This dissertation has been microfilmed exactly as received 64-3046

BRYAN, George Albert, 1929-

RELATIONSHIPS AMONG NASAL AND "ORAL" SOUND PRESSURES AND RATINGS OF NASALITY IN CLEFT PALATE SPEECH.

The University of Oklahoma, Ph.D., 1963
Speech-Theater

University Microfilms, Inc., Ann Arbor, Michigan

THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

RELATIONSHIPS AMONG NASAL AND "ORAL" SOUND PRESSURES AND RATINGS OF NASALITY IN CLEFT PALATE SPEECH

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

GEORGE ALBERT BRYAN

Oklahoma City, Oklahoma

1963

RELATIONSHIPS AMONG NASAL AND "ORAL" SOUND PRESSURES AND RATINGS OF NASALITY IN CLEFT PALATE SPEECH

APPROVED BY

Donald T. Counihan

John W. Keys

Howard B. Kuhn

Kenneth K. Faulkner

Bruce R. Pierce

DISSERTATION COMMITTEE

ACKNOWLEDGMENT

The writer is deeply grateful to Dr. Donald T. Counihan, the director of this research, for his fine counsel and guidance in the planning and completion of this project; to the members of the dissertation committee, Dr. John W. Keys, Dr. Howard B. Ruhm, and Dr. William W. Schottstaedt, for their helpful suggestions and encouragement; to Dr. Bruce R. Pierce for his helpful advice and assistance in the instrumentation and criticism in the writing; to Dr. Floyd W. Emanuel for his participation in judging the speech samples; and to Dr. Edward N. Brandt and Mr. Robert Armstrong for their assistance in the statistical treatment of the experimental data.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table		Page

LIST OF ILLUSTRATIONS

RELATIONSHIPS AMONG NASAL AND "ORAL" SOUND PRESSURES
AND RATINGS OF NASALITY IN CLEFT PALATE SPEECH

CHAPTER I

INTRODUCTION

Nasality, a defective voice quality which in lay terminology is "talking through the nose", has engaged the attention of speech scientists for many years. Most of them (1, 42, 33) agree that this voice quality results from the influence of the nasal cavities upon the speech signal and that the nasal cavities exert this influence because of a malfunctioning velum.

In normal speech, the production of the nasal consonants [m], [n], and [ŋ] is characterized by considerable nasal resonance. In addition, other sounds in normal speech involve certain amounts of nasal resonance, the limits of which are set largely by cultural preferences. For example, vowel sounds, which are resonated primarily in the oral cavity, are also characterized by varying amounts of nasal resonance (51). However, if the velum does not function adequately in closing the nasopharyngeal port, an excessive amount of nasal resonance may occur, producing the voice quality known as nasality. While it is generally agreed that the nasal cavities play an important role in nasality, the precise nature of their influence is not known. Some researchers (13, 46, 52, 6, 36) have reported complex differences in the frequency components of the speech signal in nasal speech. Others (51) have reported differences in the relationship of nasal sound intensity to the intensity of the total speech signal.

Nasality is generally classified into two types, "functional" and "organic", depending on the condition of the velum. That is, the term "functional" refers to nasality that results from inadequate use of a normal velum, while the term "organic" refers to nasality that results from dysfunction of a defective velum. Various organic conditions of the velum that may cause its dysfunction include paralysis of a velum of normal length, insufficient length of a velum of normal mobility, and a repaired cleft velum that is short and immobile.

The cleft palate condition is one of the most common causes of organic nasality. This condition, which is estimated to occur once in every 700 live births in this country (24), results from a growth disturbance which prevents the union of the maxillary and median nasal processes <u>in utero</u>. The condition is characterized by a direct communication between the oral and nasal cavities, and it has, therefore, a significant effect upon speech. After surgical repair of the palate, some cleft palate persons have an acceptable resonance balance. However, in many post-operative cases, the velum may be inadequate for speech purposes due to its shortness and/or immobility. In other cases, the velum may be adequate for some time after surgery, but eventually becomes inadequate to close the nasopharyngeal port. That is, as the nasopharyngeal port enlarges, due to development of the face and the atrophy of adenoid tissue in the nasopharynx, the velum must traverse a greater distance to contact the posterior pharyngeal wall. A velum that achieves a tenuous closure after primary repair may be unable to meet this greater demand placed upon it, and nasality may result. The problem in such cases may range from a minor unpleasantness of voice quality to a major resonance distortion which reduces intelligibility.

The nature of the cleft palate problem makes accurate speech diagnosis and evaluation of therapy imperative, and each of these is dependent upon reliable judgments of nasality. Since nasality is held to result from inadequate velar valving, surgical and/or prosthetic procedures are often employed to improve velopharyngeal closure. Accurate ratings of nasality not only help determine the need for such procedures, but also facilitate evaluation of their efficacy in reducing nasality.

In both clinical and research situations, great dependence has been placed upon subjective judgments of the presence and severity of nasality. While subjective ratings of nasality made by trained and experienced judges have been reported to be valid (56), these ratings have certain limitations. First, several researchers (56, 53) have observed that ratings of nasality may be affected by other defective voice qualities or by misarticulations present in the speech of the subject. Second, subjective ratings of nasality are usually made by means of rating scales consisting of equal-appearing intervals, and such scales do not permit a refined quantification of nasality. Third, since subjective ratings are based on perceived nasality, they do not permit investigation of the fundamental physical events that contribute to its perception.

Realizing the limitations of subjective ratings, researchers have become increasingly concerned with objective measurement of correlates of nasality. In recent years, the development of new instruments has allowed more refined physical measurements to be made. The probe-tube microphone assembly, employed by Weiss (64), is an example of such instrumentation. This assembly permits sampling and measurement of the sound pressure within the nasal cavity which may be compared with the measurement of the total sound pressure of the speech signal. Although this technique was used by Weiss to study the relationship between nasal and "oral" (total) sound pressures and subjective ratings of functional nasality, it has not been evaluated adequately for use with cleft palate persons. If measures of nasal and "oral" sound pressures correlate highly with subjective ratings of nasality in the speech of cleft palate persons, the probe-tube technique may serve as an objective means of rating nasality in these subjects. This technique would be unaffected by irrelevant factors that may affect listener ratings and could be employed by judges of varying degrees of training and experience. It would permit better quantification of nasality by means of refined measurement of a close correlate of nasality, and could provide insight into the physical events contributing to perceived nasality in cleft palate speech. It was the purpose of the present study, therefore, to investigate the relationships among measures of nasal and "oral" sound pressures and listener ratings of nasality in samples of cleft palate speech.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The subject of nasality has evoked much interest, as indicated by the large amount of literature extant, but the subject continues to be poorly understood. In part, the confusion has resulted from a lack of objective measures of the underlying physical events which contribute to the perception of nasality. While numerous attempts have been made to develop such measures for both clinical and research purposes, the results, for the most part, have been unsatisfactory. Recent advances in instrumentation have enabled researchers to make refined acoustic measurements, permitting investigation of certain underlying physical occurrences that may contribute to the perception of nasality. Some of these techniques have been used successfully to investigate functional nasality, but they have been used little in the study of cleft palate nasality.

As a background to the present study, the reports and findings in the literature will be considered under five major headings: (a) Terminology and Definitions of Nasality, (b) Causes of Nasality, (c) The Nature of Nasality, (d) Nasality and Articulation, and (e) The Measurement of Nasality.

Terminology and Definitions of Nasality

In 1943, Beighley (1) reviewed previous studies of nasality and reported that many writers defined nasality, or "rhinolalia", as ". . . one kind of unpleasant voice quality characterized by too much or too little nasal resonance." This general definition implied that there were two specific types of nasality: "rhinolalia aperta" and "rhinolalia clausa". Rhinolalia aperta was defined as ". . . unpleasant voice quality resulting from too much resonance in nasal cavities that have nothing physically wrong with them." Rhinolalia clausa was defined as ". . . unpleasant voice quality resulting from too little resonance or improper resonance in physically unhealthy, malformed or obstructed nasal cavities." A combination of these resonance distortions was denoted by the term "rhinolalia mixta".

These basic classifications have remained virtually unchanged since Beighley's review; however, some refinements in terminology have been made by writers who sought to be more precise. For example, the terms "positive" and "negative" nasality, used by Drake (17) in 1937 as substitutes for the terms rhinolalia aperta and rhinolalia clausa, respectively, were later used by West, Kennedy, and Carr (66, p. 392) in a more specific sense. They defined "positive" nasality as an excess of nasal resonance during the production of oral sounds, and "negative" nasality as a lack of nasal resonance during the production of nasal sounds. Even though most writers defined rhinolalia aperta as excessive nasal resonance, Froeschels (21) was critical of the term because it implied that any degree of nasality in speech was abnormal. He preferred the terms "hypernasality" and "hyponasality" because they suggested too much or too little of a normal phenomenon. Froeschels' concept in this regard is still widely held, and is expressed by the simpler terms "nasality" and "denasality".

Rhinolalia aperta was further subdivided into two types: "relaxed velum nasality" and "whang nasality" (49). The latter type was noted by Bell (2) as early as 1890 when he spoke of "nasal twang"; however, Raubicheck, Davis, and Carll (49, p. 227), in 1931, distinguished whang nasality from relaxed velum nasality. In both types of resonance, the nasopharyngeal port is considered to be open, allowing excessive nasal resonance to occur. The acoustic result differs, however, according to Cotton (11), due to the relative tension of the speech musculature.

The term "assimilation nasality" was used to refer to the nasalizing of vowels adjacent to nasal consonants (66, p. 398). In this phenomenon, the nasopharyngeal port does not close sufficiently for the vowel that precedes or follows a nasal consonant. In this sense, it is a type of rhinolalia aperta.

The term "cul de sac resonance" was used by Russell (50, p. 42) to refer to resonance in a closed cavity, coupled to the oral tract, as is exemplified by a partially obstructed nasal cavity. Although such resonance distortion in the nasal cavity is due to a closing of the nasal passages, it does not necessarily result in the phenomenon known as "rhinolalia clausa". This resonance distortion may be similar either to rhinolalia aperta or to rhinolalia clausa depending on the site of the nasal obstruction (42, pp. 657-658).

Although some variation in terminology is observed in the literature, substantial agreement exists regarding certain basic facts. Most writers agree that the problem is a resonance phenomenon which may be characterized either by excessive or insufficient nasal resonance. The problem has been denoted in general as "nasality". The terms "rhinolalia aperta", "positive nasality", and "hypernasality" have been used specifically to denote excessive nasal resonance; and the terms "relaxed velum nasality", "whang nasality", and "assimilation nasality" have been used to denote sub-types of excessive nasal resonance. On the other hand, the terms "rhinolalia clausa", "negative nasality", and "hyponasality" have been used specifically to denote insufficient nasal resonance. While some writers have used the term "nasality" to refer in general to a resonance problem due to excessive or insufficient nasal resonance, in the following sections the term will be used specifically to refer to excessive nasal resonance.

Causes of Nasality

The phenomenon of nasality has been attributed to a variety of structural and functional conditions. The chief cause, according to Beighley (1) is velar malfunction. Russell and Cotton (51, p. 115) wrote that ". . . nasality of any kind presupposes that the velum is not closing the passageway leading to the nose."

Many writers (59, 23, 8, 24, 12) have reported that the velum may fail to effect an adequate seal in cleft palate persons because it lacks adequate length and/or mobility. A cleft may be of such size and shape, and the amount of available tissue so deficient, that, when the separated palatal processes are surgically joined, the velum cannot accomplish nasopharyngeal closure. Scarring may contribute further to the shortness and immobility of the velum. Following primary velar repair, the velum, because of its proximity to the base of the skull and the nasopharyngeal lymphoid mass, may be adequate for closure, but as the post-velar space increases with growth, closure may become less effective.

Fletcher (19) indicated that velar closure may be impossible because of irregularities in structures contiguous to the velum, or because of malpositioning of the velum in relation to other cranio-facial structures. For example, he reported deficiencies in the hard palate in which the velum was positioned so far anteriorly and inferiorly that contact with the posterior pharynx was impossible. He also described irregularities in the posterior pharyngeal wall which prevented a velar seal (20).

The degree of velopharyngeal closure necessary for good speech has been subject to debate in the literature. Beighley (1) categorized writers on this matter into four groups: (a) those who say that the velum should close tightly in speech; (b) those who say that velar closure is necessary, without mentioning the tightness of closure; (c) those who say that the velum should be slightly open in vowel and semi-vowel production; and (d) those who say that the nasopharyngeal opening should not exceed a specified amount.

The view that the velum should close the nasopharyngeal port was expressed by Cotton (11), who indicated that ". . . there is a definite 'talking through the nose' quality if the velum does not completely close the nasal passageway." Likewise, Bell (2) stated that nasality results because the soft palate ". . . is never raised enough entirely to cut off some outflow of breath through the nose."

Various researchers have indicated that the velum appears to be open to a certain extent during the production of vowels. Williams (67) measured the size of the nasopharyngeal port on x-ray pictures taken during the production of certain vowels and reported that it was predominantly open for [ɑ] and [æ] and predominantly closed for [u] and [i]. Using a similar technique, Harrington (28) measured the extent of velar elevation during the production of [u] and [ɑ]. He reported a 7.79 millimeter elevation of the velum above the palatal plane in the production of [u], but only a 2.6 millimeter elevation for [ɑ]. Assuming that the extent of velar elevation indicated the degree of velopharyngeal closure, he concluded that the degree of closure is greater for [u] than for [ɑ]. Kelly (36) employed a device that made a graphic recording of nasal resonance in vowels, and Lindsley (38) used a similar device to record nasal emission in vowels. The reports of these investigators indicated that both nasal resonance and nasal emission vary among vowels, depending on the firmness of velopharyngeal closure required. Nusbaum, Foley, and Wells (45) studied the firmness of velar valving by exerting air pressure through the nasal cavities against the superior surface of the velum during the production of various vowels and noting the amount of pressure required to break the seal. They reported that the air pressure required to break the velopharyngeal seal varied among the vowels studied and concluded that the seal is not equally firm for all vowels. They also noted varying amounts of nasal emission during production of the vowels, even though they were normally resonated. They concluded that the nasopharyngeal port is slightly open during vowel production, giving vowel sounds a pleasant quality.

Several writers have indicated that nasality results only when the nasopharyngeal opening reaches a certain size. Dorrance (16, p. 304) reported that Schmidt found no objectionable resonance when a rubber tube, six millimeters in outside diameter, was inserted through the nasal meatus and extended through the nasopharyngeal port. Tubes of larger diameters, however, caused objectionable nasal resonance. Brown (7) contended that nasality would result if the nasopharyngeal opening exceeded one millimeter. Although they did not report their criteria, Haggerty and Hoffmeister (26) claimed that, by measuring the nasopharyngeal opening on lateral x-ray pictures taken during production of the vowel [u], they could predict nasality seventy-five per cent of the time.

Several writers have expressed the view that the size of velar opening that results in nasality varies with the individual. Kantner (34), for example, stated that nasality occurs only when the nasopharyngeal port reaches a certain critical size, which varies from person to person. MacDonald and Koepp-Baker (40) have also suggested that there is a critical point in velar closure which establishes a balance between oral and nasal resonance, and that if this critical point is not reached, nasality will result.

Tongue posture, either as a separate or as an associated cause of nasality, has been studied in both cleft palate and functionally nasal cases. Hixon (30) reported the presence of a high-riding tongue in functionally nasal cases. Fairbanks (18, pp. 203-204) postulated that an elevation of the tongue caused nasality because it restricted oral resonance. Although Kaltenborn (37) did not study tongue height per se, he measured the size of the nasopharyngeal and oropharyngeal openings on x-ray pictures taken during phonation of [æ] in a number of nasal and non-nasal subjects. He reported that the mean sizes of the nasopharyngeal opening and the oropharyngeal opening in his nasal speakers were 8.8 millimeters and 3.1 millimeters, respectively, as compared with one millimeter and eleven millimeters, respectively, for the non-nasal speakers. MacDonald and Koepp-Baker (40) hypothesized that nasality in certain cleft palate cases is caused by persistent elevation of the mandible and tongue, which reduces the size of the opening into the oral cavity and alters oral resonance. Reported studies of tongue posture in cleft palate persons, however, have not consistently borne this out. Buck (9) studied tongue carriage in a sample of cleft palate persons and reported that their vertical tongue position did not differ from normals, except in the production of [æ] and [u] in which the tongue assumed a lower position than is found in normal persons. He also reported that his cleft palate subjects had more forward movement of the tongue than normal subjects in the production of all vowels except [æ]. Graber (23), reporting McKee's results, indicated that cleft palate persons assume a lower than normal tongue position at rest and mass the tongue posteriorly in phonation. He reported that Subtelny found no high-riding tongue, but observed that the tongue was placed too far anteriorly for front vowels and too far posteriorly for back vowels.

The relationship of size of mouth opening and nasality has been of interest to a number of investigators. Cotton (11) held that nasality was associated frequently with "close-mouthed" speech and Kelly (36) reported a direct relationship between nasality and the size of mouth opening during speech. Gray and Wise (25, pp. 22-23) reported "too narrow a mouth opening" along with insufficient velopharyngeal closure as the most common cause of nasality, while Williamson (68) indicated that most of the functional nasality he observed was caused by a high-riding tongue and a narrow mouth opening. Buck (9), however, found no difference between cleft palate and normal subjects in the size of mouth opening. He concluded that ". . . this would tend to disprove the belief that smallness of mouth opening accounts for nasality in cleft palate persons."

Bullen (10) contended that a lack of tension in the lips in the production of labial sounds is an important cause of nasality. She theorized that the velum is largely passive in its movement and that it is regulated in its movement by other structures. She suggested that greater lip pressure should be employed in producing labial consonants to gain better velopharyngeal closure.

In summary, the primary causes of nasality are generally held to be inadequate use of a normal velum or dysfunction of a defective velopharyngeal mechanism, caused by insufficient length and/or mobility of the velum, malposition of the velum in relation to the nasopharyngeal wall, and irregularities of the nasopharyngeal wall. The literature suggests that the effects of inadequate velopharyngeal closure on speech may be increased in certain cases by a restricted oropharyngeal opening due to abnormal tongue position, or by a small mouth opening; that the degree of velopharyngeal closure necessary for good speech production appears to vary with different sounds; and that it may also vary with different speakers depending on the sizes and relationships of the resonating cavities.

The Nature of Nasality

Nasality is an acoustic phenomenon rather than an air flow phenomenon, according to recent investigators. That is, the phenomenon is the vibration of molecules of a sound medium rather than the stream-like movement of that medium. Early writers, for the most part, did not make this distinction. Kantner (35), for example, in listing several causes of nasality, stated that: "One of these causes and perhaps the most common is the escaping of the air stream through the nasal cavity in amounts and at times not typical of normal speech." Bullen (10) wrote that ". . . nasality is due immediately to the passage of air through the nasal cavities." However, MacDonald and Koepp-Baker (40) contended that nasal emission, the nasal escape of air associated with production of plosive and fricative consonants, should be distinguished from nasality, the excessive nasal resonance associated with vowel production. Nusbaum, Foley, and Wells (45) reported that nasal air flow may appear in the absence of excessive nasal resonance. More recently, Benson (3) and Kantner (34) indicated that the amount of nasal emission does not accurately indicate the amount of nasality present in a speaker.

The acoustic characteristics of nasality have been attributed to improper resonance and phonation. Gray and Wise (25, pp. 22-23) indicated that nasality ". . . is caused by improper use of nasal or nasopharyngeal resonance, or by restrictions within the larynx which promote improper resonance or produce an acoustic effect analogous to nasality." Peterson (46) affirmed that "relatively marked effects" on the spectrum of the oral speech signal may be made by coupling a nasal resonator to the vocal system. Russell and Cotton (51, p. 120) contended that in whang nasality, the spectrum is also altered by tensing the pharynx into a narrow tube which attenuates low frequency and accentuates high frequency components of speech. They noted abnormal phonation in cases of extreme whang nasality in which the ventricular bands were forced down on the vocal folds and the free edges of the vocal folds were strongly tensed. They speculated that this laryngeal tension was developed in an effort to talk louder and overcome the power loss caused by nasal resonance.

Researchers investigating the spectra of various kinds of nasal speech by means of the sound spectrograph have reported generally consistent findings. Several researchers (13, 29, 52, 6) have compared the spectra of vowels spoken first with normal resonance and then with simulated nasality. Curtis (13) noted that, in nasalized vowels, the intensity was increased in the area of the first and second partials or the 200-250 cps range, while the intensity of the third and fourth partials was reduced. He indicated that energy concentrations in the high frequencies did not seem to be related to the perception of nasality. In addition to increased intensity around 250 cps in nasalized vowels, Hattori, Yamamoto, and Fujimura (29) specified that there was a reduction of energy around 500 cps and the appearance of diffuse components between the vowel formants, particularly in the 1000-2500 cps range. Sax (52) stated that the spectra of nasalized vowels had broader bands of resonance and that energy was increased along the voice bar and in the 1000-2000 cps range. Bloomer (6) reported that the first formant was lowered in frequency, broadened in frequency range, and increased in intensity. The third formant was raised in frequency and/or weakened in intensity. He stated that the boundaries of the formants were less distinct in nasalized vowels, and that secondary formants appeared.

In speech characterized by assimilation nasality, Curtis (13) indicated that energy in the first three partials centering around 250-270 cps was increased, while energy in the 3200-3300 cps range was reduced and redistributed. Energy in a band extending from 500 cps upward to a variable limit was also reduced. These findings agree generally with the observations described by Peterson (46), Kelly (36), and Potter, Kopp, and Green (48).

By means of a sound spectrograph, Hanson (27) analyzed the speech of cleft palate children. He reported that he was unable to find the reinforcement of low frequency energy that had been reported by previous investigators. Dickson (14), who used the sound spectrograph to study the speech of functionally nasal and cleft palate subjects, did not consistently find the spectrum changes in nasal speech that had been reported by others. However, he reported that some extremely nasal subjects differed markedly in some respects: there was an increase in formant bandwidths; there was an increase or decrease in the intensity of harmonics; there was an increase or decrease in formant frequency; and there was a rise in fundamental frequency. Usually the nasal subjects had several of these acoustic characteristics. Dickson concluded that the acoustic aspects of nasality vary from person to person depending upon the specific configurations of the oral, pharyngeal, and nasal cavities.

Conclusions regarding nasal speech have also been made from studies of the spectra of synthetic speech. Synthetic speech is produced by generating an electrical signal, altering its spectrum with regard to frequency composition and intensity of the constituent frequencies, and then transducing the electrical signal by a loudspeaker. The procedure in such studies is to alter the spectrum of the signal until listeners report that the transduced signal resembles a specific nasal sound. The spectral characteristics of that signal are then observed. House (31) reported that the first formant of synthetic nasal vowels was raised in frequency, increased in bandwidth, and reduced in amplitude as compared with synthetic non-nasal vowels. He speculated that these changes were probably primary cues for the perception of nasality, while less systematic and pronounced changes in the second and third formants were probably secondary cues for the perception of nasality. In nasal consonants, he reported a prominence of low-frequency energy, especially near 1000 cps; however, the over-all intensity of nasal consonants was low as compared with vowels. Nakata (44) reported that nasal consonants were characterized by broadened bands of resonance in the 200-300 cps range, which he postulated were associated with a reduction of the intensity of some of these frequencies. He reported that the width of the first formant and the presence of the second formant were important in the recognition of nasal consonants.

The relative intensity of nasal resonance has also been emphasized as an important factor in the perception of nasality. Although early writers attributed nasality to excessive nasal resonance (1) or insufficient oral resonance (65), Russell and Cotton (51) were apparently the first to postulate that nasality was due to an imbalance of oral and nasal resonance. They measured the intensity of the oral and nasal speech signals during normal production and during nasalized production of vowels. In normal production of [ʌ], [o], [ɑ], and [æ], the nasal signal, averaged across subjects and various pitch levels, was about 30 db less intense than the oral signal. In normal production of [i], the nasal signal was about 17 db less intense than the oral signal. When the velum was relaxed in the production of these vowels, the intensity of nasal resonance increased from 20 db to 30 db, on the average, so that it equalled, and sometimes exceeded, the intensity of the oral signal. Russell and Cotton spoke of this increase in nasal resonance as a power loss in the speech signal due to nasal coupling, and they affirmed that the power loss indicated an inefficient use of the oral resonator.

By means of electric analog devices, House (31) demonstrated that the intensity of nasal resonance does not depend solely on the size of the velopharyngeal port, but also on the acoustic impedance of the nose and mouth. He contended that, if the nasal cavity has high impedance and the oral cavity low impedance, the effect of nasal coupling should be small. With high impedance of the oral cavity and low impedance of the nasal cavity, a patency of the nasopharyngeal port should result in greater nasality. On the basis of analog studies, House indicated that high vowels may be perceived as more nasal than low vowels in that ". . . for a given degree of nasal coupling, the spectrum of [i] will be modified more than that of [u] . . . . [i] and [u] have the highest impedance, [æ] and [ɑ] the lowest, with [ɛ] and [ɔ] in between." He affirmed that a closed nasopharyngeal port is not necessary for the production of all American English vowels.

In summary, nasality is considered to be an acoustic phenomenon characterized by excessive nasal resonance in vowel production. While nasal emission of air, associated with production of fricative and plosive consonants, may occur with nasality in cleft palate speech, the nasal emission does not constitute nasality per se, nor does it indicate the degree of nasality present. The acoustical aspects of nasality have been studied from the standpoints of differences in the spectra due to resonance and/or phonation and of differences in the relative intensity of nasal and oral resonance. The spectra of nasalized speech differ from those of non-nasalized speech, either because of resonance or of phonation. The differences reported by various investigators appear to be generally consistent. These differences seem to occur in nasal speech because energy is shifted from the high frequencies and concentrated in the low frequencies where it is arranged in broad resonant bands of relatively small amplitude, in which the boundaries of the formants become indistinct. Differences in the relative intensity of nasal and oral resonance have also been noted in non-nasalized speech and nasalized speech. Although the intensity of nasal resonance normally varies among the vowels, in nasalized speech the intensity of nasal resonance is increased, creating a nasal-oral resonance imbalance that may contribute to the perception of nasality.

Nasality and Articulation

Nasality, as a resonance phenomenon, may vary in degree among vowels, and, further, it may be influenced by the articulation of consonants spoken with the vowels. Spriestersbach and Powers (57) rated the nasality in the vowels [i], [ɛ], [ɑ], [æ], [o], [u], and [ʌ] spoken by fifty cleft palate children ranging in age from five to fifteen years and reported that:

> Tongue height appears to be the most important variable related to perception of nasality. . . . The high vowels were judged as significantly more nasal than the low vowels. With the exception of the vowels with the highest tongue placement, [i] and [u], the front vowels were judged as more nasal than the back vowels.

Van Hattum (63) rated the nasality in thirteen vowels and diphthongs spoken in isolation by twenty cleft palate persons. He reported that the mean nasality score for the group of subjects was highest for [eɪ] and [ɛ] and lowest for [ɑɪ] and [ɑ]. The mean nasality score for the group was higher for [ɪ], [ɛ], and [i] than for [ɑ], [ʌ], [ɔ], and [ʊ]. He concluded that "there is a difference among the vowels as to the degree of nasality perceived. Generally, front vowels appear to be judged more nasal than back vowels." Lintz and Sherman (39) rated the nasality of seven vowels produced in isolation by ten functionally nasal speakers and ten speakers judged to have essentially normal voice quality. Differences between the mean nasality rating for the two groups were determined for each vowel, and, on this basis, the authors concluded that the vowels [ʌ] and [ɑ] were more nasal than [u], [ɛ], [i], [æ], and [ʊ].

Lintz and Sherman also judged the nasality of the seven vowels in combination with each of eight consonants in CVC syllables. In the CVC contexts, the vowels were ordered according to severity of nasality from most to least severe: [ɑ], [ʌ], [u], [ɛ], [i], [æ], and [ʊ]. They concluded that, in all consonant environments, [ɑ] and [æ] were perceived as significantly more nasal than [u] and [ʊ]; [æ] more nasal than [i]; [i], [ɛ], and [æ] more nasal than [u] and [ʊ]; [ɑ] more nasal than other back vowels; and [ɑ] more nasal than [ɛ].

It would appear, on the basis of the data presented by Lintz and Sherman, that functionally nasal speakers are more nasal on the low vowels and front vowels than on the high vowels and back vowels. It would appear, on the basis of the data presented by Spriestersbach and Powers and by Van Hattum, that cleft palate speakers are more nasal on the high vowels than the low vowels. In high vowels, where cleft palate persons would be least likely to achieve adequate velopharyngeal closure, the greater amount of nasality may be explained by House's (31) statement that ". . . for a given degree of nasal coupling, the spectrum of [i] will be modified more than that for [ɑ]."

While nasality has been viewed traditionally as a disturbance of normal nasal resonance, some investigators (63, 57, 39) have contended that consonant articulation influences the perception of nasality, because they have observed differences between the amount of nasality perceived in vowels in isolation and that perceived in sentences. For example, Van Hattum (63) rated the nasality of thirteen vowels and diphthongs in isolation and of short phonetically balanced sentences, and obtained a correlation coefficient of .48. He postulated that consonant articulation might be partially responsible for this low correlation. He affirmed that ratings of nasality in isolated vowels could not be used as an accurate predictor of nasality in connected speech. He obtained correlation coefficients between the judged nasality in each vowel and in the sentences to determine which vowel might serve as the best predictor of nasality in the sentences. The highest correlation (r = .68) was obtained for the vowel [o], followed in order by [ɛ] (r = .59) and [ə] and [ʌ] (r = .52). Spriestersbach and Powers (57) observed the same discrepancy between ratings of nasality in isolated vowels and connected speech and suggested that the mean of nasality ratings on several vowels might be used as a predictor of nasality in sentences. They postulated that the discrepancy between nasality judgments in vowels and sentences was due to poorer reliability in judging vowels.

Lintz and Sherman (39) observed that their "non-nasal" subjects were judged to be less nasal in syllables than in isolated vowels and they speculated that consonant production aided velopharyngeal closure in the adjacent vowels, thus reducing nasality in syllables. The reduction in nasality in syllable production as compared to vowel production was not observed in the functionally nasal cases. Lintz and Sherman noted that the nasal group did not seem to be as precise as the non-nasal group in their articulatory movements.

The influence of misarticulations in the perception of nasality has been studied by several investigators (63, 41). McWilliams (41) postulated that perceived nasality in cleft palate speech was possibly an artifact of misarticulation. She reported that cleft palate persons with misarticulations were judged as being more nasal than subjects with few or no articulation errors. In her study, ratings of nasality, articulation, and intelligibility were obtained for a variety of speech samples spoken by forty-eight cleft palate subjects. Obtaining a correlation coefficient of .821 between nasality and articulation scores, she (41, p. 526) concluded:

> This indicates that these two supposedly distinct characteristics of cleft palate speech are, in reality, closely related and that any reduction in consonant errors results also in what listeners tend to call nasality.

On the basis of a correlation coefficient of .720 between the intelligibility and nasality ratings, she (41, p. 526) concluded that this

> . . . suggested that nasality ratings had to a large extent been based upon the judges' ability to comprehend the speech of these patients. It pointed further to the fact that listeners find it difficult to divorce nasality from articulation errors and ease of understanding.

An unpublished experiment by MacDonald and Van Hattum (62) also suggested that the presence of misarticulations in the speech of the subject adds to the listener's perception of nasality. One subject with a severe articulation problem, but no nasality, was placed in a group of nasal subjects, and the judges were instructed to rate the nasality of each subject. Having no prior knowledge that one of the subjects had poor articulation but normal resonance, they rated the articulation case as being more nasal than the nasal cases. Van Hattum (63) was prompted by experiment to explore the relationship between judgments of nasality and measures of adequacy of articulation. Using twenty cleft palate speakers, he rated the nasality of thirteen isolated vowels and diphthongs and of short sentences phonetically balance with these vowels and diphthongs. He also rated the adequacy of articulation in these speech samples. Obtaining a correlation coefficient of .48 between judgments of nasality in isolated vowels and diphthongs and the sentences, he concluded that a weak relationship exists between the degree of nasality present in vowels and the degree present in sentences. He obtained a correlation coefficient of .75 between articulation in syllables and articulation in sentences and concluded that articulatory ability in syllables may be used justifiably to judge articulatory ability in connected speech, but that errors of judgment may occasionally be made. A correlation coefficient of -.64 was obtained between nasality in the sentences and articulation in the sentences, which indicated that the poorer the articulation in sentences, the greater will be the nasality in sentences. On the other hand, he reported that nasality in the isolated vowels correlated poorly with articulation in the sentences (r = .07) and syllables (r = .01). By judging articulation and nasality in situations where one is not contaminated by the other, articulation and nasality were seen as relatively independent phenomena. The adequacy of articulation in sentences, however, affected the perception of nasality in sentences.

In view of the possible influence of consonant misarticulations upon ratings of nasality, Sherman (53) advocated rating nasality in sentences using the technique of backward play. She reasoned that the judges would be able to concentrate on the nasality and would not be distracted by such irrelevant factors as pitch, articulation, effectiveness in conveying meaning, and cues associated with particular voice disorders.

She obtained a correlation coefficient of .89 between judgments based on forward play and judgments based on backward play, and concluded that either method of presentation will yield reliable judgments. However, she reported that there were indications that judgments based on forward play were not as valid as those based on backward play.

Spriestersbach (56) evaluated Sherman's technique of backward play, using a population of fifty cleft palate children. Recordings were made of a variety of speech materials, and a thirty-second sample was selected from each subject's recording. The adequacy of articulation of each sample was rated. Then nasality ratings were obtained by playing the samples forward to one group of judges and backward to another group of judges. He obtained a correlation coefficient of .69 between judgments of nasality based on forward play and those based on backward play, and concluded that trained judges could make stable judgments of nasality regardless of the type of presentation. However, he indicated that certain factors, not common to both sets of judgments, were operating so as to depress the correlation. To discover which non-common factors might be operating, he obtained correlation coefficients for the articulation scores and judgments of nasality based on forward and backward play. A correlation coefficient of .47 was obtained for nasality judgments based on forward play and ratings of defectiveness of articulation, while a correlation of .07 was obtained for nasality judgments based on backward play and defectiveness of articulation. He interpreted this as meaning that misarticulation significantly affects judgments of speech samples played forward, while such is not the case when the samples are played backward.

In summary, the degree of perceived nasality seems to vary with vowels and consonant contexts. Spriestersbach and Powers (57) reported that high vowels are more nasal than low vowels, while Van Hattum (63) and Spriestersbach and Powers (57) reported that front vowels are more nasal than back vowels in cleft palate speakers. Lintz and Sherman (39) observed that low vowels are more nasal than high vowels in functionally nasal speakers. All of these researchers reported discrepancies in the degree of perceived nasality in isolated vowels and connected speech in cleft palate and functionally nasal speakers. Lintz and Sherman (39) noted less nasality in vowels in consonant context as compared with isolated vowels in functional cases, and they postulated that this was due to consonant articulation aiding velopharyngeal closure in connected speech. McWilliams (41) contended that nasality in connected speech in cleft palate persons is an artifact of misarticulations, and she advocated work on misarticulation as a means of reducing nasality. Van Hattum observed that while misarticulation may influence the perception of nasality, nasality is an independent phenomenon. In view of the influence of misarticulations upon the perception of nasality, Sherman (53) and Spriestersbach (56) advocated the backward playing of recorded speech as a more valid procedure in judging nasality.

The Measurement of Nasality

In view of the possible influence that irrelevent factors may have in the subjective rating of nasality, various researchers have attempted to employ objective measures which correlate closely with nasality. Various devices, ranging greatly in complexity and accuracy, have been constructed for this purpose. These devices can be classified under three headings in accordance with the correlate of nasality that was studied: devices to measure nasal emission of air, devices to analyze spectrum changes in the speech signal, and devices to measure sound pressure.

Devices to Measure Nasal Emission of Air

Most of the devices to measure nasal emission of air operate on the principle of volumetric air flow or of air pressure, and they are used primarily as indicators rather than refined measuring devices. The pneumograph is a device suggested by Froeschels (22) consisting of a diaphragm that is mechanically coupled to a lever and a recording stylus. Air channeled from the nose activates the diaphragm which in turn moves the lever connected to the recording stylus resulting in a graphic record of the air pressure changes. The nasometer, used by Sigman (55), was activated by the pressure of the nasally emitted air that moved a diaphragm and produced an electrical signal. The electrical signal registered on a meter, but no graphic recordings were made. The manometric flame apparatus, described by Kantner (35) and Moser (43), is a metal box consisting of two compartments separated by a diaphragm. Combustible gas enters one compartment and escapes in a flame from an orifice at the top of the compartment, while air from the nose is channeled to the other compartment. Fluctuations in the nasal air pressure move the diaphragm back and forth, affecting the amount of gas escaping from the opposite compartment, and thus causing fluctuations in the height of the flame. A rotating mirror enables one to see the flame as a rising or falling wave, which can then be photographed. Kantner (35) employed a spirometer into which nasally emitted air was introduced by means of a rubber tube. As air displaced a certain portion of the water in the cylinder, marks on the cylinder walls indicated the amount of water that was displaced, and, therefore, the amount of air that displaced it. Benson (3) made a similar measurement by means of changes in the level of a small amount of colored water in the bend of a U-shaped tube. Air emitted from the nose during production of isolated syllables was channeled to one end of the tube, forcing the water to rise in the other end. A ruler was used to measure the change of water level, and, hence, the amount of nasally emitted air. Benson reported that no direct relationship of nasal emission and nasality was observed. He added that "it is possible to be judged as sounding nasal with little emission of air, or to be judged as sounding normal with considerable emission of air." Kantner (34) said of such devices: "It follows that any device which measures the amount of air escaping through the nose cannot be relied upon to detect nasality and is not an accurate quantitative index of nasality."

Devices to Analyze Spectrum Changes

Devices to analyze spectrum changes have included the phonelloscope (36), the oscillographic camera (51), and the sound spectrograph, the last of which is the most recent and most widely used. The sound spectrograph has been used by Curtis (13), Hattori, Yamamoto, and Fujimura (29), Sax (52), Bloomer (6), Peterson (46), Potter, Kopp, and Green (48), Dickson (14), and Hanson (27) to study spectrum differences in nasalized speech. The sound spectrograph is an instrument that analyzes a complex signal as a function of time and frequency, and records the results on dry facsimile paper. The frequency range from 85-8000 cps is represented on the vertical axis, while time, up to 2.4 seconds, is represented on the horizontal axis. Intensity is represented by the darkness of the pattern. First, the signal that is to be analyzed is recorded on a magnetic disc in the instrument. This signal is reproduced repeatedly and the signal spectrum is scanned during each repetition, either by a 45-cycle or 300-cycle band-pass filter. As the recording stylus shifts gradually along the frequency scale, in synchrony with the scanning oscillator, the output of the analyzing filter is recorded electrostatically on dry facsimile paper that is fastened around a drum rotating synchronously with the magnetic disc. While most researchers have reported generally consistent information concerning spectrum differences which result in nasal speech, Dickson (14) reported that the sound spectrograph did not consistently differentiate the least nasal from the most nasal subjects, nor did it consistently differentiate the cleft palate subjects from the non-cleft palate subjects in his study. Further, Hanson (27) has suggested that the sound spectrograph may be insensitive to mild nasality. These findings suggest that the sound spectrograph may have limitations in differentiating degrees of nasality present in cleft palate speech.

Devices to Measure Sound Pressure

A number of researchers investigated the intensity of nasal resonance which was measured by converting sound energy into electrical energy by means of a microphone, and measuring the intensity of the electrical signal. Hultzen (32) placed a contact microphone on a wooden adapter that fit over the nose. The electrical signals from the microphone were amplified and registered on a meter. Russell and Cotton (51) were interested in the relative intensity of nasal and oral resonance.

By means of two rubber tubes, one equipped with a nasal olive and the other with a funnel for the mouth, they channeled the oral and nasal sound into a sound-insulated box, housing a microphone. A sliding plate on top of the box served as a switch, allowing alternate recording of the oral and nasal sound signal in a single speech sample. The electrical signals from the microphone were visualized on an oscilloscope, and photographs of the waves served as a permanent record. In all of these measurements of sound intensity, nasal olives or adapters were employed.

The probe-tube microphone was apparently first used in the study of nasality by Weiss (64), who investigated the relationship of "oral" and nasal sound pressure levels to judged severity of nasality. His subject sample was predominantly composed of functionally nasal cases. One condenser microphone was placed about eight inches in front of the subject's mouth to record the "oral" sound pressure of the speech signal. Recording of the nasal sound pressure was made by means of a probe-tube microphone that was inserted one-quarter inch into one of the nostrils. Tape recordings of the "oral" and nasal speech signals were made separately but simultaneously while the subject read a connected speech sample. The amount of nasal and "oral" sound pressure present in each of the recorded speech samples made for each subject was measured by means of a power level recorder. Intensity variations in the recorded samples resulted in deflections of a writing stylus of the level recorder that made visible tracings on calibrated chart paper. Listener judgments of the severity of nasality of the "oral" speech samples were obtained by the method of paired comparisons. Correlations of these nasality ratings and mean sound pressure levels were then made.

Weiss reported that there was a strong positive correlation between the judged severity of nasality and the difference between total and nasal sound pressure levels. He concluded that the instrumentation and methodology employed in his study were effective in providing measurements of sound pressure that were closely related to judgments of severity of nasality.

Summers (60) used Weiss' instrumentation to measure the intensity of nasal resonance in isolated vowels that were spoken at various "oral" intensity levels by normal subjects. He reported that nasal-"oral" sound pressure differences decrease when vowels are spoken at higher intensities.

Pierce (47) utilized procedures and instrumentation similar to those described by Weiss to evaluate the effect of five types of speech appliances in reducing nasality in five cleft palate subjects during the production of vowels, words, and sentences. Nasal and "oral" (total) recordings were made of the speech samples with and without the speech appliances in place. Measurements of sound pressure in the nasal and "oral" (total) speech signals of the vowels and CVC words were taken from level recorder tracings. Listener judgments of nasality were made of the "oral" recordings of the sentences. Correlations were then made between the sound pressure differences and the nasality ratings. The mean correlation coefficient for the sound pressure differences in vowels and nasality ratings in sentences was .71, while the correlation coefficient of the sound pressure differences in CVC words and nasality ratings in sentences was .67.

The possible usefulness of the probe-tube assembly in the study of nasality, reflected in these studies of functionally nasal and cleft palate subjects, points to the need for a systematic and more thorough investigation of the technique. Specifically, there is a need for more information concerning the relationships of sound pressure measures and nasality ratings among various types of speech samples produced by an adequate number of cleft palate speakers. There is a need, also, for information concerning the relationship of the major methods of rating nasality in connected speech, i. e., forward and backward play of recorded speech samples, and measurements of nasal and "oral" sound pressure. Such information might be expected to aid our understanding of the relative usefulness and effectiveness of these rating procedures. It is with these research needs that the present study is concerned.

CHAPTER III

DESIGN OF THE INVESTIGATION

The purpose of the present study was to investigate the relationships of nasal-"oral"[1] sound pressure differences[2] and subjective ratings of nasality in a sample of vowels and in a sample of sentences, judged under conditions of forward and backward play. The subject sample consisted of a group of adolescent and adult cleft palate persons. Specifically, the following research questions were asked:

1. What differences in nasal-"oral" sound pressure measures exist among six vowels and six sentences?

2. What differences in nasality ratings exist among six vowels and among six sentences played forward and backward?

3. What relationships exist between the sound pressure measures and nasality ratings for six vowels and for six sentences played forward and backward?

In the present study, objective measurements of nasal and "oral" sound pressures were obtained by means of a dual-channel audio recording system and a power level recorder. Subjective ratings of the degree of

---

[1]The "oral" speech signal, recorded eight inches in front of the mouth, was the total speech signal emitted by the speaker and included sound emitted from both the oral and nasal cavities. However, for purposes of brevity, this total speech signal will be referred to as the "oral" speech signal.

[2]The terms "nasal-'oral' sound pressure difference" and "nasal-'oral' sound pressure measure" will be employed to refer to the arithmetic difference in decibels between the nasal sound pressure and the "oral" sound pressure.

nasality present in the recorded speech samples were made along a five-point scale by judges experienced in judging of cleft palate speech. Thus, for each of the speech items produced by each subject, physical measures of nasal-"oral" sound pressure difference and ratings of perceived nasality were available for analysis. It was the plan of this study to determine, by means of appropriate statistical procedures, the relationships of these physical and subjective measures. The selection of subjects, the experimental apparatus, and the procedures followed in the collection of the data are presented in the following sections.

Subjects

Twenty adolescent and adult persons with congenital cleft palate were chosen as subjects in this study. Thirteen male and seven female subjects were selected from the files of plastic surgeons in private practice, the University of Oklahoma Speech and Hearing Center, and the Oklahoma Department of Public Welfare Cleft Palate Center. Subjects included in this sample were required to be more than fifteen years of age, to present an operated cleft palate, to present no more than a 20 db hearing loss in the speech range in the better ear, and to be capable of performing the experimental task.

The lower age limit of fifteen years was chosen to utilize subjects who had completed pubertal voice change and whose cranio-facial growth was, for the most part, accomplished. The subjects ranged in age from fifteen to forty-two years; the mean age was twenty years. The age of the male subjects ranged from fifteen to forty-two years, with a mean age of eighteen years. The age of the female subjects ranged from seventeen to thirty-six years, with a mean age of twenty-four years.

All subjects were required to present an operated cleft palate to assure a reasonable homogeneity of the subject sample. No attempt, however, was made to limit the sample with respect to type of cleft palate or type of surgery. Seven subjects presented bilateral complete clefts of the lip and palate; eight subjects, unilateral complete clefts; and five subjects, isolated clefts. To facilitate statistical treatment of the data, subjects were chosen who represented varying degrees of nasality as determined by the investigator. No attempt was made to exclude subjects presenting articulation problems because nasality in cleft palate persons is often associated with misarticulation of pressure consonants.

In order to exclude deficient hearing and, consequently, imperfect auditory monitoring of speech as a variable in this study, a pure tone sweep-frequency audiometric test was administered to each subject at a 20 db hearing level at the frequencies 500, 1000, and 2000 cps. No subject included in the sample presented a loss greater than 20 db at any frequency tested in the better ear.

Subjects were required to have sufficient intelligence to perform the experimental task. The task necessitated the ability to maintain the oral speech signal at a specified intensity level as monitored by a VU meter, as well as to read or to speak from memory the short test sentences. One subject was excluded from the study because he was unable to remember the sentences and to read them correctly.

Apparatus

This study required instrumentation for: (a) an audio recording system for the nasal and "oral" speech signals, (b) a graphic recording system to display the intensity of the nasal and "oral" speech signals, (c) a calibration system for the nasal microphone, dual-channel tape recorder, and power level recorder, (d) a playback system for the "oral" speech signal on which ratings of nasality were made, and (e) a signal system to guide the subject in the experimental task.

Description

Audio recording system.--The audio recording system consisted of: (a) two one-half inch condenser microphone cartridges (Bruel and Kjaer, Type 4134), one of which was equipped with a probe-tube (Bruel and Kjaer Probe Microphone Kit, Type UA 0040); (b) two preamplifiers (Bruel and Kjaer, Type 2415); (c) two microphone amplifiers (Bruel and Kjaer, Type 2503), one of which had an equalizing filter inserted in its circuit; and (d) a dual-channel magnetic tape recorder (Ampex, Model 354). A block diagram of the audio recording system is presented in Figure 1.

The condenser microphones were designed for precise sound pressure measurements under free sound field conditions. These microphones were calibrated by the manufacturer, and their frequency responses were reported to be flat within $\pm$ 2 db from 20-20000 cps in a sound field.

The oral microphone cartridge was equipped with a protective grid which, according to the manufacturer's specifications, does not appreciably alter the frequency response of the microphone below 10000 cps, when the microphone is placed at a 90° angle of incidence to the sound source.

The nasal microphone cartridge was identical to the "oral" microphone cartridge; however, it was modified by the addition of an

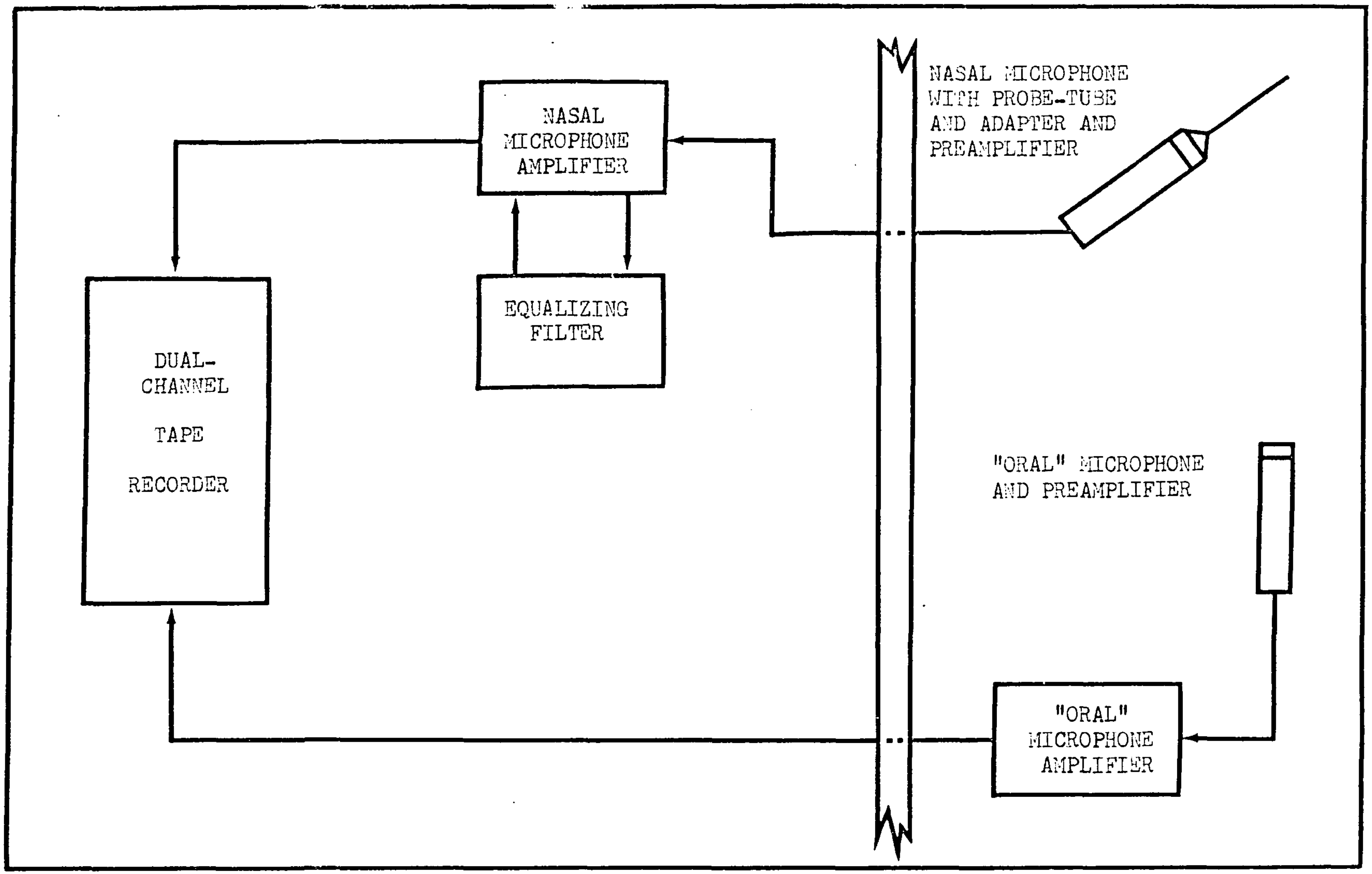


FIGURE 1.--Block diagram of the nasal and "oral" audio recording system.

adapter and a probe-tube. The probe-tube adapter screwed onto the nasal microphone cartridge, and the probe-tube was force-fitted into the adapter, providing acoustically tight seals at these points of connection. The probe-tube was one millimeter in outside diameter and six-tenths millimeter in inside diameter. An outside diameter of this magnitude allowed the tube to be inserted into the nasal meatus without contacting the columella and ala and without appreciably altering the sound pressure environment in the nose (4). The thickness of the probe-tube wall was sufficient to provide a signal-to-noise ratio as great as 44 db, according to the manufacturer's specifications. The length of the probe-tube, measured from the tip of the adapter, was three inches. This length of tube was necessary to allow placement of the nasal microphone and preamplifier out of the path of the orally emitted speech signal, thus minimizing the impedance to the oral signal. The probe-tube was made as short as possible to improve its sensitivity (5). However, the probe-tube offered considerable high-frequency damping as indicated in the frequency response curve in Figure 2, necessitating the placement of steel wool damping material in the probe-tube, as well as the use of an equalizing filter to be described later. The steel wool offered selective damping of the low frequencies, primarily, and aided in flattening the frequency response curve of the probe-tube microphone.

The microphone amplifiers were designed to amplify the voltage of small alternating currents with a potential gain of 100 db, and their reported frequency responses were linear from 2-40000 cps. When used with the Bruel and Kjaer condenser microphones, the amplifiers functioned as sound level meters, indicating sound pressure in decibels (re: 0.0002 dyne/cm^2) on the VU meter.

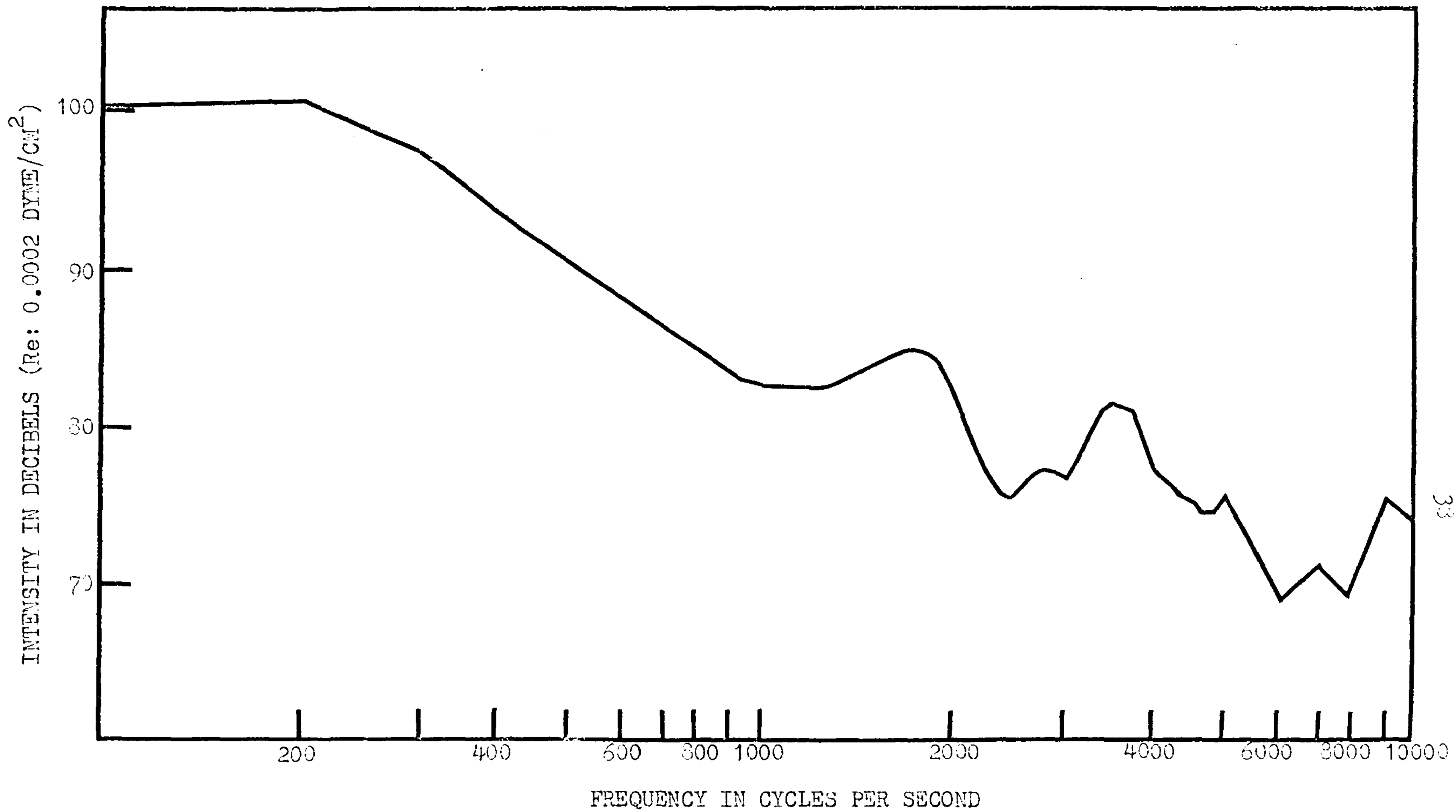


FIGURE 2.--Frequency response curve of the nasal microphone with the first probe-tube, when the reference tone was held constant at 100 db SPL.

An equalizing filter was inserted in the external filter circuit of the amplifier used with the nasal microphone. The purpose of this equalizing filter was to provide a flatter frequency response in the nasal system by damping the low frequencies approximately the same amount that the probe-tube damped the high frequencies. Two different probe-tubes and equalizing filters were used in this study. For use with the first probe-tube, an equalizing filter consisting of a 0.0196 microfarad condenser in parallel with a 27000 ohm resistor, both of which were placed in series with a 1700 ohm resistor, was constructed to produce a frequency response curve that was essentially flat within ± 4.5 db to 5000 cps, as indicated in Figure 3. However, one subject, who was unable to perform the experimental task, damaged the first probe-tube, necessitating a second probe-tube and filter to attain the desired frequency response. The second filter consisted of a 0.02 microfarad condenser in parallel with a 33000 ohm resistor, both of which were placed in series with a 1500 ohm resistor. The frequency response of the nasal microphone employing the second probe-tube and equalizing filter was essentially flat within ± 4.5 db to 5000 cps, as indicated in Figure 4.

The dual-channel magnetic tape recorder that was used in the simultaneous recording of the nasal and "oral" speech signals was matched for impedance with the microphone amplifiers, and its frequency response at an operating speed of 7.5 inches per second was ± 1 db from 40-12000 cps, according to the manufacturer's specifications.

Graphic recording system.--The nasal and "oral" signals reproduced by the tape recorder described above were introduced into a level recorder (Bruel and Kjaer, Type 2304), which recorded voltage variations within the frequency range of 20-20000 cps as a function of time. The

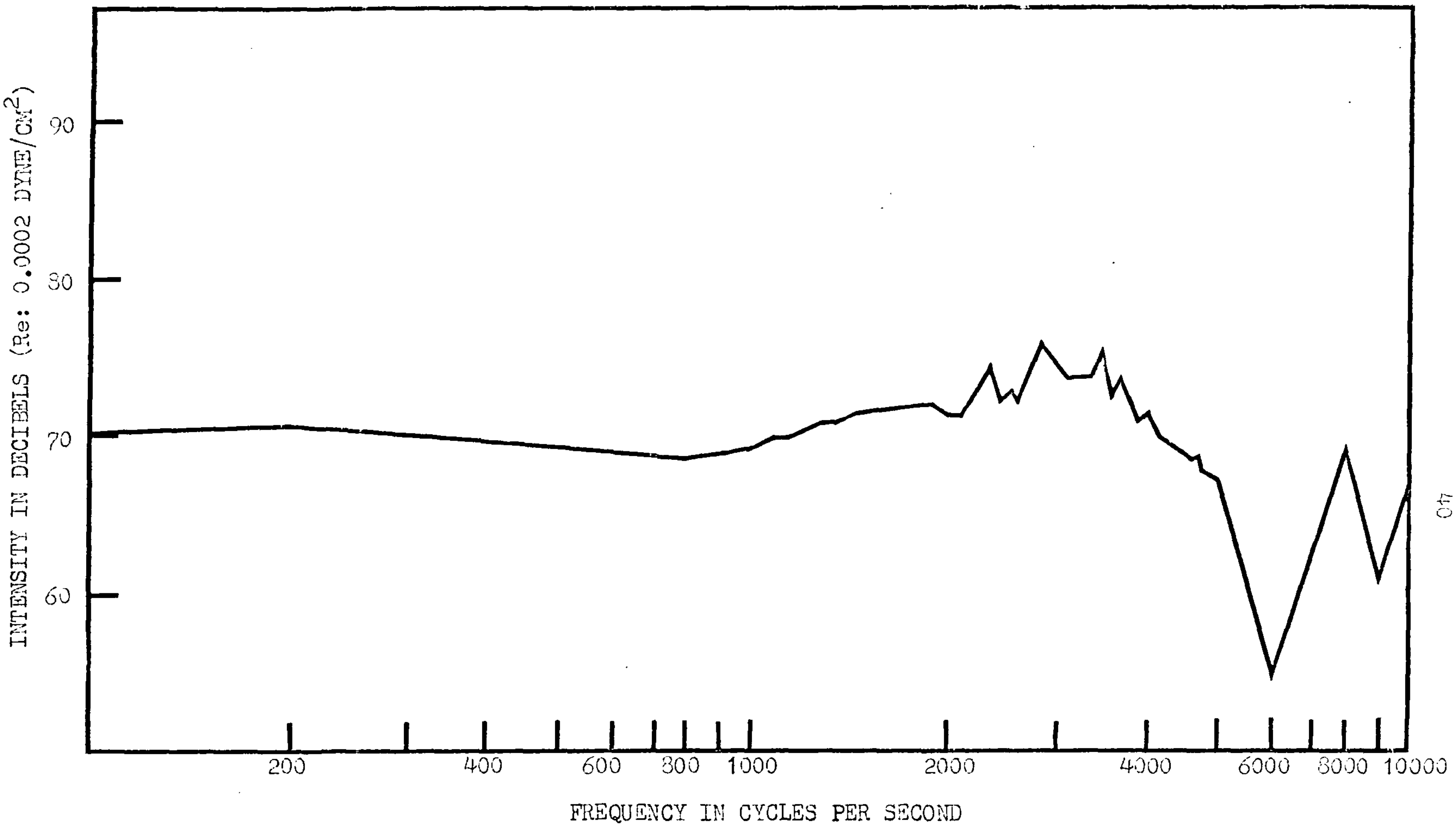


FIGURE 3.--Frequency response curve of the nasal microphone with the first probe-tube and its equalizing filter, when the reference tone was held constant at 100 db SPL.

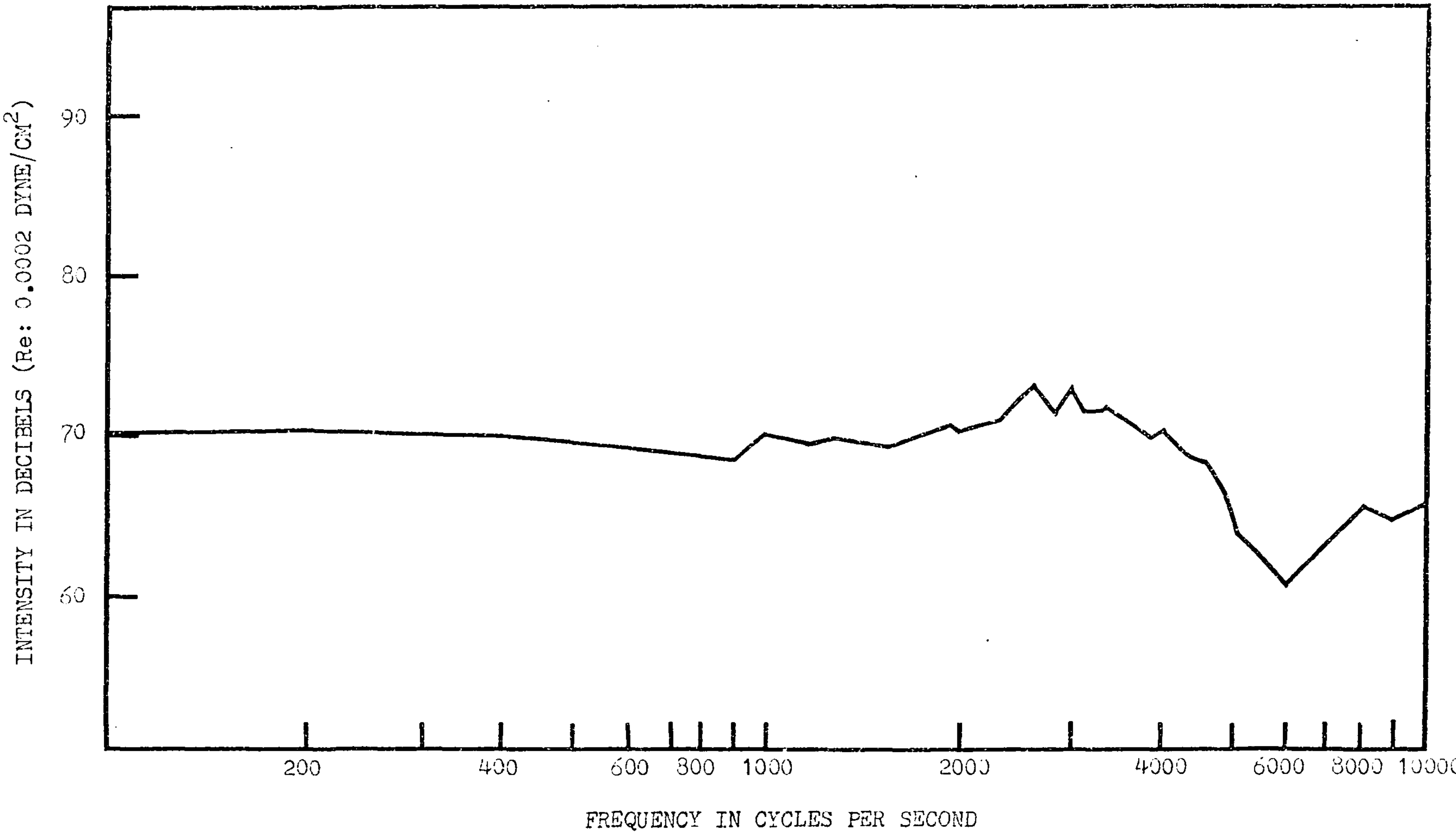


FIGURE 4.--Frequency response curve of the nasal microphone with the second probe-tube and its equalizing filter, when the reference tone was held constant at 100 db SPL.

level recorder was equipped with a 50 db input potentiometer that was accurate within ± .5 db, according to the manufacturer's specifications. When the voltage changes that were stored on the magnetic tape, representing sound pressure changes in the speech signals, were introduced into the level recorder, a deflection of the level recorder's writing stylus was produced. The stylus made tracings on chart paper that was ruled in 5 db intervals.

Calibration system.--The system for calibrating the nasal condenser microphone, dual-channel tape recorder, and power level recorder consisted of a pure tone oscillator (Hewlett Packard, Model 201-C) which drove an amplifier-speaker (Ampex, Model 620). The assembly composed of the "oral" condenser microphone and its associated amplifier served as a sound level meter in the calibration system. A block diagram of the calibration system is presented in Figure 5.

Playback system.--Two single-track tape recorders (Ampex, Model 601) were used in conjunction with an amplifier-speaker (Ampex, Model 620) as the playback system in the procedure of judging nasality in the "oral" speech signals. A hand-operated switch located between the tape recorders and the amplifier-speaker allowed the experimenter to switch quickly from one recorder to the other and to transduce the signal from either recorder over the amplifier-speaker. One of the recorders played the tape-loop of reference samples to be described later, while the second tape recorder played the "oral" speech signals that were to be rated by the judges. The amplifier-speaker was matched for impedance with the tape recorders. The tape recorders had a flat frequency response within ± 2 db from 40-10000 cps when operating at a tape speed of 7.5 inches per second, according to the manufacturer's specifications. Gain con-

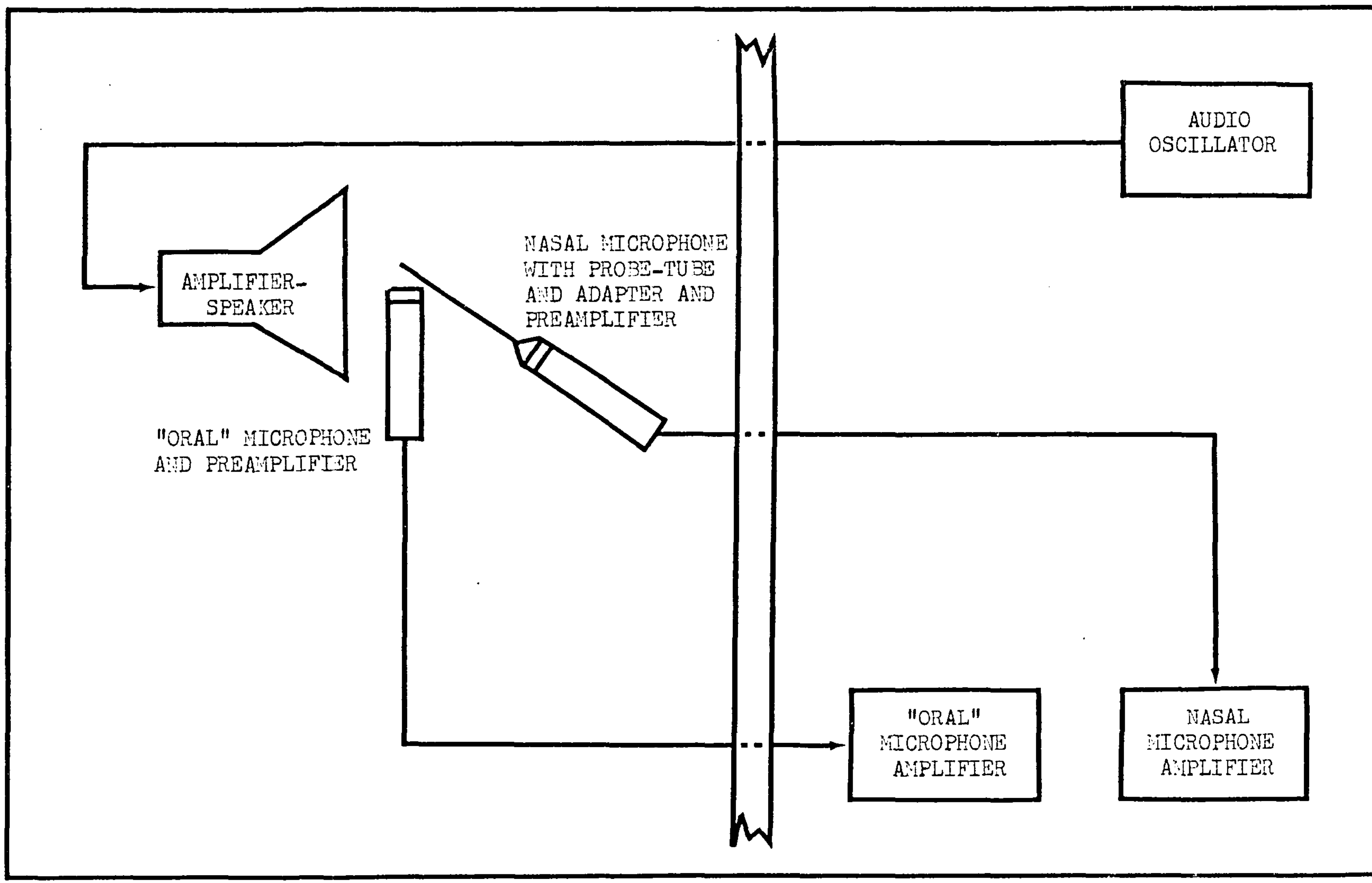


FIGURE 5.--Block diagram of the calibration system as used in calibrating the nasal microphone.

trols on the recorders and amplifier-speaker allowed adjustment of the signal to a loudness level that was comfortable for the judges.

Signal system.--The system used to signal to the subjects when they should begin and terminate phonation consisted of a simple cam timer which, when activated by the experimenter, controlled illumination of two signal lights in the subject room according to predetermined time intervals.

Calibration

Nasal microphone.--In calibrating the nasal microphone, the "oral" condenser microphone was used as a reference. The oral microphone as calibrated by the manufacturer was flat within $\pm$ 2 db from 20-20000 cps. As previously noted, when the "oral" microphone was used with its associated microphone amplifier, it served as a sound level meter.

The reference microphone was placed at a 90° angle of incidence to the amplifier-speaker at a distance of one inch from the sound source in an acoustically isolated room. The nasal probe-tube microphone was placed at an acute angle one-quarter inch above the reference microphone. The pure tone oscillator and the microphone amplifiers were located in an adjoining control room (See Figure 5).

The amplifier-speaker, driven by the pure tone oscillator, produced a tone of sufficient intensity to register 100 db SPL on the meter of the reference microphone amplifier. Concurrently, the response of the nasal probe-tube microphone was read on the meter of its associated amplifier. Such readings were taken at 100-cycle intervals through 5000 cps and at 1000-cycle intervals from that point to 10000 cps. The response of the nasal microphone with the first probe-tube and equalizing filter is found in Figure 3 and the response of the second probe-tube and equalizing filter is found in Figure 4. The response curves are essentially flat within ± 4.5 db to 5000 cps.

To obtain a single value of the attenuation provided by each of the probe-tubes, with their respective filters, the means of the sound pressure readings to 5000 cps were computed. These means were then subtracted from the intensity level of the reference tone at the diaphragm of the reference microphone as measured on the meter of the "oral" microphone amplifier, and the difference indicated the amount of attenuation in decibels. The mean attenuation was 29 db for the first probe-tube and associated filter, and 30 db for the second probe-tube and associated filter.

Dual-channel tape recorder.--Since the tape recorder used in this study was newly purchased, an audio engineer made the necessary alignments and performance checks to assure that the recorder was operating properly.

The daily calibration procedure involved adjusting the "record" level of each channel of the recorder. A 1000 cps pure tone, produced by a pure tone oscillator in the control room, was transduced by the amplifier-speaker located in the subject room. The signal was picked up by the reference microphone, placed at a 90° angle of incidence to and one inch in front of the sound source. The intensity of the signal was adjusted until it produced a 20 db deflection of the VU meter of the reference microphone amplifier. The "record" level potentiometer of the tape recorder was adjusted until the signal produced a deflection of 20 db on the tape recorder's VU meter for the "record" head.

Prior to playing back the recorded speech signals and introducing them into the power level recorder, it was necessary to adjust the tape recorder's "reproduce" level to match its "record" level. First, the "record" level was adjusted in the manner described above. Then, while the reference tone was present, the "reproduce" potentiometer was adjusted until the output signal from the "reproduce" head was equal in intensity to the output signal from the "record" head.

Power level recorder.--The power level recorder was calibrated by means of a 1000 cps signal that was produced by the audio oscillator, transduced by the amplifier-speaker, picked up by the reference microphone, and amplified by the "oral" microphone amplifier which served as a sound level meter. The intensity of the signal was adjusted to read 20 db on the VU meter of the microphone amplifier. As this signal was introduced into the level recorder, producing a tracing on the chart paper, the input potentiometer of the power level recorder was adjusted so the tracing coincided with a designated line on the chart paper. The intensity represented by this line in the chart recordings of each speech production, was equal to 20 db plus the amount of attenuation in decibels that was used when the speech production was originally tape recorded.

Procedure

Speech Sample

Six isolated vowels and six short sentences were used as the speech sample in this study. It was desirable to include both isolated vowels and sentences in this study to allow investigation of differences in sound pressure measurements and nasality ratings among different types of speech samples. Van Hattum (61) and Spriestersbach and Powers (57), for example, have observed differences between ratings of nasality in isolated vowels and those in connected speech. Spriestersbach and Powers have speculated that this may be due to greater difficulty in judging nasality in isolated vowels, while Lintz and Sherman (39) speculated that there may be a difference in the intensity of nasal resonance in vowels in isolation and in vowels in consonant context.

The vowels [i], [æ], [ɑ], [ʌ], [u], and [ɔ] were used in this study for two reasons. First, several investigators (63, 57) have observed that certain of these vowels are perceived as being more nasal than others. It was of interest, therefore, to determine if vowels also differed in nasal-"oral" sound pressure and to explore differences in the relationships of sound pressure measures and nasality ratings among vowel sounds. Second, these six vowels represent various positions in the traditional vowel triangle and allow analysis of the findings with respect to tongue placement during vowel production.

Six short sentences comprised the connected speech sample (See APPENDIX B). Nasal consonants were excluded from these sentences because of the influence these sounds might have on nasality ratings and on measurement of nasal sound pressure. The absence of nasal consonants in these sentences was considered to allow a better discrimination of subjects with varying degrees of nasality. An effort was made to include in the group of sentences an equal number of each of the vowels [i], [æ], [ɑ], [ʌ], [u], and [ɔ], as well as other major vowels in American English. An effort was also made to include in the group of sentences an equal number of fricative and plosive sounds and voiced and voiceless sounds.

Recording Procedure

All speech samples were recorded in an acoustically isolated room at the University of Oklahoma Speech and Hearing Center. The ambient noise level of this room was approximately 30 db as measured on the C-scale of a sound level meter (General Radio, Type 759).

The subject room contained only the subject's chair, a table on which the "oral" microphone amplifier and signal lights were placed, a stand to which the "oral" microphone and preamplifier were affixed, and an adjustable wall-mounted arm to which the nasal microphone and preamplifier were affixed. The control room contained the nasal microphone amplifier, the dual-channel magnetic tape recorder, and the cam timer that controlled the signal lights.

Following instruction in the use of the signal lights and monitoring VU meter (See APPENDIX C), each subject was seated in a dental-type chair. The height of the seat, inclination of the back, and position of the headrest were adjusted so that the subject's position was suitable for placement of the probe-tube. A wide, adjustable canvas strap held the subject's head to the headrest, reducing head movement and changes in the relative position of the probe-tube. The stand to which the "oral" condenser microphone was attached was moved into position so that the microphone was at a 90° angle of incidence to and approximately eight inches in front of the subject's mouth. The arm holding the nasal microphone was adjusted so that the probe-tube projected at an acute angle approximately one-quarter inch into the vestibule of the subject's least-occluded nasal meatus. The choice of nostril for placement of the probe-tube was determined by visual inspection and from condensation tracings of air exhaled through the nose upon a mirror.

To monitor the intensity of the "oral" speech signal, the subject was instructed to peak his speech production at 75 db on the VU meter of the "oral" microphone amplifier. This intensity level was chosen to assure a signal-to-noise ratio of at least 20 db. This intensity level was also chosen because, in a preliminary pilot study, it seemed to be the most comfortable phonation level for most subjects. Located above the "oral" microphone amplifier were the signal lights used to inform the subject when to begin and terminate phonation of the vowels. They were so placed that the meter, signal lights, and speech material could be viewed at a glance. When the cam timer was activated, a one-second amber light indicated to the subject that he should prepare to phonate; this was followed immediately by a three-second white light which indicated the period for phonation.

After the subject and the microphones were suitably positioned, the subject was given an opportunity to familiarize himself with the speech material and the experimental procedure. The subject was then instructed to produce selected vowels and sentences at the appropriate intensity level, during which time the investigator adjusted the attenuators on the nasal microphone amplifier so that the nasal speech signal for that subject could be accommodated within the 20 db range of the VU meter on the nasal microphone amplifier.

The experimental vowels and sentences were printed on three-by-five inch cards easily visible to the subject, and the subject was asked to repeat each of the speech items after the investigator. The vowels appeared in common words in which the vowel sound was underlined. The subject phonated only the underlined vowel sound. The order of presentation of the group of vowels and the group of sentences, as well as the order of presentation of the items in each group, was determined by a table of random numbers.

Intensity Measurements

The tape recorded nasal and "oral" speech signals were introduced separately into the power level recorder in order to produce a graphic representation of intensity. The level recorder was operated with a paper speed of thirty millimeters per second and a writing speed of 300 millimeters per second. These speeds were chosen because they provided adequate resolution of the data. The writing speed, however, was not so fast that the momentum of the writing stylus caused it to overshoot.

The calibrated chart paper (Bruel and Kjaer, QP 2350) was white-waxed black paper that was ruled in ten equal intervals, each of which represented 5 db. The chart paper allowed a recording range of 50 db.

The intensity levels of the nasal signal and of the "oral" signal for each vowel were determined by measuring the amplitude of the level recorder tracings at points five millimeters apart in the steady-state portion of the vowel and obtaining a mean of these measurements.

The intensity levels of the nasal and the "oral" signals for each sentence were also determined by measuring the amplitude of the level recorder tracings at points five millimeters apart and obtaining the mean of these measurements. In the sentences, five millimeter intervals were marked off, beginning at the point where the writing stylus intercepted the base line of the chart paper. The base line was regarded as the first line above the level where random tracings of the writing stylus occurred due to internal equipment noise and/or noise of the subject's respiration.

After the sound pressures in decibels were determined for the nasal and the "oral" signals for each speech production, an arithmetic difference was derived, and this figure expressed in decibels was the nasal-"oral" sound pressure for the speech production.

Nasality Ratings

Three judges, members of the faculty of the University of Oklahoma Department of Communication Disorders, rated the severity of nasality of the recorded "oral" speech productions. These persons hold advanced degrees in the field of speech pathology and are particularly experienced in the evaluation of cleft palate speech.

In this procedure, each of the speech samples on the original tape were played by the dual-channel tape recorder and re-recorded on another tape using an Ampex tape recorder (Model 601). By means of tape-clipping and splicing, the productions of a given speech item were randomized for presentation to the judges. The groups of speech items were presented in the following order: vowels, sentences played forward, and sentences played backward. The order of presentation of the vowels was [i], [æ], [ɑ], [ʌ], [u], and [ɔ], while the sentences, both in forward and backward play, were presented in their numerical order (See APPENDIX B).

The ratings of the speech productions took place in the acoustically isolated subject room where the speech samples were originally recorded. The three judges were seated in front of and facing the amplifier-speaker which was placed about four feet away. The tape recorders (Ampex, Model 601) used for the playback of the speech productions were located in an adjoining control room. The judges were instructed to listen to each speech production and to rate independently the severity of nasality, using a five-point rating scale in which "1" represented the mildest nasality and "5" represented the severest nasality in the twenty productions of the item being rated.

To provide the three judges with a common reference for degrees of nasality that should be rated "1" and "5", a preliminary rating of the twenty productions of each item was conducted. In the preliminary rating, the judges listened without interruption to the twenty productions of a given speech item to establish the range of nasality displayed in that item. The twenty productions were played again and each was rated independently by the judges along a five-point scale of nasality. On the basis of the preliminary rating, the two least nasal productions and the two most nasal productions of each speech item were chosen as reference samples to be used in the final rating. These four productions of each item were re-recorded on mylar magnetic tape and spliced together into a circular tape-loop.

One week later, the judges met in the setting described above and were instructed in their listening and rating task. A copy of the instructions given to the judges is presented in APPENDIX C. Before each speech production to be rated was presented, the reference samples representing the two least nasal and the two most nasal productions of that item were played, in that order. Immediately thereafter, the production to be judged was presented and rated independently by each judge on a five-point scale.

The entire procedure was repeated one month later to evaluate consistency of ratings within judges. Spearman rank correlation coefficients for the ratings on the first and second rating sessions were computed for each judge for each speech item. The mean of the correlations across all items for each judge were as follows: Judge #1, .766;

Judge #2, .756; and Judge #3, .818. These correlation coefficients indicated high intrajudge agreement.

The interjudge agreement for each speech item was determined by means of Spearman rank correlation coefficients. The mean of the correlation coefficients averaged over all combinations of the three judges were .537 for the vowels, .586 for the sentences played forward, and .489 for the sentences played backward.

In order to obtain a single value for the judged nasality of each speech production, the median of the six ratings given by the three judges in the two rating sessions was determined. This median for each speech production was regarded as the nasality rating of that production. The results of this investigation and a discussion of the findings are presented in the following section.

CHAPTER IV

RESULTS

This study was designed to investigate the relationships among nasal-"oral" sound pressure differences[1] and nasality ratings of a speech sample of six isolated vowels and six sentences produced by twenty adolescent and adult cleft palate persons. The nasal and "oral" speech signals were recorded simultaneously and the sound pressure of each of these signals in decibels[2] was determined. The arithmetic difference of the nasal and "oral" sound pressures was then obtained for each vowel and sentence produced by each subject. Trained judges rated the nasality of the "oral" recording of each vowel and sentence produced by each subject along a five-point scale. Thus, the raw data of this experiment consisted of nasal-"oral" sound pressure differences and nasality ratings for each item in the speech sample produced by each subject.

To accomplish the stated purpose of this investigation, the data were analyzed by appropriate parametric and nonparametric forms of analysis of variance, by the Duncan Multiple Range Test, and by Spearman rank correlations. An alpha level of .05 was set for these tests.

---

[1]As previously stated, the "oral" speech signal is the total speech signal emitted from the oral and nasal cavities and sampled eight inches in front of the mouth. The expressions "nasal-'oral' sound pressure difference" and "nasal-'oral' sound pressure measure" refer to the arithmetic difference of nasal and "oral" sound pressures.

[2]Re: 0.0002 dyne/cm^2.

Sound Pressure Measures

One of the major purposes of the present study was to investigate differences in the nasal-"oral" sound pressure measures among the six vowels and six sentences. In view of the fact that several researchers (63, 57) have indicated that high vowels and front vowels are perceived to be more nasal than low vowels and back vowels in cleft palate speakers, it was of interest to see if corresponding differences in nasal-"oral" sound pressures existed among the vowels. Also, it was of interest to see if the individual sentences were homogeneous in regard to their mean nasal-"oral" sound pressure differences.

Vowels

The nasal-"oral" sound pressure difference for each vowel averaged over all subjects is presented in Table 1, inspection of which shows that the largest mean difference, 38 db, was obtained for the vowel [i],

TABLE 1.--The nasal-"oral" sound pressure differences averaged over all subjects for each of the six vowels, expressed in decibels, with the standard deviation of each mean.

VOWEL	MEAN DIFFERENCE IN DECIBELS	STANDARD DEVIATION
[i]	38	3.95
[u]	35	4.54
[æ]	32	3.11
[ʌ]	32	3.08
[ɔ]	32	3.19
[ɑ]	31	3.73

followed in order by those for the vowels [u], 35 db; [æ], [ʌ] and [ɔ], 32 db; and [ɑ], 31 db. The standard deviations for the vowels ranged from 4.54 db and [u] to 3.08 for [ʌ]. Thus, greater mean sound pressure differences were found for the high vowels [i] and [u] than for the other vowels tested. The means for the vowels [æ], [ʌ], [ɔ], and [ɑ] were similar to each other. It may also be seen that the front vowels [i] and [æ], as a group, displayed greater mean differences than the group of back vowels, [u], [ɔ], and [ɑ].

To determine whether differences among the mean differences, reported in Table 1, were statistically significant, analysis of the data was performed. Variances of the sound pressure measures for the six vowels and for the twenty subjects were tested for homogeneity using the Cochran test (15, p. 180). The resulting C values indicated that the variances were homogeneous. Subsequently, an analysis of variance was made of the mean sound pressure differences between the six vowels and between the twenty subjects, the results of which are presented in Table 2.

TABLE 2.--Summary of the analysis of variance of the mean nasal-"oral" sound pressure differences between the six vowels and between the twenty subjects.

Source of variation	df	SS	MS	Observed F	Critical F*
Between vowels	5	715	143	29.36*	2.31
Between subjects	19	1050.5	55.28	3.51*	1.7
Residual	95	463.5	4.87		
Total	119	2229			

*$P \leq .05$

The observed F values, 29.36 and 3.51, presented in Table 2, indicate that significant variation existed between subjects in their performance on the group of vowels, and that the subjects as a group differed significantly in their performance on the individual vowels.

The fact that differences existed among the subject means, as shown by the significant "between subject" variance, is not unexpected, since subjects presenting varying degrees of perceived nasality were selected for this study. One might expect that subjects who differ in perceived nasality and who, presumably, differ in the extent to which their nasal and oral cavities are coupled during speech production, would display dissimilar nasal-"oral" sound pressure differences. The presence of significant differences among the means for the six vowels is of interest in view of findings which indicate that the degree of coupling of the oral and nasal cavities is not the same for all vowels (45, 31). These findings suggest the need for relating the magnitude of nasal-"oral" sound pressure differences to the size of the velopharyngeal opening during phonation of the individual vowels.

The Duncan Multiple Range Test (58, pp. 107-109) was used to locate the significant differences among vowel means detected by the analysis of variance. The results of this test are presented in Table 3 which reveals that the mean for the vowel [i] was significantly larger than that for the vowel [u] and that the means for both vowels significantly exceeded those for [ɑ], [æ], [ʌ], and [ɔ]. No other differences among means were significant. These findings indicate that the vowels [i] and [u] are associated with significantly larger nasal-"oral" sound pressure differences than the vowels [ɑ], [æ], [ʌ], and [ɔ], and that these latter vowels are characterized by similar sound pressure differences.

TABLE 3.--The Duncan Multiple Range Test for differences among the nasal-"oral" sound pressure differences averaged over all subjects for each of the six vowels.

a) Shortest Significant Ranges

p:	(2)	(3)	(4)	(5)	(6)
$r_{.05}$	2.80	2.95	3.05	3.12	3.18
R_p	1.38	1.45	1.50	1.54	1.57

b) Results

Mean:	31.15	31.6	31.95	32.4	35.3	37.95
Vowel:	[ɑ]	[ɔ]	[ʌ]	[æ]	[u]	[i]
	______	______	______	______		

Note: Any two means not underscored by the same line are significantly different at the .05 level. Any two means underscored by the same line are not significantly different at the .05 level.

It is interesting to note that, among the nasal-"oral" sound pressure differences reported for various vowels by other researchers, the differences for [i] and [u] are larger than those for other vowels. Pierce (47), for example, used instrumentation and procedures[1] similar to those of the present investigation to measure nasal and "oral" sound pressures in isolated vowels produced by five cleft palate adults with and without their speech appliances. While the investigation of sound pressure differences among vowels was not a purpose of Pierce's study, inspection of his raw data reveals a difference in magnitude of mean sound pressure differences among the vowels he tested. For the vowels produced without the appliances, the nasal-"oral" sound pressure differences reported for the high vowels [i] and [u] were greater than those reported for the low vowels [æ], [ɑ], [ʌ], and [ɔ]. Also, the nasal-"oral" sound pressure differences reported for the front vowels [i] and [æ] were greater than those reported for the back vowels [ɑ], [u], and [ɔ]. Although no statistical tests were performed to determine if these differences were significant, Pierce's findings appear to be consistent with those of the present study.

Summers (60), by means of a probe-tube assembly and procedures similar to those used in Pierce's study and in the present study, measured nasal and "oral" sound pressures in isolated vowels produced by normal speakers at various oral intensities. According to the data reported for vowels common to the present study[2], the nasal-"oral" sound pressure dif-

---

[1]Pierce's procedure differed slightly from that used in the present study in that a "comfortable level" of phonation, which varied among subjects, was used rather than a specific intensity level.

[2]This data was that for the nominal intensity level of 90 db, which most closely approximated the oral intensity level of the present study.

ference for [i] was slightly larger than that for [u], and the differences for both of these vowels were slightly larger than those for [æ], [ɑ], and [ɔ]. No statistical test for significance of differences among these five vowels was made.

A comparison of the mean sound pressure differences found for the present cleft palate sample with those extrapolated from Summers' raw data for normal speaking subjects reveals that, on the average, the cleft palate group displayed greater sound pressure differences in production of the vowels common to both studies. Thus, while the relative magnitude of sound pressure differences for the individual vowels is similar in both studies, the cleft palate group evidenced greater absolute sound pressure differences for all vowels tested.

These findings suggest that the greater sound pressure differences found for the vowels [i] and [u] are not a unique feature of cleft palate speech, but rather an exaggeration of a pattern seen in normal speakers. In normal speakers, the greater sound pressure differences seen in these vowels may be related to the greater impedance to the orally emitted speech signal caused by the position of the tongue in their production, since normal speakers produce these vowels with a tight velar seal (45, 31). In cleft palate speakers, the combined effect of high oral impedance and velar incompetency might explain the greater absolute magnitude of sound pressure differences present during vowel production.

Sentences

As previously stated, this cleft palate sample evidenced larger nasal-"oral" sound pressure differences in certain vowels than in others. To determine if the subjects, as a group, displayed similar sound pressure differences in each of the six sentences included in the speech sample, the mean sound pressure differences were compared. The means for each of the sentences are presented in Table 4, inspection of which shows that the largest mean difference was obtained for sentence #2,

TABLE 4.--The nasal-"oral" sound pressure differences averaged over all subjects for each of the six sentences, expressed in decibels, with the standard deviation of each mean.

SENTENCE	MEAN DIFFERENCE IN DECIBELS	STANDARD DEVIATION
#1	35.4	5.58
#2	36.6	5.61
#3	35.75	4.97
#4	36.05	6.25
#5	35.8	5.74
#6	35.85	5.20

36.6 db; followed in order by those for sentences #4, 36.05 db; #6, 35.85 db; #5, 35.8 db; #3, 35.75 db; and #1, 35.4 db. The standard deviations for the sentences ranged from 6 db for sentence #4 to 5 db for #3.

To determine if the difference among the means reported in Table 4 were significant, a statistical analysis of the data was made. Using the Cochran test (15, p. 180), the variances of the sound pressure differences for the six sentences and for the twenty subjects were found to be homogeneous. Subsequently, an analysis of variance was made of the sound pressure measures between sentences and between subjects. These findings are presented in Table 5. Inspection of this table reveals that the variance between subjects was significant, while the variance between sentences was not. These findings indicate that individual sub-

TABLE 5.--Summary of the analysis of variance of the mean nasal-"oral" sound pressure differences between the six sentences and between the twenty subjects.

Source of variation	df	SS	MS	Observed F	Critical F*
Between sentences	5	15	3	1.20	2.31
Between subjects	19	3307	173.9	70.12*	1.7
Residual	95	236	2.48		
Total	119	3558			

*$P \leqq .05$

jects differed significantly in mean sound pressure differences averaged over the six sentences, but that subjects, considered as a group, displayed similar mean sound pressure differences in each of the six sentences.

That differences in these sound pressure measures exist among this subject sample is expected in that cleft palate persons differ in velar competency and, consequently, in the degree of coupling of the oral and nasal cavities during speech production. The lack of significant differences among the means for the sentences suggests that each of the six sentences reflected to a similar degree the nasal-"oral" sound pressure differences present in the subject sample. The similarity of the sound pressure differences in these sentences may be related to the fact that each sentence had a similar phonetic composition.

Nasality Ratings

Another major purpose of this study was to determine if differences in nasality, as perceived by trained judges and rated along a five-point scale, existed among the six vowels and six sentences included in the speech sample. This aspect of the study was considered important for two reasons. First, since it was found that certain vowels were associated with significantly larger sound pressure differences than others, as previously stated, it was of interest to determine whether the subjects were rated more nasal on the vowels with the largest sound pressure differences. Second, it was considered important to determine if judges perceived similar nasality in sentences presenting similar sound pressure differences.

Vowels

The median nasality rating for each vowel obtained over all subjects are present in Table 6, inspection of which reveals that the vowels

TABLE 6.--The median of the nasality ratings for the group of twenty subjects for each of the six vowels.

VOWEL	MEDIAN NASALITY RATING
[i]	4
[æ]	4
[ɑ]	3.5
[ʌ]	4
[u]	3
[ɔ]	3

[i], [æ], and [ʌ] were assigned a median rating of "4"; the vowel [ɑ], a median rating of "3.5"; and the vowels [u] and [ɔ], a median rating of "3". Thus, the front vowels [i] and [æ] were perceived to be more nasal than the back vowels [ɑ], [ɔ], and [u]. The middle vowel [ʌ] was also perceived to be more nasal than the back vowels. It should be noted, however, that these differences are small, amounting at best to one scale value along a five-point scale.

To determine whether the differences among the median nasality ratings among the vowels were significant, the Friedman two-way analysis of variance (54, pp. 166-172) was employed. In this test, the nasality ratings of the vowels were ranked for each subject and a comparison of the ranks was made across all subjects to see if significant differences in ranks occurred. The resultant chi square value, .657, indicated that no significant differences existed among the vowels. It may be concluded, therefore, that the differences among the medians for the vowels could have occurred by chance.

The present findings differ from those of Spriestersbach and Powers (57) and Van Hattum (63) who have reported that front vowels are perceived to be significantly more nasal than back vowels in cleft palate subjects. Examination of the trends within the present data, however, suggests that a similar pattern existed within this cleft palate sample. There is little evidence to support the contention of Spriestersbach and Powers (57) that tongue height, per se, is the most important variable in the perception of nasality, since the high vowel [u] was judged to be among the least nasal of the vowels studied. Interestingly, the vowel [u] was reported by Lintz and Sherman (39) to be perceived as one of the least nasal vowels produced by subjects with functional nasality.

A comparison of these median nasality ratings with the findings regarding mean sound pressure differences reported in the previous section suggests that vowels which are associated with the largest nasal-"oral" sound pressure differences are not necessarily those which are perceived to be most nasal. The vowels [i] and [u] were associated with significantly larger sound pressure differences than the other vowels studied, but did not differ significantly from the other vowels in rated nasality. Indeed, the vowel [u] was among those vowels rated as least nasal.

Sentences

Nasality in the sentences was rated under the conditions of forward and backward play. The median nasality rating for each of the six sentences under conditions of forward and backward play obtained over all subjects are presented in Table 7. Inspection of Table 7 shows

TABLE 7.--The median of the nasality ratings for the group of twenty subjects for each of the six sentences played forward and played backward.

SENTENCE	MEDIAN NASALITY RATING (FORWARD)	MEDIAN NASALITY RATING (BACKWARD)
#1	4	3
#2	3.5	4
#3	4	4
#4	4	4
#5	4	3.5
#6	3	4

that, in the forward play condition, sentences #1, #3, #4, and #5 were assigned a median nasality rating of "4"; sentence #2, a median rating of "3.5"; and sentence #6, a median rating of "3". In the backward play condition, sentences #2, #3, #4, and #6 were assigned a median rating of "4"; sentence #5, a median rating of "3.5"; and sentence #1, a median rating of "3". It can be seen that, in both forward and backward play conditions, the differences in median nasality ratings are small and that, in each instance, four of the six sentences received identical median ratings. It is interesting, however, that sentence #1, which was judged to be the least nasal sentence in the backward play condition, was judged to be among the most nasal sentences in the forward play condition. Conversely, sentence #6, which was judged the least nasal sentence in forward play, was judged to be among the most nasal sentence in the backward play condition.

To determine whether significant differences existed among the median nasality ratings reported in Table 7, the Friedman two-way analysis of variance (54, pp. 166-172) was employed. The resulting chi square values, 7.82 and 5.76, for the forward and backward play conditions, respectively, indicated that the sentences ranked over subjects did not significantly differ in median nasality ratings in either rating condition. These findings suggest that the nasality present in the subject sample was reflected to a similar extent in each of the six sentences.

Relationships of Sound Pressure Differences and Nasality Ratings

A third purpose of the study was to investigate the relationships among measures of nasal-"oral" sound pressure differences and ratings of severity of nasality in the vowels and sentences comprising the present speech sample. Specifically, the study was designed to explore: (a) the relationship of sound pressure measures in vowels to sound pressure differences in sentences; (b) the relationships among nasality ratings in vowels, sentences played forward, and sentences played backward; and (c) the relationships between sound pressure differences and nasality ratings in vowels, sentences played forward, and sentences played backward. The findings related to these areas of inquiry mentioned above are presented in the following sections.

Sound Pressure Differences of Vowels and Sentences

To determine the relationships of nasal-"oral" sound pressure differences of the vowels, both individually and as a group, with those of the sentences as a group, the Spearman rank correlation coefficients presented in Table 8 were obtained (54, pp. 203-213). In view of previous findings (see page 62) that significant sound pressure differences occurred among vowels selected for study and that no significant differences in sound pressure differences or in nasality ratings were found for the individual sentences, correlations involving individual sentences were not attempted. Inspection of Table 8 shows that the coefficient of correlation for the group of vowels with the group of sentences was .52. This coefficient was statistically significant, and it indicates a moderately strong relationship between the two. That is, when nasal-"oral" sound pressure differences in vowels increase or decrease, it can be expected that the sound pressure differences in sentences tend to increase or decrease, respectively. When the correlations of the individual vowels and the group of sentences were obtained, it was found that the highest coefficient was obtained for the vowel [u], .71; followed in

TABLE 8.--Spearman rank correlation coefficients between the nasal-"oral" sound pressure differences of vowels, both individually and as a group, and those of the sentences as a group.

VOWEL	CORRELATION COEFFICIENT
[i]	.58*
[æ]	.45*
[ɑ]	.57*
[ʌ]	.52*
[u]	.71*
[ɔ]	.58*
All vowels	.52*

*$p \leq .05$

order by those for the vowels [i] and [ɔ], .58; [ɑ], .57; [ʌ], .52; and [æ], .45. All of these coefficients were statistically significant. They suggest that a strong relationship exists between nasal-"oral" sound pressure differences on the sentences and those on the vowel [u], while a moderately strong relationship exists for the other vowels. It will be observed that the correlation coefficient for the vowels as a group, .52, is exceeded in magnitude by the correlation coefficients of the vowels [i], [ɑ], [u], and [ɔ]. Thus, the nasal-"oral" sound pressure differences of any of these four vowels would better predict the sound pressure on connected speech than would the sound pressure differences of the vowels as a group. However, it appears that the nasal-"oral" sound pressure difference of the vowel [u] would give the best estimate of the nasal-"oral" sound pressure differences of connected speech.

Nasality Ratings of Vowels and Sentences

To determine the relationship of nasality ratings of vowels, both individually and as a group, with those of the sentences as a group, Spearman rank correlation coefficients were obtained as presented in Table 9. This table shows that the coefficients for the correla-

TABLE 9.--Spearman rank correlation coefficients between the nasality ratings of vowels, both individually and as a group, and those of the sentences as a group, under conditions of forward and backward play.

VOWEL	CORRELATION COEFFICIENT (FORWARD)	CORRELATION COEFFICIENT (BACKWARD)
[i]	.29	.42
[æ]	.14	.22
[ɑ]	.44	.58*
[ʌ]	.31	.33
[u]	.14	.33
[ɔ]	.54*	.65*
All vowels	.30	.55*

*$P \leq .05$

tion of the median nasality ratings of all vowels with those of all sentences played forward and of all sentences played backward were .30 and .55, respectively. Only the latter coefficient is statistically significant. These findings suggest that it would be very unlikely that perceived nasality in connected speech could be predicted accurately on the basis of the nasality perceived in vowels. On the other hand, the moderately strong relationship between nasality ratings of the group of vowels and those of the group of sentences played backward suggests that the degree of perceived nasality in vowels may give a moderately accurate prediction of the degree of nasality present in connected speech played backward. It may further suggest that rating nasality in sentences played backward may be based primarily upon the vowels present in the sentences. Sherman (53) postulated that backward play was a more valid procedure in rating nasality, because she speculated that the influence of consonant articulation was minimized while the voice quality to be judged was not altered.

Table 9 also presents the correlation coefficients obtained for the nasality ratings of individual vowels and the median nasality ratings of the group of sentences played forward. The highest correlation, .54, was found for the vowel [ɔ]; followed in order by those for the vowels [ɑ], .44; [ʌ], .31; [i], .29; [æ], and [u], .14. Only that for the vowel [ ] was statistically significant. Inspection of Table 9 shows that the highest correlation coefficient for the nasality ratings of the vowels and the nasality ratings of the group of sentences played backward was found the vowel [ɔ], .65; followed in order by those for the vowels [ɑ], .58; [i], .42; [ʌ] and [u], .33; and [æ], .22. Only those for the vowels [ɔ] and [ɑ] were statistically significant. The trends in the relationship of the nasality ratings of the individual vowels with those of the sentences played forward and played backward were similar in that the highest correlation coefficients were found for the low back vowels [ɔ] and [ɑ]. These coefficients indicate that the nasality ratings of certain vowels may better predict nasality of connected speech than would nasality ratings of the group of vowels. Whereas the nasality ratings of the group of vowels was poorly correlated with the nasality ratings of the group of sentences played forward (r_s = .30), the vowels [ɔ] and [ɑ] correlated more highly (r_s = .54 and .44, respectively). Likewise, the correlation of nasality ratings of the group of vowels with those of the group of sentences played backward (r_s = .55) was exceeded by the correlations of the vowels [ɔ] and [ɑ] (r_s = .65 and .58, respectively). It is interesting to note that nasality ratings of the low back vowels, [ɔ] and [ɑ], best predict nasality in sentences, while the nasal-"oral" sound pressure differences of the high back vowel [u] best predict nasal-"oral" sound pressure differences in sentences.

To determine the relationship between the median nasality ratings of the group of sentences played forward with those of the group of sentences played backward, a Spearman rank correlation was made. The statistically significant correlation coefficient, .84, indicated a strong relationship between nasality ratings obtained by the two methods of presentation. This coefficient is similar to that obtained by Sherman, .89, for nasality ratings of sentences under conditions of forward and backward play. This correlation coefficient indicates that ratings obtained on sentences played forward will in most cases be the same as those obtained by backward play, and vice versa.

Sound Pressure Differences and Nasality Ratings of Vowels and Sentences

A major purpose of this investigation dealt with the relationship of nasal-"oral" sound pressure differences and nasality ratings of vowels and sentences. Spearman rank correlation coefficients were obtained for each item and each group of items. The correlation coefficients for the groups of items are presented in Table 10. Inspection

TABLE 10.--Spearman rank correlation coefficients between the mean nasal-"oral" sound pressure differences and the median nasality ratings for the group of vowels and the group of sentences played forward and backward.

GROUP	CORRELATION COEFFICIENT
Vowels	.22
Sentences forward	.75*
Sentences backward	.60*

*$P \leqq .05$

of Table 10 shows that the highest correlation was found for the sentences played forward, .75; followed in order by those for the sentences played backward, .60; and for the vowels, .22. Only the correlation coefficients for the sentences were statistically significant. These findings indicate that there is a substantially greater relationship between nasal-"oral" sound pressure differences and nasality ratings in sentences than in vowels and that, in sentences, nasal-"oral" sound pressure differences are more closely related to nasality ratings of sentences played forward than of sentences played backward. They suggest that attempts to predict the degree of perceived nasality in vowels on the basis of these nasal-"oral" sound pressure differences would be difficult. They further suggest that on the basis of nasal-"oral" sound pressure differences in sentences, it is easier to predict perceived nasality in sentences played forward than in sentences played backward.

When the correlation coefficients of nasality ratings and sound pressure measures for the individual vowels are considered, as presented in Table 11, it will be observed that statistically significant coef-

TABLE 11.--Spearman rank correlation coefficients between the nasal-"oral" sound pressure differences and the nasality ratings of each of the vowels.

VOWEL	CORRELATION COEFFICIENT
[i]	.22*
[æ]	.45*
[ɑ]	.59*
[ʌ]	.20
[u]	.21
[ɔ]	.51*

*$p \leqq .05$

ficients were found for [ɑ], .59; [ɔ], .51; and [æ], .45. Low correlations of .22, .21, and .20 were found for [i], [u], and [ʌ], respectively. It is interesting to note that [i] and [u] are the two vowels that had the largest mean nasal-"oral" sound pressure differences averaged over all subjects, while [ʌ] had the lowest difference. These correlation coefficients indicate that the relationship of sound pressure differences and nasality ratings varies according to the vowel. Although vowels as a group correlate poorly (r_s = .22), this may be due to the high vowels [i] and [u] and the middle vowel [ʌ]. The low vowels [ɑ] and [ɔ], especially, afford moderately high correlations of sound pressure differences with nasality ratings, so that sound pressure differences in either vowel provide a fair estimate of the degree of nasality perceived in these vowels. It will be recalled that the sound pressure differences of the low back vowels [ɑ] and [ɔ] were also good predictors of the sound pressure differences of the sentences and that nasality ratings of these vowels were the best predictors of the degree of perceived nasality in sentences. It is interesting that these vowels which are characterized by the smallest sound pressure differences and are rated among the least nasal of the vowels tested should have the highest predictive value. House and Stevens (31) have indicated that small amounts of nasal coupling produce marked changes in the spectra of the vowels [i] and [u] and that a much greater degree of nasal coupling is needed to produce comparable changes in the spectrum of [ɑ]. Further, they reported that, as the average area of nasal coupling increases, the vowels [i] and [u] are perceived as being nasal sooner than the vowel [ɔ] and that the vowel [ɑ] is the last to be perceived as nasal. It might be speculated, therefore, that when the vowel [ɑ] is perceived as nasal, all other vowels are likely to be judged nasal; whereas when [i] and [u] are perceived to be nasal, other vowels may not be so judged. House and Stevens also reported that the vowel [æ] was perceived as nasal by their listeners even when no nasal coupling was present, and that their physical data correlated poorly with perceived nasality in this vowel. This finding is consistent with the generally low correlations found among the physical and perceptual measures for this vowel seen in the present study.

The Spearman rank correlation coefficients of the nasal-"oral" sound pressure differences of the individual sentences with nasality ratings of the individual sentences played forward are presented in Table 12.

Inspection of this table reveals that these correlations were .73, .70, .60, .75, .74, and .77 in the numerical order of the sentences. The

TABLE 12.--Spearman rank correlation coefficients between the nasal-"oral" sound pressure differences of the sentences and the nasality ratings of the sentences played forward.

SENTENCE	CORRELATION COEFFICIENT
#1	.73*
#2	.70*
#3	.60*
#4	.75*
#5	.74*
#6	.77*

*$P \leqq .05$

coefficients, which are very similar in magnitude and statistically significant, indicate a strong relationship of sound pressure differences and nasality ratings on each of the sentences. It appears from these correlation coefficients that perceived nasality in connected speech is possibly due, in large measure, to nasal-"oral" sound pressure differences.

The correlation coefficients for the nasal-"oral" sound pressure differences of individual sentences with nasality ratings of the individual sentences played backward are presented in Table 13. Inspection of this table shows a substantial relationship of sound pressure differences and nasality ratings in several sentences. The highest correlation coefficient that was statistically significant was obtained for sentence

TABLE 13.--Spearman rank correlation coefficients between the nasal-"oral" sound pressure differences of the sentences and the nasality ratings of the sentences played backward.

SENTENCE	CORRELATION COEFFICIENT
#1	.32
#2	.46*
#3	.58*
#4	.60*
#5	.36
#6	.67*

*$P \leqq .05$

#6, .67; followed in order by those for sentences #4, .60; #3, .58; and #2, .46. With the exception of the coefficients for sentences #6 and #4, none of the correlation coefficients was as large as those obtained for the sentences played forward.

It has been reported (53, 56) that nasality ratings of sentences played backward are more "valid" than ratings of sentences played forward because backward play removes irrelevant factors such as articulation of consonants, allowing the judges to perceive better the voice quality to be judged. The present findings suggest that, to the extent that nasality is due to an imbalance of nasal-"oral" sound pressures, rating sentences played forward may be a more valid procedure. While it may be argued that the validity of the two rating methods can not be determined on the basis of their relationship to a physical measure of nasal-"oral" sound pressure differences in that nasality is by definition a subjective phenomenon, the present findings raise a question concerning the relative validity of the two rating procedures which might be profitably explored in future research.

CHAPTER V

SUMMARY AND CONCLUSIONS

The present study was designed to investigate the relationships among measures of nasal-"oral" sound pressure differences and ratings of perceived nasality in cleft palate speech. It was undertaken because of the need for information regarding the acoustic events that contribute to the perception of nasality and the need for more objective and quantifiable measures of close correlates of nasality which might be used in future research. Subjective ratings by trained judges have been used extensively in investigations of nasality, but this procedure presents certain inherent limitations. While research studies (53, 56) have demonstrated that the reliability of this technique is adequate, there is reason to question its validity. A review of the pertinent literature indicates that a variety of resonance problems have, at various times, been included within the classification "nasality". The possibility exists therefore, that investigators who have studied nasality by means of rating procedures have not always been dealing with the same resonance phenonenon. It is apparent that close interjudge and intrajudge agreement can be obtained within individual studies. However, the resonance distortion rated in different studies may not be identical and, indeed, may be sufficiently dissimilar to produce discrepant findings. Furthermore, ratings of nasality may be affected by aberrances of the speech signal other than those related to resonance, e. g., misarticulations, unpleasantness of quality, and disturbances of phonation. For these reasons, attempts have been made through the years to develop objective and quantitative ways of assessing the resonance distortions which are denoted as "nasality". The present study represents such an attempt.

In this study, thirteen male and seven female cleft palate adolescents and adults were utilized as subjects. All were between the ages of fifteen and forty-two years, presented an operated cleft palate, had no more than a 20-db hearing loss in the speech range in the better ear, and were judged capable of performing the experimental task following brief instruction and practice.

Each subject produced a speech sample consisting of six isolated vowels, [i], [æ], [ɑ], [ʌ], [u], and [ɔ], and six sentences containing no nasal consonants and balanced phonetically to include a similar number of plosive and fricative sounds. The productions were recorded by means of two condenser microphones, their associated amplifiers, and a dual-channel tape recorder. One microphone was placed eight inches in front of the mouth and sampled the "oral" (total) speech signal. The other microphone, modified by the addition of a probe-tube, was inserted into the least-occluded nostril to sample the speech signal within the nasal cavity. The sound pressures of the simultaneously recorded nasal and "oral" signals of each speech production were determined by introducing the signals separately into a power level recorder. The arithmetic difference between the obtained nasal and "oral" sound pressures was computed for each speech item produced by each subject. This arithmetic difference was denoted as the "nasal-'oral' sound pressure difference".

Listener ratings of nasality were obtained of the recorded "oral" signal of each speech production. The isolated vowels were rated only in forward play; the sentences were rated under conditions of forward and backward play. Three judges, who hold advanced degrees in speech pathology and are experienced in judging cleft palate speech, rated the severity of nasality independently on a five-point scale of equal-appearing intervals, in which the scale value "1" represented the mildest nasality and the scale value "5", the severest nasality present in the twenty productions of the item being rated. The median of the judges' independent ratings was obtained for each production and was denoted as the nasality rating for that item.

The differences in sound pressure measures and nasality ratings were analyzed statistically by means of appropriate parametric and nonparametric forms of analysis of variance and by the Duncan Multiple Range test. Relationships among sound pressure measures and nasality ratings were explored using the Spearman rank correlation. A summary of the findings and of the conclusions derived from them are presented in the following sections according to the three major research questions posed in this study.

Sound Pressure Measures

The first research question asked in the present study was: What differences in nasal-"oral" sound pressure measures exist among the six vowels [i], [æ], [ɑ], [ʌ], [u], and [ɔ] and the six sentences included in this speech sample? The findings related to this question indicate that significantly greater mean sound pressure differences occurred for the vowels [i] and [u] than for the vowels [æ], [ɑ], [ʌ], and [ɔ] and that the mean difference for the vowel [i] exceeded that for [u].

All other differences among means were not significant. No statistically significant differences were found among the mean sound pressure differences for the six sentences.

These findings suggest that vowels characterized by high tongue placement are, on the average, associated with greater sound pressure differences than vowels with low tongue placement. A comparison of this finding with those of Pierce (47) and of Summers (60), who studied samples of cleft palate and normal speakers, respectively, indicates that there was a similar pattern of sound pressure differences for these vowels. The fact that Summers' normal-speaking subjects presented a pattern of sound pressure differences similar to that found in the present study suggests that the greater differences observed for [i] and [u] are not a unique feature of cleft palate speech, but, rather, an exaggeration of a pattern seen in normal speakers. Since the vowels [i] and [u] are produced with an essentially complete velar seal by normal speakers (45, 31), the greater sound pressure differences in these vowels in normal speech may be due to a greater impedance of the orally emitted speech signal caused by the high position of the tongue during their production. In cleft palate speakers, the combined effect of velar incompetency and high oral impedance might explain the greater magnitude of sound pressure differences in these vowels. This finding is given indirect support by House and Stevens (31), who reported, in an analog study of nasality, that the vowels [i] and [u] require smaller degrees of nasal-oral coupling to be perceived as nasal than do other vowels.

The lack of significant differences among the mean sound pressure measures for the six sentences suggests that each of the sentences reflected to a similar degree the subjects' sound pressure differences in connected speech. The fact that the sound pressure differences in each of the sentences were similar appears to be related to their similarity in phonetic composition.

Nasality Ratings

The second research question posed in the present study was: What differences in nasality ratings exist among the six vowels and six sentences as played forward and played backward? The findings relating to this question indicate that there were no significant differences among median nasality ratings for the six vowels. Examination of the trends within the data, however, showed that the vowels [i], [æ], and [ʌ] were rated more nasal, on the average, than the vowels [ɑ], [ɔ], and [u]. The differences in median ratings amounted at best to one scale value along a five-point scale. The trend toward higher nasality ratings for the front vowels [i] and [æ] is consistent with the reports of Spriestersbach and Powers (57) and Van Hattum (63), who state that front vowels are perceived to be more nasal than back vowels. There is little support, however, for the contention of Spriestersbach and Powers (57) that tongue height is the most important variable in the perception of nasality. It is of particular interest that the vowel [u], which House and Stevens (31) have described as a vowel whose spectral characteristics are easily altered by small degrees of nasal-oral coupling, was perceived as one of the least nasal of the vowels studied.

No statistically significant differences among the median nasality ratings of the six sentences were found. This finding suggests that each of the six sentences were perceived to be equally nasal by the judges. The fact that the sentences were similar in mean sound pressure differences and in phonetic composition might account for this finding.

Sound Pressure Differences and Nasality Ratings of Vowels and Sentences

The third research question asked in this study was: What relationships exist among the sound pressure measures and nasality ratings for the six vowels and for the six sentences played forward and backward?

The results of this study indicate that nasal-"oral" sound pressure differences for the vowels, as a group, are moderately related to the sound pressure differences for the sentences, as a group (r_s = .52). This finding suggests that the sound pressure differences which the subjects displayed in vowel production tended to correspond to the sound pressure differences they displayed in production of the sentences. It was also found that the relationship between sound pressure differences for individual vowels and those for sentences as a group, varied according to the vowel. The highest degree of relationship was found for the vowel [u] (r_s = .71). Correlations for the vowels [ɑ], [ɔ], and [i] were highly similar (r_s = .57, .58, .58) and exceeded that found for the vowels as a group. The correlation for the vowel [æ] (r_s = .45) was the lowest and was not as high as that for the vowels as a group. These findings suggest that sound pressure differences measured in certain isolated vowels are superior to those of other vowels in predicting the sound pressure differences in sentences. The high correlation for [u] might be explained by the finding of House and Stevens (31) that this vowel is sensitive to small degrees of nasal-oral coupling and, consequently, might serve as a good indicator of the presence of even slight imbalances of nasal and "oral" sound pressure. It may be noted, however, that the size of the correlation for the vowel [i], whose spectral characteristics are also easily altered by small degrees of nasal-oral coupling, was similar to those for the vowels [ɑ] and [ɔ], which are said to be relatively insensitive to the effects of nasal-oral coupling. These differences in relationships among the individual vowels might be explored profitably in future studies.

In general, the findings suggest that one cannot predict, without substantial error, the sound pressure differences in sentences on the basis of sound pressure differences in vowels. Furthermore, they indicate that the success of prediction can be expected to vary with individual vowels. It may be that the lack of a closer relationship between the sound pressure measures in vowels and sentences reflects differences in the characteristics of vowels in isolation and vowels in consonant contexts of connected speech.

When the relationships among nasality ratings of vowels, sentences played forward, and sentences played backward are examined, it is found that the ratings for the vowels as a group correlate more highly with ratings of the group of sentences played backward ($r_s = .55$) than with ratings of the group of sentences played forward ($r_s = .30$). When ratings of individual vowels were correlated with ratings of the group of sentences played forward and played backward, a similar trend obtained. Nasality ratings for each vowel were correlated more highly with the ratings of sentences played backward than with ratings of sentences played forward. These findings suggest that the perceptual task of rating vowels in isolation may be more similar to that of judging nasality in sentences played backward than in sentences played forward. The findings show that the ratings of the low back vowels [ɑ] and [ɔ] correlated most highly with the ratings of the group of sentences in both the forward and backward play conditions. The correlation coefficients for [ɑ] were .44 and .58 and those for [ɔ] were .54 and .65 for forward and backward play, respectively. The higher predictive value of the low back vowels may be related to the finding of House and Stevens (31) that these vowels require a greater degree of nasal-oral coupling than other vowels to be perceived as nasal and consequently, are better indicators of the presence of nasality in vowels. The size of the correlations suggests that, even when the nasality ratings of the vowels [ɑ] and [ɔ] are used to estimate the degree of nasality in connected speech, substantial error in prediction may occur.

The present study also indicates that a strong relationship exists between nasality ratings of the sentences played forward and those of the sentences played backward ($r_s = .84$). This finding is consistent with that reported by Sherman (53), who found a correlation of .89 between nasality judgments obtained under conditions of forward and backward play. The magnitude of the correlation indicates that judgments made under the two conditions are highly similar and suggests that subjects with a given nasality rating obtained under one condition would receive a similar rating in the other. Sherman (53) and Spriestersbach (56) have suggested that ratings of nasality made in the backward play condition are more valid in that irrelevant factors such as misarticulations do not influence the judgments. The relative validity of the two procedures, however, remains open to question.

When the relationships between the sound pressure differences and the corresponding nasality ratings of each group of speech items are considered, it is observed that the highest correlation was obtained between sound pressure differences in the sentences and nasality ratings of the sentences in the forward play condition (r_s = .75). Sound pressure differences in sentences and nasality ratings of the sentences in the backward play condition were less highly correlated (r_s = .60), while sound pressure differences and nasality ratings of the vowels were poorly correlated (r_s = .22). These findings suggest that measures of nasal-"oral" sound pressure differences and subjective ratings of nasality are more highly related in sentences than in vowels. They further suggest that the sound pressure differences were more highly related to subjective ratings of sentences played forward than sentences played backward. It would appear reasonable to speculate, on the basis of these relationships, that the relative intensity of the nasal and "oral" speech signals serves as a cue in the perception of nasality to a greater extent in sentences as they are normally heard by the listener (in the forward play condition), than it does in vowels or in sentences played backward. While the reasons for these relationships are not immediately apparent, it is of interest that nasality ratings of vowels were found to be more highly related to nasality ratings of sentences played backward than to ratings of sentences played forward. There is a suggestion, therefore, that what the listener perceives as nasality in vowels is similar to that which he perceives in sentences played backward. Further, it appears that neither of these perceptions is as highly related to sound pressure differences as that perceived in sentences played forward. It may be that the ability of the listener to utilize cues related to sound pressure differences is reduced in judgments of vowels or sentences played backward. It may also be that sound pressure differences in consonants, which are absent in isolated vowels and less well perceived in sentences played backward, affect the perception of nasality more than has been thought.

The weak relationship between sound pressure differences and nasality ratings of the vowels as a group (r_s = .22) does not hold true for all vowels. Moderately strong relationships were found for the low back vowels [ɑ] and [ɔ] (r_s = .59 and .51, respectively). It will be recalled that the sound pressure differences of these vowels were also good predictors of the sound pressure differences of the sentences and that nasality ratings of these vowels were the best predictors of the degree of perceived nasality in sentences. Presumably, the fact that the spectra of these vowels are least easily altered by nasal-oral coupling makes them better indicators of the presence of nasality in vowels. It might be speculated that when [ɑ] is perceived to be nasal, all other vowels are likely to be judged nasal.

The correlation coefficients for the sound pressure differences and nasality ratings for each of the six sentences played forward were highly similar in magnitude, while those for the individual sentences played backward evidence variations in magnitude. This suggests that the nasality ratings of each of the sentences played forward were rather uniformly related to nasal-"oral" sound pressure differences in that sentence, and that nasality ratings of each of the sentences played backward were not related to the same degree to nasal-"oral" sound pressure differences in that sentence. This finding suggests that other factors, in addition to nasal-"oral" sound pressure differences, may have been operating in the perception of nasality in the sentences played backward. To the extent that perceived "nasality" is related to nasal-"oral" sound pressure differences, it appears that nasality ratings of sentences obtained by the technique of backward play may not be as valid as those obtained on the basis of forward play.

Following is a summary of the findings of this investigation:

1. Greater mean nasal-"oral" sound pressure differences occurred for the vowels [i] and [u] than for the vowels [æ], [ɑ], [ʌ], and [ɔ]; the mean sound pressure difference for [i] exceeded that for [u].

2. Vowels characterized by high tongue placement were, on the average, associated with greater sound pressure differences than vowels with low tongue placement.

3. Sound pressure differences among the six sentences, which were similar in phonetic composition, were highly similar.

4. Statistically significant differences in nasality ratings for the six vowels were not found. Trends within the data, however, suggested that there was a tendency for front vowels to be rated more nasal than back vowels.

5. Nasality ratings of the six sentences were very similar, suggesting that each of the six sentences reflected equally the nasality present in the subject sample. This was true of ratings obtained under conditions of forward play and backward play.

6. The sound pressure differences measured in vowels were found to be moderately related to sound pressure differences measured in sentences. Among the six vowels, sound pressure differences for [u] were most highly correlated with sound pressure in sentences.

7. Nasality ratings of vowels as a group correlated more highly with ratings of the group of sentences played backward than with ratings of the group of sentences played forward.

8. Nasality ratings of the vowels [ɑ] and [ɔ] correlated more highly with ratings of the sentences as a group, in both the forward and backward play conditions, than did nasality ratings of the other vowels.

9. Nasality ratings of sentences obtained under conditions of forward and backward play were highly related.

10. Nasality ratings and sound pressure differences were more highly related in sentences than in vowels; for the sentences, sound pressure differences are more highly related to nasality ratings when obtained in forward play than in backward play.

BIBLIOGRAPHY

1. Beighley, K. C. "What The Experts Say About Nasality," Quarterly Journal of Speech, XXIX (April, 1943), pp. 199-206.

2. Bell, A. M. "The Nasal Twang," Modern Language Notes, V (March, 1890), pp. 75-76.

3. Benson, Jack Franklin. "An Experimental Study of the Relationship Between the Amount of Nasal Emission of Air and Judged Nasality," Unpublished Master's thesis, University of West Virginia, 1951.

4. Benson, Robert W. "The Calibration and Use of Probe-Tube Microphones," Journal of the Acoustical Society of America, XXV (January, 1953), pp. 128-134.

5. Beranek, L. L. Acoustic Measurements. New York: John Wiley and Sons, Inc., 1949.

6. Bloomer, Harlan. "A Spectrographic Study of Hypernasality," Cleft Palate Bulletin, V (April, 1955), pp. 5-6.

7. Brown, James B. "Elongation of the Cleft Palate to Gain Better Nasopharyngeal Closure," Journal of Speech Disorders, IV (June, 1939), pp. 157-162.

8. Brown, Spencer F. and Oliver, Dorothy. "A Qualitative Study of the Organic Speech Mechanism Abnormalities Associated With Cleft Palate," Journal of Speech Disorders, V (September, 1940), pp. 265-270.

9. Buck, McKensie. "Facial Skeletal Measurements and Tongue Carriage in Subjects With Repaired Cleft Palates," Journal of Speech and Hearing Disorders, XVIII (June, 1953), pp. 121-132.

10. Bullen, Adaline. "Nasality: Cause and Remedy of Our American Blight," Quarterly Journal of Speech, XXVIII (February, 1942), pp. 83-84.

11. Cotton, Jack C. "A Study of Certain Phoniatric Resonance Phenomena," Journal of Speech Disorders, V (December, 1940), pp. 289-293.

12. Counihan, Donald T. "A Clinical Study of the Speech Efficiency and Structural Adequacy of Operated Adolescent and Adult Cleft Palate Persons," Unpublished Ph.D. dissertation, Northwestern University, 1956.

13. Curtis, James F. "An Experimental Study of the Wave-Composition of Nasal Voice Quality," Unpublished Ph.D. dissertation, State University of Iowa, 1942.

14. Dickson, David Ross. "An Acoustic and Radiographic Study of Nasality," Dissertation Abstracts, XXII (January, 1962), p. 2506.

15. Dixon, Wilfrid J. and Massey, Frank J., Jr. Introduction to Statistical Analysis. New York: McGraw-Hill Book Company, Inc., 1957.

16. Dorrance, G. M. The Operative Story of Cleft Palate. Philadelphia: W. B. Saunders, 1933.

17. Drake, O. J. "Toward An Improved Vocal Quality," Quarterly Journal of Speech, XXIII (December, 1937), pp. 620-623.

18. Fairbanks, Grant. Voice and Articulation Drillbook. New York: Harper and Brothers, 1940.

19. Fletcher, Samuel G. "Growth and Development of the Mouth and Pharynx Region: A Review of Normal Growth Patterns and a Method of Cephalometric Evaluation Applied to Individuals Having Hypernasal Voice," Logos, II (October, 1959), pp. 71-83.

20. ________. "Hypernasal Voice As An Indication of Regional Growth and Developmental Disturbances," Logos, III (April, 1960), pp. 3-12.

21. Froeschels, Emil. "Nose and Nasality," Archives of Otolaryngology, LXVI (December, 1957), pp. 629-633.

22. __________. Speech Therapy. Boston: The Expression Company, 1953.

23. Graber, T. M. "Oral and Nasal Structures in Cleft Palate Speech," Journal of the American Dental Association, LIII (December, 1956), pp. 693-706.

24. ______. "The Congenital Cleft Palate Deformity," Journal of the American Dental Association, XLVIII (April, 1954), pp. 375-395.

25. Gray, Giles W. and Wise, Claude M. The Bases of Speech. Rev. ed. New York: Harper and Brothers, Publishers, 1946.

26. Haggerty, Robert and Hoffmeister, F. S. "Velo-Pharyngeal Closure: An Index of Speech," Plastic and Reconstructive Surgery, XIII (March, 1954), pp. 291-298.

27. Hanson, Marvin Laverne. "A Study of Velopharyngeal Competency in Children With Repaired Cleft Palates," Unpublished Ph.D. dissertation, Wayne State University, 1961.

28. Harrington, Robert. "A Study of the Mechanism of Velopharyngeal Closure," Journal of Speech Disorders, IX (December, 1944), pp. 325-345.

29. Hattori, Shiro, Yamamoto, Kenjo and Fujimura, Osamu. "Nasalization of Vowels in Relation to Nasal," *Journal of the Acoustical Society of America*, XXX (April, 1958), pp. 267-274.

30. Hixon, E. H. "An X-Ray Study Comparing Oral and Pharyngeal Structures of Individuals With Nasal and Individuals With Superior Voices," Unpublished Master's thesis, State University of Iowa, 1949.

31. House, Arthur S. and Stevens, Kenneth N. "Analog Studies of the Nasalization of Vowels," *Journal of Speech and Hearing Disorders*, XXI (June, 1956), pp. 218-232.

32. Hultzen, L. S. "Apparatus for Demonstrating Nasality," *Journal of Speech Disorders*, VII (March, 1942), pp. 5-6.

33. Irwin, John V. and Van Riper, Charles. *Voice and Articulation*. Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1958.

34. Kantner, Claude E. "Diagnosis and Prognosis in Cleft Palate Speech," *Journal of Speech and Hearing Disorders*, XIII (September, 1948), pp. 211-222.

35. ________. "Four Devices in the Treatment of Rhinolalia Aperta," *Journal of Speech Disorders*, II (June, 1937), pp. 73-76.

36. Kelly, J. P. "Studies in Nasality," *Archives of Speech*, I (1934), pp. 26-42, abstracted in *Cleft Palate Bulletin*, XI (April, 1961), pp. 36-37.

37. Kaltenborn, Arthur Lewis, Jr. "An X-Ray Study of Velopharyngeal Closure in Nasal and Non-Nasal Speakers," Unpublished Master's thesis, Northwestern University, 1948, abstracted by David G. Phillips, *Speech Monographs*, XVI (September, 1949), pp. 343-344.

38. Lindsley, Charles F. "The Psycho-Physical Determinants of Voice Quality," *Speech Monographs*, I (September, 1934), pp. 79-116.

39. Lintz, Lois Brien and Sherman, Dorothy, "Phonetic Elements and Perception of Nasality," *Journal of Speech and Hearing Research*, IV (December, 1961), pp. 381-396.

40. MacDonald, Eugene T. and Koepp-Baker, Herbert. "Cleft Palate Speech: An Integration of Research and Clinical Observation," *Journal of Speech and Hearing Disorders*, XVI (March, 1951), pp. 9-20.

41. McWilliams, Betty J. "An Experimental Study of Some of the Components of Intelligibility of the Speech of Adult Cleft Palate Patients," Unpublished Ph.D. dissertation, University of Pittsburg, 1953.

42. Moore, Paul. "Voice Disorders Associated With Organic Abnormalities," *Handbook of Speech Pathology*. Edited by L. E. Travis, New York: Appleton-Century-Crofts, Inc., 1957.

43. Moser, Henry M. "Diagnostic and Clinical Procedures in Rhinolalia," Journal of Speech Disorders, VII (March, 1942), pp. 2-4.

44. Nakata, Kazuo. "Synthesis and Perception of Nasal Consonants," Journal of the Acoustical Society of America, XXXI (June, 1959), pp. 661-666.

45. Nusbaum, Edward A., Foley, Lena and Wells, Charlotte. "Experimental Studies of the Firmness of the Velar-Pharyngeal Occlusion During the Production of the English Vowels," Speech Monographs, II (October, 1935), pp. 71-80.

46. Peterson, Gordon E. "Parameters of Vowel Quality," Journal of Speech and Hearing Research, IV (March, 1961), pp. 10-29.

47. Pierce, Bruce R. "Nasal Resonance Differences Resulting From Speech Appliance Modifications in Cleft Palate Adults," Unpublished Ph.D. dissertation, Northwestern University, 1962.

48. Potter, Ralph K., Kopp, George A., and Green, Harriet C. Visible Speech. New York: D. VanNostrand Company, Inc., 1947.

49. Raubicheck, L., Davis, E. H. and Carll, L. A. Voice and Speech Problems. New York: Prentice-Hall Inc., 1931.

50. Russell, G. O. Speech and Voice. New York: Macmillan Co., 1931.

51. Russell, G. O. and Cotton, J. C. Causes of Good and Bad Voices. National Research Foundation, undated.

52. Sax, Mary T. "A Comparative Analysis of the Acoustic Structure of Vowel Sounds Produced With and Without Nasal Resonance," Speech Monographs, XVII (June, 1950), pp. 306-307.

53. Sherman, Dorothy. "The Merits of Backward Playing of Connected Speech in the Scaling of Voice Quality Disorders," Journal of Speech and Hearing Disorders, XIX (September, 1954), pp. 312-321.

54. Siegel, Sidney. Nonparametric Statistics for the Behavior Sciences. New York: McGraw-Hill Book Company, Inc., 1956.

55. Sigman, Jack L. "A Study of Nasality Comparing the Subjective Judgments of Speech Experts With Readings on the Nasometer," Unpublished Master's thesis, Ohio University, 1948.

56. Spriestersbach, D. C. "Assessing Nasal Quality in Cleft Palate Speech of Children," Journal of Speech and Hearing Disorders, XX (September, 1955), pp. 266-270.

57. Spriestersbach, D. C. and Powers, Gene R. "Nasality In Isolated Vowels and Connected Speech of Cleft Palate Speakers," Journal of Speech and Hearing Research, II (March, 1959), pp. 40-45.

58. Steel, Robert G. D. and Torrie, James H. Principles and Procedures of Statistics. New York: McGraw-Hill Book Company, Inc., 1960.

59. Subtelny, Joanne D. and Subtelny, J. Daniel. "Intelligibility and Associated Physiological Factors of Cleft Palate Speakers," Journal of Speech and Hearing Disorders, II (December, 1959), pp. 353-360.

60. Summers, R. R. "The Nasal Sound Pressure Levels of Vowels Produced at Specified Intensities," Unpublished Ph.D. dissertation, Purdue University, 1955.

61. Van Hattum, Rolland J. "Articulation and Nasality in Cleft Palate Speakers," Journal of Speech and Hearing Research, I (December, 1958), pp. 383-387.

62. Van Hattum, Rolland J. "Interrelationships Among Measures of Nasality and Articulation," Cleft Palate Bulletin, V (October, 1955), pp. 3-5.

63. Van Hattum, Rolland J. "The Interrelationships Among Measures of Articulation and Nasality in Cleft Palate Speakers," Unpublished Ph.D. dissertation, Pennsylvania State University, 1954.

64. Weiss, Arthur I. "Oral and Nasal Sound Pressure Levels As Related to Judged Severity of Nasality," Unpublished Ph.D. dissertation, Purdue University, 1954.

65. West, Robert, Kennedy, Lou and Carr, Anna. The Rehabilitation of Speech. New York: Harper and Brothers, 1937.

66. ________. The Rehabilitation of Speech. New York: Harper and Brothers, 1947.

67. Williams, R. L. "A Serial Radiographic Study of Velopharyngeal Closure and Tongue Position in Certain Vowel Sounds," Northwestern University Dental School Bulletin, LII (June, 1952), pp. 9-12.

68. Williamson, A. B. "Diagnosis and Treatment of Eighty-four Cases of Nasality," Quarterly Journal of Speech, XXX (December, 1944), pp. 471-479.

APPENDIX A

Oral Examination Form

Oral Examination Form

Name______________________________ Birthday__________ Sex___ Subject #___

Address____________________________________ Phone ___________ Date________

Type of Cleft______________________ Surgery__________________ Date________

Probe #____ Filter #____ __________________ Date________

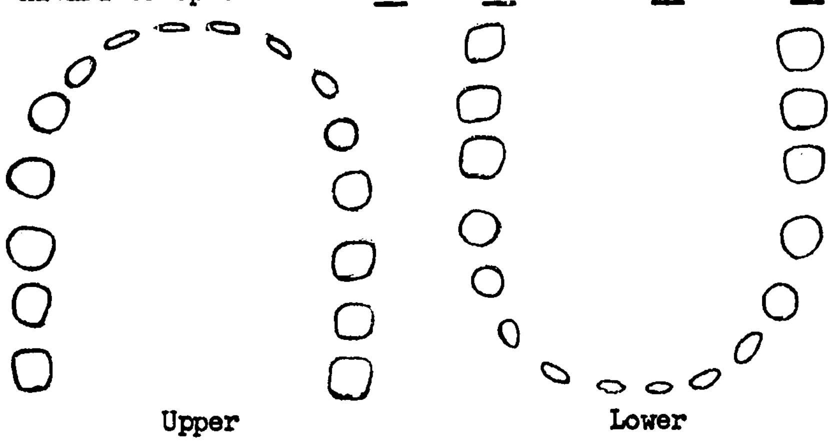
Lips
Describe deviations, scars, mobility_____________________________________
Pucker and Swing: Right_____ Left _____
Protrusion-retraction______ Rate/5 seconds_____
Smiling: Is there deviation to one side?_____ (Right___ Left___)
Number of times subject can say "bah" in 5 seconds_____
Mouth size: Small__ Average__ Large__ Opening during speech_____________

Tongue
Can subject point tongue on protrusion?_____
Is there deviation to one side?_____ (Right___ Left___)
Adequacy of grooving: Good__ Fair__ Poor__ Unable to do__
Can subject lateralize tongue?_____ Rate/10 seconds_____
Does tip elevate to alveolar ridge (Mandible stable)?____ Rate/10 sec_____
Number of times subject can say "tah" in 5 seconds_____
Number of times subject can say "kah" in 5 seconds_____

Dentition
Type of version / Edentulous spaces
- Labio--la
- Lingua--li
- Infra--i
- Supra--s

1. Missing tooth with space equal to that tooth.
2. Missing tooth with space somewhat less than that tooth.
3. Missing tooth with only small space.

Probable hazard to speech: None__ Mild__ Moderate__ Severe__



Upper Jaw
Occlusion: Normal__ Neutroclusion__ Distoclusion__ Mesioclusion__
Crossbite: None__ Right__ Left__
Open Bite: None__ Right__ Left__ Front__

Degree of Malocclusion: None__ Mild__ Moderate__ Severe__
Probable hazard to speech: None__ Mild__ Moderate__ Severe__

Maxillary and Mandibular Arches
Comparison of maxillary arch width to mandibular arch width:
Wider__ Equal__ Narrower__ Much narrower__
Probable hazard to speech: None__ Mild__ Moderate__ Severe__
Rate of opening and closing mandible in 10 seconds____.

Hard Palate
Palatal vaulting: Unusually high__ Average__ Low__ Unusually low__
Probable hazard to speech: None__ Mild__ Moderate__ Severe__

Velum
Velar length: Adequate for closure__ Short__ Very short__
Velar mobility: (Gag reflex) Good__ Fair__ Trace__ None seen__
(Phonation) Good__ Fair__ Trace__ None seen__
Symmetry of levator action: Greater on right__ Greater on left__ Equal__
Direction of velar movement: Is there evident backward movement?____
General nasopharyngeal closure: Inadequate__ Fair__ Good__

Posterior Pillars
Do the posterior pillars move in the direction of the pharyngeal wall during phonation? No__ Slightly__ Moderately__ Touch back wall__

Pharynx
Width: Narrow 1 2 3 Wide
Depth: Shallow 1 2 3 Deep
Anterior movement: None__ Fair__ Good__
Lateral movement: None__ Fair__ Good__

Nasal Cavity
Septum: Deviated to right__ Deviated to left__ Normal__
Size of nostrils: Small__ Average__ Moderately large__ Large__
Degree of obstruction: None__ Minimal__ Almost complete__
Most patent nostril: Right__ Left__ Equal__

Nasality: 5 4 3 2 1 0 -1 -2 -3 -4 -5

Nasal Emission: 5 4 3 2 1 0

Hearing:

	500	1000	3000
Right			
Left			

APPENDIX B

Speech Materials

Sentences Used In Study

1. Dad caught Sue's turtles by the shed.
2. They hid Toots' birthday cake Effie bought.
3. She bought bottles of pop over at those booths.
4. He should see if Sue's book is good.
5. Show Zed Bob's topcoat he has to take up.
6. The cook fed her fat hogs.

APPENDIX C

Instructions

Instructions To Subjects

Please be seated comfortably in this chair. During the experiment, it is important that you hold your head very still, so sit in a comfortable position and rest your head on the headrest.

In this experiment you will speak six vowel sounds and six short sentences into the microphone. The vowel sounds you are to produce are the underlined sounds in the words printed on the cards: [i] as in b<u>ee</u>; [æ] as in c<u>a</u>t; [ɑ] as in h<u>o</u>t; [ʌ] as in b<u>u</u>t; [u] as in b<u>oo</u>t; and [ɔ] as in b<u>a</u>ll. You are not to say the entire word but only the part that is underlined. My assistant will hold the cards so they can be easily seen by you during the recording of the vowels and the sentences. He will also say each speech item immediately before you speak it.

You should say the vowel sounds loudly enough that the needle on the VU meter will peak at "10". You will be given two signals on the signal lights. The yellow light will come on briefly, indicating that you are to take a breath and get ready to make the sound. When the white light comes on, you will begin making the sound. You will continue making the sound as long as the white light is on, or for about three seconds. Be very careful to peak the needle on the meter at "10". Some of the sounds are weak sounds and will have to be spoken loudly to peak at "10". Some of the sounds are strong sounds and will not have to be spoken as loudly to peak the needle at "10". You will be given an opportunity to practice peaking the needle on the vowel sounds before actually making the recording.

The six sentences will be similarly spoken when the signals are given. Take a breath and get ready to speak when the yellow light comes on, and then begin to speak the sentence when the white light comes on.

Speak in your normal rate of speech and with your normal inflection. If the white light goes off before you have finished the sentence, continue speaking until the sentence is finished. You will not be able to keep the needle on the meter peaked at "10" throughout the sentences. However, it should be peaked at "10" on the louder words in the sentences. The quieter portions of the sentences should be spoken loudly enough that the needle does not fall below "5" on the meter. You will be given an opportunity to practice the sentences before we actually make the recordings.

The probe-tube will be inserted about a quarter of an inch into one of your nostrils. It will not touch the walls of your nose, but it may touch some hairs and tickle slightly. If you will turn a tissue around in your nostril, you can push the hairs back to the side of the nostril so the probe-tube will hardly touch them. Be sure that you do not raise or lower your head once the probe-tube has been put in place. Your head will be loosely strapped to the headrest to discourage movement of the head. However, if it should be necessary for you to sneeze during the experiment, you can lift your head up from the probe-tube, and then push away the adjustable arm on which the probe-tube microphone is affixed. Are there any questions?

Instructions To Judges

You are to listen to eighteen speech items produced by twenty cleft palate subjects in order to rate the nasality of each production. The speech items are six isolated vowels, six sentences played forward and the same six sentences played backward. The productions of a given speech item by the twenty subjects will be played in a series. Before the playing of each production, a sample of four speakers, representing the two mildest and the two severest cases of nasality among the twenty productions of that item, will be presented. These four samples will serve as a reference of mild and severe nasality. Following the playing of the four samples, the production that is to be judged will be presented. You are to rate the nasality of this production on a scale from "1" to "5" in which "1" represents mild nasality and "5" represents severe nasality. Please disregard as much as possible such factors as articulation, pitch, rhythm, inflection, phrasing, and voice qualities other than nasality. Are there any questions?

APPENDIX D

Nasal Sound Pressures

TABLE 14

NASAL SOUND PRESSURES IN DECIBELS[1]
FOR EACH VOWEL BY SUBJECTS

SUBJECT	VOWEL					
	[i]	[æ]	[ɑ]	[ʌ]	[u]	[ɔ]
1	119	113	112	113	117	115
2	117	111	111	112	115	112
3	122	117	114	117	116	114
4	121	118	112	116	118	115
5	115	108	106	108	115	107
6	116	111	107	108	110	109
7	123	114	113	116	123	112
8	117	116	114	115	117	113
9	117	107	107	107	116	109
10	119	107	108	109	117	108
11	124	117	113	116	124	114
12	116	109	107	110	113	109
13	123	117	115	116	121	116
14	126	117	116	117	123	117
15	123	115	116	115	117	116
16	129	117	117	119	116	116
17	116	112	111	115	117	112
18	118	114	110	112	109	113
19	124	117	118	120	122	118
20	114	113	110	113	115	113

[1]Re: 0.0002 dyne/cm^2

TABLE 15

NASAL SOUND PRESSURES IN DECIBELS[1]
FOR EACH SENTENCE BY SUBJECTS

SUBJECT	SENTENCE					
	1	2	3	4	5	6
1	113	113	112	113	113	113
2	106	108	106	107	107	108
3	100	97	99	102	101	98
4	114	113	114	114	113	111
5	108	106	110	112	109	109
6	101	102	101	102	101	98
7	115	111	113	113	111	109
8	110	109	110	107	108	108
9	108	105	107	109	108	106
10	111	113	114	114	110	111
11	116	116	119	111	115	114
12	102	102	98	99	101	104
13	118	115	114	115	113	115
14	114	115	113	115	113	110
15	119	119	119	121	116	118
16	117	119	117	119	120	116
17	114	116	113	115	117	113
18	109	106	106	108	105	107
19	117	118	114	118	117	116
20	108	106	111	108	109	108

[1]Re: 0.0002 dyne/cm^2

APPENDIX E

"Oral" Sound Pressures

TABLE 16

"ORAL" SOUND PRESSURES IN DECIBELS[1]
FOR EACH VOWEL BY SUBJECTS

SUBJECT	VOWEL					
	[i]	[æ]	[ɑ]	[ʌ]	[u]	[ɔ]
1	82	80	79	80	81	83
2	80	80	79	81	79	78
3	81	83	81	82	84	81
4	80	80	80	82	80	78
5	79	78	78	79	79	79
6	80	80	80	80	83	80
7	83	83	81	83	83	81
8	84	82	81	80	85	81
9	82	80	82	79	82	83
10	82	80	79	80	83	80
11	82	82	80	80	81	80
12	83	83	80	82	81	81
13	82	84	81	83	83	82
14	83	82	80	82	81	82
15	83	81	80	82	80	81
16	83	83	83	84	82	83
17	83	83	84	85	82	84
18	82	83	83	84	83	83
19	83	82	81	83	80	83
20	83	83	83	84	83	84

[1]Re: 0.0002 dyne/cm^2

TABLE 17

"ORAL" SOUND PRESSURES IN DECIBELS[1]
FOR EACH SENTENCE BY SUBJECTS

SUBJECT	SENTENCE					
	1	2	3	4	5	6
1	75	76	73	75	75	74
2	72	73	72	71	71	72
3	77	74	73	79	75	74
4	73	74	74	74	72	73
5	76	72	75	77	77	74
6	77	72	75	75	77	71
7	78	71	77	76	74	72
8	77	76	78	76	78	76
9	76	72	75	75	73	75
10	74	76	77	74	73	74
11	75	74	78	75	73	73
12	74	72	70	75	73	75
13	77	74	74	75	72	73
14	78	77	75	77	77	76
15	77	77	78	75	75	76
16	76	77	77	76	78	74
17	76	73	75	75	76	75
18	74	71	72	72	72	73
19	76	72	71	73	73	74
20	74	75	76	76	77	71

[1]Re: 0.0002 dyne/cm^2

APPENDIX F

Nasal-"Oral" Sound Pressure Differences

TABLE 18

NASAL-"ORAL" SOUND PRESSURE DIFFERENCES IN DECIBELS FOR EACH VOWEL BY SUBJECTS

SUBJECT	VOWEL					
	[i]	[æ]	[ɑ]	[ʌ]	[u]	[ɔ]
1	37	33	33	33	36	32
2	37	31	32	31	36	34
3	41	34	33	35	32	33
4	41	38	32	34	38	37
5	36	30	28	29	36	28
6	36	31	27	28	27	29
7	40	31	32	33	40	31
8	33	34	33	35	32	32
9	35	37	25	28	34	26
10	37	27	29	29	34	28
11	42	35	33	36	43	34
12	33	26	27	28	32	28
13	41	33	34	33	38	34
14	43	35	36	35	42	35
15	40	34	36	33	37	36
16	46	34	34	35	34	33
17	33	29	27	30	35	28
18	36	31	27	28	26	30
19	41	35	38	37	42	35
20	31	30	27	29	32	29

TABLE 19

NASAL-"ORAL" SOUND PRESSURE DIFFERENCES IN DECIBELS FOR EACH SENTENCE BY SUBJECTS

SUBJECT	SENTENCE					
	1	2	3	4	5	6
1	38	37	39	38	38	39
2	34	35	34	36	36	36
3	23	23	26	23	26	24
4	41	39	40	40	41	38
5	32	34	35	35	32	35
6	24	30	26	27	24	27
7	37	40	36	37	37	37
8	33	33	32	31	30	32
9	32	33	32	34	35	31
10	37	38	37	40	37	37
11	41	42	41	36	42	41
12	28	30	28	24	28	29
13	41	41	40	40	41	42
14	36	38	38	38	36	34
15	42	42	41	46	41	42
16	41	42	40	43	42	42
17	38	43	38	40	41	38
18	35	35	34	36	33	34
19	41	46	43	45	44	42
20	34	31	35	32	32	37

APPENDIX G

Nasality Ratings

TABLE 20

MEDIAN NASALITY RATINGS FOR EACH VOWEL BY SUBJECTS

SUBJECT	VOWEL					
	[i]	[æ]	[ɑ]	[ʌ]	[u]	[ɔ]
1	1	2	3	2	2	1.5
2	5	3.5	3.5	4	1	5
3	4	5	3.5	5	2	3
4	4.5	5	5	5	5	4.5
5	3	4	3	3	5	3
6	3	2.5	1	1	1	1
7	5	1	2	4	2.5	3
8	4.5	5	3.5	3.5	3.5	2.5
9	3.5	3	1	2.5	4	2
10	3	1	1	1	1	1
11	5	2.5	5	4	2.5	4.5
12	5	5	4	5	4	4.5
13	4	4	4.5	5	5	5
14	1	3	2	2	3	2
15	5	5	5	5	5	5
16	4	5	4.5	5	5	5
17	4	3.5	1	4.5	2	2
18	3	3	3.5	5	2	4
19	5	5	5	3	3.5	4
20	2.5	2	4	2.5	3.5	3.5

TABLE 21

MEDIAN NASALITY RATINGS FOR EACH SENTENCE
(FORWARD PLAY) BY SUBJECTS

SUBJECT	SENTENCE					
	1	2	3	4	5	6
1	3.5	3	3.5	3	2.5	3
2	4	5	5	5	4.5	4
3	1	1	1	1	1	1
4	4	4	4.5	5	4	4
5	3	4	3.5	4	3	3
6	1	1	1	1	1	1
7	3.5	3	3	4	4	3
8	2	2	1.5	1.5	1.5	1.5
9	3	3	4	3	2.5	2.5
10	2.5	3	3	3	2	2.5
11	4.5	4	5	4	5	4
12	2	2	1	1	2	1.5
13	3	3	3	3	3.5	3
14	3	3	3	3	3	3
15	4.5	5	5	5	5	5
16	5	5	5	5	5	5
17	5	4.5	4.5	4.5	4.5	4
18	4.5	5	5	4	5	4
19	5	5	5	5	5	5
20	3	3	4	3	3	2

TABLE 22

MEDIAN NASALITY RATINGS FOR EACH SENTENCE
(BACKWARD PLAY) BY SUBJECTS

SUBJECT	SENTENCE					
	1	2	3	4	5	6
1	3	3	3	3	2.5	3
2	5	5	5	5	4	4.5
3	3	3	2	1.5	3.5	2.5
4	3.5	4	4.5	4.5	3.5	4
5	4	2.5	3.5	4	4	3.5
6	1	1	1	1	1	1
7	2	3	3.5	3.5	3	3
8	3	3.5	1	2	1.5	2
9	4	4	4	3.5	3.5	4
10	1	2.5	2.5	2.5	1	2.5
11	4.5	5	5	5	4.5	4.5
12	3.5	3	2.5	2.5	2	2
13	3	3	3.5	3	3	3
14	1	1	1	2	2.5	1
15	4	4.5	4.5	5	4	5
16	5	5	5	5	5	5
17	3	4	3	4.5	3	4
18	4	4	4	4	4	4
19	5	5	5	5	5	5
20	3	4	3.5	3.5	4	3