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THE RELIABILITY OF NASAL AND "ORAL" SOUND PRESSURE LEVELS

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CHAPTER I

INTRODUCTION

It is generally agreed both by speech scientists and speech clinicians that nasality results from excessive resonance of the laryngeal sound in the nasal cavities. Such excessive nasal resonance is further believed to be directly related to inadequate velopharyngeal closure, which may reflect, in the individual case, improper use of a normal velum or structural inadequacies such as those characterizing the cleft palate condition.

Reliable evaluation of nasality by the speech pathologist is prerequisite to meaningful diagnosis, prognosis, and therapy. Although attempts have been made to objectify nasality through the measurement of nasal air pressure and volume, velopharyngeal aperture, and spectral characteristics, the presence and degree of severity of nasality, as with all vocal quality deficiencies, remains fundamentally a matter of personal perception. The subjective judgment of nasality, however, presents obvious limitations in both clinical and research situations. A means for evaluating nasality in a valid, reliable, and objective manner would provide the information on which impartial diagnostic and therapeutic decisions could be made by those concerned with the rehabilitation of the individual patient. Such information would be of value not only in the diagnosis of nasality and in the evaluation of the progress of therapy, but also in the choice of surgical and/or prosthetic procedures for the cleft palate patient.

A recent attempt at the objectification of nasality has involved the utilization of the probe-tube microphone assembly to measure nasal sound pressure levels in speech. These measurements are usually compared with measures of the simultaneously produced "oral" (i.e., total) speech signal, and the nasal-"oral" sound pressure level differences thus obtained have been found to correlate highly with subjective judgments of nasality. No information, however, is available relative to the reliability of such measures. The legitimate use of any evaluation procedure, and, in fact, its validity, is based upon the reliability of that procedure. The increasing use of the probe-tube microphone in research investigations of nasality underscores the need for the determination of the reliability of measurements made with this instrumental assembly. It was the purpose of this study to obtain objective data toward this end.

CHAPTER II

REVIEW OF THE LITERATURE

While the presence and severity of nasality is dependent ultimately upon the judgment of the listener, increasing clinical and research attention has been turned to the objective measurement of various acoustic and physiologic correlates of this vocal quality deficiency. Earlier efforts in this respect yielded but relatively crude measures of nasal air flow or pressure or, at best, signalled the presence or absence of sound in the nasal cavities. More recently, however, advances in electronic instrumentation have allowed increasingly accurate and sensitive measurement of nasal resonance, such as that provided by the probe-tube microphone assembly. Measurements of the speech of nasal subjects made with the probe-tube microphone have been shown to correlate highly with subjective measurements of those speech signals. Information regarding the reliability of measurements obtained by means of the probe-tube microphone assembly, however, is unavailable in the literature.

As a background to the present study, the literature will be reviewed under three major headings: (a) The Nature of Nasality, (b) The Measurement of Nasality, and (c) The Reliability of Measurement.

The Nature of Nasality

Although terminology varies considerably and descriptions of voice quality are often ambiguous, nasality is relatively distinct in nature and is generally considered to be "the quality of speech sounds when the nasal cavity is used as a resonator" (65). Variously termed "nasality", "hypernasality", or "rhinolalia", this vocal quality deficiency was defined by the forty-four speech authorities surveyed by Beighley (2) as ". . . the unpleasant voice quality resulting from too much resonance in nasal cavities that have nothing physically wrong with them". The majority of writers concur that nasality is a matter of excessive nasal resonance. Moore (41, p. 657), for example, writes: "Acoustically, the nasal voice is composed of the customary sounds of speech with a simultaneous overlay of nasal sound. That is, the vowels are recognizable, yet they are distorted by the additional nasal element." Similarly, West, Kennedy, and Carr (61, p. 392) define nasality as ". . . an excess of nasal resonance during the production of oral sounds".

Several types of nasality have also been defined. Cotton (11) recognizes "relaxed velum nasality", characterized by relatively little muscular contraction, and "whang nasality", the physiologic aspect of which is excessive muscular contraction, particularly of the pharyngeal and other supraglottal muscles. Moore (41, p. 657) similarly describes nasal voices that are "openly resonant" and others that are "twangy", and Johnson and others (31, p. 335) differentiate cleft palate nasality from ". . . the penetrating 'twang' of the hillbilly singer".

Recognition of nasality as a resonance phenomenon has prompted investigators to attempt to determine the characteristic harmonic structure of this voice quality deficiency. In this respect, Kantner (32), describing the nasality of cleft palate speech, writes:

> . . . the presence or absence of nasality can be considered as the result of changes in the over-tone structure of the voice. It might conceivably be caused either by the addition of certain overtones or partials to the so-called normal, non-nasal voice, or by the absence of certain partials, or by a change in the relationship of the partials.

While specific spectral patterns by which nasality might be quantified, or even identified consistently, have not yet been established, Dickson (17), lists four characteristics which he found to occur with some regularity in reports of the evaluation of the speech productions of nasal speakers: (a) an increase in formant band width, (b) an increase in the intensity of harmonics, (c) an increase or decrease in formant frequency, and (d) a rise in the fundamental frequency. In his own spectrographic investigation of nasality, Dickson found differences in the intensities of vowel harmonics to be of one or more of the following types: decrease in high frequency energy, interformant fill, interformant resonance peaks, and reduced intensity of the third harmonic. This type of lack of definitive information has led Bloomer and Peterson (7) to comment:

> Although we may presume that there is a direct relationship between the auditory signal, the physiological conditions of the utterance, and the acoustic structure of the sound, the relationship is not always clear, and varies sufficiently from individual to individual so that conclusions should be made with caution.

Although elevated tongue positions, narrow mouth openings, and other aspects of speech production physiology have been suggested to be of significance to the degree of severity of nasality, there is essentially universal agreement in the literature that nasality, as excessive nasal resonance, implies a malfunctioning velum. Cotton (11), for example, in an early study of resonance phenomena, states that "nasality of any kind presupposes that the velum is not closing the passageway to the nose", and Subtelny, Koepp-Baker, and Subtelny (55), in a more recent study of cleft palate nasality, maintain that "research has shown that hypernasality results from inadequate velopharyngeal valving which permits excessive coupling of the nasal cavity with the rest of the vocal tract and consequently the transmission of air and sound energy through the nasal cavity".

The exact relationships between perceived nasality and velopharyngeal opening, however, are not well understood. In this respect, Kantner (32) observes:

> The amount of nasality in the voice does not seem to be directly related to the amount of air escaping through the nose or to the degree of opening of the soft palate during phonation. . . It does appear that if the soft palate is left open far enough, a nasal quality is almost inevitable . . . However, there is no reason to believe that the amount of nasality in the voice increases and decreases in direct proportion to the size of the the opening into the nasopharynx.

McDonald and Koepp-Baker (37) also theorize a critical point in velopharyngeal valving, at which a balance or ratio is established between oral and nasal resonance and beyond which nasality is perceived. This hypothesis is supported by the results of a study of the relationship between the velopharyngeal dimensions and speech proficiency of cleft palate speakers reported by Subtelny, Koepp-Baker, and Subtelny (55); while no one group of phonemes was found to resist loss of intelligibility, a greater degree of velopharyngeal closure was necessary for intelligibility in fricatives than in other phonetic groups. This same condition, i.e., more efficient velopharyngeal valving, was found to be required for non-nasal speech compared to intelligible speech production. Those cleft palate speakers who were judged to be non-nasal were found to have generally good velopharyngeal function, while cleft palate speakers who were judged to be nasal were found to present increased velum-to-pharyngeal-wall dimensions as speech became progressively more nasal.

These relationships between quality and physiology are further obscured by the fact that, contrary to traditional phonetic theory, some degree of velopharyngeal opening is characteristic of many vowel sounds in non-nasal speech. Russell (45), Nusbaum, Foley, and Wells (43), and more recently, Wolfe (64), Williams (62), Senty (46), and Hagerty and others (20) have used a variety of measurement devices to demonstrate that speakers with normal resonance quality exhibit greater velopharyngeal closure on high vowels than low vowels. These findings are confirmed by Moll (40), who also found that varying consonant environments, except for [n], have little effect on the degree of closure across vowels.

Lintz and Sherman (36) found that the degree of perceived nasal resonance increases progressively from the high to the low vowels for both functionally nasal and normal speakers and that velopharyngeal closure in normal speakers is characteristically complete for the high vowels but not for the low vowels. In addition, variation in perceived nasality was noted in relation to tongue position, with increased nasality from high to mid to low tongue placement. Although the relationship was not so marked as with tongue height, severity of nasality was also reported to be related to the front-back classification of vowels, with the front vowels always perceived as more nasal than the back vowels. Van Hattum (58) also reports the degree of nasality perceived among the vowels produced by cleft palate speakers to be greater for the front vowels than for the back vowels. House and Stevens (26), deriving data from outputs of electrical analogs of the oral and nasal cavities, report the same difference in the front-back classification. They also found that a small degree of nasal-oral coupling results in marked changes in the spectra of the high vowels, changes which they speculate serve as cues for the identification of nasality. Spriestersbach and Powers (52), studying nasality on isolated vowels for cleft palate speakers, found that nasality increased from low to high, with the vowel [ɑ] the least nasal, [i] and [u] most nasal. In commenting upon the apparent conflict between these results and their own, Lintz and Sherman (36) point out:

> The reversal in order of severity of nasality for vowels produced by the speakers in the present study appears related to the amount of velopharyngeal closure. Where adequate closure is a problem, as is likely with cleft palate speakers, it would be expected that the high vowels, which require the most complete closure for non-nasal production would be perceived as more severely nasal than the low vowels, which typically require less complete closure.

In summary, nasality, a relatively distinct voice quality deficiency, is generally considered to be a matter of excessive nasal resonance resulting from a malfunctioning velum. Several types of nasality have been enumerated, which may explain, in part, why no specific pattern of spectral characteristics has been consistently identified as representative of nasal voice quality. Evaluation of this resonance imbalance has been complicated by the fact that some degree of velopharyngeal opening is characteristic of vowel production in non-nasal speech. Since closure is usually complete for the high vowels and not so for the low vowels, judgments of perceived nasality have varied in relation to tongue placement for normal speakers. The relationship has been found to be reversed for cleft palate speakers.

The Measurement of Nasality

In both clinical and research activities, the presence and degree of severity of nasality is routinely established on a subjective basis; that is, speech is "nasal" to the extent that the listener judges it to be so according to his personal perceptual criteria. It is apparent that such judgments are influenced by the training, experience, and native perceptual abilities of individual judges. Furthermore, research evidence indicates that listener judgments of nasality may be influenced by speech factors other than nasal resonance, e.g., misarticulations in the speech of cleft palate subjects (58). While studies by Sherman (48) and Spriestersbach (51) have suggested that judgments of the severity of nasality are more valid, i.e., that such "halo effects" are eliminated, for tape recorded speech samples played backward than for those played forward, the definition of the severity of cleft palate nasality still remains largely the result of perceptual judgment which may vary considerably from listener to listener. The need for greater objectivity in the evaluation of nasality has long been recognized and numerous devices and procedures have been utilized toward this end.

Most early attempts of this nature were undertaken on the presumption that the demonstration of nasal air escape during speech was indicative of velopharyngeal incompetency and, therefore, nasality. Among the devices used were balloons, pith balls, feathers, cold mirrors, and stethoscopes (38, 42, 59, p. 383). Instruments later employed to quantify nasal air flow or pressure included the pneumograph, the manometer, wet and dry spirometers, and the strain gauge (9, 10, 24, 33). With advances in electronic technology and the focus of experimental attention upon nasality as an acoustic rather than a pneumatic phenomenon, instruments such as the contact microphone (27), the harmonic analyzer (34), and the oscillograph (14) were employed, with varying degrees of sensitivity and accuracy. One of the more frequently used instruments in recent studies of the acoustic nature of nasality has been the sound spectrograph (21, 22, 50), a wave analyzer designed to produce a permanent visual record of the distribution of energy in an audio signal as a function of frequency, intensity, and time. Although nasal voices present certain gross spectrographic characteristics, no consistent and specific spectral patterns have been identified.

The probe-tube microphone, an adaptation of a standard condenser microphone in which a length of small-bore tubing is acoustically coupled to the microphone's diaphragm, has also been utilized in contemporary investigations of nasality. Originally designed for explorations of the sound pressure field around the head and the sound pressure along the auditory canal (4, p.731), the probe-tube microphone was first employed in the evaluation of nasality in 1954. Studying a sample composed predominantly of functionally nasal speakers (three of the seventeen subjects were cleft palate), Weiss (60) investigated the relationship of "oral" (total) and nasal sound pressure levels to judged severity of nasality. Separate but simultaneous recordings of the "oral" and nasal speech signals were made while each subject read a paragraph of connected speech at an intensity level of 70 dB as monitored on a sound level meter. The "oral" recordings were made with a condenser microphone placed eight inches in front of the subject's lips. The nasal recordings were obtained by means of a probe-tube microphone inserted approximately one-quarter inch into one of the subject's nostrils.

Visible tracings of the intensity variations in the "oral" and nasal recordings were made on a high-speed power level recorder, and mean peak sound pressure levels were calculated for each. Listener judgments of the severity of nasality of the "oral" speech samples were obtained by the method of paired comparisons. On the strength of correlations computed between the nasality ratings and the mean sound pressure levels of the "oral" and nasal speech samples, the difference between nasal and "oral" sound pressure levels, and the direct ratio of nasal and "oral" sound pressure levels, Weiss concluded that these ". . . correlations demonstrate that a method employing a probe-tube microphone, associated amplification apparatus, and sound pressure measuring devices is effective in providing measurements of sound pressure level which are related to judgments of severity of hypernasal voice quality".

Essentially the same probe-tube instrumentation and recording procedures were utilized by Summers (56) to compare "oral" and nasal sound pressure levels of eight vowel sounds at four intensity levels produced by sixteen male and fourteen female normal-speaking subjects. Among his findings, he reports that females as a group had lower "oral" but higher nasal sound pressure levels than males. Sound pressure levels for the high front vowels and the high back vowels were higher than those for the middle vowels. Nasal-"oral" sound pressure differences decreased as vowels were spoken at higher "oral" intensities. While Summers reports requiring each subject, following the thirty-two experimental vowel productions, to repeat two of the vowels at one of the experimental intensities as a check on their reliability in producing sounds at specified levels, no other reliability data are presented.

Pierce (44) found a similar probe-tube assembly applicable to the evaluation of resonance differences afforded by various types of prosthetic speech appliances in adult cleft palate speakers. The sound pressure level measurements differentiated the speech appliances on the basis of pharyngeal bulb placement, and, on the basis of correlations between the sound pressure level measurements and listener judgments, Pierce concluded, "The results of this study appear to support those of Weiss that the probe-tube assembly is effective in providing measurements of sound pressure level which are positively related to listener judgments of nasality." No reliability data for the sound pressure measurements are reported.

The probe-tube microphone assembly and associated sound measuring instrumentation was also used by Bryan (8) in comparing the nasal-"oral" sound pressure differences and listener ratings of nasality of sustained vowels and short sentences produced by adult cleft palate subjects. Pertinent findings of this investigation included: (a) high vowels were associated with greater mean nasal-"oral" sound pressure level differences than were low vowels, (b) sound pressure differences in vowels were moderately related to sound pressure differences in sentences, the relationship varying with the vowel, and (c) sound pressure differences and listener ratings were more highly related in sentences than in vowels, and, for the sentences, sound pressure differences were more highly related to nasality ratings obtained in forward play than in backward play. Bryan reports no reliability data for the sound pressure measurements.

Essentially the same instrumental assembly was utilized by Counihan and Pierce (12) to study a larger speech sample of a larger number of both adult cleft palate and normal subjects. Among the significant findings of this research were: (a) greater mean nasal-"oral" sound pressure differences occurred in isolated, sustained vowels, in the vowels of CVC syllables, and in sentences for the cleft palate subjects than for normals, (b) the range of differences across vowels in the sustained vowels and the vowels in CVC syllables was greater for the cleft palate subjects than for normals, (c) for the cleft palate group, the means for vowels in [z] and [s] contexts in CVC syllables exceeded those for vowels in [d] and [t] contexts, while for normals, the means for vowels in [z] and [d] contexts were greater than those for vowels in [s] and [t] contexts, (d) for both normal and cleft palate subjects, the mean sound pressure differences for the vowels [i] and [u] were greater than those for the other vowels studied in all consonant environments; and vowels combined with [z] and [d] averaged greater mean sound pressure differences than those combined with [s] or [t], and (e) correlation coefficients between mean nasal-"oral" sound pressure differences and nasality ratings of each of the nine judges ranged from -.08 to .25 for isolated vowels, from .19 to .34 for CVC syllables, from .49 to .65 for sentences in the forward-play condition, and from .43 to .63 for sentences in the backward-play condition.

In summary, early claims to the objectification of nasality were based for the most part upon the use of procedures, devices, or instruments designed to demonstrate or quantify changes in nasal air escape during speech. More recent research attention has been turned to the acoustic properties of nasality, and the probe-tube microphone assembly, which has been used in studies of both functional and cleft palate nasality, appears to be a promising tool in this respect. While relatively high and consistent correlations are reported between nasal-"oral" sound pressure differences and judgments of perceived nasality, the reliability of these sound pressure measurements remains to be evaluated.

The Reliability of Measurement

The two critical characteristics of any measurement instrument or procedure are validity and reliability. Validity, the extent to which a test measures what it purports to measure, is established by correlation of the test with some accepted standard or with other criteria which are accepted by experts as the best evidence of the characteristic to be measured by the test; the results of the comparison are often less than perfect. As Hebb (23, p. 241) points out, ". . . validity is the correlation of the test with a perfect measure of what we are trying to get at . . . . In practice, we have no good perfect measures; and so we have no good way of determining validity quantitatively". The fundamental prerequisite of validity is reliability; if a test's reliability is zero, it cannot be correlated with any standard or criterion, or even itself.

Reliability refers to the extent to which a test yields consistent results on retesting or, as Anastasi (1, p. 94) describes it, ". . . the consistency of scores obtained by the same individuals on different occasions or with different sets of equivalent items". Reliability is the accuracy with which a test instrument or procedure measures whatever it is that it measures, rather than transitory or irrelevant items --- more precisely, it is the consistency, replicability, or predictability of a test.

Since all measurement is subject to error, reliability is always a matter of degree. The differences between the test scores of individuals in a group may be attributed either to true differences in the characteristic under test or to inaccuracies of measurement. A test is unreliable in proportion to the variation of measurement that is due to those inaccuracies of measurement, i.e., the "error variance"; if there were no error variance, the reliability of the test would be perfect. The sources of measurement inaccuracy may be defects inherent in the test instrument or procedure itself, chance factors or conditions operative at the time of test, or fluctuations in the performance of the subjects under test. Estimations of reliability are usually made by means of one of three methods -- test-retest, split-half, or comparable forms.

In the experimental investigation of human behavior, reliability of measurement depends in chief upon the consistency of test environment and procedures and the consistency of performance of investigator, subjects, and instrumentation. These sources of variation, either singly or in combination, are frequently subjected to evaluation in research investigations into human communication behavior. For example, descriptions of calibration procedures, which are, in essence, evaluations of the reliability of experimental instrumentation, are routinely included in the research literature. Too, studies dealing with listener judgments as a method of measurement of speech characteristics frequently rely upon the test-retest method to establish interjudge and intrajudge reliability. In view of the possible influence of factors such as pitch and intelligibility upon judgments of voice quality, Sherman (48) concluded that such perceptual ratings would be more valid and reliable if made under conditions of backward play. Spriestersbach (51) required his judges to repeat their ratings of the experimental speech samples in order to obtain information concerning the reliability of nasality evaluations utilizing backward play. Lintz and Sherman (36) describe a similar procedure in their study of the relative effects of certain phonetic elements upon the perception of nasality. The first one hundred samples were repeated at the end of the listening session to provide an estimate of judgment reliability. This method of comparing an original rating against a subsequent rating of the same speech sample has allowed numerous investigators

(8, 12, 21, 58) to report the level of reliability obtained by judges or observers. Similar procedures have been reported relative to observer consistency in judgments of articulation proficiency (54), in the recording of language responses (18), and in the establishment of the consistency effect in stuttering (13).

In addition to observer reliability, attention has also been directed to the reliability of certain test instruments or methods utilized in research investigations dealing with human communication. Siegel (49) suggests that, for some items in articulation testing, considerable intrasubject variability is evident for different words and for different methods of sound elicitation. Darley and Moll (15), in a study relating to adequacy of item sampling in language evaluation, concluded that the mean length of response scores based upon fifty responses of five-year-old children were sufficiently reliable for most research purposes, but that structural complexity scores based on the fifty response sample were not.

Minifie et al (39) were concerned with the temporal reliability of such language measures, that is, the consistency of individual performance on the same test over a period of time. In general, the results reported indicate relatively low temporal reliability for all seven language measures investigated. These investigators point out that, while language measures obtained from retests of single fifty response language samples are not appreciably consistent from day to day, the mean for three separate fifty response language samples appears to be of adequate reliability for most research purposes.

The temporal reliability of articulation testing was assessed by Winitz (63), who tabulated the number of correct and incorrect responses of five-year-old children to a forty item test in two separate sessions. The number of correct responses did not change sufficiently from one testing session to the other when each item was considered separately; more intrasubject variability, however, occurred for some sounds than for others. Winitz points out:

> In group studies correct articulation productions of subjects for a sound element are grouped for some purpose, such as developing norms. In correlation studies specific articulation items are studied with respect to some variable, and subjects are either (a) assigned to subgroups on their production of a sound element, or, (b) correlations between articulation production and some variable are determined.

In light of these considerations, the reliability of articulation responses appears sufficient for group studies, but, at least for some test items, inadequate for correlation studies.

This apparent lack of consistency has been noted in many aspects of speech production or related functions. Repeated utterances of the same vowel phoneme by a speaker or speakers may result in variations in perceived phonetic quality as well as in measurable acoustic characteristics. Although Black (5, 6) has demonstrated that phonetic context influences vowels, others (25, 40, 57) have observed important intersubject and intrasubject variations when phonetic context is held constant. Inconsistencies of subject performance have also been reported in speech-related activities such as nasal air escape. Shelton, Bankson, and Brooks (47) report a rather substantial discrepancy of water displacement in mean test-retest measurements utilizing a U-tube water manometer. Young (66), using a strain gauge manometer, observed considerable variability in the intranasal air pressure of both normal and cleft palate subjects.

After determining that the correlations between oral breath pressures, articulation skills, and measures of velopharyngeal adequacy from lateral x-rays were relatively low, Spriestersbach and Powers (52) point to the need for the establishment of reliability in such performances:

> The absence of higher relationships is not surprising in view of individual variability and the complexity of the speech process. It should be remembered that each of the measures was obtained only once for each subject. No research has been done to determine how stable the x-ray and pressure measurements are on repeated tests of individuals with cleft palates.

Reliability estimates made in probe-tube studies of nasality have included (a) assessment of subject reliability in producing a specific oral intensity (56), (b) evaluation of the consistency of repeated power level recorder tracings of "oral" and nasal sound pressures (60), (c) calibration of instrumentation (8, 12, 44, 56, 60), and, (d) assessment of interjudge and intrajudge reliability (8, 12, 44, 60). The reliability of sound pressure level measurements obtained by means of the probe-tube microphone apparatus, however, has not been investigated.

In summary, reliability refers to the consistency throughout a series of measurements. All scientific measurement is subject to error which may derive from subject, instrument, or procedural variability, or, indeed, a composite of all three factors. Since reliability information serves to provide an estimate of the confidence that may be placed in any given measure, the validity of any measurement process cannot be ascertained until the reliability has been established. No reliability information on nasal-"oral" sound pressure measurements obtained by means of the probe-tube microphone assembly is reported in the literature.

CHAPTER III

DESIGN OF THE INVESTIGATION

While the probe-tube microphone assembly has provided data that have been useful in the evaluation of nasality, no information appears in the literature with respect to the reliability of these measures. Such information is critical not only to the interpretation of previous research but also to the planning for further investigations utilizing this instrumentation. The purpose of this study, therefore, was to determine the reliability of "oral"[1] and nasal sound pressure level measurements obtained by means of the probe-tube microphone assembly and associated sound pressure recording instrumentation.

Subjects in this investigation included two groups of adult cleft palate patients and a third group of normal-speaking individuals without velopharyngeal problems. The experimental speech sample included four isolated, sustained vowels, sixteen consonant-vowel-consonant syllables, and one short sentence containing no nasal consonant sounds. Utilizing the probe-tube microphone apparatus, simultaneous "oral" and nasal magnetic tape recordings of each subject were made at two separate sessions,

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[1]The "oral" speech signal, recorded eight inches in front of the lips, included sound from both the oral and the nasal cavities. Following the practice observed in prior investigations and for the sake of clarity, this total speech signal, although recognized to contain both oral and nasal components, is hereafter referred to as the "oral" signal.

each session consisting of two consecutive productions of the speech sample. Measurement of the graphic level recorder tracings of the successive tape recorded speech samples provided the primary data for this study. The research question and descriptions of the subjects, speech sample, instrumentation, and procedures employed in this investigation are presented in the following sections.

The Research Question

The following research question was formulated for this investigation:

> What differences exist in the nasal-"oral" sound pressure measurements of adult cleft palate and normal-speaking subjects in repeated productions of sustained vowels, sentences, and consonant-vowel-consonant syllables?

Subjects

Fifteen male adults, ten with operated cleft palate or cleft lip and palate and five without, served as subjects in this study. The cleft palate subjects presented varying degrees of nasality; the speech of the non-cleft palate subjects was within normal limits. Individuals who met the other experimental requirements were selected as subjects and assigned to one of three subject groups on the basis of the mean of three oral manometer (Hunter, Model 360) ratios. Group I was composed of five cleft palate subjects whose mean oral manometer ratios were below .70, with a group mean of .43. Group II included five cleft palate subjects whose mean oral manometer ratios were between .70 and .90, with a group mean of .82. Group III was composed of the five non-cleft palate subjects whose mean oral manometer ratios were all 1.0. The mean oral manometer ratios for the fifteen subjects are presented in Table 9 in the

Appendix.

All subjects selected for this study were between the ages of 17 and 45 years, in order to preclude variations in voice and speech production associated with adolescence or older ages. The mean ages of the subjects in Groups I, II, and III were 28.6, 27.2, and 28.8 years, respectively.

All subjects were required to have essentially normal hearing in at least one ear. Audiometric screening results indicated that no subject had a loss greater than 15 dB in the better ear at 500, 1000, and 2000 cps.

On the basis of grade-level achievement and occupation, all subjects were estimated to be within or above the limits of normal intelligence.

No restrictions with respect to type of cleft or operative procedure were established for the cleft palate subjects. All five non-cleft subjects were without major oral structural deviation.

Speech Sample

The experimental speech sample produced by each subject consisted of:

a. four isolated vowels, [i], [æ], [ɑ], and [u], each sustained for three seconds,

b. sixteen consonant-vowel-consonant (CVC) syllables, composed of the consonants [t], [d], [s], and [z] individually combined with each of the above vowels, and

c. a short sentence, "The cook fed her fat hogs", containing no nasal consonants.

Isolated vowels, CVC syllables, and sentence materials were included in this study on the basis of reports (8, 12, 36, 52, 60) of differences between or among the three types of speech signal in perceived nasality and/or nasal-"oral" sound pressure level measurements. The vowels [i], [æ], [ɑ], and [u] were selected in order to allow study of vowels that differ in velopharyngeal valving (40), tongue position (62), relative acoustic power (25), and nasal-"oral" sound pressure difference (12). Consonants for the CVC syllables were chosen to allow comparison of voicing and manner of production, place of articulation held reasonably constant; House and Fairbanks (25) have shown that vowel power and duration are influenced more by manner of production and voicing than by place of articulation. The single sentence selected for use in this study was that sentence found by Bryan (8) to demonstrate the highest correlation between perceived nasality and nasal-"oral" sound pressure level difference.

Instrumentation

The instrumentation utilized in this investigation was similar to that used in previous studies of nasal-"oral" sound pressure level differences in speech (8, 12, 44, 56, 60). This consisted of an audio recording system, by which simultaneous "oral" and nasal magnetic tape recordings of the subjects' speech samples were made, and a graphic recording system, by which continuous visual tracings of the intensity in the speech samples were obtained.

Description

The audio recording assembly used in this study was a dual-channel system designed to allow the separate, but simultaneous, recording of (a) the subject's "oral" speech production, with a microphone placed approximately eight inches from the lips, and (b) the speech signal in the subject's least-occluded nasal fossa, by means of a probe-tube microphone inserted into the nostril. The components of this recording system included:

a. two half-inch condenser microphone cartridges (Bruel and Kjaer, Model 4134), one modified by the addition of an adapter and a miniature-bore probe-tube (Bruel and Kjaer, Model UA 0040),

b. two cathode followers (Bruel and Kjaer, Model 2615), to which the microphone cartridges were attached,

c. two microphone amplifiers (Bruel and Kjaer, Model 2603), one of which was modified by the circuit insertion of a custom-designed equalizing filter, and

d. a dual-channel magnetic tape recorder (Ampex, Model 354).

The condenser microphone cartridges, specifically designed for sound measurement under free-field conditions, were individually calibrated by the manufacturer to present a frequency response of ±2 dB from 20 to 20,000 cps in a diffuse sound field. The microphone cartridge in the "oral" recording system was used with its protective grid in place and at a 90-degree angle of incidence to the speech source. According to the manufacturer's specifications (28), there is relatively little effect on the frequency response curve of the microphone below 15,000 cps under these conditions.

The nasal microphone cartridge was identical to the oral except for removal of the protective grid and the addition of a probe-tube and its adapter. The stainless steel probe-tube was one millimeter in outer diameter, six-tenths millimeter in inner diameter, and measured from the tip of the adapter, three inches in length. The magnitude of the outer diameter allowed the placement of the probe-tube in the nasal meatus without contacting the columella or ala and without appreciably altering the sound pressure environment in the nasal cavity (3, 4). The thickness of the probe-tube wall, two-tenths millimeter, was sufficient, according to the manufacturer's calibration (28) to provide a signal-to-noise ratio of more than 40 dB at all frequencies from 100 to 5000 cps. The probe-tube was long enough to allow placement of the nasal microphone cartridge and cathode follower out of the path of the orally emitted signal, but was made as short as possible to improve its sensitivity (4).

The condenser microphone cartridges of both the "oral" and nasal recording systems were connected to cathode followers, transforming the high source impedance of the microphone cartridges to the relatively low impedance required for the succeeding microphone amplifiers. The microphone amplifiers presented linear frequency responses (±.5 dB) from 2 to 35,000 cps, provided a maximum amplification of 100 dB, and, with the condenser microphone cartridges and cathode followers, conformed to the specifications for standard sound level meters, indicating sound pressure level in decibels re .0002 dyne/cm^2 (29).

The dual-channel magnetic tape recorder, matched in impedance with the microphone amplifiers, had a frequency response at 7.5 ips of ±2 dB from 40 to 12,000 cps. Its frequency response was verified at the beginning of this investigation, and its "record" and "reproduce" potentiometer settings were adjusted to a white noise of known intensity prior to the recording of each subject.

The tape recorded "oral" and nasal speech signals were reproduced from the dual-channel tape recorder directly into the graphic level recorder, a high-speed instrument for recording signal level variations as a function of time within a frequency range of 20 to 20,000 cps. The 50-dB logarithmic potentiometer used with the level recorder was accurate

±.5 dB within that frequency range, according to the manufacturer's specifications (30).

Calibration

A miniature-bore probe-tube has a relatively constant high-frequency attenuation per octave. Calibration of the probe-tube used in this study revealed an attenuation of approximately 5 dB per octave, as is illustrated by the frequency response curve in Figure 1. In order to compensate for this high-frequency attenuation, the bore of the probe-tube was packed with steel wool, as suggested by the manufacturer, and, further, a custom-designed equalizing filter was constructed for insertion in the external filter circuit of the amplifier used with the nasal microphone. The filter consisted of a .02-microfarad condenser in parallel with a 33,000-ohm resistor, both in series with a 1500-ohm resistor. With the steel wool in the probe-tube and the equalizing filter in the amplifier circuit, the frequency response of the nasal microphone was ±2 dB to 5000 cps, as illustrated in Figure 2.

The nasal probe-tube microphone and amplifying system were calibrated against the "oral" microphone and amplifying system, the frequency characteristics of which had been verified immediately after receipt from the manufacturer and which, as previously indicated, were utilized in this study as a precision sound level meter. The "oral" microphone was placed at a 90-degree angle of incidence to and one inch from an amplifier-speaker (Ampex, Model 620) in an acoustically isolated room. The tip of the probe-tube was placed at approximately a 45-degree angle of incidence to the amplifier-speaker and one-quarter inch above the grid of the "oral" microphone. The amplifier-speaker, driven by a beat frequency

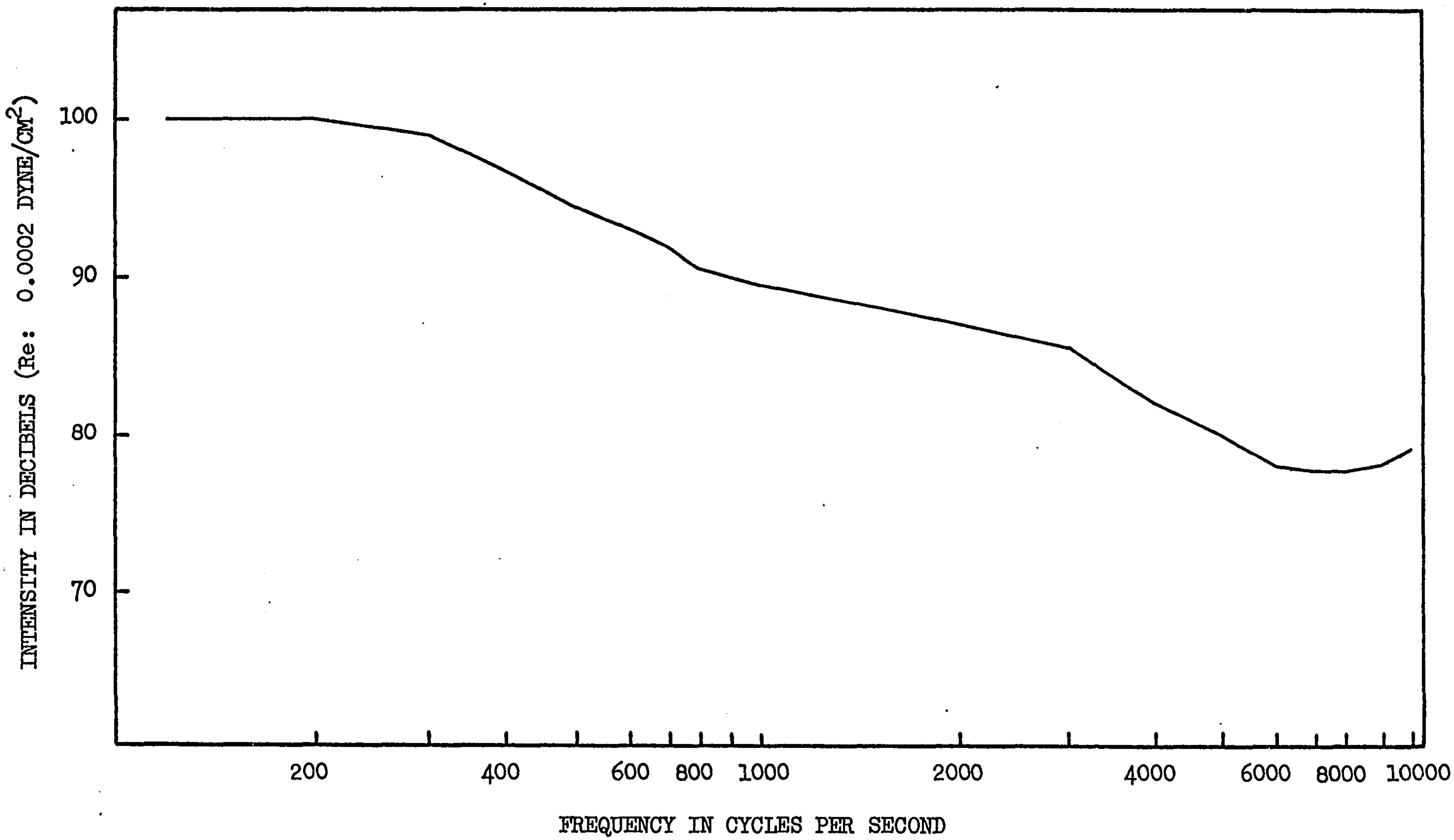

Figure 1.—Frequency response curve of the nasal microphone and an uncompensated probe tube to a 100-dB SPL tone.

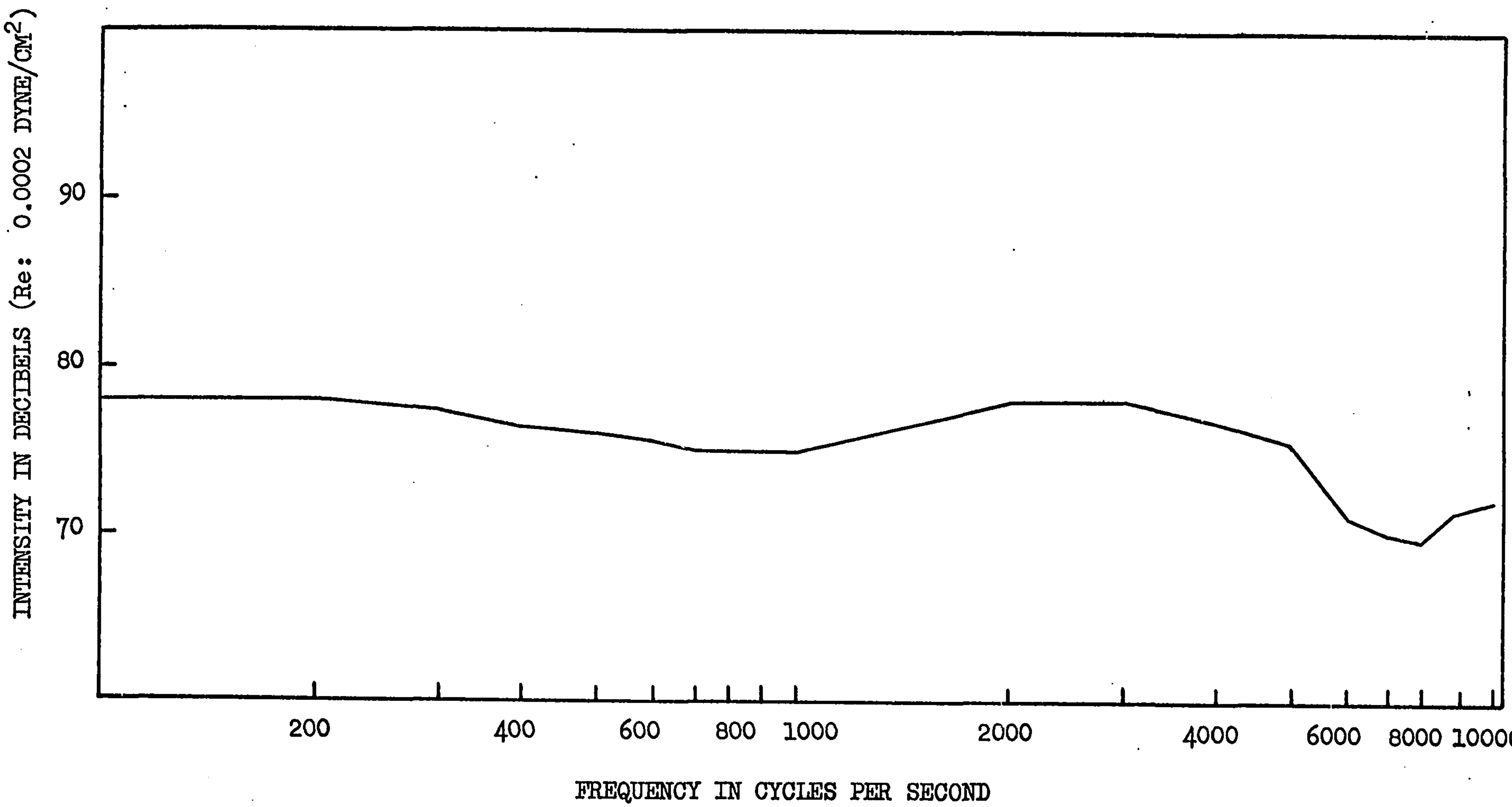

Figure 2.—Frequency response curve of the nasal microphone, probe tube and equalizing filter to a 100-dB SPL tone.

oscillator (Bruel and Kjaer, Model 1014) in the adjoining control room, produced a tone of sufficient intensity to register 100 dB SPL on the volt meter of the "oral" microphone amplifier. The concurrent response of the nasal probe-tube microphone was read on the meter of its associated amplifier. Such readings were taken at 100-cycle intervals from 100 through 5000 cps and at 1000-cycle intervals from that point to 10,000 cps. As detailed above, the frequency response of the nasal probe-tube microphone was essentially flat to 5000 cps. The mean attenuation introduced by the probe-tube and the accompanying equalizing filter was 31 dB from 100 to 5000 cps.

The graphic level recorder was also calibrated against the "oral" microphone and amplifying system. Utilizing white noise, 5-dB increments on the meter of the microphone amplifier resulted in identical increments on the chart paper of the graphic level recorder.

Procedures

The experimental procedures in this investigation included (a) the magnetic tape recording of the "oral" and nasal speech signals and (b) the derivation and measurement of graphic level recorder tracings of the tape recorded speech signals.

Recording Procedures

All speech samples were recorded in a two-room, sound-isolated suite at the Speech and Hearing Center, University of Oklahoma Medical Center. The ambient noise level within the test room was below 30 dB as measured on the "C" scale of a sound level meter (General Radio, Model 793). The nasal microphone amplifier and the tape recorder were situated in the adjoining control room and were monitored during the recording sessions by a speech pathologist experienced in their operation. The test room contained the subject's chair, the "oral" and nasal condenser microphone cartridges and their cathode followers, and the "oral" microphone amplifier. In front of the subject's chair and in proximity to the volt meter of the microphone amplifier were a rack to hold the speech sample cards and the signal lights to indicate the beginning and end of the three-second phonation period for the vowel sounds. The examination chair in which the subject was seated was provided with an adjustable back and headrest. Stability of the head was achieved by means of a wide elastic band placed around the subject's head and the headrest, assuring not only a uniform distance from the mouth to the microphone, but also that the subject's lateral head movements would not bring the probe-tube into contact with the margins of the nostril.

After the subject was seated, the stands to which the test microphones were affixed were moved into position so that the "oral" microphone was eight inches from the lips of the subject, with the diaphragm of the microphone in a horizontal plane with the center of the mouth. The nasal microphone was positioned in such a way that the probe-tube projected at an acute angle one-fourth inch into the least-occluded nasal fossa; this angle approximated 45 degrees, although varying with the nostril and facial planes of individual subjects. Nostril choice for placement of the probe-tube was determined during the preliminary examination of the patient by taking the average of three manometer pressure readings with each nostril occluded individually.

Having been familiarized with the speech samples, the subject practiced peaking the production of each item in the speech sample at an intensity level of 75 dB SPL on the volt meter of the "oral" microphone amplifier. The decision to require a uniform intensity level for all subjects and speech samples was made on the basis of Summers' findings (56) that the relationships of nasal-"oral" sound pressure differences among vowels are altered at different intensity levels. The 75-dB intensity level, selected in order to assure a signal-to-noise ratio of greater than 20 dB and to provide a level easily attainable by all subjects, was consistent with that used by Bryan (8) for cleft palate subjects. During this practice period, the attenuator settings on the nasal microphone amplifier were adjusted so that the nasal signals, when thus attenuated, would be accommodated within the 20-dB range of the amplifier meter. Timing of the phonation period for the vowels was also practiced. Controlled by a cam timer in the control room, a one-second red light alerted the subject to prepare to phonate; a three-second amber light signalled him to sustain the vowel production at the 75-dB intensity level. The experimental speech samples were produced upon oral cue from the investigator and, in addition, were printed on three-by-five-inch cards placed in view of the subject. The subjects were recorded at random; for each subject, the order of presentation of the vowels, CVC syllables, and the sentence, as well as the order of items within the vowel and syllable groups, were randomized for each of the four trials.

In this investigation, magnetic tape recordings of each subject were made at two separate recording sessions. During Session I, simultaneous "oral" and nasal recordings were made of two consecutive productions of the entire speech sample, hereinafter referred to as Trial 1 and Trial 2. Insofar as was possible, the conditions of the two trials were kept constant, except for re-randomization of the speech sample for Trial 2. In particular, such factors as head position and stabilization, placement of the "oral" microphone, and depth and angle of the insertion of the probe-tube remained unchanged for the two trials.

Upon completion of the two trials of Session I, the subject was removed from the recording assembly and left the test room. All parts of the experimental equipment and instrumentation that would normally be adjusted to the individual subject, that is, the headband, the headrest of the examination chair, the microphone stands, and the clamps which controlled the positions of the two microphones, were moved out of the positions in which they were used during Session I. After not less than fifteen minutes, the subject was recalled to the test room for Session II, seated, and repositioned in the recording assembly as previously described. Every effort was made to duplicate the subject and microphone positioning of Session I, with particular attention to such variables as head position, distance of the "oral" microphone from the mouth, and depth and angle of the insertion of the probe-tube. Session II also consisted of two consecutive productions of the entire speech sample, Trials 3 and 4.

Measurement Procedures

Separate visual tracings of the variations in intensity recorded by both the "oral" and probe-tube microphones were obtained by means of the graphic level recorder. Throughout this investigation the level recorder was operated at a chart-paper speed of 30 millimeters per second and a stylus writing speed of 300 millimeters per second. The graphic level recorder chart-paper (Bruel and Kjaer, QP 2350) used was designed for use with the 50-dB logarithmic potentiometer; two and one-half inches in width and ruled in ten equal intervals, it allowed a recording range of 50 dB.

White noise of a known sound pressure level was recorded on both the "oral" and the nasal channels of the tape recorder just prior to Session I for each subject. This signal provided a reference tracing on the level recorder chart-paper from which measurements could be made of the tracings of the recorded speech samples in decibels re .0002 dyne/cm^2. The reference signal for the "oral" recordings was 85 dB, for the nasal recordings, 116 dB. The difference in the reference signal intensities reflected the attenuation introduced by the addition of the damped probe-tube and the equalizing filter.

The tracings of the sustained vowels did not always indicate a constant intensity during the three-second phonation. The intensities of the "oral" and nasal vowel signals, therefore, were determined by averaging the measured amplitudes of the level recorder tracings at three points fifteen millimeters apart in the middle steady-state portion of the vowel, i.e., through approximately the middle one second of the three-second production. The intensities of the "oral" and nasal signals in the CVC syllables were measured at the peak amplitudes of the vowels in the level recorder tracings of these syllables. In the sentence, the intensities of the "oral" and nasal signals were determined by averaging the measured amplitudes of all peaks in the "oral" and nasal level recorder tracings. In this analysis, a "peak" was defined as the high point of an upward-downward excursion of the signal tracing that was 5 dB or more above the low points of the preceding and following downward-upward excursions of the tracing. Peaks more than 20 dB below the reference tracings were not measured; this criterion allowed measurement of every major peak in the "oral" and nasal tracings and eliminated from measurement the low-intensity, short-duration peaks that were atypical of the major "oral" and nasal resonances seen for the subject.

"Oral" and nasal tracings of every speech production for each of the four trials for all subjects were measured independently twice. Any discrepancies between the first and second measures were resolved by a third measurement; in no instance was the third measure different than one or the other of the first two measures. The arithmetic difference of the "oral" and nasal measurements was then computed for each item in the speech sample.

The data derived for analysis in this investigation, then, consisted of the nasal-"oral" sound pressure level differences of four isolated, sustained vowels, sixteen CVC syllables, and a short sentence produced by three groups of adult male subjects. The results of this investigation and a discussion of the findings are presented in the following chapter.

CHAPTER IV

RESULTS AND DISCUSSION

Only the nasal-"oral" sound pressure differences obtained in this study were subjected to statistical and descriptive analysis. Had the "oral" sound pressure levels been constant, the analysis could have been limited to the nasal sound pressure level measurements; however, since the oral sound pressure levels varied slightly, the nasal-"oral" differences were judged to be the most meaningful data for analysis. Furthermore, such difference scores have comprised the data reported in previous investigations of nasal and "oral" sound pressure levels. The results of the analyses of the nasal-"oral" data and a discussion of these findings are presented in the following sections.

Results

Statistical Analysis

The nasal-"oral" differences obtained in this study were analyzed by partially-nested analyses of variance with factorial arrangement of treatments, with an experimental confidence level of .05. Where appropriate, the Duncan Multiple Range Test (53), also with a confidence level of .05, was utilized to locate significant differences among the means contributing to the significant F-ratios in the analyses. The main effects for the vowels included groups, sessions, trials, and vowels; for the sentence, groups, sessions, and trials; and for the syllables, groups, sessions, trials, vowels, and consonants. The sessions and trials main effects and the interactions involving these variables were, of course, of paramount importance in the determination of the reliability of the sound pressure level measurements made in this investigation.

Summaries of the analyses of variance for the mean nasal-"oral" sound pressure level differences of the experimental vowels, sentence, and syllables are presented in Tables 1, 2, and 3. Inspection of these tables reveals that none of the sessions or trials main effects achieved the experimental confidence level in any of the analyses.

The failure of the sessions main effects to achieve significance in the three analyses indicates that none of the nasal-"oral" sound pressure differences for the three types of speech sample, when averaged over all subjects for each of the three types of speech sample, differed significantly from Session I to Session II. The means for Session I were 30.93, 29.15, and 30.06 dB and for Session II, 30.80, 28.88, and 30.01 dB for the vowels, sentence, and syllables, respectively. These nasal-"oral" sound pressure differences are equivalent to those reported in previous investigations utilizing the probe-tube microphone assembly.

The lack of significance of the trials main effects in the three analyses indicates that the nasal-"oral" sound pressure measures of the vowels, sentence, and syllables recorded during the first production of the speech sample in each session did not differ significantly from those obtained during the second production in each session. The means contributing to the trials main effects in each of the analyses were all within .5 dB of those for the sessions main effects.

Inspection of Tables 1, 2, and 3 also reveals that in none of the

TABLE 1

SUMMARY OF THE ANALYSIS OF VARIANCE OF THE MEAN NASAL-"ORAL" SOUND PRESSURE DIFFERENCES FOR THE SUSTAINED VOWELS PRODUCED BY FIFTEEN SUBJECTS

Source	df	ms	F	F.05
Groups (A)	2	408.29	3.15	3.89
Error B/A (Subjects within Groups)	12	129.52		
Sessions (C)	1	.89	.04	4.75
Groups x Sessions (AC)	2	5.21	.25	3.89
Error BC/A	12	21.01		
Trials (D)	1	1.29	.08	4.75
Groups x Trials (AD)	2	1.41	.08	3.89
Error BD/A	12	16.71		
Sessions x Trials (CD)	1	6.27	.84	4.75
Groups x Sessions x Trials (ACD)	2	9.53	1.28	3.89
Error BCD/A	12	7.44		
Vowels (E)	3	304.04	15.18	2.86
Groups x Vowels (AE)	6	149.23	7.45	2.36
Error BE/A	36	20.02		
Sessions x Vowels (CE)	3	8.59	1.62	2.86
Groups x Sessions x Vowels (ACE)	6	4.53	.86	2.36
Error BCE/A	36	5.29		
Trials x Vowels (DE)	3	.84	.30	2.86
Groups x Trials x Vowels (ADE)	6	2.40	.86	2.36
Error BDE/A	36	2.79		
Sessions x Trials x Vowels (CDE)	3	2.76	.92	2.86
Groups x Sessions x Trials x Vowels (ACDE)	6	2.04	.68	2.36
Error BCDE/A	36	2.99		
Residual	0	0.00		

TABLE 2

SUMMARY OF THE ANALYSIS OF VARIANCE OF THE MEAN NASAL-"ORAL" SOUND PRESSURE DIFFERENCES FOR THE SENTENCE PRODUCED BY FIFTEEN SUBJECTS

Source	df	ms	F	F.05
Groups (A)	2	256.74	2.90	3.89
Error B/A	12	88.53		
Sessions (C)	1	1.09	.18	4.75
Groups x Sessions (AC)	2	5.19	.85	3.89
Error BC/A	12	6.11		
Trials (D)	1	2.20	.40	4.75
Groups x Trials (AD)	2	.53	.09	3.89
Error BD/A	12	5.58		
Sessions x Trials (CD)	1	.14	.06	4.75
Groups x Sessions x Trials (ACD)	2	.63	.26	3.89
Error BCD/A	12	2.42		
Residual	0	0.00		

TABLE 3

SUMMARY OF THE ANALYSIS OF VARIANCE OF THE MEAN NASAL-"ORAL" SOUND PRESSURE DIFFERENCES FOR THE SIXTEEN CVC SYLLABLES PRODUCED BY FIFTEEN SUBJECTS

Source	df	ms	F	F.05
Groups (A)	2	4021.89	6.21	3.89
Error B/A	12	647.85		
Sessions (C)	1	.60	.005	4.75
Groups x Sessions (AC)	2	9.46	.07	3.89
Error BC/A	12	127.57		
Trials (D)	1	171.70	4.17	4.75
Groups x Trials (AD)	2	40.26	.98	3.89
Error BD/A	12	41.23		
Sessions x Trials (CD)	1	78.20	3.28	4.75
Groups x Sessions x Trials (ACD)	2	43.47	1.82	3.89
Error BCD/A	12	23.84		
Vowels (E)	3	140.23	2.16	2.86
Groups x Vowels (AE)	6	259.44	3.91	2.36
Error BE/A	36	66.28		
Sessions x Vowels (CE)	3	3.92	.46	2.86
Groups x Sessions x Vowels (ACE)	6	9.84	1.15	2.36
Error BCE/A	36	8.55		
Trials x Vowels (DE)	3	.97	.18	2.86
Groups x Trials x Vowels (ADE)	6	5.48	1.00	2.36
Error BDE/A	36	5.47		
Sessions x Trials x Vowels (CDE)	3	4.84	.90	2.86
Groups x Sessions x Trials x Vowels (ACDE)	6	2.13	.40	2.36
Error BCDE/A	36	5.36		

TABLE 3—Continued

Source	df	ms	F	F.05
Consonants (F)	3	325.52	6.47	2.86
Groups x Consonants (AF)	6	175.17	3.48	2.36
Error BF/A	36	50.34		
Sessions x Consonants (CF)	3	5.63	.52	2.86
Groups x Sessions x Consonants (ACF)	6	6.89	.63	2.36
Error BCF/A	36	10.86		
Trials x Consonants (DF)	3	4.81	.83	2.86
Groups x Trials x Consonants (ADF)	6	9.62	1.65	2.36
Error BDF/A	36	5.82		
Sessions x Trials x Consonants (CDF)	3	6.86	.80	2.86
Groups x Sessions x Trials x Consonants (ACDF)	6	9.98	1.17	2.36
Error BCDF/A	36	8.53		
Vowels x Consonants (EF)	9	17.54	2.08	1.96
Groups x Vowels x Consonants (AEF)	18	13.60	1.62	1.66
Error BEF/A	108	8.42		
Sessions x Vowels x Consonants (CEF)	9	5.00	.87	1.96
Groups x Sessions x Vowels x Consonants (ACEF)	18	2.16	.38	1.66
Error BCEF/A	108	5.72		
Trials x Vowels x Consonants (DEF)	9	1.98	.46	1.96
Groups x Trials x Vowels x Consonants (ADEF)	18	8.90	2.08	1.66
Error BDEF/A	108	4.28		
Sessions x Trials x Vowels x Consonants (CDEF)	9	10.17	1.49	1.96
Groups x Sessions x Trials x Vowels x Consonants (ACDEF)	18	6.23	.91	1.66
Error BCDEF/A	108	6.84		
Residual	0	0.00		

three analyses did the F-ratios of the sessions-by-trials interaction achieve the experimental confidence level, indicating that the nasal-"oral" differences for each of the three types of speech sample did not differ significantly across the four trials. The maximum difference between the means contributing to this interaction was only .47 dB for the vowels, .65 dB for the sentence, and 1.42 dB for the CVC syllables.

Of the thirty-three remaining interactions involving the sessions and/or trials variables in the three analyses, only the third-order groups-by-trials-by-vowels-by consonants interaction in the analysis of the CVC syllables was significant. The failure of the interactions involving the sessions and/or trials variables to achieve significance in these analyses indicates that the nasal-"oral" differences did not differ significantly for the sessions and trials variables when considered in relation to each other or to the subject groups and/or individual types of speech sample. The significant F-ratio for the groups-by-trials-by-vowels-by-consonants interaction in the analysis of the CVC syllables indicates that the nasal-"oral" sound pressure differences differed significantly across the vowel-consonant combinations as produced by the three subject groups within the first and second trials of each session. Examination of the group, trial, consonant, and vowel means contributing to this interaction reveals that the mean measurement for [u] in [d] contexts is considerably higher for Group I, the cleft palate subjects with relatively low oral manometer ratios, on the second trials of each session. Further inspection of these data, however, fails to reveal major trends that might account for the significance of the interaction, and its interpretation remains unclear.

Descriptive Analysis

The analyses of variance of the nasal-"oral" sound pressure differences for the three types of speech sample revealed no significant differences attributable to the sessions or trials main effects or to the interaction of these variables with other variables in the analyses. However, this statistical method tests only for the significance of differences among mean scores and provides little information with respect to variation of individuals within any subject group. Toward this end, therefore, evaluation of the magnitude of the mean differences between session and trial scores, across speech sample types for each subject group, was undertaken.

In this analysis, the difference between the nasal-"oral" measures of Trial 1 and Trial 2 and the difference between the measures of Trial 3 and Trial 4 were obtained for each speech sample item produced by each subject, and the means and ranges of these two groups of difference scores were computed for each of the three subject groups. In addition, the maximum difference between the two nasal-"oral" measures of Session I and the two measures of Session II was derived for each speech sample by each subject, and the means and ranges of these maximum intersession difference scores were computed for each of the three groups.

Vowels. The means and ranges of the difference scores for the sustained vowels by the three groups of subjects are presented in Table 4. Inspection of the Trial 1-Trial 2 mean difference scores reveals that, with the exception of the .8-dB mean for [ɑ] by Group II, these scores are quite similar and, when averaged over all vowels, are essentially identical for each of the subject groups. While the ranges of the Trial 1-Trial 2 differences scores are generally of the same magnitude

TABLE 4

MEANS AND RANGES OF DIFFERENCES IN DECIBELS BETWEEN TRIALS 1 AND 2 AND BETWEEN TRIALS 3 AND 4 AND MEANS AND RANGES OF DIFFERENCES IN DECIBELS BETWEEN SESSIONS I AND II FOR FOUR SUSTAINED VOWELS PRODUCED BY THREE SUBJECT GROUPS

Group		Trial 1 - Trial 2 [i]	[æ]	[ɑ]	[u]	$\bar{x}$
I	Means	2.0	1.6	1.8	3.0	2.1
	Ranges	1-4	0-6	0-4	0-5	
II	Means	2.6	2.0	.8	2.6	2.0
	Ranges	1-7	1-5	0-2	0-8	
III	Means	2.0	1.6	2.6	1.6	2.0
	Ranges	0-4	0-4	1-7	0-2	
$\bar{x}$		2.2	1.7	1.7	2.4	

Group		Trial 3 - Trial 4 [i]	[æ]	[ɑ]	[u]	$\bar{x}$
I	Means	2.2	2.6	2.4	1.2	2.1
	Ranges	1-4	1-4	1-4	0-3	
II	Means	3.2	2.6	2.4	3.6	3.0
	Ranges	1-9	0-7	1-3	1-11	
III	Means	1.6	3.6	2.8	1.4	2.4
	Ranges	0-2	0-8	1-8	0-4	
$\bar{x}$		2.3	2.9	2.5	2.1	

Group		Session I - Session II [i]	[æ]	[ɑ]	[u]	$\bar{x}$
I	Means	6.0	4.8	3.2	3.2	4.3
	Ranges	2-8	2-7	1-5	2-6	
II	Means	5.2	4.0	3.8	7.0	5.0
	Ranges	1-12	1-7	3-6	1-14	
III	Means	3.6	4.2	4.2	3.2	3.8
	Ranges	2-5	2-6	1-9	2-4	
$\bar{x}$		4.9	4.3	3.7	4.5	

from group to group for each of the vowels, the ranges of Group II are, on the average, slightly greater than the ranges of the other two subject groups. The Trial 3-Trial 4 mean difference scores are also similar for each of the vowels for each subject group, but, when averaged over all vowels, are somewhat higher for Group II. The ranges of the difference scores for Group II are, on the average, again slightly higher than those observed for the other two groups.

The Trial 1-Trial 2 mean difference scores, when considered across groups, are equivalent for the four vowels, although the mean differences for [æ] and [ɑ] are, on the average, lower, by less than 1 dB, than those for [i] and [u]. The ranges of the Trial 1-Trial 2 difference scores across groups are highly similar for each of the vowels. The Trial 3-Trial 4 mean difference scores across groups are also very similar for each of the vowels; however, in this instance, the means for [æ] and [ɑ] are higher, by less than 1 dB, than the means for [i] and [u]. The ranges of the Trial 3-Trial 4 mean difference scores are, as a group, slightly higher for [æ] and [u] than for the other two vowels.

Inspection of Table 4 also reveals that the Session I-Session II difference scores, while considerably larger than the between-trials difference scores, as might be expected, are similar for each of the vowels for each of the subject groups, but, when averaged over all vowels, are higher by approximately 1 dB for Group II. Examination of the individual subject scores reveals that extreme scores of two subjects are responsible for the mean of 7.0 dB for [u] by Group II. The ranges of the Session I-Session II mean difference scores vary rather widely for each of the groups from vowel to vowel, but are markedly higher, on the average, for Group II; in this instance, the ranges of 12 and 14 dB for [i] and

[u], respectively, are attributable to the difference scores of a single subject. The means and ranges of the Session I-Session II mean difference scores, when considered across groups, are equivalent for the four vowels, although both means and ranges are slightly lower for [æ] and [ɑ] than for [i] and [u].

<u>Sentence</u>. The means and ranges of the difference scores for the sentence in the experimental speech sample are presented in Table 5, in-

TABLE 5

MEANS AND RANGES OF DIFFERENCES IN DECIBELS BETWEEN TRIALS 1 AND 2 AND BETWEEN TRIALS 3 AND 4 AND MEANS AND RANGES OF DIFFERENCES IN DECIBELS BETWEEN SESSIONS I AND II FOR THE SENTENCE PRODUCED BY THREE SUBJECT GROUPS

Group		Trial 1-Trial 2	Trial 3-Trial 4	Session I-Session II
I	Means	2.0	3.0	5.2
	Ranges	0-5	1-7	2-9
II	Means	2.6	1.6	3.2
	Ranges	1-4	0-4	2-5
III	Means	1.8	.4	3.4
	Ranges	0-3	0-1	2-6
$\bar{x}$		2.1	1.7	3.9

spection of which reveals scores that are similar to those obtained for the isolated, sustained vowels. For the sentence, the Trial 1-Trial 2 mean difference scores are equivalent for the three subject groups, approximately 2 dB. The Trial 3-Trial 4 mean difference scores are relatively more variable, ranging from 3.0 dB for Group I to .4 dB for Group III, but, averaged over the three groups, are similar to the Trial 1-Trial 2 scores. The ranges of the Trial 1-Trial 2 and Trial 3-Trial 4 difference scores are equivalent and comparable to those for the sustained vowels; it can be seen, however, that the ranges for Group I are larger than those for Group II and that those for Group II are larger than those for Group III. The Session I-Session II mean difference scores for the sentence are similar to those for the vowels, but, for the sentence, that for Group I is somewhat higher than those for the other two groups, which are equivalent. The ranges for the three subject groups are similar, although that for Group I is slightly higher that that for either of the other two subject groups.

Syllables. The means and ranges of the Trial 1-Trial 2 difference scores for the CVC syllables produced by the three subject groups are presented in Table 6, inspection of which reveals that, on the average, the mean difference scores for Group I are larger than those for Groups II and III, which are equivalent. For Group I, the means of the mean difference scores for the consonant context groups are very similar, except for that of the [z]-context syllables which is approximately 1 dB lower than the others. While the means of the mean difference scores for the [t]-, [d]-, and [s]-context syllables for Group I are equivalent, the wide variation of the means and ranges of the difference scores for syllables in the [d]-context is remarkable; the syllable [dæd] resulted in a mean difference score of only .8 dB, with a range from 0 to 2 dB, while the syllable [dud] resulted in a mean difference score of 8.8 dB and a range from 3 to 28 dB. The ranges of Trial 1-Trial 2 difference scores for the CVC syllables are also greater for Group I than for the other two subject groups. For Group I, the ranges for the [d]- and [s]-context syllables are notably higher than those for the [t]- and [z]-context syllables. For Group I, also, the

TABLE 6

MEANS AND RANGES OF DIFFERENCES IN DECIBELS BETWEEN TRIALS 1 AND 2 FOR THE SIXTEEN CVC SYLLABLES PRODUCED BY THREE SUBJECT GROUPS

	Trial 1–Trial 2						
	Group I		Group II		Group III		
Syllable	Means	Ranges	Means	Ranges	Means	Ranges	$\bar{x}$
[tit]	3.2	0-8	3.0	0-6	1.8	0-4	2.7
[tæt]	4.6	2-7	1.8	0-4	1.0	0-3	2.5
[tɑt]	6.0	1-16	1.6	0-8	3.2	1-6	3.6
[tut]	2.2	0-5	2.8	0-12	1.4	0-3	2.1
$\bar{x}$	4.0		2.3		1.9		
[did]	3.6	0-10	2.0	1-5	1.6	0-3	2.4
[dæd]	.8	0-2	1.4	0-5	5.0	1-12	2.4
[dɑd]	2.8	2-4	4.2	0-16	1.4	0-4	2.8
[dud]	8.8	3-28	5.8	4-10	2.6	0-5	5.7
$\bar{x}$	4.0		3.4		2.7		
[sis]	4.8	0-10	2.0	0-4	1.6	0-4	2.8
[sæs]	4.0	1-10	3.4	1-9	2.0	0-4	3.1
[sɑs]	4.2	2-11	2.8	1-7	2.4	0-7	3.1
[sus]	4.6	1-13	1.4	1-2	1.0	0-3	2.3
$\bar{x}$	4.4		2.4		1.8		
[ziz]	4.8	0-11	.8	0-2	2.2	0-5	2.6
[zæz]	3.4	2-7	2.0	0-5	2.4	1-5	2.6
[zɑz]	1.6	0-5	2.2	0-4	4.6	0-9	2.8
[zuz]	3.4	1-6	1.6	1-2	2.6	1-8	2.5
$\bar{x}$	3.3		1.7		3.0		
$\bar{X}$	3.9		2.5		2.4		

ranges of the difference scores for the syllables are consistently larger than those for either the sustained vowels or the sentence in the speech sample.

The means of the Trial 1-Trial 2 mean difference scores for the four consonant context groups for Group II are lower and, when considered by consonant context group, more variable than those for Group I. The mean for the [d]-context syllables is approximately 1 dB higher than the means for the [t]- or [s]-context syllables and approximately 2 dB higher than that for the [z]-context syllables; this appears attributable, in large part, to the mean difference scores of 4.2, 5.8, and .8 dB for the syllables [dɑd], [dud], and [ziz], respectively. For Group II, the ranges of difference scores are greater for the [t]- and [d]-context syllables than for the [s]- and [z]-context syllables. As noted for Group I, the ranges of difference scores for the syllables for Group II are consistently larger than those for the sustained vowels or the sentence.

While the mean difference scores over the sixteen syllables for Group III are, on the average, equivalent to those for Group II, the means of the mean difference scores for the [t]-, [d]-, and [s]-context syllables are smaller for Group III than for Group II. The mean for the [z]-context syllables for Group III is larger than that for Group II, in part because of the mean difference score of 4.6 dB for the syllable [zæz]. As was evident for Group II, the mean of the mean difference scores for the [d]-context syllables for Group III is larger than those for the [t]- and [s]-context syllables; this appears attributable primarily to the mean difference score of 5.0 dB for the syllable [dæd]. The ranges of Trial 1-Trial 2 difference scores for the syllables for Group III are smaller, as a group, than for Groups I and II. The ranges of difference scores for the syllables for Group III are larger than those for the sustained vowels or the sentence in the speech sample, but this trend is not so pronounced as it is for Groups I and II.

The Trial 1-Trial 2 mean difference scores, when considered across subject groups, are highly similar, 2.5-3 dB, for all sixteen syllables, although the means for the [d]-context syllables, as a group, are higher than those for the other consonant context groups. The means of 3.6 dB for [tɑt] and 5.7 dB for [dud] seem primarily attributable to the Group I mean differences of 6.0 dB for [tɑt] and 8.8 dB for [dud] and to the Group II mean difference of 5.8 dB for [dud], all of which reflect the extreme difference score of a single subject in each of the subject groups. By contrast, the mean difference score of .8 dB, with a range from 0 to 2 dB, produced by Group I for [dæd] and Group II for [ziz], was the lowest for any syllable for any subject group. The ranges of difference scores, when considered across subject groups, are very similar among the consonant context groups, although those of the [d]-context syllables are slightly elevated.

The Trial 3-Trial 4 mean difference scores for the CVC syllables, shown in Table 7, are, when averaged over all syllables, highly similar to those evident in the Trial 1-Trial 2 analysis. The scores for Group I are, on the average, again larger than those for Groups II and III, which are again equivalent. For Group I, the Trial 3-Trial 4 means of the mean difference scores for the individual consonant context groups are similar, although the means for the [z]- and [d]-context syllables are somewhat larger than those for the [s]- and [t]-context syllables. Table 7 also indicates that the ranges of the Trial 3-Trial 4 difference scores for the syllables are, on the average, again greater for Group I than for the

TABLE 7

MEANS AND RANGES OF DIFFERENCES IN DECIBELS BETWEEN TRIALS 3 AND 4 FOR THE SIXTEEN CVC SYLLABLES PRODUCED BY THREE SUBJECT GROUPS

	Trial 3-Trial 4						
	Group I		Group II		Group III		
Syllable	Means	Ranges	Means	Ranges	Means	Ranges	$\bar{x}$
[tit]	2.2	0-4	1.2	0-2	2.0	0-3	1.8
[tæt]	2.6	0-7	1.4	0-3	2.2	0-4	2.1
[tɑt]	2.0	0-5	1.0	0-2	3.2	1-7	2.1
[tut]	2.2	1-4	2.2	1-4	1.8	0-3	2.1
$\bar{x}$	2.3		1.5		2.3		
[did]	4.2	1-10	2.4	0-5	2.6	0-7	3.1
[dæd]	3.8	1-7	3.6	2-5	4.2	2-10	3.9
[dɑd]	4.4	0-10	2.8	1-5	4.8	1-12	4.0
[dud]	2.8	2-5	2.4	1-6	2.8	0-5	2.7
$\bar{x}$	3.8		2.8		3.8		
[sis]	3.2	0-9	4.0	0-9	2.4	0-5	3.2
[sæs]	2.6	1-6	3.4	1-7	3.0	0-12	3.0
[sɑs]	3.8	1-9	3.2	0-7	1.6	1-3	2.9
[sus]	2.0	0-5	1.2	0-3	1.0	0-3	1.4
$\bar{x}$	2.9		3.0		2.0		
[ziz]	3.6	1-9	2.8	1-9	1.2	0-2	2.5
[zæz]	4.2	0-11	2.8	1-5	3.6	2-8	3.5
[zɑz]	4.4	2-9	2.2	1-4	2.4	0-7	3.0
[zuz]	4.0	0-9	2.2	0-5	2.8	2-5	3.0
$\bar{x}$	4.1		2.5		2.5		
$\bar{X}$	3.3		2.5		2.7		

other two subject groups, although the extreme ranges evident in the Trial 1-Trial 2 data are not apparent. For Group I, the ranges of the [z]-context syllables are somewhat higher than those for the other three consonant context groups. The ranges of difference scores for Group I are again larger for the syllables than for the sustained vowels or the sentence, although the ranges of difference scores for [t]-context syllables are similar to those for the other two types of speech sample.

For Group II, the Trial 3-Trial 4 mean difference scores, when averaged over all syllables, are identical to those for this subject group in the Trial 1-Trial 2 analysis. The Trial 3-Trial 4 means of the mean difference scores for the individual consonant contexts are similar, although the mean of the [t]-context syllables is lower by 1 dB or more than the other Group II means. This mean is the lowest of this kind for any of the consonant context groups by any subject group in either the Trial 1-Trial 2 or Trial 3-Trial 4 analyses. The ranges of difference scores for Group II are, on the average, smaller than those for Group I. For Group II, the ranges of the [s]-context syllables are somewhat higher than those for the other three consonant context groups. The ranges for the [d]-, [s]-, and [z]-context syllables are comparable to those for this subject group for the sustained vowels and the sentence, while the ranges for the [t]-context syllables are lower for the syllables than for the vowels (it will be recalled that Group II manifested greater variation in ranges of difference scores on the vowels than did the other two subject groups).

The Trial 3-Trial 4 mean difference scores for the syllables for Group III are, on the average, equivalent to those for Group II and to the Trial 1-Trial 2 mean difference scores for Group III. The means of the mean difference scores for Group III for the individual consonant context groups are similar, although the mean for the [d]-context syllables is more than 1 dB higher than that for any of the other syllable groups; this seems attributable primarily to mean difference scores of 4.2 and 4.8 dB for [dæd] and [dɑd], respectively. The ranges of the Trial 3-Trial 4 difference scores for Group III are similar across the syllables, although higher for the [d]-context syllables, and, on the average, are comparable to those for Group II; extreme ranges of 1 to 12 and 0 to 12 dB are evident for [dɑd] and [sæs], respectively. The ranges for the syllables for the syllables for Group III are similar to those for that subject group for the sustained vowels and the sentence.

The Trial 3-Trial 4 mean difference scores, when considered across subject groups, are similar, although the means for the [t]-context syllables, as a group, are markedly smaller than those for the other three consonant context groups. The means for [tɑt] and [dud], which were notably larger in the analysis of the Trial 1-Trial 2 data, are not unlike those of the Trial 3-Trial 4 mean difference for the other syllables. The ranges of difference scores for the individual syllables across subject groups are similar, although those for the [t]-context syllables are appreciably smaller than those for the other consonant context groups.

The means and ranges of the Session I-Session II difference scores for the CVC syllables are presented in Table 8, which indicates, as might be expected, that the intersession means and ranges are considerably higher than the intertrial means and ranges. The Session I-Session II mean difference scores for Group I, as for the intertrial scores, are, on the average, larger than those for Groups II and III, which are equivalent. Among the means of the mean difference scores for the individual consonant context groups, those of Group I are in every instance larger

TABLE 8

MEANS AND RANGES OF DIFFERENCES IN DECIBELS BETWEEN SESSIONS I AND II FOR THE SIXTEEN CVC SYLLABLES PRODUCED BY THREE SUBJECT GROUPS

	Session I-Session II						
	Group I		Group II		Group III		
Syllable	Means	Ranges	Means	Ranges	Means	Ranges	$\bar{x}$
[tit]	5.4	1-11	4.4	2-7	3.6	0-7	4.5
[tæt]	6.0	3-10	4.4	2-7	3.6	2-6	4.7
[tɑt]	6.4	1-13	3.2	1-7	5.6	4-8	5.1
[tut]	5.2	1-9	5.2	2-9	3.2	1-6	4.5
$\bar{x}$	5.8		4.3		4.0		
[did]	6.4	3-13	4.6	1-10	4.4	1-8	5.1
[dæd]	6.4	1-14	6.8	3-12	8.4	2-15	7.2
[dɑd]	8.0	5-11	7.4	1-19	4.2	1-8	6.5
[dud]	9.2	3-22	4.8	2-7	4.2	2-6	6.1
$\bar{x}$	7.5		5.9		5.3		
[sis]	9.6	4-19	5.4	1-11	3.4	0-5	6.5
[sæs]	7.0	2-12	6.4	2-12	3.8	2-10	5.7
[sɑs]	9.2	3-17	4.8	3-7	3.4	2-6	5.8
[sus]	8.0	1-14	2.8	1-4	2.6	1-4	4.5
$\bar{x}$	8.5		4.9		3.3		
[ziz]	6.4	2-10	3.4	1-7	4.6	3-6	4.8
[zæz]	8.6	2-16	4.4	2-7	6.4	2-11	6.5
[zɑz]	6.8	2-10	3.4	1-6	5.0	2-9	5.1
[zuz]	5.8	2-11	3.8	1-7	5.6	2-10	5.1
$\bar{x}$	6.9		3.8		5.4		
$\bar{X}$	7.2		4.7		4.5		

than those for Group II, and those of Group II, except for the [z]-context syllables, are larger than those for Group III. For Group I, the mean of the mean difference scores for the [s]-context syllables is the largest, followed in order by those for the [d]-, [z]-, and [t]-context syllables. The individual [s]-context syllable difference scores exceed the scores for all other syllables except [dɑd], [dud], and [zæz], which are approximately of the same magnitude. The ranges of the Session I-Session II difference scores for the syllables vary widely and can be seen to be markedly greater for Group I than for the other two subject groups. For Group I, the ranges for the [s]- and [d]-context syllables are notably higher than those for the [z]- and [t]-context syllables. The range of 20 dB for [dud] is extraordinary, but ranges of 16, 15, 15, 14, and 13 are evident for [sis], [zæz], [sɑs], and [tɑt], respectively.

For Group II, the means of the Session I-Session II difference scores are, on the average, lower, and less variable than those for Group I. The mean of the mean difference scores for the [d]-context syllables is 1 dB or more higher than those for the other consonant context groups, which appears attributable primarily to the mean difference scores of 6.8 and 7.4 dB for [dæd] and [dɑd], respectively. The ranges of difference scores for Group II are smaller, on the average, than those for Group I, but somewhat larger than those for Group III. The ranges of the difference scores for the [d]-context syllables are greater than for the other consonant context groups for Group II. Except for the [d]-context syllables, the ranges of the Session I-Session II difference scores for the syllables approximate the ranges of such scores for the sustained vowels and the sentence produced by Group II.

For Group III, the Session I-Session II mean difference scores for the [z]- and [d]-context syllable groups are essentially equal and 1-2 dB higher than those for the [t]- and [s]-context groups; the mean difference scores for the [z]-context syllables are all elevated to a similar extent, and the mean difference score of 8.4 dB for [dæd] appears to be contributing primarily to the elevated mean for the [d]-context syllables. The ranges of difference scores for Group III are smaller than those for Group II. For Group III, the ranges of the [d]-context and [z]-context syllables are higher than those for the [t]- and [s]-context groups.

The Session I-Session II mean difference scores, when considered across subject groups, are highly similar for all syllables, although those for the [d]-context syllables, as a group, are somewhat higher and those for the [t]-context syllables, as a group, are somewhat lower than those for the [s]- and [z]-context syllable groups. The ranges of difference scores for the individual syllables vary rather widely, but, when considered by consonant context groups, are similar, except for a slight elevation of the ranges of the [d]-context syllables.

Discussion

In the present investigation, neither trial nor session means differed sufficiently to reach the experimental significance level for any of the three types of speech sample. With a single exception, and this a third-order interaction, no interactions involving these variables achieved statistical significance. These findings indicate that the mean nasal-"oral" sound pressure measurements of the individual subject groups and speech samples did not vary significantly from session to session or from trial to trial within sessions. The descriptive analysis of the mean differences between trials, approximately 2-3 dB, and between sessions, approximately 4-5 dB, illustrates this relative constancy of both subject groups and speech sample types from production to production.

While the individual difference scores contributing to these means were also generally small, exaggerated mean difference scores for a given speech item production by a given subject group were generally found to be the result of the inconsistent performance of a single subject. Differences between trials for certain individual subjects, for example, were as great as 11 dB for the vowels, 7 dB for the sentence, and 28 dB for the syllables; individual differences between sessions were as great as 14 dB for the vowels, 9 dB for the sentence, and 22 dB for the syllables. Similar intrasubject variability has been discussed in reports of investigations of various other aspects of both normal and abnormal speech production, e.g., by Minifie et al (39) for language measures, by Winitz (63) for articulation scores, and by Shelton, Bankson, and Brooks (47) for nasal air pressure measurements.

The relative consistency of group measurements but occasional inconsistency of individual subject measurements indicated by the findings of this study bear critically on the utilization of the probe-tube microphone assembly in the evaluation of nasality. The mean of the nasal-"oral" sound pressure level differences obtained for a group of subjects apparently reflects a reliable measure of the performances of these subjects, as a group. If, on the other hand, the nasal-"oral" sound pressure measure is to be utilized for the experimental or clinical evaluation of a single subject, the risk of extreme performances on single measurements is markedly increased. Furthermore, insofar as nasal-"oral" differences are correlated with perceptual judgments of nasality, the variability of ratings of nasality of repeated speech item productions by a single subject may be attributable as much to subject variability as to other variables in the judgment situation. It can be speculated that correlations between nasal-"oral" sound pressure differences and perceived nasality might be increased by establishing the reliability of subjects' performance in this respect prior to the judgment of severity of nasality.

Failure of the interactions involving the subject groups and the sessions and/or trials to achieve statistical significance for any of the speech sample types suggests that the subject groups were equivalently reliable. The descriptive analysis, however, reveals relatively consistent, although slight, differences in the performances of the three subject groups. Group I, the cleft palate subjects with low oral manometer ratios, displayed greater magnitudes of mean differences and ranges across speech samples. Group II, the cleft palate subjects with relatively high oral manometer ratios, and Group III, the normal speakers, manifested lower but generally equivalent ranges and mean differences between both trials and sessions over all speech samples. While the difference scores for any given speech sample item were similar among the subjects of Group II, the mean difference scores of this subject group, as a unit, were more inconsistent across the items of the speech sample than those of Group I or III. For most speech sample items, the differences and ranges for Group II approximated those for Group III; for some speech sample items, however, the mean differences for Group II equalled, or, in the case of the sustained vowels, exceeded those for Group I. The consistency of the intergroup differences, as well as the occasional extreme scores of individual subjects in the repeated productions of given speech sample items, indicates strongly that the variability among the subject group scores is attributable to fluctuations of subject performance rather than to inconsistencies in recording and/or measurement procedures. Such subject group variability may well have implications for subject selection in future research investigations of cleft palate speech utilizing the probe-tube microphone assembly.

Both the statistical and descriptive analyses suggest that the measurements of the vowels, sentence, and syllables, over subject groups, are equivalent from trial to trial and from session to session. Closer evaluation of the descriptive data, however, reveals a tendency for the syllables to be marked by larger mean differences and greater ranges, particularly for Group I, than for the other speech samples both between trials and between sessions. The means and ranges for the sustained vowels and the sentence are quite similar, although those measures for the sentence are frequently lower than those for the vowels. These trends in the difference score data suggest that, insofar as nasal-"oral" sound pressure level differences are related to perceived nasality, more consistent nasality judgments might be obtained for connected speech than single words. Such differences between speech sample types, while small, may influence speech item selection in future investigations of cleft palate speech utilizing the probe-tube microphone assembly.

In summary, the results of this investigation indicate that the probe-tube assembly provides a reliable means to assess nasal-"oral" sound pressure differences. Briefly, these results include: (1) the subject groups produced nasal-"oral" sound pressure differences which were not statistically different on two consecutive productions (Trials 1 and 2 and Trials 3 and 4) of the same speech sample; specific differences were found to be influenced by the subject group and the speech sample; (2) the nasal-"oral" sound pressure level differences for speech samples produced by the subject groups upon two separate occasions (Session I and Session II) were not significantly variable; the magnitude of the difference scores between sessions may be expected to be larger than the difference scores between trials and to vary slightly with subject group and speech sample; (3) the degree of variability observed across trials and/or sessions, when considered for all types of speech sample, was slightly larger for the cleft palate subjects with low oral manometer ratios than for the other two subject groups, although not of sufficient magnitude to reach statistical significance; and (4) while the differences between the three types of speech sample utilized in this study, across subjects, were small, the means and ranges of difference scores were generally larger for the CVC syllables than for the sustained vowels or the sentence.

CHAPTER V

SUMMARY AND CONCLUSIONS

Numerous attempts have been made to isolate measurable correlates of nasality and to develop objective and quantitative procedures by which the assessment of this resonance distortion might be improved. The probe-tube microphone assembly affords one such method, but examination of the investigations making use of this instrumentation reveals no findings relative to the reliability of measurements so derived. It was the purpose of this study, therefore, to determine the variance of nasal and "oral" sound pressure level measurements of repeated speech productions.

Fifteen adult males, ten with operated cleft palate or cleft lip and palate and five non-cleft normal speakers, served as subjects in this investigation. Each was of normal intelligence and none had a hearing loss of more than 15 dB in the better ear. Each was assigned to one of three experimental groups on the basis of the average of three oral manometer breath pressure ratios: Group I consisted of five cleft palate subjects with mean oral manometer ratios below .70; Group II consisted of five cleft palate subjects with mean oral manometer ratios between .70 and .90; and Group III consisted of the five normal-speaking subjects, each of whom had a mean oral manometer ratio of 1.0. The speech sample included: (a) four isolated, sustained vowels, (b) sixteen consonant-vowel-consonant syllables, and (c) a sentence containing no nasal consonants.

Each subject, after a practice period to familiarize himself with the experimental task, produced the entire speech sample two times, Trial 1 and Trial 2, at a uniform, monitored intensity level. No changes were made in the position of the instrumentation or of the subject during these two productions, which together constituted Session I. Subsequently, the subject was removed from the test room and the equipment changed from the position in which it had been used during the initial data collection. Following a period of not less than fifteen minutes, the subject was returned to the test room and an attempt was made to duplicate the subject and equipment positions of Session I. Session II, then, consisted of Trials 3 and 4, two consecutive productions of the entire speech sample.

A dual-channel tape recording system was used to record the speech productions of each subject. By modifying one microphone of this system with the addition of a miniature-bore probe-tube, it was possible to record simultaneously the "nasal" speech signal within the nasal meatus and the "oral" speech signal at a point eight inches from the speaker's lips. The recorded nasal and "oral" speech samples were played into a power level recorder, which provided continuous graphic tracings of the variations in intensity of the speech signals that were measurable in decibels re .0002 dyne/cm^2 by reference to a tracing of white noise of known intensity recorded on each tape prior to the recording of each subject.

Measurements of each speech sample in the two tracings were made, and the arithmetic difference between the obtained nasal and "oral" sound pressures was computed for each speech item produced by each subject.

These nasal-"oral" sound pressure differences were analyzed by means of partially nested analyses of variance with factorial arrangement of treatments. In addition, the magnitudes of the means and ranges of the intertrial and intersession difference scores across speech sample types for each subject group were also analyzed.

The results of the statistical analyses indicate that no trials or sessions main effect and only one of thirty-six interactions involving these variables attained the .05 experimental significance level. Evaluation of the means and ranges of intertrial and intersession difference scores revealed slight though relatively consistent differences among the three subject groups and among the three types of speech sample. In general, Group I, the cleft palate subjects with the lower oral manometer ratios, was the most variable of the three groups, particularly for the experimental sentence and CVC syllables; Group III produced the lowest difference scores and ranges across all speech samples; and Group II, while generally similar in performance to Group III, occasionally manifested scores that equalled or even exceeded those for Group I. Among the types of speech sample, the CVC syllables were found to be characterized by higher mean differences and larger ranges across all groups than were the sustained vowels or the sentence, which were generally equivalent.

The results of this investigation are, of course, limited to the conditions under which the data were gathered. Possible sources of error include: (a) the failure to incorporate listener judgments of the degree of the severity of nasality in the speech of the cleft palate subjects to be utilized in conjunction with oral breath pressure ratios in subject selection and placement in groups; and, (b) articulatory errors in the speech of the cleft palate subjects which may have influenced the level recorder tracings.

In view of these possible errors and within the limitations imposed by the relatively small number of subjects within each group, it appears warranted to conclude that repeated productions of identical speech samples by cleft palate and normal speakers result in reliable nasal-"oral" sound pressure differences when averaged across groups and across speech sample types.

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APPENDIX

TABLE 9

MEANS OF THREE ORAL MANOMETER RATIOS PRODUCED BY THE FIFTEEN SUBJECTS

Subject Group I			
Subject 1	.63		
Subject 2	.16		
Subject 3	.26		
Subject 4	.56		
Subject 5	.54	Group mean	.43
Subject Group II			
Subject 1	.83		
Subject 2	.90		
Subject 3	.83		
Subject 4	.81		
Subject 5	.71	Group mean	.82
Subject Group III			
Subject 1	1.00		
Subject 2	1.00		
Subject 3	1.00		
Subject 4	1.00		
Subject 5	1.00	Group mean	1.00

TABLE 10

NASAL-"ORAL" SOUND PRESSURE LEVEL DIFFERENCES OF THE FOUR SUSTAINED VOWELS PRODUCED BY THE FIVE SUBJECTS OF GROUP I FOR FOUR TRIALS

		Trial 1	Trial 2	Trial 3	Trial 4
Subject 1					
Vowel	[i]	31	33	35	39
	[æ]	28	28	28	30
	[ɑ]	27	27	26	28
	[u]	32	33	32	35
Subject 2					
Vowel	[i]	41	40	39	40
	[æ]	39	33	33	35
	[ɑ]	32	35	34	35
	[u]	40	45	43	43
Subject 3					
Vowel	[i]	39	37	37	35
	[æ]	34	34	29	30
	[ɑ]	33	33	30	32
	[u]	35	35	33	34
Subject 4					
Vowel	[i]	33	29	36	37
	[æ]	32	33	30	34
	[ɑ]	26	30	27	30
	[u]	36	41	37	37
Subject 5					
Vowel	[i]	38	37	33	30
	[æ]	29	30	27	23
	[ɑ]	29	27	28	24
	[u]	37	33	35	33

TABLE 11

NASAL-"ORAL" SOUND PRESSURE LEVEL DIFFERENCES OF THE FOUR SUSTAINED VOWELS PRODUCED BY THE FIVE SUBJECTS OF GROUP II FOR FOUR TRIALS

		Trial 1	Trial 2	Trial 3	Trial 4
Subject 1					
Vowel	[i]	34	36	35	37
	[æ]	27	28	29	30
	[ɑ]	27	28	29	30
	[u]	32	33	32	33
Subject 2					
Vowel	[i]	30	37	35	38
	[æ]	26	31	25	26
	[ɑ]	26	26	20	22
	[u]	30	38	31	35
Subject 3					
Vowel	[i]	39	40	40	39
	[æ]	27	26	28	24
	[ɑ]	26	26	26	23
	[u]	35	38	36	35
Subject 4					
Vowel	[i]	22	21	33	24
	[æ]	28	26	33	26
	[ɑ]	24	25	28	25
	[u]	20	20	34	23
Subject 5					
Vowel	[i]	39	41	39	40
	[æ]	32	33	33	33
	[ɑ]	30	28	27	30
	[u]	41	40	32	31

TABLE 12

NASAL-"ORAL" SOUND PRESSURE LEVEL DIFFERENCES OF THE FOUR SUSTAINED VOWELS PRODUCED BY THE FIVE SUBJECTS OF GROUP III FOR FOUR TRIALS

		Trial 1	Trial 2	Trial 3	Trial 4
Subject 1					
Vowel	[i]	31	33	31	29
	[æ]	31	31	31	25
	[ɑ]	30	29	29	30
	[u]	28	30	29	26
Subject 2					
Vowel	[i]	29	25	30	30
	[æ]	29	30	32	33
	[ɑ]	31	30	31	34
	[u]	24	26	27	27
Subject 3					
Vowel	[i]	25	25	27	25
	[æ]	32	32	29	32
	[ɑ]	23	25	28	20
	[u]	23	23	25	25
Subject 4					
Vowel	[i]	34	37	32	34
	[æ]	32	35	33	33
	[ɑ]	30	32	31	30
	[u]	29	31	29	33
Subject 5					
Vowel	[i]	27	26	25	27
	[æ]	32	28	26	34
	[ɑ]	32	25	24	23
	[u]	26	24	27	27

TABLE 13

NASAL-"ORAL" SOUND PRESSURE LEVEL DIFFERENCES OF THE SENTENCE PRODUCED BY THE FIVE SUBJECTS IN GROUP I FOR FOUR TRIALS

Subject No.	Trial 1	Trial 2	Trial 3	Trial 4
1	26	27	30	31
2	36	36	34	39
3	38	39	37	38
4	17	22	23	24
5	38	35	36	29

TABLE 14

NASAL-"ORAL" SOUND PRESSURE LEVEL DIFFERENCES OF THE SENTENCE PRODUCED BY THE FIVE SUBJECTS IN GROUP II FOR FOUR TRIALS

Subject No.	Trial 1	Trial 2	Trial 3	Trial 4
1	31	27	30	29
2	30	32	27	31
3	33	37	35	33
4	25	24	26	25
5	30	32	32	32

TABLE 15

NASAL-"ORAL" SOUND PRESSURE LEVEL DIFFERENCES OF THE SENTENCE PRODUCED BY THE FIVE SUBJECTS IN GROUP III FOR FOUR TRIALS

Subject No.	Trial 1	Trial 2	Trial 3	Trial 4
1	28	25	22	22
2	21	22	24	24
3	24	24	21	22
4	30	32	30	30
5	27	24	24	25

TABLE 16

NASAL-"ORAL" SOUND PRESSURE LEVEL DIFFERENCES OF THE SIXTEEN CVC SYLLABLES PRODUCED BY THE FIVE SUBJECTS OF GROUP I FOR FOUR TRIALS

S*	T*	[tit]	[tæt]	[tɔt]	[tut]	[did]	[dæd]	[dɔd]	[dud]	[sis]	[sæs]	[sɔs]	[sus]	[ziz]	[zæz]	[zɔz]	[zuz]
1	1	31	24	23	30	29	26	25	28	32	26	26	32	31	26	25	31
	2	32	28	27	30	31	26	29	33	32	29	28	33	33	29	30	33
	3	38	28	30	34	33	26	25	33	37	28	29	32	39	28	31	35
	4	35	26	27	30	34	33	33	35	36	31	27	33	35	32	34	34
2	1	38	33	28	38	38	32	36	35	40	43	43	47	40	42	40	42
	2	36	31	34	40	38	32	34	38	41	44	41	44	40	44	39	41
	3	37	34	32	36	36	32	31	35	37	38	44	40	38	40	38	40
	4	37	34	33	38	35	31	29	38	41	40	47	45	39	36	41	43
3	1	38	35	32	36	36	35	30	32	41	41	41	37	40	39	39	37
	2	38	31	33	36	34	36	32	36	36	39	39	40	37	37	38	35
	3	38	34	33	35	34	36	33	33	40	39	42	41	38	37	35	38
	4	37	36	33	36	39	38	35	38	40	40	38	38	39	39	37	38
4	1	29	30	22	32	19	25	25	19	24	25	20	26	21	22	20	25
	2	37	37	38	37	29	27	23	47	32	35	31	39	32	25	21	31
	3	36	36	35	29	22	32	16	25	31	35	37	39	28	27	29	22
	4	40	38	30	30	32	27	26	27	40	29	28	40	31	38	24	31
5	1	31	26	27	31	31	37	33	34	33	33	44	47	30	33	37	32
	2	36	30	30	35	35	36	37	38	43	37	40	44	38	40	37	38
	3	32	27	25	29	33	23	26	30	24	26	28	33	37	29	36	34
	4	29	20	24	26	29	27	26	32	26	25	27	33	28	29	27	27

S* = Subjects
T* = Trials

TABLE 17

NASAL-"ORAL"SOUND PRESSURE LEVEL DIFFERENCES OF THE SIXTEEN CVC SYLLABLES PRODUCED BY THE FIVE SUBJECTS OF GROUP II FOR FOUR TRIALS

S*	T*	[tit]	[tæt]	[tɑt]	[tut]	[did]	[dæd]	[dɑd]	[dud]	[sis]	[sæs]	[sɑs]	[sus]	[ziz]	[zæz]	[zɑz]	[zuz]
1	1	29	25	26	30	30	26	28	28	33	25	34	32	31	29	28	36
	2	34	29	27	30	29	27	27	32	33	28	41	33	32	29	32	34
	3	34	29	27	33	33	29	31	33	34	37	36	36	33	28	34	33
	4	36	29	26	35	33	34	36	32	34	30	36	35	34	31	32	33
2	1	23	19	20	21	34	29	24	27	38	24	25	33	33	28	29	38
	2	29	20	17	33	39	34	40	34	34	33	29	32	32	27	26	36
	3	24	19	20	26	29	22	21	27	27	25	22	30	26	24	24	31
	4	25	18	19	30	33	27	26	33	36	28	27	33	35	27	28	33
3	1	39	29	25	36	41	34	31	40	41	32	28	37	42	32	30	38
	2	36	32	24	35	39	34	31	37	39	31	27	36	40	32	30	37
	3	37	26	25	36	37	31	30	38	38	30	25	37	40	28	30	37
	4	37	28	27	34	40	33	31	39	39	31	32	36	39	33	31	38
4	1	19	24	22	26	24	26	30	31	22	26	28	23	27	28	27	26
	2	19	25	25	26	23	26	27	21	19	23	29	25	27	23	29	25
	3	25	31	29	18	25	32	32	27	22	30	31	22	26	30	30	29
	4	24	28	28	19	20	34	33	25	27	26	28	21	24	28	27	26
5	1	33	27	28	33	34	31	31	38	36	32	30	34	37	35	33	40
	2	32	27	28	34	33	30	32	33	35	31	31	36	37	31	35	38
	3	32	30	30	33	33	28	30	34	37	34	34	36	36	35	34	36
	4	34	29	30	35	33	32	32	36	32	32	33	36	37	36	33	41

S* = Subjects
T* = Trials

TABLE 18

NASAL-"ORAL" SOUND PRESSURE LEVEL DIFFERENCES OF THE SIXTEEN CVC SYLLABLES PRODUCED BY THE FIVE SUBJECTS OF GROUP III FOR FOUR TRIALS

S*	T*	[tit]	[tæt]	[tɑt]	[tut]	[did]	[dæd]	[dɑd]	[dud]	[sis]	[sæs]	[sɑs]	[sus]	[ziz]	[zæz]	[zɑz]	[zuz]
1	1	26	24	17	23	32	25	22	23	27	26	22	23	31	30	26	27
	2	26	24	20	23	30	29	23	28	28	27	29	26	30	31	30	29
	3	22	25	22	24	26	19	26	28	29	25	24	22	25	32	27	26
	4	24	22	21	23	24	23	20	24	24	25	23	23	25	24	28	21
2	1	25	28	27	18	24	25	29	22	19	28	27	19	21	28	29	31
	2	22	28	24	20	22	32	27	22	21	30	29	19	24	27	29	23
	3	29	30	28	24	27	36	25	23	22	30	30	23	25	29	32	21
	4	26	30	25	21	27	33	29	24	24	31	31	23	26	31	32	24
3	1	23	27	24	22	25	29	28	26	24	27	29	23	25	25	21	24
	2	23	26	27	21	28	28	28	27	24	27	29	23	25	30	29	25
	3	23	21	19	22	25	27	27	27	24	29	27	23	24	22	28	23
	4	23	24	26	22	28	25	28	25	24	27	28	22	22	19	21	21
4	1	27	30	33	25	34	33	30	28	25	30	29	24	30	32	29	31
	2	31	31	27	28	33	32	34	32	29	33	31	25	32	31	31	30
	3	30	29	29	23	34	31	33	34	24	31	28	26	32	30	31	30
	4	27	30	30	26	33	33	34	29	25	31	31	26	33	33	29	32
5	1	21	30	23	23	28	34	32	23	24	22	21	23	25	23	20	24
	2	23	27	22	24	28	22	32	20	25	26	22	22	30	27	29	25
	3	24	24	29	21	33	27	36	26	26	32	22	21	26	29	20	28
	4	22	28	25	23	26	37	24	24	22	20	20	24	24	31	22	26

S* = Subjects
T* = Trials