembly (Hirano, Takeuchi, and Hiroto, 1966; Sheldon, Know, Arndt, and Elbert, 1967; and Counihan and Pierce, 1965). The system allowed the simultaneous recording of speech signals from the mouth and nose. The dual microphones allowed the oral and nasal signals to be recorded then passed through a graphic level recorder. The derived measurement was the sound pressure level of either signal. Probably the most common sound pressure level measurement is the comparison of decibel differences between oral and nasal sound pressures (Counihan, 1971).

Fletcher (1970) designed electronic instrumentation intended to separate the acoustic output from the nasal and oral cavities. Although the instrumentation has improved, the final judgment as to what quality of voice is nasal remains a human factor. As Kanter (1948) wrote, the human ear is "the final detector and arbiter of nasality."

Quantitative Measurements

Cognizant of the limitations of oral and nasal airflow instrumentation described by Counihan (1971) and of the lack of reliable quantitative nasal and oral sound pressure levels, the measuring of two possible alternatives may be valuable: (1) evaluation of nasal airflow may be accomplished with a miniature accelerometer (Lippmann, 1981) and (2) sound pressure level measures may be gained using the TONAR II (Fletcher, 1970). The following sections provide a discussion of each instrument:

TONAR: This is a bioelectronic device designed by Fletcher (1970). He began development of TONAR in 1966; however, the commercial model eventually sold as TONAR II.

TONAR was designed to meet the following criteria (Fletcher, 1972):

1. Be capable of separating the acoustic output from the oral and nasal cavities during continuous speech.

2. Contain filter networks capable of simultaneously scanning identical frequency ranges in the two acoustic channels.

3. Be capable of analyzing all frequencies between 50 Hz and 20,000 Hz and selected bands within this range without distortion.

4. Provide instantaneous computation of ratios between sound levels in each of the channels and within selected frequency bands between the frequency limits.

5. Provide a graphic readout to display sound characteristics of each channel and of the computed interchannel ratio.

6. Yield the ratio data in quantitative form that could be readily interpreted by clinicians (p. 330).

Quick examination of the six criteria reveals marked similarity toward reducing the limitations mentioned by Counihan (1971).

<u>TONAR II</u>: According to Fletcher (1972) the prototype was able to meet all of the six established criteria except number four -- the "instantaneous computation of the ratios." In the early experiments with TONAR it was necessary to assign a score to an analogue tracing on calibrated oscillographic paper. The authors stated that although the computation was swift, it was not instantaneous.

Fletcher (1972) discussed the clinical management potential of TONAR. He explained that with improved feedback to the user, the potential for behavioral modification could be increased. Attempting to provide both instantaneous feedback to the user and to develop a clinical tool, Fletcher (1972) set the following goals for the design of TONAR II:

1. The nasal/oral acoustic ratio must be computed and instantaneously displayed on a calibrated meter on the operator control panel.

2. A goal ratio gate must be provided that is triggered by reduction in nasality to a level digitally specified on the control panel.

3. The goal ratio should be variable so that the "success" may be defined differently for different speakers and appropriately reinforced.

4. Provision must be made to operate in both success-by-trial mode of reinforcement and a success-by-time mode so that improved performance may be stabilized over time.

5. The subject's reinforcement panel must be connected with the main control system in such a way that he can be systematically and instantaneously notified of success each time he meets the specified goal ratio and criterion of performance.

6. The schedule of reinforcement must be programmable to allow a shift from instrumental control to control by self-monitoring when behavior reaches optimum levels of performance.

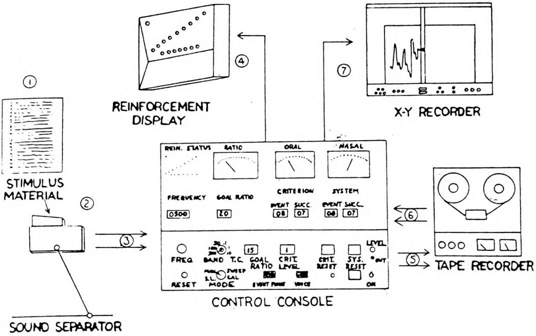
7. All responses and successes must be detected and stored on counters on the operator's control panel (p. 331).

Comparison of the developmental criteria for TONAR and TONAR II indicates the successful development of instrumentation capable of providing accurate sound pressure level measurements. Fletcher (1972) confirmed the completion of all proposed goals and criteria. A discussion of the instrumental characteristics of TONAR II will precede the discussion of its reliability for measuring nasal resonance.

<u>TONAR II Design Features</u>: Separation of the oral and nasal cavity is the initial function of the instrument. A dual chamber coupler with impacted nasal and oral microphones

serves as the source of acoustic input. The oral and nasal acoustic signals are separated by a lead baffle that partitions the upper (nasal) and lower (oral) sections of the coupler. The coupler is large enough to adapt to the contour of the face. The speaker must be positioned in the coupler with the upper lips and cheeks placed comfortably against the lead baffle separator.

Figure 1. TONAR II



When connected speech is analyzed, sound pressure variations are separated into the oral and nasal compartments by the lead shield baffle. These variations are then converted by the microphones suspended from the rear of each compartment and the acoustic signal is transduced into electrical form. The electrical signals of the oral and nasal cavity are then filtered by "tunable four-pole

Butterworth band-pass filters" (Fletcher, 1978). The band-pass filters are frequently set at 500 Hz with a 3-dB band width of 300 Hz. After the signal is filtered, it is rectified and averaged via an RC network with a variable setting time constant of 0.1, 1.0 or 10.0 seconds. The interaction of the system provides average values of the oral (O) and nasal (N) channels. These averages are used to compute a "nasalance" ratio (R) derived from the following formula:

$$R = \frac{\overline{N}}{\overline{N} + \overline{O}}$$

The ratio will be between 0 and 1. By multiplying R by 100, a nasalance percentage is expressed. The nasalance percentage is not to be construed as a ratio of the signal power in the oral versus nasal channel. The power ratio can be expressed as

$$P = \frac{\overline{N}^2}{\overline{N}^2 + \overline{O}^2}$$

A schematic diagram of the oral nasal acoustic ratio system is shown in Figure 2.

Psychophysical Scaling Studies: The advancement of TONAR II was accompanied by studies comparing psychophysical scaling procedures to the nasalance measurement of TONAR II. Fletcher (1970) discussed the inherent impact of the "halo effect" upon psychophysical judgments. The scaling procedures were "plagued" by the uncontrolled effects of pitch differences, speech sound articulation, and language competence. Often the labeling of nasality was erroneous because of the intrinsic association of these audible psycholinguistic factors.

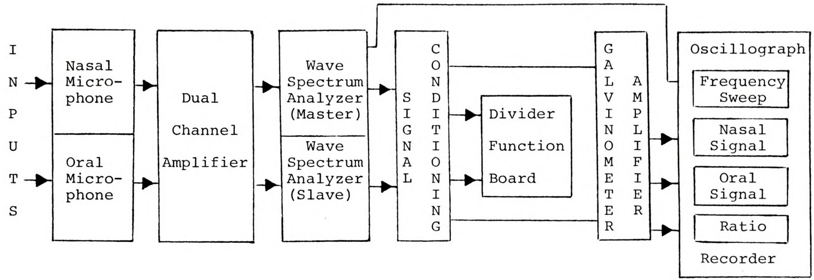
The nasalance score of TONAR II allowed the user to disregard the psychophysical impact of the halo effect, and permits the use of the single percentage score as the nasality rating. Fletcher's norms encompassed a wide range extending from "hyponasality" (< 5%) to "very severe hypernasality" (> 61% < 75%). For examination of the divisions of the range of nasality see Appendix G.

Reliability of TONAR II as a Measure of Nasality: Recognizing the influence of listener bias when psychophysical scaling procedures are employed, Fletcher and Bishop (1970) endeavored to correlate nasalance scores to listener judgments. In the study, ten trained observers were required to judge the connected speech of 20 children with surgically repaired palatal clefts. Observers performed a magnitude estimation task in which both forward played (FRN) and backward played recordings (BRN) of speech samples were scored and rank ordered.

The observers were asked to rank order both sets of data. The subsequent Spearman rho correlation coefficient was 0.84 and found to be significant beyond the .01 level.

Comparison of the TONAR II measurement to the psychophysical scaling demonstrated the following correlations: comparison of BRN values and TONAR II indicated a Spearman rho correlation coefficient of .70;

Figure 2. Diagram of the Oral Nasal Acoustic Ratio (TONAR) System*



*Fletcher (1970)

comparison of FRN values and TONAR II indicated a Spearman rho correlation coefficient of .74. Both correlations were found to be significant beyond the 0.01 level.

Based upon these correlations, Fletcher and Bishop (1970) concluded "that TONAR does in fact analyze parameters which affect listeners' ratings of nasality." The resultant TONAR II classification is likely to be similar to the psychophysical estimate of the listener. In that light, TONAR II provided a reliable, instantaneous estimate of the nasality of connected speech. In a more recent study Fletcher (1976) reported additional supportive results related to the relationship between nasalance and listener judgment of nasality.

Clinical Applications of TONAR: Prior to the fabrication of TONAR II, Fletcher (1972) suggested that behavior modification was the ultimate goal of his instrumentation. Although the amount of applied research using TONAR II is not expansive, the device has been effectively used in clinical practice.

Of course, Fletcher (1972 and 1976) has used TONAR II as an assessment tool and as a measure of nasalance change in a clinical setting. His work was primarily done with cleft palate children paired with "normal" control groups.

Other authors have utilized TONAR II as a device to reduce or eliminate specific communication deficits. In 1974, Daly and Johnson presented the case studies of three mentally retarded children. TONAR II was incorporated as the measure of nasality in the baseline and criterion conditions.

Daly and Johnson (1974) reported that each of the three subjects either: (1) improved their overall levels of speech intelligibility, (2) reduced their levels of hypernasality, or (3) improved their articulation skills. The authors stated that their "data do suggest that bioelectronic modification systems, such as TONAR, have clinical application for some mentally retarded persons with excessive nasal resonance" (p. 505).

Bioelectronic modification of nasalance of hearing impaired speakers was studied by Fletcher and Daly (1976) and Fletcher and Higgins (1980). The primary purpose of the Fletcher and Daly (1976) project was to compare nasalance measurements of hearing-impaired speakers to those of speakers with normal hearing acuity. The authors concluded that obtained nasalance scores were significantly higher in the hearing impaired subjects than in the control group.

Fletcher and Higgins (1980) also studied a hearing impaired population. The twelve experimental subjects were required to read two selected paragraphs and a battery of ten sentences. Based on the baseline measurement of TONAR II, specific treatment activities were implemented. Resonance shaping activities required the use of TONAR II as a feedback device, as well as a behavioral measure of ongoing change.

Fletcher and Higgins (1980) reported that not only did the majority of subjects reduce the degree of nasal resonance in the training and control trials, but these subjects were able to maintain the reduced levels from one treatment period to the next. The authors provided confirming information on "deaf speech," and utilized TONAR II as a practical tool for changing a select vocal behavior.

Colyar and Christensen (1980) examined the nasalance patterns of eight laryngectomized speakers. Based on the TONAR II nasalance percentage derived from two selected readings and a vowel prolongation, the authors determined that although all the subjects injected the esophageal air charges, "these esophageal speakers have functional velopharyngeal mechanisms capable of a range of activity reflecting the nasal consonant ratio of the material being spoken" (p. 46). Essentially, the TONAR II measurement enabled the researchers to predict that esophageal speakers can, in fact, voluntarily open the velopharyngeal port to produce nasal consonants.

The impetus for the current study originated from the work of Hutchinson, Robinson, and Nerbonne (1978). In their study of sixty older adults, Hutchinson, et al. (1978) utilized the same stimuli and TONAR II analysis as Colyar and Christenson (1980). In their project, Hutchinson, et al. (1978) required that each speaker read two short passages and prolong the vowel /a/. All three stimuli were recorded and analyzed to provide a nasalance score. "Tonagrams" were generated using an X-Y plotter paired with a Time Base. The use of the graphic record allowed for visual display of the nasalance pattern.

Hutchinson et al. (1978) reported that based on the analysis of the tonagrams, four separate patterns of nasalance were demonstrated. The patterns were:

1. normal configuration - nasalance values of less than 15 percent;

2. pervasive nasalance - nasalance values of greater than 15 percent but less than 50 percent;

3. momentary loss of velar control - nasalance values greater than 50 percent; and

4. progressive loss of velar control - nasalance values increasing in duration and intensity near the end of the utterance.

Because of this evidence, the authors concluded that irregular tonagrams were more common in older adults than younger adults, that older women demonstrated more irregular tonagrams than older men, and that there was "no systematic increase in abnormal tonagrams as a function of age" (p. 475). These three conclusions led the authors to infer the broad finding that when continuous velopharyngeal closure is necessary, older individuals demonstrate "notably less competence than normal young adults" (p. 476).

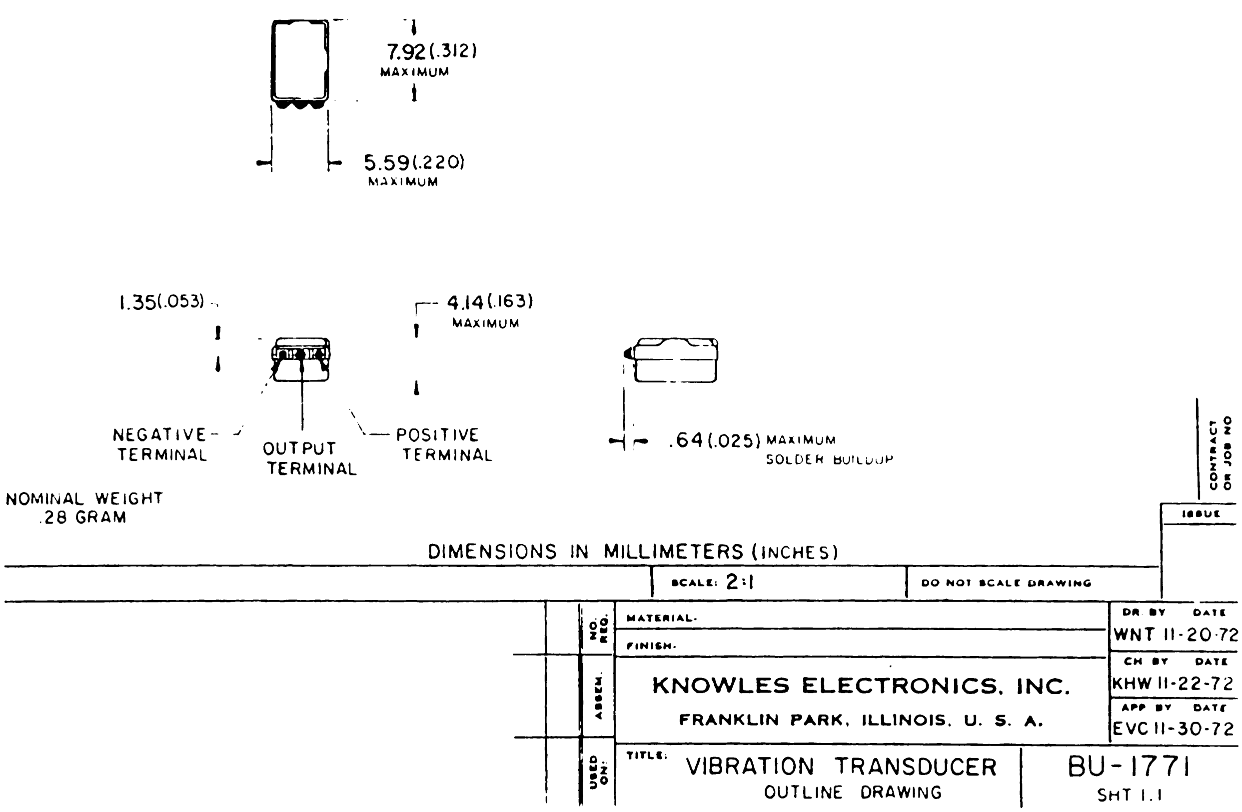
The findings of the study by Hutchinson et al. (1978) stimulated some of the research questions posed in the present study. It would be beneficial to know to what extent older individuals do perform differently on velopharyngeal valving activities from their younger counterparts.

<u>Nasal Accelerometer</u>: Unlike the sound pressure level measurement of TONAR II, the nasal accelerometer acts as a vibration transducer and provides a measure of nasal tissue movement. Nasal vibration can, of course, be initiated by airflow passing through the nares during speech. Nasal vibration may also be caused by nasal airflow during passive respiration, movements of the head, or mechanical artifact

due to the movement of the electrical connections to the accelerometer.

A miniature accelerometer is a small transducer that may be attached to nearly any surface. See Figure 3 for a description of size and physical dimensions.

Figure 3. Size and Description of a Nasal Accelerometer



In use, the accelerometer can be attached to an oscilloscope. Thus, the oscilloscopic tracing allows the analysis of wave frequency, duration, and time. Depending upon the need, accelerometers can also be connected to other output devices such as digital readouts or VU meters.

Use of the accelerometer in the speech pathology literature is, indeed, limited. Horii (1980) developed the

Horii Oral-Nasal Coupling Index (HONC) based on calculations from lightweight accelerometer measurements. The study used accelerometers placed on the nose and neck in an attempt to determine the "ratio of nasal amplitude level to the vocal amplitude level" (p. 254). The index may be expressed as

$$HONC = A_{rms(n)}/K \quad A_{rms(v)}$$

In the equation, $A_{rms(n)}$ is the root-mean-square amplitude of the accelerometer placed on the nose, and $A_{rms(v)}$ is the root-mean-squre amplitude of the accelerometer placed on the neck (voice). According to Horii (1980), the index provides a noninvasive approach to determining the nasal coupling during connected speech and protracted phonation.

Other studies utilizing accelerometers have been primarily in areas of applied research. Stevens, Kalikow and Willemain (1975) used accelerometers simultaneously placed on the nose and neck to measure both nasalization and glottal waveform. Because of the lightweight construction, instrument sensitivity, resistance to damage, and low power consumption, Stevens et al. (1975) suggested acceleromters might be helpful in analyzing those "speech-related signals" that require visual display. In that instance, these authors recommended the clinical use of accelerometers as speech reception or training aids for the deaf, as feedback devices for individuals with velopharyngeal incompetence, or in selected forms of articulation therapy.

Of particular interest in the studies of Stevens et al. (1975) and Stevens, Boothroyd, and Rollins (1976) were their discussions of nasalization detection. The authors stated that acoustic energy passing through the velopharyngeal apparatus into the nose is "signaled unequivocally" by the subsequent vibration of nasal tissue. Again, as earlier stated, nasality can be represented visually; but "the question of how the visual display correlates with subjective judgments of nasality remains to be answered" (Stevens et al., 1975, p. 598). Since TONAR II has reliably matched listeners' subjective judgments of nasality, the possibility of pairing a nasal accelerometer measure with the TONAR II nasalance measure might provide a part of the answer.

Lippmann (1981) attempted to define the best recording placement for accelerometers attached to the nose. Using a smaller, lighter accelerometer than those used by Stevens et al. (1975), Lippmann attached nasal accelerometers to ten normal speakers. From subjects' readings of five sentences containing only nasal consonants and five sentences containing only non-nasal consonants, Lippmann (1981) found the best placement location to be on "the upper side of the nose over the lateral nasal cartilage, just in front of the nasal bone" (p. 24). Lippmann (1981) referred to this location as "position six." In short, position six provided the optimal position for accelerometer sensitivity to record both the nasal and non-nasal sentences.

In summary, there is a recognized need to equate quantified measurements of nasality with the perceptual estimates of nasality made by the listener. The instruments used in this study are capable of detecting nasality;

however, only one reliably approximates auditory-perceptual classifications of nasality at the present time. Nasality abnormalities of gerontologic subjects have been identified, as well as nasality irregularities found in other communicatively handicapped groups.

CHAPTER III

SUBJECTS, EQUIPMENT, MATERIALS, AND PROCEDURES

The intent of this study was to examine resonance changes that may occur in a group of 50 older people. Two separate instruments were used to measure sound pressure level and nasal airflow during speech. Each of the subjects participated in two experiments. Each experiment required the subject to read selected materials designed for analysis by one of the two instruments.

Subjects

A total of 50 adults, 25 males and 25 females, between the ages of 50 and 75 years were involved in the study. Subjects were matched according to age group and sex.

Each subject was questioned about his or her health history. Subjects were required to have no history of neurotrauma or language loss, motor speech impairment, hearing impairment, or evidence of surgical procedures within the nasal or oral cavity. Evidence of any unreported speech or language difficulty was reviewed by a certified speech-language pathologist during a practice reading and in conversational speech. Each subject was required to pass a pure-tone hearing screening.

A list of subjects meeting the selected criteria was obtained from the files of a local university club for retired employees. From this list of retirees each individual was contacted by telephone, given an explanation of the study, and was asked to participate in the study. Thirty of the 50 subjects were contacted by telephone. Each potential subject verbally confirmed his or her overall oral communication skill through answers to general questions about his or her physical health status. Of the 30 subjects older than 60 years of age, nearly all of them were retired professional people. Most were retired university faculty members or university administrators. Thus, such a group might be readily conscious of their abilities to verbally communicate.

For those subjects who had not reached retirement age, local church groups were contacted in search of volunteers; and university personnel and faculty were approached as volunteers. The same situation that occurred with the group of subjects older than 60 years was apparent with the 20 subjects younger than 60. The younger subjects also were professional, outgoing people. Such a sample contained a majority of individuals who were likely to rely on good, effective oral communication and if that were so, the group of subjects might have been more aware of the ongoing changes in their vocal resonance.

Equipment

TONAR II: The study was designed to compare two specific instruments: TONAR II and the nasal accelerometer. In this study the TONAR II used was manufactured by Quan-Tech, Incorporated. TONAR II, a dual chamber sound separator with oral and nasal microphones separated by a lead baffle, received acoustic input through an adjustable wooden and fiberglass coupler. The coupler was designed to conform to the facial contour. The oral and nasal microphones were suspended in fiberglass packing at the rear of the coupler.

Acoustic input into the coupler was filtered by tunable band-pass filters, then rectified and averaged by an RC network with three settings for the appropriate time constant. The output was an electronically-computed ratio of nasal sound pressure level to total sound pressure level. The ratio, expressed as a percentage of nasalance (Fletcher, 1970) is

$$\frac{\text{Nasal SPL}}{\text{Nasal SPL + Oral SPL}} \times 100 = \%\ \text{Nasalance}$$

Instrument settings were as follows:

PROGRAM switch:	MIC
FREQUENCY:	500 Hz
BANDWIDTH:	300 Hz
TIME CONSTANT:	0.1 for sound separator; 10.0 for reading activity
MODE:	MANUAL
VOICE:	HOLD for sound separator (0.1 sec. T.C.); RUN for reading (10.0 sec. T.C.)
POWER:	ON

Nasal accelerometer: The output of a pair of nasal accelerometers was the second quantitative measurement. Two low cost miniature accelerometers were used. The accelerometers, model BU-1771, were developed by Knowles Electronics and selected for the study because of the cost factor, sensitivity and power specifications, and the consistently high signal recording accuracy of the BU-1771 as reported by Lippman (1981).

The power supply of the nasal accelerometers consisted of two nine-volt batteries connected in series. Each accelerometer was connected to a binary power switch for simultaneous or selective control of either transducer.

Visual display of the output was provided by a Tektronix 5115 storage oscilloscope. Simultaneous storage of both signals on the screen was achieved simply by disengaging two of the four possible channel options. Such separation allowed for storage and analysis of the upper (left nasal accelerometer) and lower (right nasal accelerometer) tracings.

A Tracoustics Program III clinical audiometer housed in a standard double wall IAC sound-treated booth was used to screen the hearing of 48 of the 50 subjects. Two subjects refused to enter the sound suite and were subsequently screened on a Beltone 10D portable audiometer in a quiet environment.

Materials

TONAR II: Measurement of nasalance via the TONAR II required that each subject read "The Zoo Passage" (Fletcher, 1970). This short, 70 word nonsense paragraph was written at approximately the second or third grade reading level, and by design the paragraph contained all oral consonants and no nasal consonants. See Appendix D for examination of the "Zoo Passage." Each subject read the paragraph aloud into the coupler at least once.

Nasal accelerometer: Each subject read aloud five of the non-nasal sentences developed by Lippman (1981). See Apendix C for a list of these stimuli.

Procedures

Each subject completed the requested activities in an established order. The order of events was as follows:

- Phase I: conversational speech sample and case history review to identify potential subjects;
- Phase II: hearing screening test;
- Phase III: TONAR II nasalance measurement; and
- Phase IV: nasal accelerometer airflow measurements.

Each phase will be discussed in order of occurrence.

Phase I: During this time a clinically certified speech and language pathologist elicited from each subject a sample of spontaneous speech. Articulation, voice, and language skills were informally reviewed during the sample to assess minimal oral communication skills.

Next, each subject was interviewed in order to rule out organic factors that could affect the control of oral and nasal resonance.

Subjects not included were those with positive histories which included neurotrauma or cerebrovascular accident with residual language loss or cognitive deficits, motor speech impairment, hearing impairment, or recent surgical procedures on the nose or mouth.

Phase II: Passing criteria on the hearing screening test were the same as those of Hutchinson et al. (1978) in their study of older adults. Each subject was required to pass the hearing screening conducted at 25 dB HTL at the frequencies of 500, 1000, and 2000 Hz (re: ANSI, 1969) in at least one ear. Subjects wearing hearing aids were not included in the study.

Phase III: Each subject was given verbal instructions describing proper positioning in the coupler. Each subject was then asked to sit with comfortable posture and was requested to keep his or her face in the coupler until told to move away from it. Prior to the reading of the "Zoo Passage" (Fletcher 1970), each subject was positioned in the coupler with the upper lip snugly against the lead shield. Using the 0.1 second time constant, each subject was asked to prolong the nasal consonant /m/. This preliminary sound separator measurement allowed for continuous monitoring of the electronic calibration of the instrument.

If accurate electronic calibration was maintained, the time constant was changed to 10.0 seconds. Each subject read the "Zoo Passage" (Fletcher, 1970) at least once or until the "% nasalance" digital display stabilized. The percent nasalance was recorded and the subject was asked to move away from the coupler.

Phase IV: After the TONAR II measurement, each subject was provided with an alcohol prep and asked to wipe clean the outer surface of both sides of the nose. Upon completion, double-sided adhesives were carefully placed on the upper side of the nose over the lateral nasal cartilage, slightly anterior to the nasal bone. This position was the site of best accelerometer signal detection as reported by Lippman (1981).

One miniature accelerometer was then placed on each side of the nose and secured with approximately two inches of one-half inch hypoallergenic tape. Each subject was asked to sit comfortably and to avoid unnecessary extraneous movements while reading.

Each of the five non-nasal sentences was read one at a time. After the reading of each sentence, a measurement of the maximum peak to peak excursion was taken. After the five readings and subsequent measurements were completed, the resulting voltages were averaged to obtain the averaged nasal voltage (ANV). See Appendix C for an example of the recording form.

After completion of the readings, the nasal accelerometers were removed, and the purpose of the study was explained to each subject who indicated an interest in the outcome.

Summary

Although each subject followed the same four procedures, the participation of subjects in the study occurred entirely at random. Appointments were made for each subject according to the individual's daily schedule and not according to age or sex.

Subjects were provided with directions to the Oral-Facial Anomalies Laboratory on the campus of Michigan State University. The experiments were conducted during the entire month of May, 1983.

The initial data were collected, grouped, and prepared for computer-assisted analysis. The data derived from each instrument were quantified via a 2 x 5 analysis of variance for each set of data. Pearson product moment correlation was used to investigate the relationship between the TONAR II and the nasal accelerometer.

CHAPTER IV

RESULTS AND DISCUSSION

In Chapter I three experimental questions were proposed. The questions were designed to allow attempts to examine the changes in the resonance characteristics in the voices of older people as measured by quantitative instrumentation. The questions were as follows:

1. Does vocal resonance change as an individual ages?

2. Does vocal resonance change as the individual ages, and if so, is there a difference between males and females?

3. Does the nasal accelerometer provide a measurement comparable with TONAR measurement?

To systematically analyze the experimental questions, data analysis was divided into three separate statistical procedures. Analyses examining age and gender differences as measured by TONAR II were accomplished via a 2 x 5 analysis of variance random effects model. Age and gender differences as derived from the nasal accelerometers were examined using the same analysis of variance design.

A Pearson Product Moment correlation coefficient was used to compare the results of the TONAR II and the nasal accelerometer.

Fifty older adults participated in the study. Twenty-five males and twenty-five females were matched

according to age group. The sample was divided into age groups with five-year boundaries. Table 1 indicates the mean age, standard deviation, and variance of the ten subjects assigned to each age group.

Table 1. Descriptive Analysis of the Sample (n = 50)

Age Group		Gender: Male	Gender: Female
50-54 Years			
$\bar{X}$		51.80	51.0
S		1.64	1.0
S^2		2.16	.8
Mean Age	51.40		
55-59 Years			
$\bar{X}$		57.60	57.60
S		1.14	.89
S^2		1.04	.64
Mean Age	57.60		
60-64 Years			
$\bar{X}$		62.60	62.40
S		1.34	1.51
S^2		1.44	1.84
Mean Age	62.50		
65-69 Years			
$\bar{X}$		66.60	66.60
S		1.14	.54
S^2		1.04	.24
Mean Age	66.60		
70-74 Years			
$\bar{X}$		73.00	72.20
S		1.22	1.48
S^2		1.20	1.76
Mean Age	72.60		

TONAR II

A 2 x 5 analysis of variance was utilized to determine the statistical presence of resonance changes in the voices of older people according to age, gender, or in the possible combinations of age and gender.

Main effects: The results of the analysis of variance indicated there were no statistically significant differences in the TONAR II nasalance scores across the five age groups ($F = 4.08$, $p > .05$). On the basis of the test statistic, it would appear that the computed nasalance ratio derived from TONAR II remained fairly consistent with age, and that any change in the ratio was not systematic or indicative of ongoing vocal resonance change.

Comparison of male and female scores also revealed no statistically significant differences in the nasalance scores of either of the sexes ($F = 2.61$, $p > .05$). It would seem that, since there are no main effects for age and sex, the nasalance ratio remained stable within the sample studied.

Interactions: Like the main effects, the analysis of variance indicated no statistically significant differences between the factors of age and sex ($F = 2.61$, $p > .05$). Table 2 presents the summary table.

Table 2. Summary Table: 2 x 5 ANOVA - TONAR II

Source	SS	DF	MS	F
Gender	.019	1	.019	.000
Age	85.479	4	21.369	.506
Gender Age	145.480	4	36.370	.862
Error	1686.399	40	42.159	
TOTAL	1917.379	49		

The consistency of the TONAR II grouped data best exemplifies the limited score variability and the lack of group differentiation. Table 3 includes the mean nasalance score, standard deviation, and variance of each gender and age group. Table 4 indicates the average nasalance scores for both males and females in each age group.

Table 3. Mean, Standard Deviation, and Variance by Gender and Age - TONAR II

Gender		50-54	55-59	60-64	65-69	70-74	Grand $\overline{X}$
	$\overline{X}$	11.39	5.19	7.00	10.19	10.19	8.80
M	S	5.10	4.43	4.24	8.04	4.60	
	S^2	25.20	19.62	17.97	64.64	21.26	

Gender		50-54	55-59	60-64	65-69	70-74	Grand $\overline{X}$
	$\overline{X}$	8.60	11.80	6.00	10.00	7.80	8.84
F	S	12.01	3.42	1.58	5.43	9.20	
	S^2	144.24	11.69	2.49	29.48	84.64	

Table 4. Mean Nasalance Score of Each Age Group

Age Group	50-54	55-59	60-64	65-69	70-74
$\overline{X}$	10.00	8.50	6.50	10.10	9.00

Inspection of the descriptive statistics shows the similarity of male-female and age group scores. In particular, comparison of the overall male and female means of 8.0 and 8.84, respectively, suggests the near proximity of the male-female nasalance ratio. Closer examination of age group and gender differences indicates informal estimates analagous to the analysis of variance findings; that is, the degree of score invariability is likely to reveal nonsignificant differences between the independent variables.

Based on the statistical evidence, the null hypothesis regarding age-related resonance differences as measured by TONAR II was not rejected. The resonance changes across either gender and age groups were not sufficient, at least in this sample, to warrant another conclusion regarding the null hypothesis.

Nasal Accelerometer

A 2 x 5 analysis of variance for random effects was used to test the hypothetical resonance differences across sample ages and sexes. Table 5 presents the results of the analysis of variance.

Table 5. Summary Table: 2 x 5 ANOVA - Nasal Accelerometer

Source	SS	DF	MS	F
Gender	23.943	1	23.943	.667
Age	103.901	4	25.975	.723
Gender Age	128.066	4	32.016	.891
Error	1435.823	40	35.895	
TOTAL	1691.735	49		

Main Effects: Examination of the table indicated there were no statistically significant differences for gender (F = 4.08, $p > .05$) or for age (F = 2.61, $p > .05$). The data suggested that the measurement of the averaged nasal

vibration (ANV) did not reveal a systematic pattern of differences across either gender or the five age groups.

Interactions: Again there was no statistically significant difference for the interaction of the independent variables between males and females of different ages ($F = 2.61$, $p > .05$).

Table 6 presents the grouped data, including the mean averaged nasal vibration (ANV), standard deviation, and variance of each gender and age group.

Table 6. Mean, Standard Deviation, and Variance of the ANV by Gender and Age Group - Nasal Accelerometer

Gender		50-54	55-59	60-64	65-69	70-74
	$\bar{X}$	9.78	10.72	9.02	9.39	11.80
M	S	4.13	8.68	5.02	4.76	4.69
	S^2	17.05	75.34	25.20	22.65	21.99
	$\bar{X}$	15.68	9.08	8.18	14.01	10.68
F	S	8.29	3.99	1.93	7.80	6.85
	S^2	68.72	15.92	3.72	60.84	46.92

Table 7 presents the mean averaged nasal vibration (ANV) of each of the five age groups.

Table 7. Mean ANV of Each Age Group

	50-54	55-59	60-64	65-69	70-74
ANV	12.73	9.90	8.60	11.71	11.24

After examining the grouped data, a t-test of independent means was used to compare the mean ANV of the male and female 65-69 year-old age group. Graphing of the group ANV's revealed a possible interaction; however, the computed t test indicated there was no statistical significance between the two most disparate means (t computed = 1.331; t tabled, two tailed = 2.010, $p > .05$).

Based upon the statistical analysis it was concluded that there was no systematic pattern of ANV differences across either gender or age groups. The results indicated that although the nasal accelerometer may be a viable estimate of nasal vibration during connected speech, the ANV's as currently calculated did not reveal systematic differences in the variables studied. Because of this finding, the null hypothesis that the nasal accelerometer revealed no resonance changes according to age and gender was accepted.

In an effort to examine the impact of small sample sizes upon the analysis of variance, both the TONAR II and nasal accelerometer data were collapsed to perform 2 x 3 analysis of variance procedures. Consequently, each age group was increased from ten to twenty scores per cell. Tables 8 and 9 present the summary table of each 2 x 3 analysis of variance.

Table 8. Summary Table: 2 x 3 ANOVA - TONAR II

Source	SS	DF	MS	F
Gender	1.512	1	1.512	.035
Age	7.275	2	3.637	.085
Gender Age	34.974	2	17.487	.410
Error	1873.699	44	42.584	

Table 9. Summary Table: 2 x 3 ANOVA - Nasal Accelerometer

Source	SS	DF	MS	F
Gender	10.512	1	10.512	.283
Age	12.642	2	6.321	.170
Gender Age	24.600	2	12.300	.331
Error	1632.557	44	37.103	

Observation of the summary tables demonstrated that even though cell sizes were increased by the 2 x 3 design, in either instances the F ratios were low. Since the 2 x 3 configuration was exploratory, the tabled F values were not reported; however, it was noted that the actual tabled values for any variable or factor were not statistically significant ($p > .05$).

Correlations

The question that remained to be answered dealt with the potential correlation between the TONAR II nasalance and nasal vibration (ANV). A Pearson Product Moment correlation coefficient was computed on the basis of the 50 paired scores. The resulting positive, low correlation coefficient was $r = +.319$. Examination of the r revealed a statistically significant correlation between the instruments (r-tabled = +.273, df = 48, $p < .05$). The low correlation coefficient may suggest a relationship between the scores of the two instruments; however, the coefficient of determination derived from the r^2 was +.101. With only ten percent of the variance of one set of scores accounted for by the second set of scores, the likelihood of clinical significance was not high for the comparative use of the two instruments.

Additional correlations were completed comparing the scores of each gender to both instruments. The scores of the 25 males derived from each instrument produced a Pearson Product Moment correlation coefficient of +.187. It was not a statistically significant finding (r-tabled = +.396, $p > .05$). However, the correlation of the 25 female scores to the two measurements demonstrated a statistically significant relationship. The computed correlation coefficient of +.420 was significant at the .05 level (r-tabled = +.396, $p < .05$). Since causative statements could not be developed from correlational data, the logic of the stronger female relationship cannot be empirically stated. Recognizing that a significant relationship did exist between female scores on

both instruments, the correlation of the males ($r = +.187$) on both measures was compared to the female correlation coefficient ($r = +.420$) by transforming each correlation coefficient into a z-score. Z-scores were derived for each correlation coefficient via Fisher's z transformation (Weinberg and Goldberg, 1977). Comparison of the calculated differences between the transformed correlation coefficients revealed a z-score of -.82. Analysis of the z-score indicated there was no statistically significant difference between the two correlations (z-tabled = .293; $p > .05$).

Although no research hypothesis was set forth to test for such male and female correlations, the correlation coefficient comparing the female scores on each instrument was interesting. Several possible reasons for the relationship in the male-female correlations were explored. Those relationships relate specifically to the upcoming section and will be addressed in the discussion.

Discussion

TONAR: In their study Hutchinson, Robinson, and Nerbonne (1978) reported the general finding that "where relatively continuous demands for velopharyngeal closure are required, gerontologic subjects exhibit notably less competence than normal younger adults" (p. 476). This finding was based upon not only the nasalance scores of 60 older adults but also the graphic analysis of velopharyngeal activity. The authors based their conclusions on a ratio score and upon the "tonagram" patterns which provided

quantitative analysis of velopharyngeal functioning. The present study was designed to measure the possibility of vocal resonance changes which might occur with the increasing chronological age of male or female speakers. Statistical analysis of the TONAR II nasalance scores compiled from the performance of 25 males and 25 females suggested that the quantitative measurement of nasalance does not change with increased chronological age. No difference between males and females was reported.

Although Hutchinson et al. (1978) found that the velopharyngeal competence of older adults was different from that of younger adults, there was no discussion of any audible resonance changes within their sample. The results of the present study would suggest that based upon the TONAR II nasalance ratio, the audible perception of nasality remained relatively stable as chronological age increased or at least consistent with the norm data. Nasalance scores did not vary significantly across the 25-year age difference in the sample studied herein. In fact, the average nasalance score of the sample, male and female scores included, was 8.82 percent. A nasalance score of 8.82 percent falls well within Fletcher's (1970) norms indicating "normal" nasalance. Certainly some scores in the sample were above or below the "normal" level, but such differences can be expected to vary within the normal population.

Vocal resonance then, as judged by TONAR II, remained consistent and unchanged in older males and females, at least for the type of sample participating in this study.

Possibly, it was the type of sample selected which may have eventually affected the outcome of the study. Participants in the study were primarily well-educated, retired professionals in good general health. Perhaps the level of education of the subjects paired with good health histories, adequate group health insurance coverage, and access to diverse medical services predisposed the results of the study to an unusually high level. Many of the subjects were retired university professors who were not only socially active and reliant on verbal skills but also cognizant of their individual speech and voice characteristics. Had the sample been from a group of older adults living in congregate housing, for example, the results may have been different. That is, of course, only speculative.

It was also plausible that the results may have been biased due to the sample size studied. Perhaps the performance of 50 subjects was not a sample of adequate size to infer conclusions about the geriatric population as a whole.

Hutchinson et al. (1978) stated that without further physiologic research "it is difficult to ascertain the influence of aging on intersex differences in velopharyngeal function" (p. 479). The present study adds empirical support to that contention; that is, resonance changes may be signaled by abnormal nasalance scores; but the analysis of velopharyngeal function in older adults requires research methodology which treats nasality as a diverse, multifaceted entity rather than a single score. The single score classification is advantageous, indeed; but the relationship between articulation, auditory perception, and neuromuscular movements is complex and requires more than one form of measurement before nasality can be identified. Pairing a sound pressure level measurement with a nasal airflow measurement may be a possible option, but the measures should be considered separately before a discussion on vocal resonance and the patency of the velopharyngeal port can be determined.

Resonance differences between the males and females were not statistically evident in the present study; however, such differences may not have been discovered for the same reasons that age-related resonance changes were not found. Again, the need for a physiologic measure would be helpful. McKearns and Bzoch (1970) found that females utilized patterns of velopharyngeal closure that were different from male closure patterns. Their results were based on cineradiographic analysis. Although the present study does not refute the McKearns and Bzoch (1970) finding, there was evidence that even though the velopharyngeal closure pattern of males and females may be different, females in the study demonstrated nasalance scores similar to their male counterparts. Although the velopharyngeal closure patterns may not be alike, the nasalance ratings of both groups were similar. The relationship suggests that vocal and nasal resonance of males and females remains fairly constant, even with nasal couplings which may be achieved by different patterns of velopharyngeal closure.

Nasal Accelerometer: The present study exemplifies the value of the nasal accelerometer as at least an estimate of nasal vibration; and as such, it may be a useful assessment tool if properly modified. Proper placement of the nasal accelerometer allowed for relatively comfortable, noninvasive assessment of nasal tissue vibration. Computation of the ANV was not necessarily the most accurate index of quantitative measurement, however. To clarify, the method employed in the present study sampled ten segments from five utterances. During the experiment it became apparent that the maximum peak to peak excursion of the oscilloscopic tracing often occurred at the onset of the utterance. At that point, subglottal air pressure was higher, vocal intensity was elevated accordingly, and the onset of phonation contributed to the initial displacement of either naris. It was conceivable that these three factors either singly, or in combination, could have artificially increased the normal rate of nasal vibration. As the utterance progressed, the amount of nasal vibration apparent in the oscilloscopic tracing decreased.

Calculation of the ANV may be better achieved if more trials were incorporated into the averaging process. If, for example, the speech stimuli required a sample of continuous speech and the accelerometer was coupled with a measurement device capable of rapid voltage estimates or transformations every three seconds for a five minute period, 100 measurements could be averaged. Such a system would provide

a large enough pool of results to counteract the effects of the three vocal parameters previously mentioned.

Other recording artifacts should be cautiously controlled whenever nasal accelerometers are used to measure nasal airflow. Extraneous movement of the subject should be deliberately controlled, since unnecessary movements of the body, including the face, will register on the oscillographic tracing.

A practical consideration also deserves mention -- eye glasses should not be worn. It seems that the weight of the frames can reduce the motility of the nares. Also, the double-sided adhesives used to secure accelerometers in position could stick to the nasal contact of the eye glass frame and suppress the output vibration.

If those artifacts were better controlled, perhaps more reliable estimates of nasal vibration could be obtained. The nasal accelerometer undeniably measures nasal tissue vibration, but to reference the derived vibration to any norm has yet to be established. In the sample studied the mean ANV for 50 subjects was 10.83. Since normative voltage data were not available at the time the study was conducted, the mean ANV could at least be used as an elementary reference.

As encountered in the TONAR II data, the results of the nasal accelerometers did not reveal any systematic differences in nasal vibration as chronological age increased or between males and females. It would appear that in the sample studied, nasal airflow remained constant with increased age.

An interesting pattern appeared during the nasal accelerometer experiment. In nearly every subject, especially the males, there was one naris that evidenced greater peak-to-peak wave excursion. In other words, the path of the nasal airflow seemed to be toward a dominant side of the nasal cavity, or one naris was more vibrant than its counterpart. Although proper placement of the accelerometers was cautiously observed, most subjects' oscillographic tracings displayed larger voltage levels in one of the nostrils. This peculiarity was consistent in speakers with "normal" nasal passages, as well as individuals with histories that included fractured noses or septal deviations.

Finally, like the nasalance results of TONAR II, the ANV data analysis may have been affected by the overall health characteristics of the participants or by the size of the sample studied.

Comparison of TONAR II and the Nasal Accelerometer: The correlation coefficient comparing the scores of both instruments revealed a low, but positive, relationship ($r = +.319$). The low correlation would suggest that clinical evaluation of nasality might be accommodated using both instruments with careful deliberation of the combined results. Each instrument explicitly measured a distinct characteristic: sound pressure level or rate of nasal vibration. Descriptive classification and quantitative assessment of the "nasality construct" might eventually be accomplished using both measures; however, since reliability data such as that provided by Fletcher (1970) were not available, the nasal accelerometer should be used only in contrast to other assessment procedures, including psychophysical scaling techniques.

Several operative considerations pertaining to the combined use of TONAR II and the nasal accelerometer should be identified. First and probably the most practical is the fact that at this time TONAR II is no longer commercially available for purchase. Because of factors such as calibration maintenance, cost, and technological advances outdating its electronic capabilities, the commercial production of TONAR II ended. TONAR II has been reliably used as a sound pressure level measurement device; however, because it cannot be purchased at the present time, the nasal accelerometer might provide a possible alternative form of nasality measurement.

TONAR II and the nasal accelerometer do not correlate highly, but since they both measure inherently different characteristics, it would be reasonable to expect little functional relationship between the two. As a measure of nasal airflow, the nasal accelerometer could, if accurate methodology is developed, fulfill the quantitative assessment needs of the practicing clinician. The nasal accelerometer is an unequivocal measure of nasal vibration, but the relationship between nasal vibration and velopharyngeal function needs to be approached and clarified. Theoretical questions regarding velopharyngeal function, nasal airflow, and vocal resonance can be posed and studied further. The nasal accelerometer then can be viewed as a relatively inexpensive instrument that provides an uncomplicated analysis of the physical vibration of nasal tissue. The importance of the subsequent tissue vibration needs to be better defined and documented before the complexities of velopharyngeal function can be fully understood.

Among the theoretical questions to be posed is the question of instrumental validity. The basic question pertains to the value of nasal tissue vibration as a measure of nasal airflow. Informal observation of the 50 older adults suggests that of the two nares, one was usually more vibrant than the other. Coincidentally, the correlations of gender versus instrument indicated that males obtained a lower gender:instrument relationship. In fact, six subjects or 24 percent of the males reported histories which included fractured noses, deviated septums, or "skin problems." It seems reasonable to suspect that such histories might affect the motility of the nasal tissue on either or both sides of the nose.

Because of this male feature pertinent only to this sample of 50 adults, the question of nasal vibration differences between males and females arises again. Possibly studying a larger sample of older adults or a controlled comparison study contrasting younger subjects with older individuals might provide information regarding the general sensitivity of nasal tissue to airflow passing through the nose.

Finally, a more fundamental aspect of velopharyngeal function should be addressed. In the presence of abnormal nasal resonance the variation of nasal vibration has not been qualified. In effect, nasal vibration during hypernasal speech, for example, may not be an objective indicator of inappropriate nasal resonance. This relationship needs to be explored.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The general population in the United States continues to increase in size and in life expectancy. Advancements in medical care, better control of infectious diseases, and improved lifestyles are only a few of the major changes that have precipitated the extended life expectancy in this country (Atchley, 1980). As the general population increases in number and in age, the need for age-appropriate applied research also increases (Mueller and Peters, 1981; Cape, 1978; and Kart and Manard, 1976).

The present study was designed to contribute to the need for applied research, in particular to provide the empirical analysis of the vocal resonance characteristics of older adults. The analysis of the vocal resonance charactristics was based upon the bioelectronic computation of sound level pressure differences known as nasalance and the averaged nasal voltage attributable to nasal vibration instigated by sound or airflow passing through the nasal cavities.

In the study 50 adults between the ages of 50 and 75 years were matched according to gender and age group. Potential subjects were screened to reduce the influences of such confounding factors as palatal cleft, motor speech deficit, cognitive or language disorders, structural anomaly, or hearing impairment. Following informal eligibility procedures, each subject passed an audiological screening at the frequencies of 25 dB HTL at the frequencies of 500, 1000, and 2000 Hz (re: ANSI, 1969) in at least one ear.

Acceptable subjects were then required to complete two experiments. First, each subject read "The Zoo Passage" (Fletcher, 1970), a short, nonsense paragraph into a quantitative, bioelectronic instrument known as TONAR II. A nasalance ratio was derived from the reading. Next, vibration transducers known as nasal accelerometers were attached simultaneously on each side of the nose. Accelerometer placement was consistent throughout the study. Each subject was requried to read five short sentences which contained no nasal consonants. The maximum peak to peak excursion of the left and right accelerometers was recorded from an oscilloscopic tracing. Each measurement was multiplied by a voltage constant to provide a total vibratory voltage. Each of the five voltages was used to compute the averaged nasal voltage (ANV) of each subject.

The procedures allowed the comparison of nasalance scores and voltage scores for the sample. Each set of scores was incorporated into a 2 x 5 analysis of variance. A Pearson Product Moment correlation was used to compare the scores of the TONAR II and the nasal accelerometer.

The results of the analyses of variance indicated that based on the nasalance scores of TONAR II, the ratio of nasal sound pressure level to the sum of oral and nasal sound pressure levels remained relatively constant as chronological age increased. Also, there was no significant difference between the nasalance scores of males and females and no significant interactions for the combined effects of chronological age and gender were reported.

Hutchinson, Robinson, and Nerbonne (1978) reported that as chronological age increased, gerontologic subjects generally demonstrated "less competence" than younger adults on activities requiring continuous velopharyngeal closure. Although that finding was not challenged by the results of the present study, it was apparent that velopharyngeal performance during connected speech maintained sufficient velopharyngeal closure to preserve "normal" levels of nasalance.

Analysis of the ANV derived from the nasal accelerometers revealed findings similar to those of TONAR II nasalance scores. The analysis of variance indicated that as chronological age increased, vibration of the nasal tissue remained fairly constant across the five age groups. Variation between males and females was not statistically significant, although for a number of reasons the sample selection may have predisposed the female scores to be slightly higher. It is important to note that the male-female ANV dichotomy has not been confirmed; it is only conjecture based on the informal observation of the investigator.

Finally, comparison of the two instruments revealed a significant low, positive correlation coefficient. Since each instrument measures different physical properties, the subsequent low relationship between instruments was not unexpected. Since TONAR II has been used as a reliable estimate of nasalance, it can be so used in the future. However, clinical and experimental use of the nasal accelerometer has been limited, at least to date. Studies of the influence of nasal vibration during connected speech, nasal airflow variations correlated to psychophysical scaling techniques, and establishment of normative data need to be performed before the nasal accelerometer can begin to be used as a quantitative measure of nasality. The relationship between velopharyngeal function and the consequent nasal vibration is not yet clearly defined.

Conclusions

Based on the scores provided by the TONAR II nasal accelerometer, the following conclusions are set forth:

1. Vocal resonance as measured by sound pressure level variations and nasal tissue vibration does not vary systematically as chronological age increases.

2. Vocal resonance of males and females during connected speech remains consistent.

3. The nasal accelerometer can be used as a relatively uncomplicated measure of nasal tissue vibration; however, there is not yet a body of statistical support to warrant its use as an indicator of velopharyngeal closure or patency.

Recommendations

Based on the findings of the present study, and recognizing the limitations of the study, the following recommendations for future research are proposed:

1. A study or studies should be conducted to determine the relationship between nasal tissue vibration, vocal resonance, and/or nasal resonance.

2. A study or studies should be conducted which attempt to determine the average nasal vibration of all age groups ranging from childhood to the aged.

3. A study should be performed in which the results of the nasal accelerometer are compared to the perceptual nasality ratings of both trained and unsophisticated listeners.

4. Studies designed to develop methodology to determine more accurate estimates of the ANV should be completed.

5. A study comparing "abnormal" nasalance scores to the nasal tissue vibration should be conducted in an attempt to qualify the relationship between nasal vibration, nasality, and nasalance.

APPENDICES

APPENDIX A

RAW DATA - MALE SUBJECTS

Age Group	Subject	Age	Nasalance %	ANV
50 - 54	D. M.	51	9	8.8
	G. M.	53	7	4.5
	G. M.	51	10	16.0
	J. S.	50	20	10.4
	B. W.	54	11	9.2
55 - 59	H. H.	56	4	11.2
	B. D.	58	2	25.4
	R. G.	58	13	3.2
	F. T.	57	3	6.4
	W. W.	59	4	7.4
60 - 64	D. H.	61	4	7.4
	R. R.	64	13	8.3
	B. B.	62	2	6.0
	V. S.	64	8	5.6
	R. S.	62	8	17.8
65 - 69	G. D.	65	3	8.0
	W. J.	68	22	17.8
	C. C.	67	5	7.2
	N. P. R.	67	6	8.0
	L. D.	66	15	6.0
70 - 74	W. H.	71	9	6.2
	J. R.	73	5	8.4
	G. P.	74	15	17.6
	L. B.	74	7	11.6
	R. M.	73	15	15.2

APPENDIX B

RAW DATA - FEMALE SUBJECTS

Age Group	Subject	Age	Nasalance %	ANV
50 - 54	N. D.	52	2	15.2
	E. S.	50	30	28.0
	C. F.	50	5	10.0
	K. B.	52	3	6.6
	J. H.	51	3	18.6
55 - 59	M. D.	57	10	5.8
	M. U.	57	13	5.6
	E. E.	58	13	12.2
	J. V.	59	7	7.4
	B. S.	57	16	14.4
60 - 64	L. B.	60	7	10.3
	E. H.	64	5	9.5
	L. L.	63	6	7.2
	L. J.	62	4	8.5
	A. D.	63	8	5.4
65 - 69	F. R.	67	6	7.2
	D. R.	67	3	17.2
	M. N.	67	14	18.0
	M. M.	66	16	23.1
	M. H.	66	11	4.6
70 - 74	A. G.	72	7	22.5
	D. C.	73	1	8.1
	E. A.	72	23	9.8
	A. L.	70	8	4.8
	F. G.	74	0	8.2

APPENDIX C

STIMULI AND RECORD FORM FOR COLLECTION OF ANV

CH. 1
L

2
R

We'd better buy a bigger dog.

	CM*V/DIV	=	VOLTAGE
LEFT	______		______
RIGHT	______		______
	AVERAGE VOLTAGE		______

CH. 1
L

2
R

It's easy to tell the depth of a well.

	CM*V/DIV	=	VOLTAGE
LEFT	______		______
RIGHT	______		______
	AVERAGE VOLTAGE		______

CH. 1
L

2
R

Four hours of steady work faced us.

	CM*V/DIV	=	VOLTAGE
LEFT	______		______
RIGHT	______		______
	AVERAGE VOLTAGE		______

APPENDIX C (cont'd.)

CH. 1
L

2
R

Her purse was full of useless trash.

	CM*V/DIV	=	VOLTAGE
LEFT	______		______
RIGHT	______		______
	AVERAGE VOLTAGE		______

CH. 1
L

2
R

Wipe the grease off his dirty face.

	CM*V/DIV	=	VOLTAGE
LEFT	______		______
RIGHT	______		______
	AVERAGE VOLTAGE		______

	L	+	R		
1.	______	+	______	=	______
2.	______	+	______	=	______
3.	______	+	______	=	______
4.	______	+	______	=	______
5.	______	+	______	=	______

/5 = ______ANV

APPENDIX D

STIMULUS AND RECORD FORM FOR COLLECTION OF NASALANCE DATA

Subject Name:____________________________

Subject No.:___________

ZOO PASSAGE

Look at this book with us. It's a story about a zoo. That is where bears go. Today it's very cold out of doors. But we see a cloud overhead that's a pretty, white, fluffy shape. We hear that straw covers the floor of cages to keep the chill away; yet a deer walks through the trees with her head high. They feed seeds to birds so they're able to fly.

TONAR:

Separation test: (.1 sec.) _______%

Zoo Passage: (10.0 sec.) _______%

Classification:
(check one)

hypo___ normal___ mild___ moderate___ severe___ very severe__

APPENDIX E

Frequency Distribution: Grouped Data - TONAR II

Score	F	CF	P	CP
0 - 1	4	4	.08	.08
2 - 3	9	13	.18	.26
4 - 5	7	20	.14	.40
6 - 7	9	29	.18	.58
8 - 9	4	33	.08	.66
10 - 11	2	35	.04	.70
12 - 13	5	40	.10	.80
14 - 15	5	45	.10	.90
16 - 17	0	45	.00	.90
18 - 19	1	46	.02	.92
20 - 21	1	47	.02	.94
22 - 23	1	48	.02	.96
24 - 25	0	48	.00	.96
26 - 27	0	48	.00	.96
28 - 29	1	49	.02	.98

APPENDIX F

Frequency Distribution: Grouped Data - Nasal Accelerometer

Score	F	CF	P	CP
3 - 4	4	4	.08	.08
5 - 6	9	13	.18	.26
7 - 8	14	27	.28	.54
9 - 10	6	33	.12	.66
11 - 12	3	36	.06	.72
13 - 14	1	37	.02	.74
15 - 16	3	40	.06	.80
17 - 18	6	46	.12	.92
19 - 20	0	46	.00	.92
21 - 22	1	47	.02	.94
23 - 24	1	48	.02	.96
25 - 26	1	49	.02	.98
27 - 28	1	50	.02	1.00

APPENDIX G

Mean Percent Nasality Scores: Normative Data - "Zoo Passage" (Fletcher, 1970)

Nasality	Percent
HYPONASAL	
normal	< 5
mild	5 - 15
HYPERNASAL	
moderate	31 - 45
severe	46 - 60
very severe	61 - 75

LIST OF REFERENCES

LIST OF REFERENCES

Atchley, R. C. The Social Forces in Later Life. (3rd ed.). Belmont, California: Wadsworth, Inc., 1972.

Azzan, N. A., and Kuehn, D. P. The morphology of the musculus uvulae. Cleft Palate Journal, 1977, 14, 78-87.

Bjork, L. Velopharyngeal function in connected speech. Acta Radiologica, Supplementum 202, 1961.

Black, J. W. The pressure component in the production of consonants. Journal of Speech and Hearing Disorders, 1950, 15, 207.

Boone, D. R. The Voice and Voice Disorders. (2nd ed.). Englewood Cliffs: Prentice-Hall, 1977.

Cape, R. Aging: Its Complex Management. Hagerstown: Harper & Row, 1978.

Carrell, J. A cinefluorographic technique for the study of velopharyngeal closure. Journal of Speech and Hearing Disorders, 1952, 17, 224-228.

Chaco, J., and Yules, R. B. Velopharyngeal incompetence post tonselloadenoidectomy. Acta-Otolaryngologica, 1969, 68, 276-278.

Colyar, T. C., and Christensen, J. M. Nasalance patterns in esophageal speech. Journal of Communication Disorders, 1980, 13, 43-48.

Counihan, D. T. Oral and nasal airflow and air pressure measures. In K. R. Bzoch (Ed.), Communicative Disorders Related to Cleft Lip and Palate. Boston: Little, Brown & Co., 1971.

Counihan, D. T. Oral and nasal sound pressure measures. In K. R. Bzoch (Ed.), Communicative Disorders Related to Cleft Lip and Palate. Boston: Little, Brown & Co., 1971.

Counihan, D. T., and Pierce, B. R. Measurement of cleft palate nasality. Final Report, Research Grant No. NB 04216-02, University of Oklahoma Medical Center, 1965.

Croft, C. B., Shprintzen, R. J., and Daniller, A. The occult submucous cleft palate and the musculus uvulae, Cleft Palate Journal, 1978, 15, 150-154.

Daly, D. A. Bioelectronic measurement of nasality in trainable mentally retarded children. Journal of Speech and Hearing Disorders, 1977, 42, 436-439.

Daly, D. A., and Johnson, H. P. Instrumental modification of hypernasal voice quality in retarded children: Case reports. Journal of Speech and Hearing Disorders, 1974, 39, 500-507.

Ferreri, G. Senescence of the larynx. Italian General Review of Oto-Rhino-Laryngology, 1959, 1, 640-709.

Fletcher, S. G. Theory and instrumentation for quantitative measurement of nasality. Cleft Palate Journal, 1970, 7, 601-609.

Fletcher, S. G. Contingencies for bioelectronic modification on nasality. Journal of Speech and Hearing Disorders, 1972, 37, 329-346.

Fletcher, S. G. "Nasalance" vs. listener judgment of nasality. Cleft Palate Journal, 1976, 13, 31-44.

Fletcher, S. G. Diagnosing Speech Disorders from Cleft Palate. New York: Grune & Stratton, Inc., 1978.

Fletcher, S. G., and Bishop, M. E. Measurement of nasality with TONAR. Cleft Palate Journal, 1970, 1, 610-621.

Fletcher, S. G., and Daly, D. Nasalance in utterances of hearing impaired speakers. Journal of Communication Disorders, 1976, 9, 63-73.

Fletcher, S. G., and Higgins, J. M. Performance of children with severe to profound auditory impairment in instrumentally guided reduction of nasal resonance. Journal of Speech and Hearing Disorders, 1980, 45, 181-194.

Hess, D., and McDonald, E. T. Consonantal nasal pressure in cleft palate speakers. Journal of Speech and Hearing Research, 1960, 3, 201.

Hirano, M., Takeuchi, Y., and Hiroto, I. Intranasal sound pressure during utterance of speech sounds. Folia Phoniatricia, 1966, 18, 218.

Horii, Y. An accelerometric approach to nasality measurement: A preliminary report. Cleft Palate Journal, 1980, 17, 254-261.

Hutchinson, J. M., Robinson, K. L., and Nerbonne, M. A. Patterns of nasalance in a sample of normal gerontologic subjects. Journal of Communication Disorders, 1978, 11, 469-481.

Kantner, C. E. Diagnosis and prognosis in cleft palate speech. Journal of Speech and Hearing Disorders, 1948, 13, 211.

Kart, C. S., and Manard, B. B. Aging in America. Sherman Oaks: Alfred Publishing Co., 1976.

Kelleher, R. E., Webster, R. C., Coffey, R. J., and Quigley, L. Nasal and oral air flow in normal and cleft palate speech; velocity and volume studies using warm wire meter and two channel recorder. Cleft Palate Bulletin, 1960, 10, 66.

Kiuchi, S., Sasaki, J., Arai, T., and Suzuki, T. Functional disorders of the pharynx and esophagus. Acta Oto-Laryngologica, 1969, Supplementum 256.

Lippmann, R. P. Detecting nasalization using a low-cost miniature accelerometer. Journal of Speech and Hearing Research, 1981, 24, 314-317.

Lubker, J. F., and Moll, K. L. Simultaneous oral-nasal airflow measurements and cinefluorographic observations during speech production. Cleft Palate Journal, 1965, 2, 257-272.

Masland, M. W. Testing and correcting cleft palate speech. Journal of Speech Disorders, 1946, 11, 309-320.

McKearns, D., and Bzoch, K. R. Variations in velopharyngeal valving: The factor of sex. Cleft Palate Journal, 1970, 7, 652-662.

Moll, K. L. Cinefluorographic techniques in speech research. Journal of Speech and Hearing Research, 1960, 3, 227-241.

Moll, K. L. Velopharyngeal closure on vowels. Journal of Speech and Hearing Research, 1962, 5, 30-37.

Moore, G. P. Organic Voice Disorders. Englewood Cliffs: Prentice-Hall, Inc., 1971.

Mueller, P. B., and Peters, T. J. Needs and services in geriatric speech-language pathology and audiology. ASHA, 1981, 23, 627-632.

Newby, H. A. Audiology. (3rd ed.). Englewood Cliffs: Prentice-Hall, 1972.

Nicolosi, L., Harryman, E., and Kresheck, J. Terminology of Communication Disorders: Speech-Language-Hearing. Baltimore: Williams & Wilkins Co., 1978.

Pigott, R. W. The nasendoscopic appearance of the normal velopharyngeal mechanism. Plastic Reconstructive Surgery, 1969, 43, 19-24.

Pigott, R. W., Bensen, J. F., and White, F. D. Nasendoscopy in the diagnosis of velopharyngeal incompetency. Plastic Reconstructive Surgery, 1969, 43, 141-147.

Powers, G. R. Cinefluorographic investigation of articulatory movements of selected individuals with cleft palates. Journal of Speech and Hearing Research, 1962, 5, 59-69.

Shelton, R. L., Knox, A. W., Arndt, W. B., and Elbert, M. The relationship between nasality score values and oral and nasal sound pressure level. Journal of Speech and Hearing Research, 1967, 10, 549-557.

Sherman, D. The merits of backward playing of connected speech in the scaling of voice quality disorders. Journal of Speech and Hearing Disorders, 1054, 19, 312-321.

Spriestersbach, D. C., and Powers, G. R. Articulation skills, velopharyngeal closure, and oral breath pressure of children with cleft palate. Journal of Speech and Hearing Research, 1959, 2, 318-325.

Stevens, K. N., Nickerson, R. S., Boothroyd, A., and Rollins, A. M. Assessment of nasalization in the speech of deaf children. Journal of Speech and Hearing Research, 1976, 19, 393-416.

Stevens, K. N., Kalikow, D. N., and Willemain, T. R. A miniature accelerometer for detecting glottal waveforms and nasalization. Journal of Speech and Hearing Research, 1975, 18, 594-599.

Warren, D. W., and DuBois, A. B. A pressure-flow technique for measuring velopharyngeal orifice area during continuous speech. Cleft Palate Journal, 1964, 1, 52-71.

Weinberg, S., and Goldberg, K. Basic Statistics for Education and the Behavioral Sciences. Boston: Houghton Mifflin, 1977.

Zaino, C., and Benventano, T. C. Functional, involutional and degenerative disorders. In Zaino, C., and Benventano, T. C. (Eds.), Radiologic Examination of the Oropharynx and Esophagus. New York: Springer-Verlag, 1977.

BIBLIOGRAPHY

BIBLIOGRAPHY

Aronson, A. E. Clinical Voice Disorders An Interdisciplinary Approach. New York: Thieme-Stratton, Inc., 1980.

Borg, W. R., and Gall, M. D. Educational Research. (3rd ed.). New York: Longman, Inc., 1979.

Greene, M. C. L. The Voice and Its Disorders. Kent, England: Pitman Medical Publishing, 1972.

Huntsberger, D. V., and Billingsley, P. Elements of Statistical Inference. (5th ed.). Boston: Allyn and Bacon, Inc., 1981.

Linton, M., and Gallo, P. S. The Practical Statistician: Simplified Handbook of Statistics. Monterey, Calif.: Brooks/Cole Publishing Co., 1975.

Oyer, H. J., and Oyer, E. J. (Ed.). Aging and Communication. Baltimore: University Park Press, 1976.

Schow, R. L., Christenson, J. M., Hutchinson, J. M., and Nerbonne, M. A. Communication Disorders of the Aged. Baltimore: University Park Press, 1978.

Winer, B. J. Statistical Principles in Experimental Design. (2nd ed.). New York: McGraw-Hill, 1962.