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AN INVESTIGATION OF NASAL-"ORAL" SOUND PRESSURE LEVEL DIFFERENCES AT FOUR VOCAL INTENSITY LEVELS IN NORMAL AND CLEFT PALATE SPEAKERS

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AN INVESTIGATION OF NASAL-"ORAL" SOUND PRESSURE LEVEL

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IN NORMAL AND CLEFT PALATE SPEAKERS

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CHAPTER I

INTRODUCTION

To understand the effects of nasal tract coupling upon the speech signal, researchers within the field of communication disorders have attempted to identify and quantify acoustic changes that are associated with velopharyngeal inadequacy. One area of inquiry has involved the study of the nasal-"oral" sound pressure difference measure. In this line of investigation, the sound pressure level of the nasal speech signal, measured using a probe-tube microphone placed within the nasal meatus, is compared with the sound pressure of the "oral" (overall) speech signal, measured a given distance from the lips. The difference, in decibels, between the nasal and "oral" signals has been used frequently as the criterion measure.

A growing body of information related to the nasal-"oral" sound pressure difference measure, as it relates to nasal tract coupling, has been accumulated over the past two decades. In sum, the results of research studies indicate that this acoustic measure provides an index of nasal tract coupling area in individual speakers (28, 29, 30, 38).

Further, mean nasal-"oral" sound pressure difference measures obtained for groups of normal speakers differ significantly from those obtained for groups of cleft palate speakers with velopharyngeal incompetency (8). In addition, while the degree of relationship reported by different investigators varies, the size of the nasal-"oral" sound pressure difference has been found to be related positively to perceptual measures of the severity of hypernasality (4, 8, 29, 30, 38, 43). Mean nasal-"oral" sound pressure difference measures obtained for both normal and cleft palate groups have been found to be highly reliable (±1 dB) (31). On the basis of the data at hand, it is reasonable to conclude that the nasal-"oral" sound pressure difference measure is related to the degree to which the nasal and oral cavities are coupled during speech.

Results of investigations in this area also show that the size of the nasal-"oral" sound pressure difference for both normal (8, 18, 41) and cleft palate speakers (4, 8) varies according to the phonetic composition of the speech sample. High vowels, such as /i/ and /u/, which are produced by normal speakers with a more complete velar seal (25, 44) are characterized by greater mean nasal-"oral" sound pressure differences than are the low vowels /æ/ and /ɑ/, which are produced with some degree of velopharyngeal opening. Differences between the mean nasal-"oral" sound pressure difference measures for groups of normal and cleft palate speakers have been found to vary as a function of the vowel which is produced. Greatest intergroup differences occur when means for high vowels are compared.

Normal and cleft palate speaking groups (41, 8) have been compared for sex differences relative to mean nasal-"oral" sound pressure difference measures for vowels. While the findings have not always reached levels of statistical significance, there has been a consistent trend toward greater mean nasal-"oral" sound pressure differences for females than for males. The differences between the means for the sexes have been found to be inversely related to reported differences in the relative power of male and female voices (11, 45).

It is suggested in the literature that changes in vocal intensity result in changes in the nasal-"oral" sound pressure difference measures for vowels. Two studies, one by Summers (41) employing normal subjects and one by Ochsner (28) employing a single male cleft palate subject, have indicated the existence of an inverse relationship between the nasal-"oral" sound pressure difference measure for vowels and the intensity of the "oral" signal. The effects of changes in vocal intensity on the magnitude of the nasal-"oral" sound pressure difference measure, however, is substantially different as reported in the two experiments.

If the intensity at which a vowel is produced has an influence upon the magnitude of the nasal-"oral" sound pressure difference measures, it is important that this effect be specified. Further, if the effect differs for normal subjects and subjects with velopharyngeal incompetency, it is important that the nature of this difference, including direction and magnitude, be known. Since the data relating to persons with velopharyngeal incompetency are predicated upon the performance of a single cleft palate subject, it would seem important to determine the extent to which the reported relationships hold when groups of cleft palate speakers are studied. If, as reported, sex differences exist with respect to nasal-"oral" sound pressure difference measures, the need to study both male and female subjects seems apparent. To permit direct comparisons of normal and cleft palate subjects, it is important that subjects in each group be similar in age and that the vocal intensity levels employed be identical for the two groups.

To date, the relevant variables noted above have not been controlled in any single experiment with the result that pertinent relationships must be inferred from data extracted under disparate experimental circumstances. The hazard inherent in such extrapolations is apparent. It is for this reason that the present study was undertaken.

CHAPTER II

REVIEW OF THE LITERATURE

An existing method of identifying and quantifying acoustic changes that are associated with velar inadequacy involves the utilization of the probe-tube microphone assembly. Several investigators (10, 14, 19, 29, 32) have demonstrated that by coupling the nasal and the oral tracts, there is a resulting reduction of overall vowel intensity and an accompanying increase in the intensity of the nasal signal. The probe-tube microphone permits sampling and measurement of the sound pressure level (SPL) within the nasal cavity which may be compared with the measurement of the total sound pressure level (SPL) of the speech signal derived from the placement of a microphone at a given distance from the mouth. The probe-tube microphone itself is an adaptation of the condenser microphone in which a length of small-bore tubing is acoustically coupled to the microphone's diaphragm and placed a short distance into the least occluded nostril. The most commonly used SPL measure employed in studies of nasal and non-nasal speakers is that of the difference in decibels between oral or total sound pressure of the speech signal, and nasal sound pressure (nasal-"oral" SPL difference measure.)

Richards (31) investigated the reliability of the nasal-"oral"

SPL difference measure obtained with the probe-tube microphone assembly. She utilized two groups of cleft palate speakers and one group of normal speakers who were directed to produce four isolated vowels, sixteen CVC syllables, and one sentence containing no nasal consonant sounds during two separate but procedurally identical testing situations. Following the computation of the nasal-"oral" SPL difference measure for each speech item produced by each subject, an analysis was made of the extent of the mean differences between session and trial scores across speech sample types for each subject. Richards found that mean nasal-"oral" SPL difference measures obtained for both normal and cleft palate speakers in repeated productions of the same speech sample were highly reliable with differences among means for repeated trials seldom exceeding 1 decibel. Individual variation was more pronounced. The maximum change in nasal-"oral" SPL difference measures for individual subjects repeating the same speech item averaged 4 to 5 dB, with a few individual subjects exhibiting considerable inconsistency from trial to trial. Concerning the reliability of this measure, Richards concludes that mean nasal-"oral" SPL difference measures obtained for both normal and cleft palate groups are highly reliable although substantial variation can occur in productions of the same speech sample by individual subjects.

In an electrical analog study, House and Stevens (19) found that the overall intensity level of artificial vowels decreases as coupling of the oral and nasal cavities is increased. These investigators indicate that by coupling the oral and nasal cavities, an acoustic power loss during vowel production is introduced, related to the increased damping effect of the nasal tract on the vocal sound generated at the larynx.

Russell and Cotton (32) measured the intensity of "oral" and nasal speech signals during normal production of vowels. Their findings indicate that, when averaged across subjects and frequencies, the nasal signal is 30 dB less intense than the "oral" signal during the production of /ɑ/, /o/, /ɔ/, and /æ/. The nasal signal was 17 dB less intense than the "oral" signal during non-nasal productions for the vowel /i/. Thus, when the vowels are nasalized, the intensity of the nasal signal increases by 20 to 30 dB on the average so that it equals or in some instances, exceeds, the "oral" signal.

Fant (14) examined the influence of four nasal tract coupling conditions upon the spectra of four vowels. By increasing the area of coupling, spectral changes in the vowels are introduced which include increases in formant bandwidth and a reduction of formant intensity. The degree of change varies with the vowel and with the size of the coupling. He speculates that a reduction of formant intensities results, in part, from an interaction between the resonances and anti-resonances which typify the oral and nasal cavities. A shunting side-branch with resonances and anti-resonances at discrete frequencies determined by the cavity characteristics and the size of the coupling is produced by the coupling of the nasal to the oral tract. When the resonant frequencies of the two tracts coincide, there is an increase in the amplitude of the formant frequency. On the other hand, if these pole frequencies do not coincide, those attributable to nasalization effects appear as added resonances in the speech spectrum. When the zero or anti-resonance of the nasal tract coincides with the pole of the vocal tract, there is a reduction in the intensity of the formant frequency. Anti-resonance effects appear as a reduced intensity of the harmonics adjacent to the formant when the pole and zero do not coincide.

The frequency characteristics of the nasal pole-zero pairs is affected by the size of the coupling. With a large area of coupling, the pole and zero frequencies are widely separated and interact with vocal tract resonances and anti-resonances. If the coupling area is small, the pole and zero will be so close as to allow only minimal interactions with vocal tract resonance. The pole and zero coincide and cancel out the nasal tract influence upon the formant structure when there is no coupling. In addition, Fant notes that, with nasal tract coupling, the frequency of the nasal-cavity anti-resonance may coincide with the resonant frequency of the first formant of the nasalized vowel and result in a reduction of the intensity level of that formant. Because the frequency of the first formant varies among the vowels, a constant area of coupling could introduce anti-resonances in some vowels which would be at a frequency above or below the oral resonance of those vowels and not produce any intensity reduction.

Curtis (10) states that the acoustic impedance characteristics of the oral and nasal cavities produce a marked effect on the intensity of the resulting "oral" and nasal output. The relative impedances of the oral and nasal cavities will determine, in a large part, the effect that a coupling of these will have. For example, if the nasal cavity has a high impedance while the oral cavity has a low impedance, the consequence of coupling these two resonators is minimal. On the other hand, if the opposite impedance relationship exists, coupling the two cavities will result in a greater influence on the speech signal.

The usefulness of nasal-"oral" SPL difference measures, obtained using the probe-tube microphone assembly, as an index of the degree to which the oral and nasal tracts are coupled during speech has been explored in a number of studies (8, 28, 29). Pierce (30) evaluated acoustic differences provided by various types of prosthetic speech appliances in a group of adult cleft palate speakers. He found significantly smaller nasal-"oral" SPL differences for subjects who were wearing speech appliances than for the same subjects with their appliances removed. Shelton, Knox, Arndt, and Albert (38) made measurements of nasal SPL in subjects speaking with obturators in place and removed. Nasal SPL measurements were smaller when the obturators were in place than when they were removed.

In a subsequent study by Shelton, et al. (36), a group of twenty-one subjects with well-fitted speech bulbs were compared for nasal SPL with a group of thirteen subjects having a moderate deficiency of palatopharyngeal closure. Both groups produced an identical single sentence and a ten-second segment of connected speech. They found significantly greater nasal SPL measures for the group with inadequate closure as compared to the group wearing obturators. In addition, Pearson correlation coefficients of .48 and .50 were obtained when correlating mean palatopharyngeal gaps as determined by cineflurographic films, with nasal SPL measures obtained during the single sentence and connected speech sample.

Olson (29) explored the effect of controlled changes in nasal tract coupling upon nasal and "oral" SPL measures of the speech of a single non-nasal speaker. The normal subject was fitted with a speech appliance, which permitted varying the size of the velopharyngeal aperture. Utilizing the probe-tube microphone assembly, Olson was able to demonstrate a significant relationship between velopharyngeal aperture dimensions and nasal-"oral" SPL difference measures. Specifically, rank correlations between these SPL measures for individual vowels and vowels in CVC contexts and measures of the size of nasal opening ranged from 0.32 to 1.0. Correlations between the measures for vowels combined and for syllables combined were each 1.0.

In 1968, Ochsner (28) investigated the relationships among controlled variations in nasal tract coupling and oral and nasal sound pressures in a single cleft palate subject. She recorded and analyzed recorded speech samples of the four vowels, /i/, /u/, /æ/, and /ɑ/, at each of four intensity levels (70, 75, 80, and 85 dB SPL) under each of six nasal coupling conditions (from 0 to 0.785 cm^2). Chief among her findings is that, for all vowels at all intensity levels, an increase in the size of the nasal aperture is associated with increases in the nasal SPL and the nasal-"oral" SPL difference measure.

Since nasal-"oral" SPL difference measures appear to be related to variations in the degree of oral-nasal coupling, it is not surprising that normal and cleft palate speakers have been found to differ with respect to this measure. Counihan and Pierce (8) employed the probe-tube microphone assembly to study the speech of forty normal-speaking adult subjects in isolated vowels, CVC syllables, and sentences. These investigators report mean nasal-"oral" SPL difference measures of 22.46 dB for vowels, 19.61 dB for CVC syllables, and 20.07 dB for sentences when these speech samples are produced at a constant oral intensity level of 75 dB. From these data, the authors conclude that the influence of nasal tract coupling on vowel production is changed very little by placing the vowel in a consonant context.

Richards (31) computed the difference between the nasal and "oral" sound pressure levels for normal speakers producing vowels at an "oral" intensity of 75 dB. She found a mean nasal-"oral" SPL difference measure of 28.85 dB.

Hirano, Takeuchi, and Hiroto (18) measured the ratio of intranasal sound pressure to syllabic speech power in eight normal-speaking adults producing sixty Japanese monosyllables. As a group, the normal subjects in this study presented a mean measure of 23.95 dB for their non-nasal consonant-vowel monosyllables. As might be expected, higher nasal sound pressures were obtained during the production of nasal consonant-vowel syllables.

Employing the probe-tube microphone assembly, Summers (41) examined the nasal and "oral" SPL measures for vowels at various levels of vocal intensity in a group of male and female normal-speaking subjects. His data reveal somewhat higher mean nasal-"oral" SPL difference measures than that reported in similar studies of normal speakers at comparable intensity levels. For example, Summers reports mean nasal-"oral" SPL differences of 35.22, 34.94, 33.04, and 28.31 dB at mean over-all intensity levels of 58.45, 66.95, 75.99, and 84.39 dB, respectively. The values reported by Summers for his normal speakers is substantially greater than that reported by Counihan and Pierce (8), Hirano, Takeuchi, and Hiroto (18), or Richards (31). An examination of the instrumentation, calibration, and data collection procedures employed across these studies fails to reveal the reason for this disparity.

A review of those studies that have investigated nasal-"oral" SPL difference measures for cleft palate and functionally nasal speakers indicates that these measures tend to be larger than those obtained for normal-speaking subjects. Counihan and Pierce (8) studied a group of forty cleft palate speakers who produced vowels, CVC syllables, and sentences at a constant vocal intensity level of 75 dB. They report a mean nasal-"oral" SPL difference measure of 31.58 dB for vowels, 29.97 dB for CVC syllables, and 32.43 dB for sentences.

Bryan (4) obtained nasal-"oral" SPL difference measures for twenty adolescent and adult cleft palate persons when they produced vowels and sentences at a constant vocal intensity level of 75 dB. This investigation found a mean nasal-"oral" SPL difference measure of 34.20 dB for the vowels and 35.91 dB for the sentences. In her investigation of the reliability of the nasal-"oral" SPL difference measure, Richards (31) reports a mean nasal-"oral" SPL difference measure of 33.25 dB for vowels produced at an overall vocal intensity level of 75 dB by a group of subjects with velar incompetency.

Weiss (43) employed the probe-tube microphone assembly in studying nasal-"oral" SPL difference measures for fourteen persons exhibiting functional nasality and three persons presenting cleft palate speech. He instructed his subjects to read a passage of connected speech at an oral intensity level of 70 dB as "oral" and nasal speech signals were recorded separately but simultaneously. This experimenter reports a mean nasal-"oral" SPL difference measure for his subjects of 33.10 dB.

The literature contains studies that have investigated the possible existence of sex differences relating to mean nasal-"oral" SPL difference measures for various speech samples. Counihan and Pierce (8), in their study of normal and cleft palate speakers, and Summers (41), in his study of normal speakers, found no significant differences between the female and male subjects in the obtained nasal-"oral" SPL difference measures for vowels. There is a trend, however, in each of these studies toward greater mean nasal-"oral" SPL difference measures for females than for males. In both of these studies, the size of the difference between the means for the sexes are inversely related to reported differences in the relative power of female and male voices (11, 45). Interestingly, Counihan and Pierce (8) did find a significantly greater mean nasal-"oral" SPL difference measure for female than for male subjects when these measures were obtained for CVC syllables.

Research efforts over the last two decades suggest that the magnitude of the nasal-"oral" SPL difference measure varies according to the vowel produced regardless of the size of the coupling of the oral and nasal tracts. Counihan and Pierce (8) found that, in both their normal and cleft palate speakers, the high vowels, which are produced in normal-speaking subjects with a more complete velar seal, are associated with greater mean nasal-"oral" SPL difference measures than the low vowels. Essentially similar relationships among these vowel means for normal (8, 18, 41) and cleft palate subjects (4, 8) can be found in the literature. In addition, Olson (29) and Ochsner (28) both found in their experiments with adjustable speech appliances that their single subjects displayed greater mean nasal-"oral" SPL difference measures for high vowels than for low vowels at all coupling areas.

There presently appears to be some evidence that the acoustic features of vowels are altered differentially by changes in nasal tract coupling conditions. In a study of the acoustic effects of nasalization, Fant (14) examined the influence of four nasal tract coupling conditions upon the spectra of four vowels, /i/, /e/, /ɑ/, and /u/. Input impedances equal to velopharyngeal coupling area dimensions of 0.00 cm^2, 0.16 cm^2, 0.32 cm^2, 0.65 cm^2, and 2.6 cm^2 were used to evaluate the effects of coupling. Fant found that increasing the area of the coupling introduces spectral changes in the vowels including increases in formant band-width and the reduction of formant intensity, but the degree of change varies according to the vowel and the size of the coupling. Generally, as the area of coupling is increased, the intensity of the first formant decreases and the intensity level of the nasal output increases.

House and Stevens (19) report that the overall intensity level of artificial vowels decreases as coupling of the oral and nasal cavities is increased. In their electrical analog study, they employed five conditions of velopharyngeal port opening, i.e., no coupling and velopharyngeal port cross-sections of 0.25, 0.71, 1.68, and 3.72 cm^2. Specifically, the high vowels /i/ and /u/ demonstrate the weakest overall intensity level, while the low vowels /ɑ/, /æ/, and /ɔ/ evidence a relatively greater loss of acoustic power as the extent of coupling is increased. In addition, they found that the high vowels /i/ and /u/ are more sensitive to small areas of opening than /æ/ and /ɑ/, which are sounds that have more open vocal tract configurations.

Greater differences between mean nasal-"oral" SPL difference measures for the high vowels and the low vowels appear to exist when the area of coupling is large than when it is small. That is, present research suggests that the means for /i/ and /u/ exceed those for /æ/ and /ɑ/ to a greater extent when the area of coupling is large than when it is small. For example, Ochsner (28) designed an appliance for her subject which contained five concentric aluminum rings within the central portion of its pharyngeal section. By removing one or more of the rings, six coupling conditions of oral-nasal coupling, ranging from .0000 cm^2 to .7850 cm^2 area of opening, could be produced. She obtained a range of mean nasal-"oral" SPL difference measures for the vowels /i/, /u/, /æ/, and /ɑ/ of 3.8 dB and 3.4 dB at her two smallest coupling conditions across four intensity levels. Summers (41) and Counihan and Pierce (8) report ranges among the vowel means of 3 dB and 3.8 dB, respectively, for their normal subjects. The means of the former study were averaged over four intensity levels while the means of the latter investigation were obtained at a single intensity level.

Schwartz (35) obtained measurements of relative intra-nasal sound intensity for the vowels /i/, /I/, /ɛ/, /æ/, /ɑ/, /ɔ/, and /u/ for female and male normal subjects when these subjects read an eight-sentence list at a comfortable intensity level. A range of means for the vowels sampled was determined by expressing the levels of all other vowels in relation to that of the least intense vowel, /i/. When the vowel means of the relative intra-nasal sound intensities were averaged over both female and male subjects, the range of vowel means was approximately 4.0 dB. Interestingly, when the vowel means were analyzed for sex differences, the female subjects showed a significantly greater range of means (6.5 dB) than that of the males (2.2 dB).

Cleft palate speakers with presumably greater nasal tract coupling present larger ranges of vowel means than normal speakers with small coupling areas. Ochsner (28) found a range of vowel means of 6.6 dB for her single subject at the largest coupling condition (.7850 cm^2) across four intensity levels. Counihan and Pierce (8) indicate that the range of mean nasal-"oral" SPL difference measures for vowels produced at a single intensity level (75 dB) by their cleft palate group was approximately 10 dB. Bryan (4) reports a vowel range of 6 dB and Richards (31) a vowel range of 8.3 dB for their respective cleft palate groups at a constant vocal intensity level (75 dB).

It is suggested in the literature that nasal-"oral" SPL difference measures obtained for vowels vary with changes in vocal intensity. In 1955, Summers (41), utilizing the probe-tube microphone assembly, explored the relationship between nasal and "oral" sound pressure and vocal intensity in a group of male and female normal-speaking subjects. His subjects phonated eight vowels at each of the four vocal intensity levels 60, 70, 70, and 90 dB SPL. He reports that as vocal intensity was increased by his normal subjects from 57 to 84 dB, the mean nasal-"oral" SPL difference measure for the normal vowels decreased from 35 to 28 dB. This represents a mean decrease of 7 dB in the nasal-"oral" SPL difference measure with a 27 dB increase in "oral" intensity. It also can be detected from Summers' data that greater nasal-"oral" SPL difference measures are found at the lower than at the higher "oral" intensity levels.

An important aspect of Ochsner's (28) recent study was her investigation of effects of controlled variations in oral and nasal tract coupling and vocal intensity on nasal-"oral" sound pressure differences measured in four vowels produced by a single adult cleft palate speaker. The subject was required to phonate four vowels, /i/, /u/, /æ/, and /ɑ/ at each of four intensity levels, 70, 75, 80, and 85 dB SPL at each of six coupling conditions of oral-nasal coupling ranging from .0000 cm^2 to .7850 cm^2 area of coupling. For each item of the speech sample, "oral" and nasal SPLs were obtained and the arithmetic difference was calculated between these two measures. An analysis of Ochsner's data, relative to the effects of intensity changes on nasal-"oral" SPL difference measures for vowels, suggests that increments in "oral" intensity result in decrements in the nasal-"oral" SPL difference measure when means are averaged over all vowels and coupling conditions. Specifically, the mean SPL difference for the controlled "oral" intensity levels of 70, 75, 80, and 85 dB were 41.7, 36.7, 34.0, and 30.8 dB, respectively. It may be seen from these data that the greatest decrease (5.0 dB) in the nasal-"oral" SPL difference measure occurred between 70 and 75 dB, followed by that between 75 and 80 dB, 2.6 dB, and between 80 and 85 dB, 3.2 dB.

Ochsner (28) also found that increments in "oral" intensity are associated with greater decrements in the nasal-"oral" SPL difference measure when the area of coupling is large than when it is small. At coupling conditions I (.0000 cm^2) and II (.0314 cm^2), which were the two smallest coupling areas, a 2.7 dB and a 7.3 dB decrease in the nasal-

"oral" SPL difference were obtained with a 15 dB increase in "oral" intensity. The same increment in "oral" intensity resulted in decreases of 14, 13.7, 14.3, and 13.6 dB in the nasal-"oral" SPL difference measure as the area of coupling was increased to .1261, .2827, .5036, and .7850 cm^2, respectively.

In spite of the increased amount of data relative to nasal-"oral" sound pressure difference measures there remain some unanswered questions. Differences in design of the studies that have been conducted limit the scope of comparisons and interrelationships that might be drawn. Some studies (18, 41) have employed normal subjects alone while other studies (4, 43) have used only cleft palate or functionally nasal subjects. In studies that have used matched groups of normal and cleft palate speakers, data was obtained only at one uniform vocal intensity level. If the relationships of vocal intensity variations and nasal-"oral" SPL difference measures are to be clearly understood, additional data is needed. The only data extant concerning this relationship in cleft palate speakers has been derived from data obtained by Ochsner (28) for a single cleft palate male subject who produced vowel samples under a variety of conditions of nasal tract coupling at specified vocal intensity levels. The extent to which one can extrapolate from the Ochsner data to the performance of groups of both female and male cleft palate speakers with velar incompetencies, at this point, is unknown. Therefore, it seems important that the relationship between vocal intensity variations and the nasal-"oral" SPL difference measure be examined under conditions where the data for normal and cleft palate speakers can be compared in performance of the same experimental task, including identical speech samples and vocal intensity levels; using procedures and instrumentation that are identical; and a subject sample that is matched according to age and sex. It is the purpose of the present study to explore this relationship under such conditions.

CHAPTER III

DESIGN OF THE INVESTIGATION

The purpose of this study was to investigate nasal-"oral"[1] SPL difference measures[2] of four selected vowels produced at four different intensity levels by groups of normal speakers and by cleft palate subjects with velopharyngeal incompetency.

Specifically, the following research questions were asked:

1. What differences in nasal-"oral" SPL difference measures exist between the normal-speaking and cleft palate groups in the production of each of the vowels: /i/, /u/, /æ/, and /ɑ/?

2. What differences in nasal-"oral" SPL difference measures of these vowels exist between normal-speaking and cleft palate groups when the data are analyzed according to the sex of the subjects?

3. Are these differences in nasal-"oral" SPL difference measures, if present, similar at each of the four intensity levels used in this study?

Subjects

An experimental group of sixteen cleft palate persons, eight

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[1] The so-called "oral" speech signal was recorded in front of the lips and, consequently, contained components of both the oral and nasal signals. However, in this investigation this "overall" speech signal was termed the "oral" speech signal to differentiate it from the signal emitted from the nasal cavity.

[2] Nasal-"oral" SPL difference measure refers to the arithmetic difference expressed in decibels between the nasal sound pressure level and the "oral" sound pressure level.

male and eight female, was selected to serve as subjects in this investigation. A control group of sixteen normal-speaking subjects was matched to the cleft palate sample in age and sex. Each normal-speaking subject was within one year of age of the cleft palate subject to whom he was matched. All experimental subjects were required to exhibit velopharyngeal incompetency but no restrictions were established relative to the extent or type of cleft or manner of operative repair. Some of the cleft palate subjects retained in this experiment wore speech appliances. With these subjects, all data was obtained with the appliance removed. In evaluating velopharyngeal competency, oral breath-pressure ratios were obtained for all cleft palate subjects using an oral manometer (Hunter, Model 360) and following the procedure suggested by Spriestersbach and Powers (39). For purposes of this investigation, each experimental subject was required to attain a mean breath-pressure ratio less than .75. This procedure was followed in that Shelton, Bankson, and Brooks (37) have reported that persons with essentially normal velopharyngeal closure may achieve mean ratios as low as .80.

Only those subjects who demonstrated sufficient ability to perform the experimental task of producing and sustaining each of four isolated vowels for a four-second interval at specified intensities were included in the study. In addition, all subjects were required to pass audiometric screening at 20 dB re. ANSI for the octave intervals 500, 1000, and 2000 Hz, at least unilaterally.

Speech Sample

The speech sample employed in this study consisted of four isolated vowels: /i/, /u/, /æ/, and /ɑ/ each sustained for four seconds at each of four intensities. These four vowels were chosen because they differ in degree of velar valving (25), relative acoustic power (3, 13, 24, 33, 34), tongue height and placement within the oral cavity (44), and judged degree of perceived nasality (26, 42). In addition, recent studies have indicated that some of these individual vowels present a greater mean nasal-"oral" SPL difference measure than do others (4, 8, 28, 29, 31).

The Intensity Levels

The four controlled intensity levels utilized in this study included 70, 75, 80, and 85 dB re .0002 dyne/cm^2 and were selected because they represented a range of intensities from "normal" to "very loud" speech (15).

Instrumentation

The instrumentation used in data collection in this study included a signal system to guide the subject in the experimental task, an audio-recording system for the nasal and oral signals, and a graphic-recording-system to display the intensity of the nasal and "oral" speech signals.

Description

The Signal System. An electro-mechanical cam timer which was activated by the experimenter, controlled the illumination of panel lights used to signal subjects to begin and terminate test vowel phonation. The cycling of the signal system was established for predetermined time intervals.

The Audio-Recording System. The audio-recording system used in this study permitted the separate, but simultaneous, recording of each subject's "oral" speech sample, with a microphone placed approximately eight inches from the lips, and the nasal signal, using a probe-tube microphone inserted into the subject's nostril. The components of the audio system consisted of: (a) two one-half inch condenser microphone cartridges (Bruel and Kjaer, Type 4134), one of which was equipped with a probe-tube (Bruel and Kjaer Probe Microphone Kit, Type Ua 0040); (b) two cathode-followers (Bruel and Kjaer, Type 2615); (c) two microphone amplifiers (Bruel and Kjaer, Type 2603); and (d) a dual-channel magnetic tape recorder (Ampex Model AG 440).

The condenser microphone cartridges were designed for precise sound pressure measurements under sound field conditions and were calibrated by the manufacturer to have a flat frequency response within ± 2 dB from 20 to 20,000 Hz. In order to evaluate their agreement with the manufacturer's specifications, frequency responses for the two microphones were obtained before and after the data collecting sessions. While originally identical, each microphone cartridge was modified slightly to adapt it to the experimental task. The oral microphone was equipped with a protective grid which, according to the manufacturer's specifications, does not significantly change the frequency response of the microphone below 15,000 Hz when the microphone is positioned at a 90° angle of incidence to the sound source (20). The modification of the nasal microphone involved the addition of an adapter and probe-tube. Because the addition of a probe-tube to the nasal microphone results in significant high frequency damping, an equalizing filter was employed to improve the frequency response. To further decrease the effect of the high frequency damping, steel wool was inserted into the probe-tube. The stainless steel probe-tube was one millimeter in external diameter, six-tenths millimeter in internal diameter, and measured three inches in length from the tip of the adapter. The dimension of the outer diameter permitted the probe-tube to be positioned in the nasal cavity without touching the columella or ala and without significantly altering the sound pressure level in the nasal cavity (1, 2). According to the manufacturer's calibration (20), the thickness of the probe-tube wall, two-tenths millimeter, was sufficient to provide a signal-to-noise ratio of 44 dB from 100 to 5000 Hz. In addition, the three-inch length of the probe-tube allowed the placement of the nasal microphone cartridge and cathode-follower out of the path of the orally emitted speech signal, thus eliminating a possible source of signal contamination. The probe-tube length was maintained as short as possible to insure its sensitivity (2). Two such probe-tubes were utilized in this investigation. The preparation of a second probe-tube was necessitated after the original was irreparably damaged by a subject during the data collection.

In assembly, the probe-tube adapter and the nasal microphone cartridge were connected after which the probe-tube itself was force-fitted into the adapter so that an acoustically-tight seal was achieved at each of these two connections. The condenser microphone cartridges of both the nasal and "oral" recording systems were attached to cathode followers which served as impedence-matching devices for the high output impedance of the microphone cartridges and the low input impedance of the succeeding microphone amplifiers. The microphone amplifiers were designed to amplify voltages with a potential gain of 100 dB and provided essentially linear frequency responses. The combined assembly of the amplifiers with the condenser microphone and their cathode followers functioned as a precision sound level meter, indicating sound pressure in decibels re .0002 dyne/cm^2 (22). The nasal microphone was equipped with a filter consisting of a .02-microfarad condenser in parallel with a 33,000-ohm resistor, both of which were placed in series with a 1,500-ohm resistor. This filter was employed to compensate for the high frequency damping of each of the probe-tubes and resulted in a flat response from the nasal microphone within ±3 dB from 100 to 4800 Hz and ±3 dB from 100 to 4700 Hz for the first and second probe-tubes, respectively.

A dual-channel tape recorder which was matched for impedence with the microphone amplifiers was used to record simultaneously the "oral" and nasal speech signals. When operated at a speed of 7.5 ips, the tape recorder presents a frequency response of ±2 dB from 40 to 12000 Hz. This frequency response was verified at the beginning and end of data collection. Just prior to the initiation of each recording session, the "record" and "reproduce" potentiometer settings were adjusted with a white noise of known intensity so that a 20-dB deflection on the microphone amplifier voltmeter would peak the recorder VU meter at 0 dB.

The Graphic Recording System. The nasal and "oral" signals were reproduced by the dual-channel tape recorder for later introduction into a graphic level recorder. The Bruel and Kjaer, Type 2334 graphic level recorder employed in this investigation, records signal level variations as a function of time within a frequency range of 20 to 20000 Hz. A 20-dB input potentiometer was used with the level recorder and was reported by the manufacturer to be accurate ±5 dB within a 20-20000 Hz frequency range (21).

Calibration

Nasal Microphone. The "oral" microphone and its amplifying system was used as a reference in the calibration of the nasal probe-tube microphone and amplifying system. The "oral" microphone, as calibrated by the manufacturer, is flat within ±2 dB from 20 to 20000 Hz and, when used with its associated microphone amplifier, can be employed as a precision sound level meter. The reference "oral" microphone was positioned at a 90° angle of incidence at a distance of one inch from an amplifier-speaker (Ampex, Model 620) in an acoustically isolated room. The nasal probe-tube microphone was placed at an angle of approximately 45°, one-fourth inch above the grid of the reference microphone. A pure-tone audio oscillator (Hewlett Packard Model 200 ABR) was used to drive the amplifier-speaker, producing a tone of 100 dB SPL on the reference microphone amplifier voltmeter. At the same time, the response of the nasal probe-tube microphone was indicated and read from the voltmeter of its associated amplifier. Readings were taken at 100-Hz intervals from 100 through 5000 Hz and at 1,000-Hz intervals from 100 through 5000 Hz and at 1,000-Hz intervals from that point to 10000 Hz. The frequency response of the first nasal microphone was found to be essentially flat to 4800 Hz while the second nasal microphone was essentially flat to 4700 Hz. In order to obtain a single value representing the attenuation introduced by each probe-tube and accompanying equalizing filter, the means of the sound pressure measurements from 100 to 4800 Hz for the first probe-tube and 100 to 4700 Hz for the second probe, were computed and subtracted from the intensity level of the reference sound at the oral microphone as measured on its associated amplifier voltmeter. The derived mean attenuation was approximately 32.5 dB and 35.0 dB for the first and second probe-tubes, respectively. The response curves of the first nasal microphone and uncompensated and compensated probe-tube are shown in Figures 1 and 2, respectively. The response curves of the second nasal microphone and uncompensated and compensated probe-tube closely resembled that of the first probe-tube.

Graphic Level Recorder. The calibration of the graphic level recorder also was accomplished by using the "oral" microphone and its amplifier as a reference. Utilizing white noise as a sound source, it was determined that 5-dB increments in noise as measured on the microphone amplifier voltmeter resulted in 5-dB increments on the chart paper of the graphic level recorder.

Procedures

Recording Procedures

All speech samples were recorded in an acoustically-isolated, two-room testing suite with a low ambient noise level at the University of Oklahoma Medical Center's Speech and Hearing Center.

The test room contained the subject's chair, the two condenser microphones with their respective cathode followers, a table on which the "oral" and nasal microphone amplifiers were placed, a rack which held the speech sample cards, and the lights of the signal system which indicated to the subject the beginning and end of the four-second phonation period for the vowel sounds. The "oral" microphone and its cathode follower were fastened to a movable stand while the nasal microphone and its cathode follower were positioned on an adjustable, well-mounted arm.

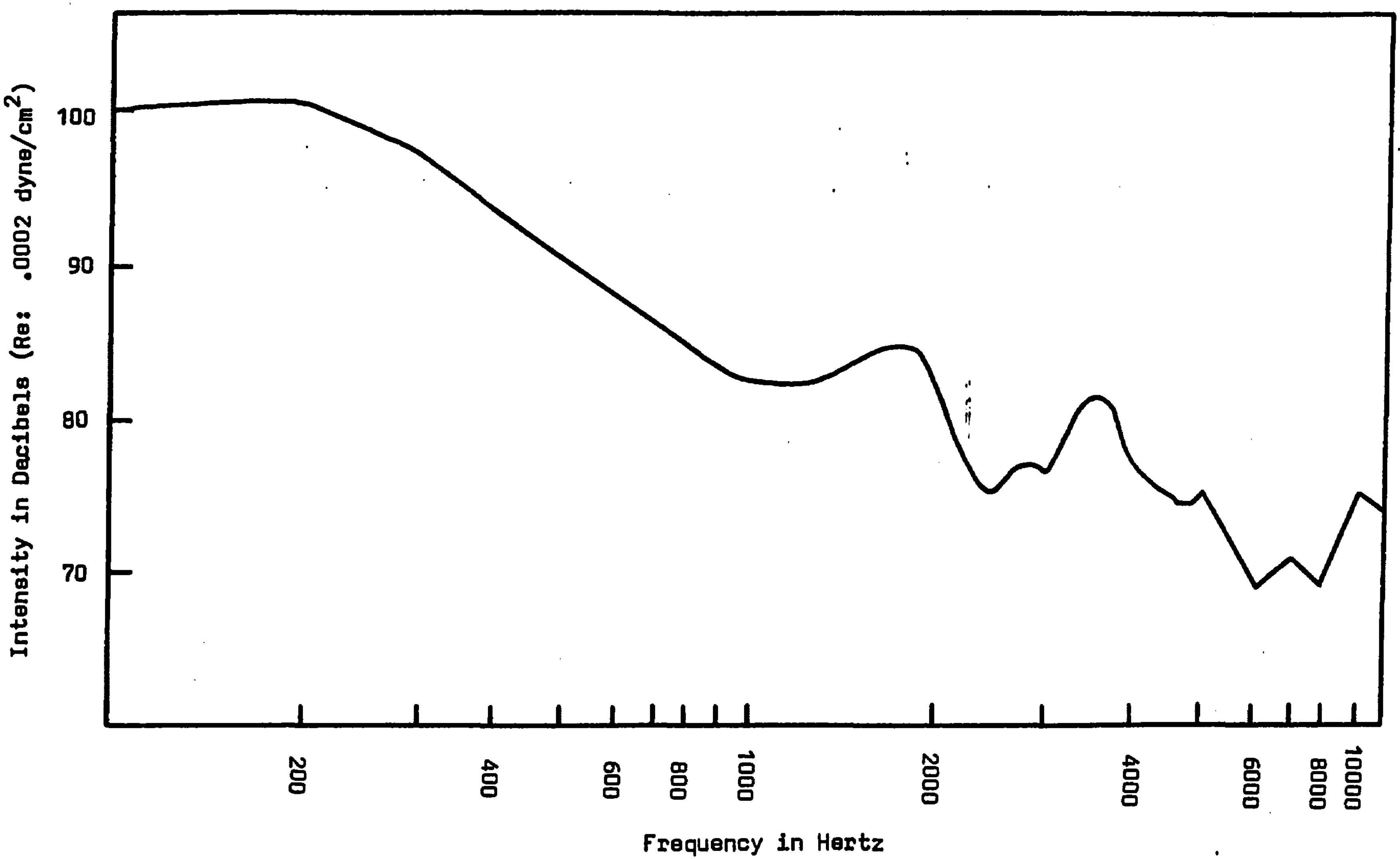

Fig. 1—Frequency Response Curve of the Nasal Microphone and the First Uncompensated Probe Tube to a 100-dB SPL Tone.

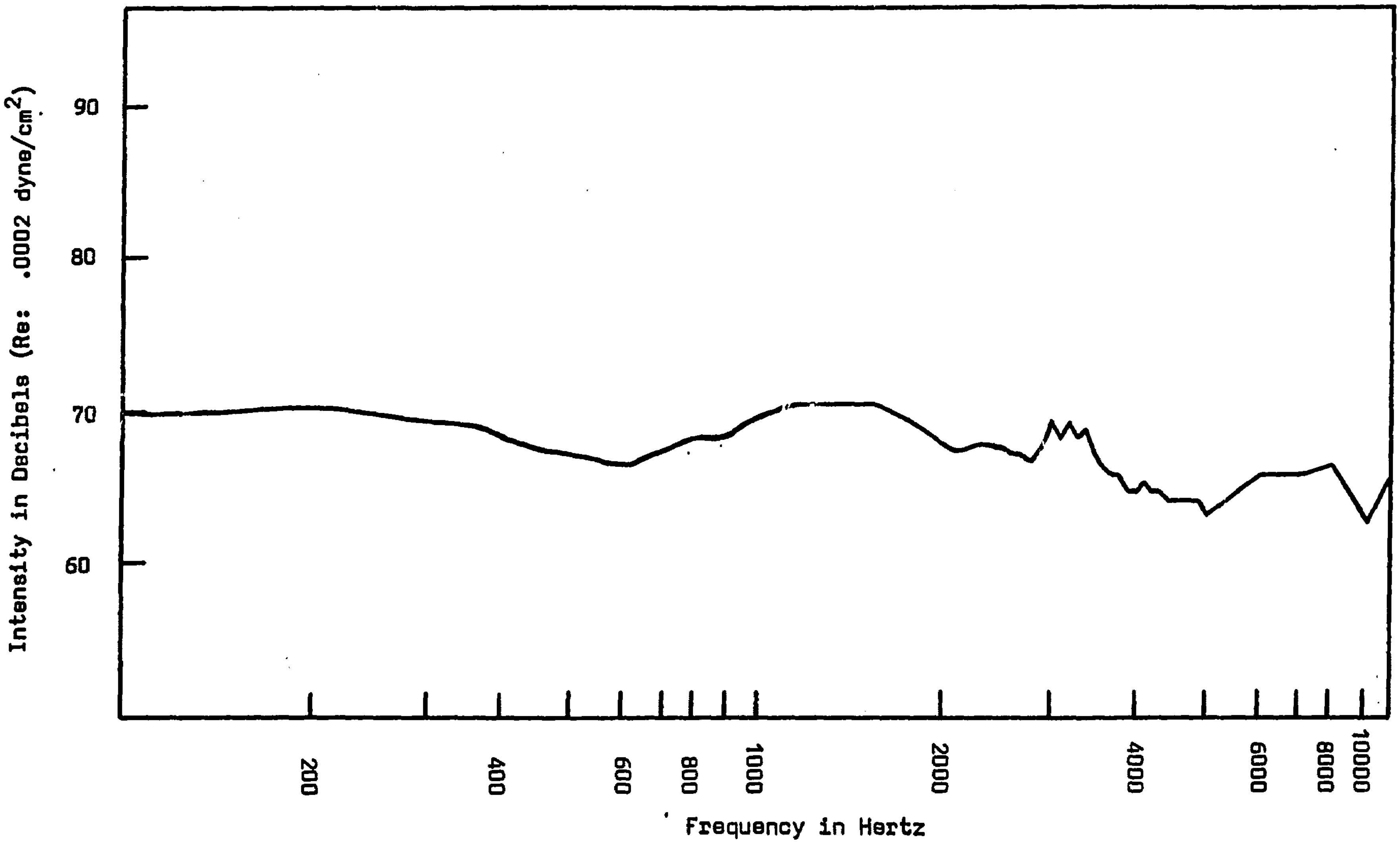

Fig. 2—Frequency Response Curve of the Nasal Microphone, First Probe Tube, and Equalizing Filter to a 100-dB SPL Tone.

The control room housed the dual-channel magnetic tape recorder, and a cam timer which provided the control for a test room signal light.

Each subject was familiarized with the experimental procedure and then seated in an examination chair. The chair, equipped with an adjustable back and headrest, was adjusted for appropriate height, inclination of the back, and position of the headrest so that the subject's position was suitable for placement of the probe-tube. The subject's head was stabilized during data collection by means of an elastic head-band placed around the subject's head and the chair's headrest. The "oral" microphone amplifier was placed immediately in front of the subject on a small table. The subject was asked to observe the voltmeter of the "oral" microphone amplifier for purposes of monitoring the intensity level of his phonation. The signal lights were mounted on the top surface of the "oral" microphone amplifier and consisted of an amber-colored light of one-second duration which indicated to the subject that he should prepare for phonation and a four-second red signal light which remained lighted during the time the subject was to sustain his phonation. As indicated earlier, this signal light system was operated by a cam timer and was under the experimenter's control.

In this investigation, each of four isolated vowels /i/, /u/, /æ/, and /ɑ/, was recorded at each of four intensity levels, 70, 75, 80, and 85 dB SPL. The vowel to be phonated was displayed on a printed card as it appears in some common word. The subject was directed to produce only the underlined vowel in each printed word. When the subject was familarized with the speech material, he practiced phonating each vowel at each of the four intensities after the investigator while he monitored these intensities on the voltmeter of the "oral" microphone amplifier. During this practice period, the attenuator settings on the nasal microphone's amplifier were adjusted so that the nasal speech signal was accommodated within the 20-dB range of the amplifier's Vu meter.

When the subject demonstrated the ability to successfully perform the experimental task under practice conditions, actual data gathering was undertaken using the same procedures. The order of presentation of each vowel at each intensity was determined by a randomization procedure using a table of random numbers.

Measurement Procedures

The tape-recorded nasal and "oral" speech signals were introduced separately into a power level recorder which supplied a graphic representation of the amplitude variations of the two signals. The level recorder was operated at a chart-paper speed of 30 millimeters per second and a writing speed of 300 millimeters per second. These speeds are fast enough to provide adequate resolving power for the intensity of the signal without the writing stylus's momentum causing the stylus to overshoot. The chart-paper (Bruel and Kjaer, QP 2350) of the graphic level recorder was designed for use with the 50-dB logarithmic potentiometer. This paper is two and one-half inches in width, and ruled in ten equal intervals with each interval corresponding to 5 dB, thus allowing a recording range of 50 dB.

At the beginning of each recording session and with each new tape, a white noise of a specified sound pressure level was introduced into the "oral" and nasal channels of the tape recorder. This noise signal supplied a reference base on the graphic level recorder tracings which permitted measurements of the recorded vowels in decibels re .0002 dyne/cm^2.

In order to determine the sound pressure level of each vowel for the four intensity levels, the amplitude displacement for each vowel at each intensity level was measured at three points 15 millimeters apart in the center of the steady-state portion of the sustained vowel, and a mean amplitude displacement was calculated. A correction in this derived mean value was then made in decibels for the amount of attenuation of the amplifier settings. Two independent measurements of the "oral" and nasal tracings for each of the vowels phonated at each of the four intensities were made. If any discrepancies between the first and second measures appeared, a third measurement was made. The nasal and "oral" sound pressure levels and the arithmetic differences of the nasal and "oral" sound pressure levels then were computed for each vowel and expressed in decibels.

CHAPTER IV

RESULTS AND DISCUSSION

This study was designed to investigate nasal-"oral" sound pressure differences of four selected vowels produced at four different intensity levels by a group of normal speakers and by a group of cleft palate speakers with velopharyngeal incompetency. Sixteen cleft palate subjects, eight female and eight male, and sixteen normal-speaking subjects matched to them with respect to age and sex, sustained the vowels /i/, /u/, /æ/, and /ɑ/ at intensity levels of 70, 75, 80, and 85 dB SPL at a mouth-to-microphone distance of eight inches. Each vowel was recorded by means of a high-fidelity recording system and introduced into an instrumental assembly, previously described, which permitted the measurement of "oral" (overall) and nasal sound pressure levels for each vowel at each intensity level. The arithmetic difference between the nasal and "oral" sound pressure levels was obtained for each vowel and these difference measures provided the quantitative acoustic data of this study.

For purposes of evaluating the experimental data, an overall analysis of variance with factorial arrangement of treatments was utilized in which the factors were condition (cleft palate or normal), sex, vowels, and intensity. A significance level of .05 was selected for this investigation.

The results of the overall analysis of variance of the nasal-"oral" SPL difference measure data are summarized in Table 1. Examination of this table reveals that the condition, vowel, and intensity main effects as well as condition-by-vowel and condition-by-intensity interactions are significant. All other main effects and interactions are not significant.

As a supplementary statistical analysis, individual analyses of variance were performed to examine the simple effects occurring within each condition-sex group. The results of these supplementary analyses of variance presented in Table 2 and Table 3 show that within each subject group, as with the overall analysis of variance, the vowel-by-intensity interaction is not significant. Therefore, in the interpretation of the analysis for each group, interest is focused on vowel and intensity simple effects. Examination of the simple effects shown in Tables 2 and 3 reveals that vowel simple effects are significant for the female and male cleft palate subject groups but not for the female and male normal subject groups. The intensity simple effects are significant for all subject groups.

For purposes of discussion, the findings of the study will be presented in four sections: (a) findings related to conditions, including the condition and sex main effects and the condition-by-sex interaction as shown in the overall analysis of variance; (b) findings related to vowels, including the vowel main effect and appropriate vowel interactions; (c) findings related to intensity, including the intensity main effect and appropriate intensity interactions; and (d) a discussion

TABLE 1

SUMMARY OF THE OVERALL ANALYSIS OF VARIANCE FOR NASAL-"ORAL" SPL DIFFERENCE MEASURE

Source	df	ms	F
Condition (A)	1	13845.2266	6.025[a]
Sex (B)	1	4.5940	< 1
AB	1	218.6678	< 1
Subjects (C)/AB	28	229.7780	
Vowels (D)	3	622.6240	22.23[a]
AD	3	105.0356	3.75[a]
BD	3	50.6781	1.81
ABD	3	55.7751	1.99
CD/AB	84	28.0074	
Intensity (E)	3	788.9708	82.43[a]
AE	3	53.2214	5.56[a]
BE	3	8.4679	< 1
ABE	3	2.3499	< 1
CE/AB	84	9.5709	
DE	9	4.3303	< 1
ADE	9	3.7619	< 1
BDE	9	1.7445	< 1
ABDE	9	5.0532	< 1
CDE/AB	252	7.8838	

[a]$p = < .05$

TABLE 2

SUMMARY OF THE ANALYSIS OF VARIANCE FOR NORMAL FEMALE AND MALE SUBJECT GROUPS

Source	df	ms	F
Normal Female Subject Group			
Vowel (A)	3	78.1945	2.73
Intensity (B)	3	360.7199	22.04_a
AB	9	2.7868	< 1
Normal Male Subject Group			
Vowel (A)	3	95.6300	1.79
Intensity (B)	3	261.4373	42.81_a
AB	9	4.4670	< 1

$^{a}p = < .05$

TABLE 3

SUMMARY OF THE ANALYSIS OF VARIANCE FOR CLEFT PALATE FEMALE AND MALE SUBJECT GROUPS

Source	df	ms	F
Cleft Palate Female Subject Group			
Vowel (A)	3	549.5115	49.33_a
Intensity (B)	3	123.7466	16.99_a
AB	9	4.1686	< 1
Cleft Palate Male Subject Group			
Vowel (A)	3	110.7414	5.85_a
Intensity (B)	3	107.0694	12.55_a
AB	9	3.4794	< 1

$^{a}p = < .05$

of the results of the study. Use of the supplementary analysis of variance for each group of cleft palate and normal subjects will be made where appropriate to further interpret the data of this experiment.

To facilitate the presentation of results, the "oral" (overall) intensity levels at which each vowel was produced, 70, 75, 80, and 85 dB SPL, will be designated Intensity Levels I, II, III, and IV, respectively. The terms "SPL difference measure" or "SPL difference" will be used to refer to the arithmetic difference between nasal and "oral" sound pressure levels.

Conditions

One of the purposes of the present investigation was to determine if variations in SPL difference measures exist between normal speakers and cleft palate speakers. Table 1, showing the overall analysis of variance, reveals that the condition main effect is significant. These data are displayed in Figure 3. Figure 3 graphically illustrates that the cleft palate group exhibits a 10.4 dB greater mean SPL difference measure than the normal group. The specific means, averaged over all sexes, vowels, and intensity levels, are 34.6 dB for the cleft palate group and 24.2 dB for the normal subjects. The size of the difference between the means for these normal and cleft palate subjects may be considered large from the standpoint of acoustic power.

Inspection of Table 1 also shows that the sex main effect is not significant. Examination of the data involved in this main effect shows that the female subjects display a mean SPL difference measure of 29.50 dB; the males show a mean SPL difference of 29.31. Thus, it may be seen readily that the means for the two sexes are very similar. From

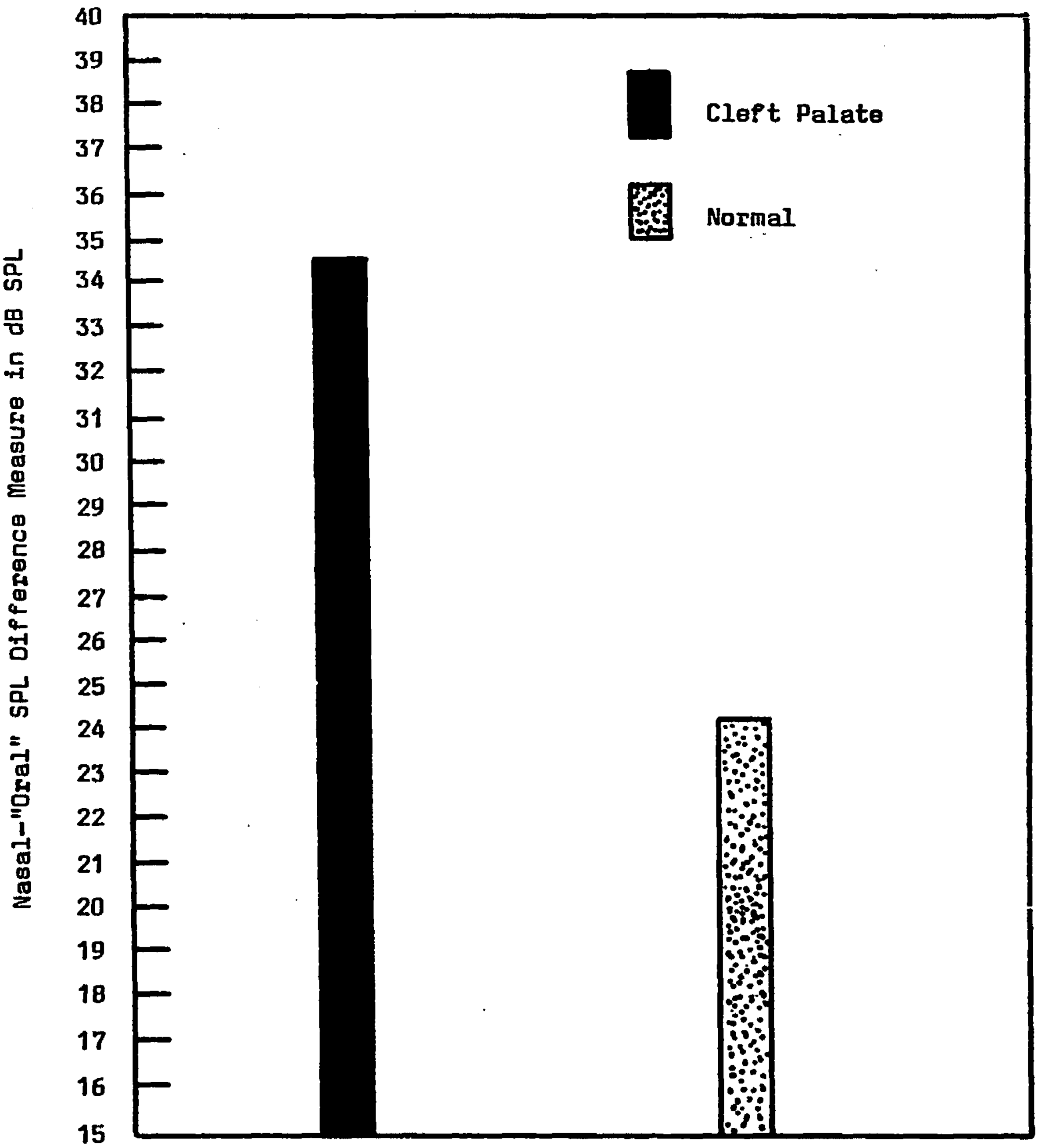

Fig. 3—Nasal-"Oral" Sound Pressure Level (SPL) Difference Means for Cleft Palate and Normal-Speaking Subjects. The Means are Derived over All Sexes, Vowels, and Intensities.

these data and the statistical analysis, it seems reasonable to conclude that the means for the two sexes do not differ significantly.

Consistent with the findings of the sex main effect is the lack of a significant condition-by-sex interaction. Specifically, the normal female and male groups exhibit a mean SPL difference measure across vowels and intensity levels of 24.95 dB and 23.45 dB, respectively; while the cleft palate female and male subjects present a mean SPL difference measure of 34.04 dB and 35.16 dB, respectively. These findings indicate that the mean SPL difference found for normal and cleft palate groups do not vary significantly for the sexes within each condition group. Thus, the differences found between these cleft palate and normal groups of speakers can be expected to be similar for male and females within each group.

On the basis of analyses of the condition and sex main effects and interaction, it appears that cleft palate subjects in this study present significantly greater mean SPL differences in vowel production than the normal subjects studied. Further, the differences found between these subject groups do not vary significantly for female and male subjects within each group.

Vowels

The data involved in the significant vowel main effect detected by the overall analysis of variance are displayed graphically in Figure 4. Figure 4 shows that the mean SPL difference is greatest for the vowel /i/, 32.24 dB, followed in order by those for /u/, 30.24 dB, /æ/, 27.95 dB, and /ɑ/, 27.39 dB. These means are averaged over all conditions, sexes, and intensity levels. The presence of a significant vowel

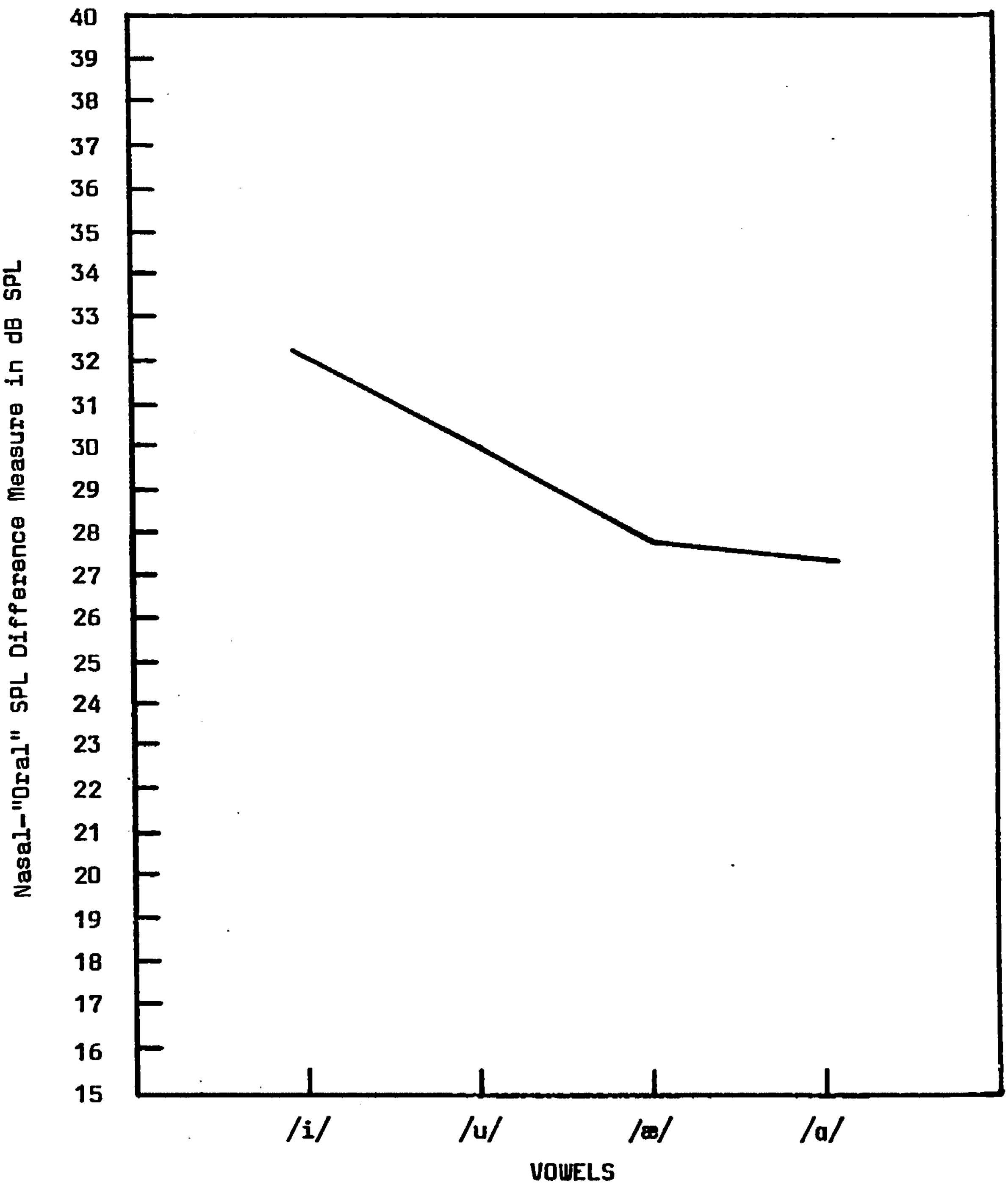

Fig. 4--Nasal-"Oral" Sound Pressure Level (SPL) Difference Means for Each of Four Vowels. The Means Are Derived over All Conditions, Sexes, and Intensities.

main effect indicates that the four vowels studied differ with respect to the SPL difference measures. The plot of means in Figure 4 suggests that the high vowels /i/ and /u/ are associated with somewhat greater SPL differences than the low vowels /æ/ and /ɑ/.

The presence of a significant condition-by-vowel interaction limits interpretation of the vowel main effect by indicating that the differences among the vowel means differ for the normal and cleft palate speakers. The means involved in this interaction, averaged over sexes and intensity levels, are plotted in Figure 5. Figure 5 reveals that, for normal subjects, the greatest mean SPL difference occurs for /i/, 26.42, followed in order by those for /u/, 23.90 dB, /æ/, 23.70 dB, and /ɑ/, 22.78 dB. For the cleft palate subjects, the greatest mean SPL difference is seen for /i/, 38.05, followed in order by means for /u/, 36.14 dB, /æ/, 32.21 dB, and /ɑ/, 32.0 dB. While the plot of means in Figure 5 shows that the order of the vowel means is the same for the normal and cleft palate subjects, the range of the means is considerably greater for the cleft palate than for the normal subjects. Specifically, the range of means for the normal speakers is 3.64 dB; for the cleft palate speakers, the range is 6.05 dB. Figure 5 also shows a difference in the pattern of vowel means between normal and cleft palate speakers. For the cleft palate subjects, the means for both high vowels, /i/ and /u/, are seen to exceed substantially those for /æ/ and /ɑ/. While the mean for /i/ is again the greatest for the normal speakers, the differences among the means for the vowels /u/, /æ/, and /ɑ/ are extremely small.

The supplementary analyses of variance, displayed in Tables 2

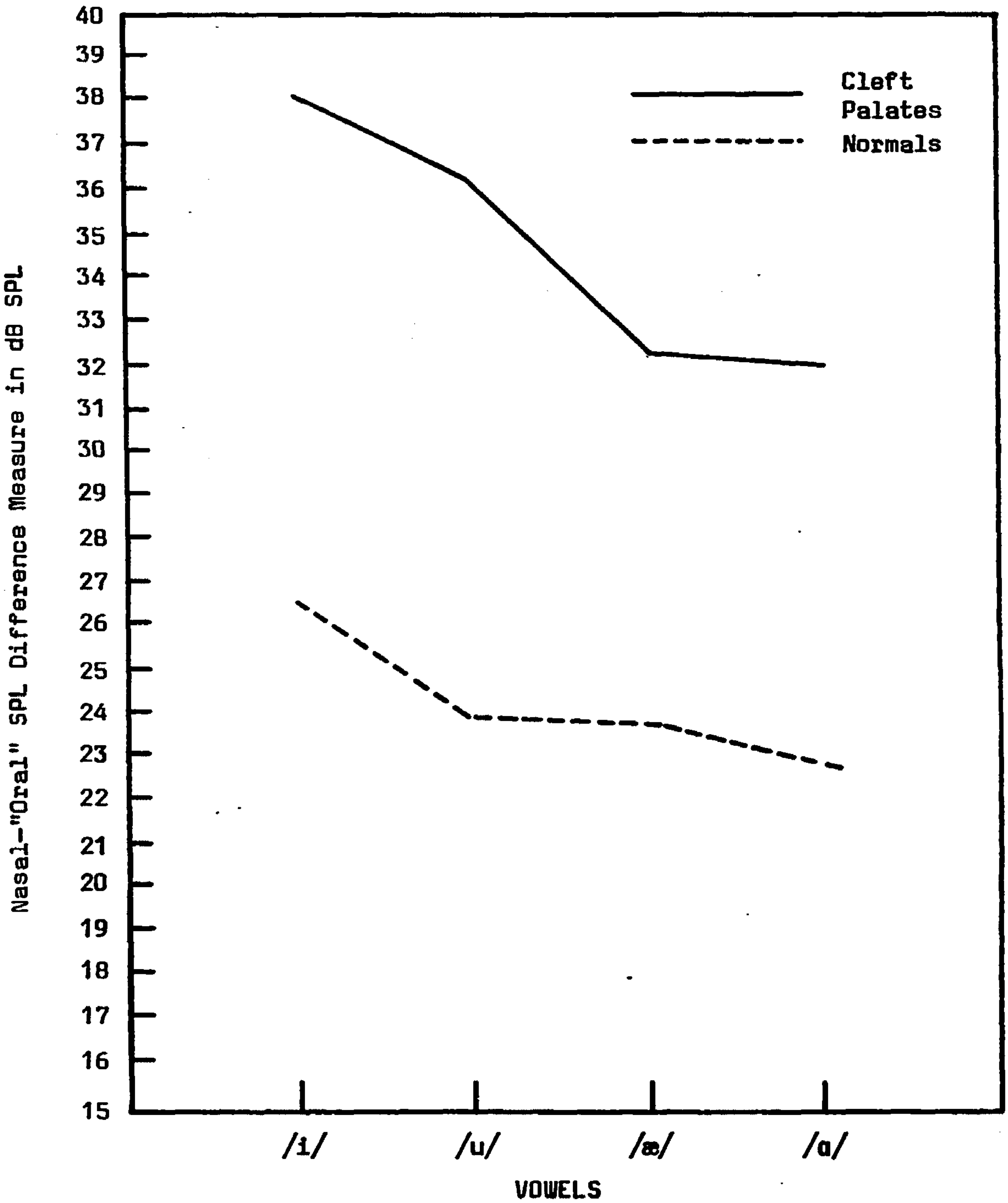

Fig. 5—Nasal-"Oral" Sound Pressure Level (SPL) Difference Means for Cleft Palate and Normal-Speaking Subjects for Each of Four Vowels. The Means Are Derived over All Sexes and Intensities.

and 3, show that while the vowel simple effect is significant for both male and female cleft palate speakers, the vowel effect is not significant for either male or female normals. Thus, the significant condition-by-vowel interaction detected by the overall analysis of variance appears to result from the presence of significant vowel differences for the cleft palate speakers and the absence of such differences for the normals.

It may be noted here that differences between the mean SPL difference measures for the normal and cleft palate speakers, previously shown in the condition main effect, varies as a function of the vowel produced. For example, the difference between the two subject groups for /i/ is 11.63 dB; for /u/, 12.24 dB; for /æ/, 8.51 dB; and for /ɑ/, 9.22 dB. These data suggest that greater differences between the means for cleft palate and normal speakers exist in the production of high than of low vowels.

While the overall analysis of variance failed to reveal a significant condition-by-sex-by-vowel interaction, the trends within this interaction are of some interest and may be useful in understanding the condition-by-vowel interaction. The means involved in this interaction, averaged over all intensity levels, are plotted in Figure 6. Specifically, for cleft palate females, the greatest mean SPL difference measure occurs for /i/, 38.64 dB, followed by those for /u/, 36.45 dB, /ɑ/, 30.63 dB and /æ/, 30.45 dB. For normal-speaking female subjects, the greatest mean SPL difference measure is seen for /i/, 27.28 dB, followed by that for /u/, 24.34 dB, /ɑ/, 24.22 dB, and /æ/, 23.95 dB. For cleft palate males, the greatest mean SPL difference occurs for /i/, 37.47 dB,

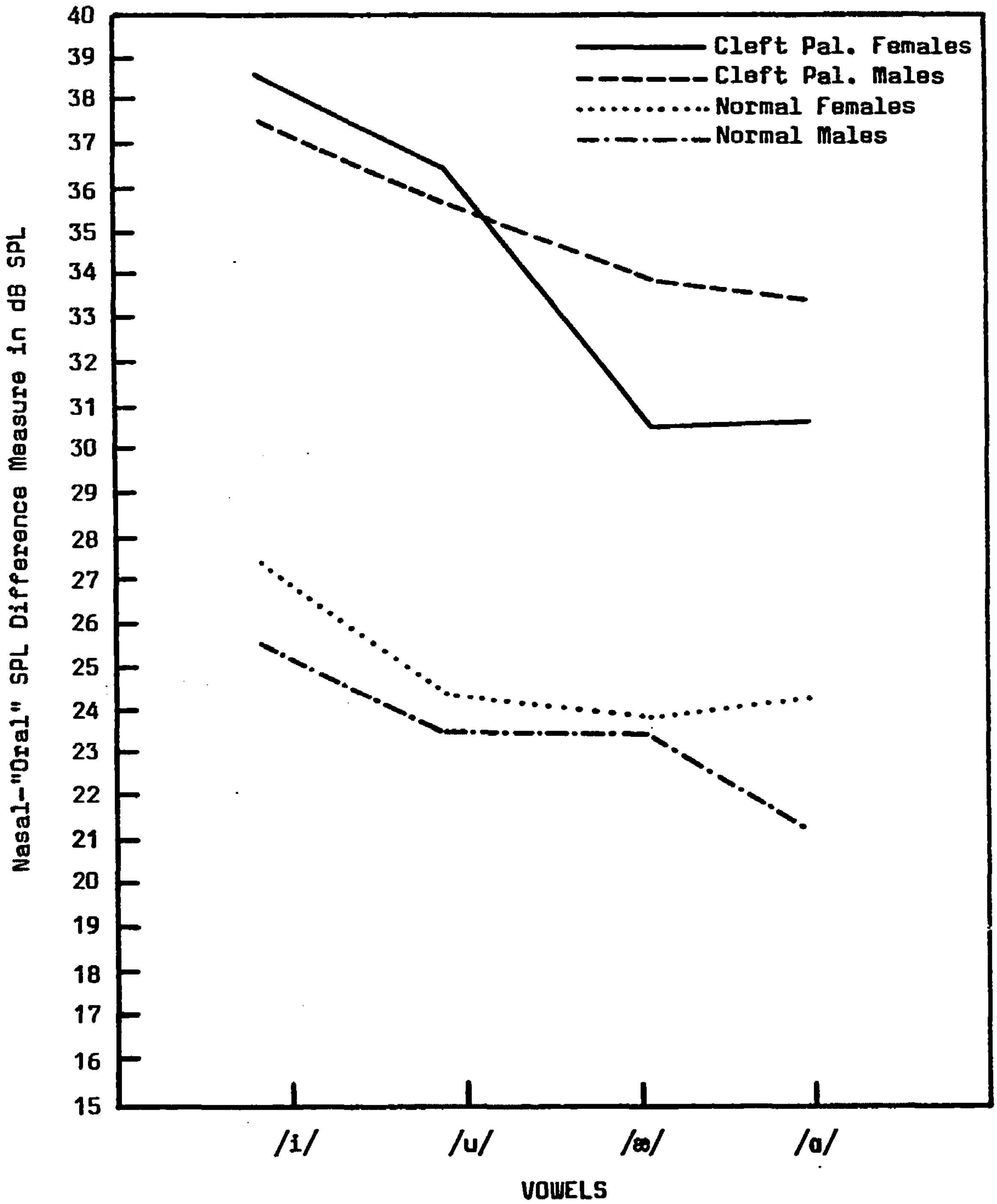

Fig. 6—Nasal-"Oral" Sound Pressure Level (SPL) Difference Means for Each of Four Vowels for Normal Female and Male, and Cleft Palate Female and Male Subjects. Means Are Derived over All Intensity Levels.

followed by those for /u/, 35.83 dB, /æ/, 33.97 dB, and /ɑ/, 33.37 dB. For normal males, the greatest mean SPL difference measure is seen for /i/, 25.58 dB, followed by those for /u/, 23.45 dB, /æ/, 23.44 dB, and /ɑ/, 21.34 dB.

It may be seen from Figure 6 that the range of vowel means for the cleft palate female subjects, 8.19 dB, substantially exceeds that for cleft palate males, 4.10 dB, normal males, 4.24 dB, or normal females, 3.33 dB. It would appear from these data that the difference in mean SPL measures between high and low vowels, seen for cleft palate speakers in the condition-by-vowel interaction, is attributable to a significant degree to the performance of the cleft palate female speakers. Interestingly, the pattern of vowel means for the cleft palate males more nearly resembles the pattern seen for the normal male and female speakers. It is possible, that, were larger samples of speakers employed in this study, a significant condition-by-sex-by-vowel interaction might have been obtained. This relationship deserves further study.

Intensity Levels

Figure 7 presents a plot of the means involved in the significant intensity main effect detected by the overall analysis of variance. This Figure shows that, averaged across conditions, sexes, and vowels, the mean SPL difference measure for each of the four intensity levels is 32.30 dB, 30.41 dB, 28.29 dB, and 26.60 dB for Intensity Levels I (70 dB), II (75 dB), III (80 dB), and IV (85 dB) respectively. These data suggest that the mean SPL difference measure varies as a function of vocal intensity level. The data show that a consistent

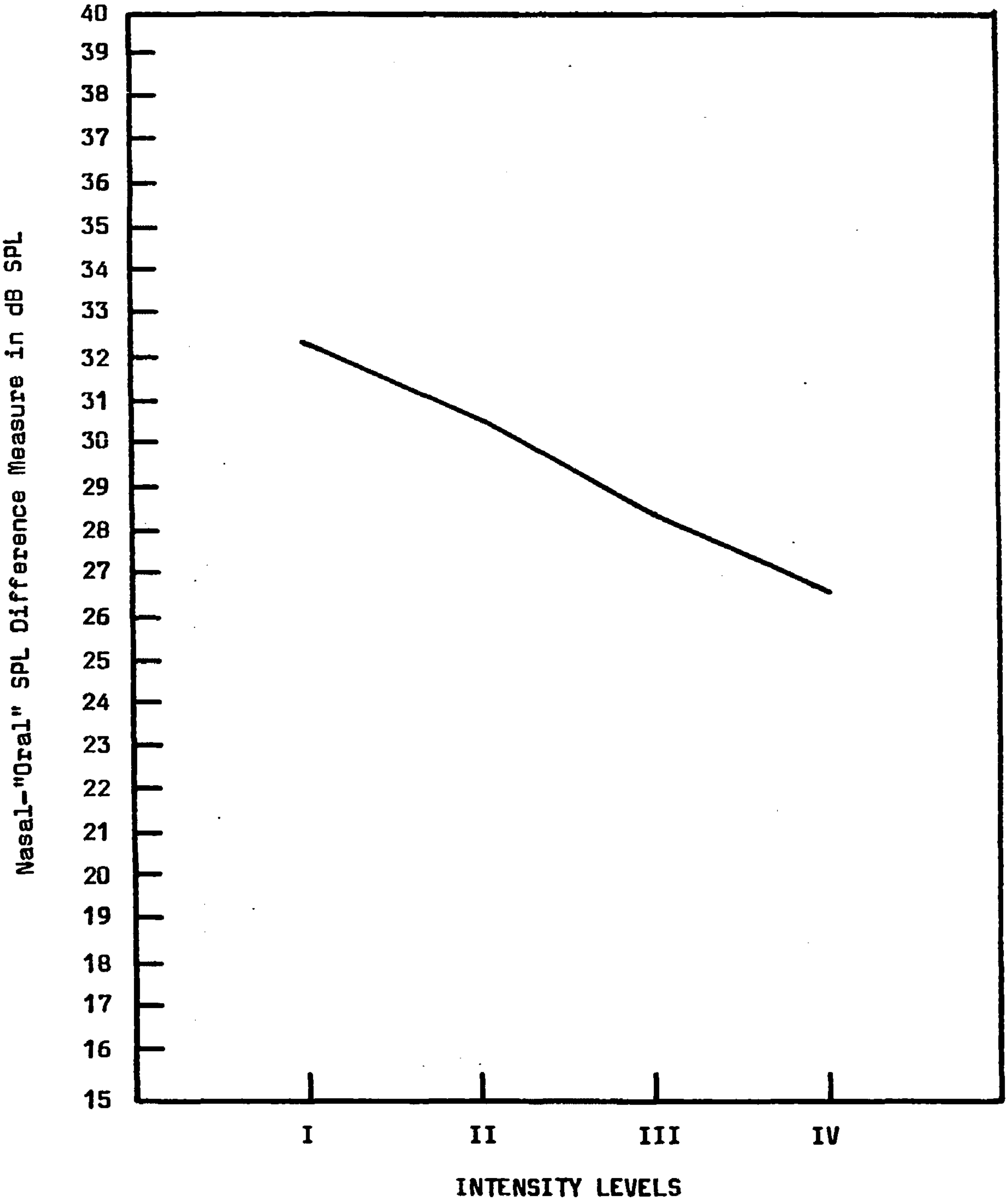

Fig. 7—Nasal-"Oral" Sound Pressure Level (SPL) Difference Means for Each of Four Intensities. The Means Are Derived over All Conditions, Sexes, and Vowels.

decrease in the mean SPL difference is associated with each 5 dB increment in vocal intensity from 70 to 85 dB SPL. The amount of decrease in the mean SPL difference measure is similar between each successive Intensity Level: 1.89 dB between Intensity Levels I and II, 2.12 dB between Intensity Levels II and III, and 1.69 dB between Intensity Levels III and IV.

The presence of a significant condition-by-intensity interaction indicates that the effects of vocal intensity level on the SPL difference measure, cited above, differs for the normal and cleft palate speakers. Means involved in this interaction averaged over all sexes and vowels, are displayed in Figure 8. Inspection of the means in Figure 8 shows that the mean SPL difference measure of the cleft palate subjects at Intensity Level I is 36.63 dB; at Intensity Level II, 35.50 dB; at Intensity Level III, 33.96 dB; and at Intensity Level IV, 32.31 dB. The mean of the normal subjects at Intensity Level I is 27.97 dB; at Intensity Level II, 25.32 dB; at Intensity Level III, 22.63 dB; and at Intensity Level IV, 20.89 dB.

It may be seen that while both groups of subjects evidence a decrease in the SPL difference measure with each 5 dB increment in vocal intensity, the amount of decrease is not the same for each group. The normal subjects, for example, show a decrease in the mean SPL difference measure of 2.65 dB between Intensity Levels I and II, 2.69 between Intensity Levels II and III, and 1.74 between Intensity Levels III and IV. The cleft palate subjects evidence a decrease in the mean SPL difference measure of 1.13 dB between Intensity Levels I and II, 1.54 dB between Intensity Levels II and III, and 1.65 dB between Intensity

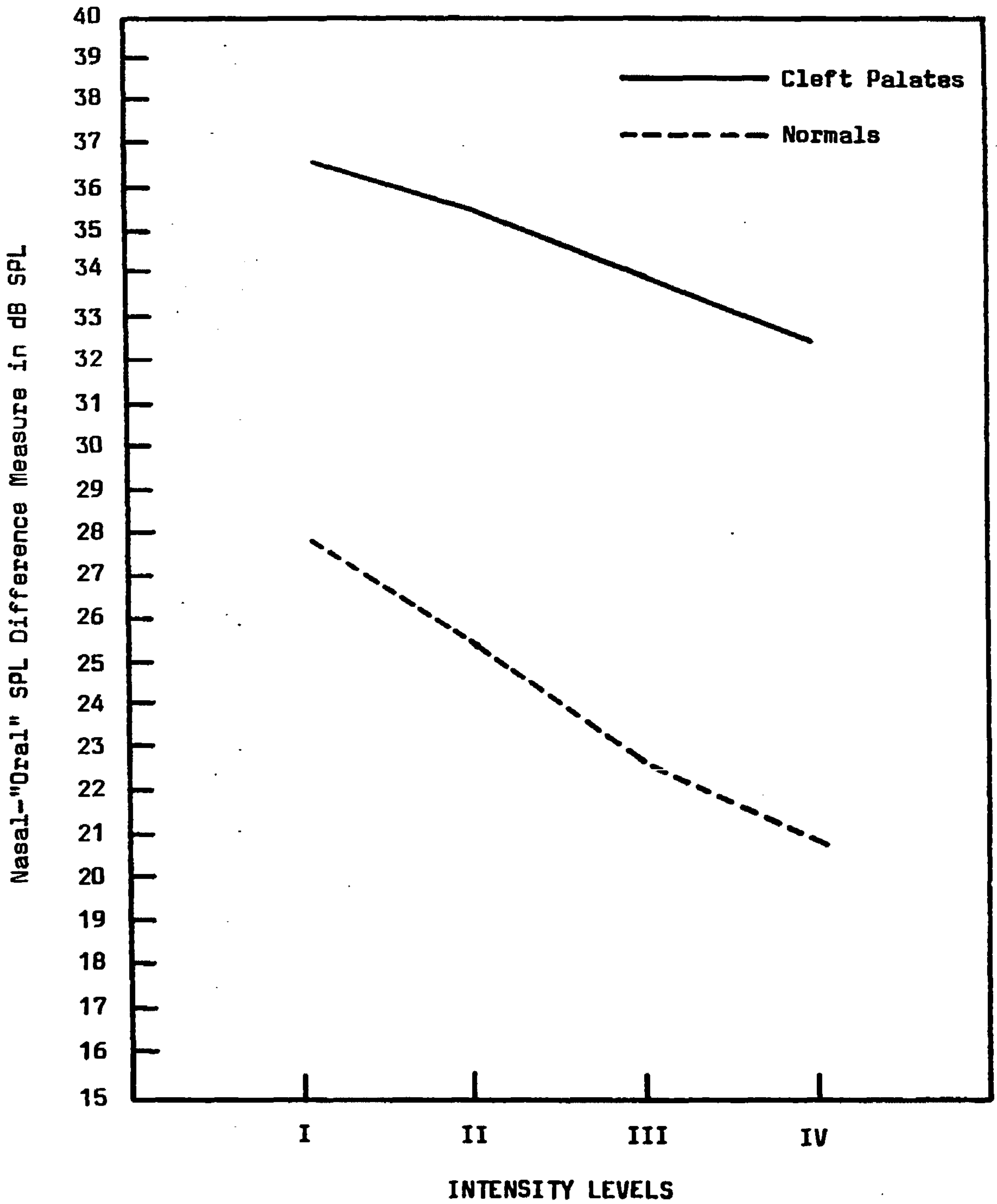

Fig. 8—Nasal-"Oral" Sound Pressure Level (SPL) Difference Means for Cleft Palate and Normal-Speaking Subjects for Each of Four Intensities. The Means Are Derived over All Sexes and Vowels.

Levels III and IV. From the lowest to the highest intensity levels, the decrease in the mean SPL difference measure for the normal subjects is 7.08 dB. For the cleft palate subjects, this decrease is 4.32 dB.

The supplementary analysis of variance, displayed in Tables 2 and 3, show that the intensity simple effect is significant for both male and female cleft palate and normal speakers. This indicates that not only is there a significant intensity effect on the SPL difference measure between the normal and cleft palate groups, but there is also a significant intensity effect for both male and female subjects within each group.

Inspection of Figure 8 further shows that the differences between the mean SPL measures for normal and cleft palate speakers, previously shown in the condition main effect, obtain at each of the four intensity levels in this study. It may be seen that at each intensity level, the mean SPL difference for the cleft palate speakers substantially exceeds that for normals. These intergroup differences amount to 8.66 dB at Intensity Level I, 10.18 dB at Intensity Level II, 11.33 dB at Intensity Level III, and 11.42 dB at Intensity Level IV. Thus, the intergroup differences increase as vocal intensity level is increased.

Discussion

The findings of the present study show that the magnitude of the mean nasal-"oral" SPL difference measure differs significantly for the normal and cleft palate speakers. The means obtained in the present study are similar to those obtained in other studies of the SPL difference measure in which the subject and vowel samples, instrumentation, and experimental procedures are directly comparable. For instance, Bryan (4), Counihan and Pierce (8), and Richards (31) utilized a highly similar apparatus and procedure to study SPL differences in production of isolated vowels by either normal and/or cleft palate speakers at a single vocal intensity level (75 dB SPL). If the present data at the 75 dB level are compared with the findings of these studies, similar relationships are seen to obtain. For instance, Richards (31) and Counihan and Pierce (8) report mean SPL differences for their normal-speaking groups of 28.85 dB and 22.0 dB, respectively. In the present investigation, the mean SPL difference found for normal speakers at the 75 dB level is 25.32 dB. In their study of cleft palate speakers, Bryan (4) and Counihan and Pierce (8) report mean SPL differences of 34.2 dB and 32.0 dB, respectively. Richards (31) reports a mean SPL difference of 33.25 dB for cleft palate subjects with presumed velopharyngeal inadequacy. These means may be compared with the mean SPL difference of 35.50 dB obtained for the present cleft palate group at the 75 dB level. Considering the differences in subject sample size and the expected heterogeneity of the subject samples studied, these data would appear to be in reasonably close agreement.

The present data for normal speakers is also generally compatible with mean SPL differences reported by Hirano, Takeuchi, and Hiroto (18) who studied normal Japanese vowels in a variety of consonant contexts. The mean SPL difference, calculated from raw data presented by these investigators (excluding data for vowels in nasal consonant contexts), is 23.59 dB. This mean is well within the range of means for normal vowels reported above. Weiss (43), investigating SPL differences for hypernasal speakers, including some cleft palate subjects, reports a mean SPL difference of 33.10 dB for this subject group. This mean is similar to those obtained for cleft palate subject groups reported previously. Summers (41), however, using the same apparatus employed by Weiss (43), studied vowels produced by normal speakers at four vocal intensity levels (from 58 dB to 84 dB SPL). He found a mean SPL difference, over all intensity levels, of 33.0 dB. This mean, it may be seen, is similar to that obtained across all intensity levels for the cleft palate group in the present investigation and to that obtained by Weiss for hypernasal speakers (43).

The reasons for the relatively high mean values reported by Summers for normal speakers are not immediately apparent. In any case, the weight of the data across studies suggests that mean SPL differences obtained for groups of cleft palate subjects tend to be substantially greater than those obtained for groups of normal subjects.

Comparisons of the differences between the means for normal and cleft palate groups suggest that differences of the magnitude of 4 to 10 dB may be expected when such groups are compared. In the present study and that of Counihan and Pierce (8), intergroup differences approximate 10 dB. Richards (31) reports an intergroup difference of 4 dB and Shelton, Knox, Arndt, and Albert (38), comparing mean SPL differences for the same fifteen cleft palate speakers with and without obturators in place, report an intergroup difference of 6 dB.

That cleft palate and normal groups should differ with respect to the SPL difference measure might be expected on the basis of studies employing single subjects with specified and controlled increments in nasal tract coupling area. It will be recalled that Olson (29) found a rank correlation (Kendall Tau) of 1.0 between nasal-"oral" SPL difference measures and size of the naso-pharyngeal aperture when he employed a single normal subject who wore a speech appliance with a variable nasal orifice. Through the use of a similar experimental speech appliance which permitted controlled variations in the degree of oral-nasal coupling with a single, male cleft palate subject, Ochsner (28) found systematic increases in the nasal SPL and SPL difference measure with increases in the size of the nasal aperture. On the basis of the present data, it would appear reasonable to speculate that the SPL difference measure is sensitive to oral-nasal tract coupling and that this acoustic measure may be useful in discriminating speakers with abnormally large velopharyngeal openings from those with small velopharyngeal apertures.

The present investigation shows that the sex main effect and all sex interactions are not significant. This suggests that the findings of the condition, vowel, and intensity main effects and interactions do not vary significantly for female and male subjects. The absence of a significant sex main effect or interaction is consistent with findings of other investigations of SPL differences. Counihan and Pierce (8) in their study of normal and cleft palate speakers, and Summers (41) in his investigation of normal speakers found similar nonsignificant sex main effects and interactions. It is of interest that both investigators, on examining trends within their data, noted somewhat greater mean SPL differences for females than for males, approximating 3 dB. This pattern was not observed in the present study. Female subjects, across conditions, vowels, and intensities, display a mean SPL difference measure of 29.50 dB while the males show a mean SPL difference of 29.31 dB. Thus, if greater SPL difference measures exist consistently for female than for male speakers, it is not demonstrated in the present investigation.

The present study also indicates that mean SPL differences vary as a function of the vowel produced for cleft palate but not for the normal speakers. For the cleft palate speakers, substantially greater mean SPL differences are found for the high vowels /i/ and /u/ than for the low vowels /æ/ and /ɑ/. This finding is consistent with existing data (4, 8, 31). For the normal speakers, a slightly greater mean SPL difference measure is found for the high vowel /i/ than for the other vowels studied. The differences between means are, however, small and fail to reach statistical significance. It is of interest, however, and this trend is seen in other studies (8, 18, 41), that the rank order of the vowel means for the normal speakers is similar to that seen for the cleft palate group. This has caused the speculation (8) that the pattern of vowel means seen in cleft palate speakers represents an exagerration of a pattern observed in normal speech, rather than a pattern that is different in kind.

It would appear from the present study and correlative data from other studies that one effect of coupling the nasal to the oral tracts is to increase the SPL difference for the high relative to the low vowels. This is reflected in an increased range of vowel means for the cleft palate relative to the normal speaking group. In the present study, the range of vowel means for the normal speakers is 3.64 dB, while for the cleft palate speakers it is 6.05 dB. These data are quite consistent with the findings of other studies. For normal speakers, ranges of 3 dB and 3.8 dB are reported by Summers (41) and by Counihan and

Pierce (8), respectively. For cleft palate speakers, ranges of 10 dB, 8.3 dB, and 6 dB are reported by Counihan and Pierce (8), Richards (31), and Bryan (4), respectively. Ochsner's (28) data for isolated vowels produced under various conditions of nasal tract coupling are also relevant here. Under a no-coupling condition, the range of vowel means for her single subject is 3.8 dB; under the largest area of nasal tract coupling (.785 cm^2), the range is 6.6 dB.

The trends toward greater mean SPL differences for the high vowel /i/ than for the low vowels /æ/ and /ɑ/ in the normal data, suggest that factors other than velopharyngeal opening affect the size of the SPL difference. A high vowel such as /i/ is produced in normals with a more complete velar seal than are the low vowels /æ/ and /ɑ/ (25). If velopharyngeal opening were the only determinant of the size of the SPL difference, low rather than high vowels should display greater SPL differences. The fact that this is not found to be the case, points to the importance of oral impedance. It seems reasonable to speculate that a greater proportion of sound energy is radiated into the nasal tract when the tongue is high in the mouth, as it is for /i/, than when it is low, as it is for /ɑ/ or /æ/.

The greatly increased SPL differences for high than for low vowels in subjects with velopharyngeal incompetency also fits in with this reasoning. Assuming a constant area of nasal opening, it is evident that a proportionally greater amount of acoustic energy will be distributed through the nasal tract when oral impedance is high than when it is low. If this is so, one would expect a heightened intra-nasal sound pressure level and a greater nasal-"oral" SPL difference measure for high relative to low vowels. The present data tend to support the concept advanced by Curtis (10) that when assessing the distribution of acoustic energy through the vocal tract, the size of the velopharyngeal opening cannot be considered apart from the amount of oral tract impedance.

One other factor needs to be considered, and this relates to the procedures employed in the present experiment. If one requires all vowels to be produced by subjects at a uniform intensity level, measured some constant distance from the lips, the amount of energy generated at the glottal source cannot be assumed equal for all vowels. It is well-established that (13, 24, 34) there are differences in the relative power of natural vowels. The differences between the power of the weakest vowel /i/ and a vowel with relatively great power such as /ɑ/ may be as great as 5 dB (13). To achieve a given uniform intensity level at some point outside the mouth, a substantially greater source energy must be generated for /i/ than for /ɑ/. Again, assuming a constant area of nasal coupling, it can be assumed that some proportion of this increased source energy will be radiated through the nasal tract, increasing the intra-nasal sound intensity to a greater extent for "weak" than for "strong" vowels. The increased intra-nasal sound intensity found for the weaker high vowels, /i/ and /u/, provided by cleft palate speakers may relate to the requirement of the present study that all vowels must be produced at specified uniform intensity levels.

Recently, Schwartz (35) has reported significantly different patterns of intra-nasal sound pressure levels for vowels produced by male and female normal speakers. He has noted that normal females show significantly greater intra-nasal sound pressure for high than for low vowels, while normal males show no significant differences in nasal sound pressures across vowels. The absence of sex interactions in the present study suggests that, if such differences exist between male and female normal speakers, it is not demonstrated by the present experiment. To the contrary, inspection of the raw data suggests that the range of vowel means for normal males exceeds that for normal females. Trends within the present data suggest, however, that cleft palate females display a substantially greater range of SPL differences for vowels than cleft palate males. When means are averaged over all intensity levels, the range of vowel means for cleft palate females, 8.19 dB substantially exceeds that for males, 4.10 dB.

The findings of the present study also indicate that variations in vocal intensity, within the intensity range specified (70-85 dB SPL), have an effect upon the size of the SPL difference measure, and that this effect differs significantly for the normal and cleft palate speakers. Present findings indicate that while the size of the mean SPL difference tends to decrease with each 5 dB increase in vocal intensity level, the amount of decrease is greater for the normal than for the cleft palate speakers. The overall decrease in the SPL difference from 70 to 85 dB SPL for the normals is 7.08 dB; for the cleft palate speakers, the decrease is 4.32 dB.

The present data are in general agreement with data previously reported by Summers (41), who studied a group of normal speakers, and by Ochsner (28) who studied a single subject under various conditions of nasal tract coupling. These investigators report a decrease in the size of the SPL difference as a function of increased vocal intensity.

Summers (41), for instance, reports a decrease of 7 dB in the SPL difference as vocal intensity is increased from 57 to 84 dB SPL. Ochsner (28) noted that, as vocal intensity was increased from 70 to 85 dB, there was a decrease of 2.7 dB in the SPL difference in the 0 cm^2 coupling condition and a decrease of 7.3 dB in the .0314 cm^2 coupling condition, her second smallest coupling condition. Since all normal vowels are not produced with a complete velar seal, comparisons of the present with the Ochsner data under conditions of less than complete nasal tract closure would seem defensible. The present data, which show a 7 dB decrease in the SPL difference with a vocal intensity increase from 70 to 85 dB, would seem to be compatible with both the Summers and the Ochsner data.

The present findings related to cleft palate speakers, however, differ from those reported by Ochsner (28) for her single subject under the largest conditions of nasal opening (5.036 cm^2 and .785 cm^2). Ochsner reports a substantially greater decrease in the SPL difference measure with increased vocal intensity in these larger coupling conditions than in the no-coupling or small area (.0314 cm^2) coupling conditions. In the .785 cm^2 coupling condition, for example, Ochsner reports that a 15 dB increment in vocal intensity level resulted in a 13.6 dB decrease in the SPL difference. In the present study, the decrease in the SPL difference with a 15 dB increase in vocal intensity averaged only 4.32 dB. The maximum decrease in the SPL difference evidenced by any single subject in the present study was 7.38 dB. It seems reasonable to conclude that the amount of decrease in the SPL difference evidenced by cleft palate speakers with velopharyngeal incompetency, within the present range of vocal intensity, is substantially less than might be inferred from the Ochsner data. Further, contrary to the Ochsner study, the present study suggests that a greater decrease in the SPL difference measure occurs with increased vocal intensity when the area of nasal tract coupling is small rather than when it is large. The data further suggest that the performance of Ochsner's single subject may not be representative of the performance of cleft palate subjects presenting velopharyngeal incompetency.

In contrasting the present data with those of Ochsner (28), several factors should be borne in mind. First, direct comparisons of the present cleft palate group with Ochsner's single subject at the largest coupling conditions employed in that experiment is open to some question. The extent to which the range of coupling conditions studied by Ochsner represent the areas of nasal tract coupling seen in the present cleft palate group is unknown, since no precise measures of velopharyngeal closure were made in the present study. Second, the range of coupling conditions studied by Ochsner may be too restrictive. Fant (14), for example, notes that nasalization effects come into play when the area of nasal tract coupling exceeds .68 cm^2. The largest coupling area employed in the Ochsner study only slightly exceeds this critical point. The Ochsner data provide no firm data concerning the relationships of concern beyond the .785 cm^2 coupling area. It is possible that the present cleft palate subjects, selected on the basis of velar inadequacy, evidenced coupling areas well in excess of those included in the Ochsner study. Third, and related to the preceding point, it is possible that subjects are capable of substantial vocal tract adjustments which may compensate for nasal tract coupling effects, specifically adjustments of lingual height and degree of mouth opening. Such adjustments may be relatively effective within a relatively narrow range of velar openings, but less effective once a sufficiently large area of coupling is reached. Fourth, the present data deal exclusively with comparisons of normal subjects and subjects with presumed velopharyngeal incompetence. No attempt was made to explore or specify the SPL differences that an individual subject might obtain in response to variations in both vocal intensity and nasal tract coupling area. The experimental tasks required in the present study and in the Ochsner study may be quite different in kind.

The present findings, nonetheless, appear consistent with expected relationships. First, it seems reasonable to expect that increases in glottal source intensity will be reflected in increases in intra-nasal sound intensity to a greater extent when the area of nasal tract coupling is large than when it is small. Second, assuming that source intensity must be increased to a greater extent when the area of coupling is large than when it is small, due to the increased energy absorption of the vocal tract, the amount of acoustic energy available for transmission through the nasal tract is greater when the area of coupling is large than when it is small. Both of these factors should have the effect of increasing intra-nasal sound intensity and, assuming a uniform vocal (oral) intensity level, of increasing the size of the nasal-"oral" SPL difference measure.

It might be argued on these premises that the cleft palate speakers should not demonstrate any appreciable decrease in the SPL difference measure with increased vocal intensity. The Ochsner data (28) is relevant to this point. She reports that 5 dB increments in vocal intensity level are not reflected in identical increments in intra-nasal sound intensity. The nasal tract, because of its smaller size and greater damping, radiates much less energy than the mouth when nasal vowels are produced. For this reason, it seems likely that 5 dB increases in vocal intensity would result in somewhat lesser increases in nasal sound intensity. This is seen in the Ochsner data. It is because increments in vocal intensity are not reflected in equivalent increases in the intensity of the nasal signal that the size of the SPL difference decreases with increased vocal intensity level.

The finding that increased vocal intensity exerts a significant effect on the SPL difference would seem important in light of the use of the SPL difference measure as an acoustic correlate of nasality. Research (4, 8, 38, 43), thus far, indicates that perceptual ratings of the severity of nasality are related positively to the size of the SPL difference, that is, more severe nasality ratings are assigned vowel samples with larger than with smaller SPL differences. Research (7) also shows that, when listeners are permitted to hear vocal intensity differences among speech samples, they tend to assign more severe nasality ratings to more intense than to less intense speech samples. In experiments in which speech productions are allowed to vary from speaker to speaker or, more explicitly, where productions of the same speaker are permitted to vary in intensity, the relationship between the SPL difference measure and nasality ratings could be expected to be diminished. Further, it seems likely that the relationship between the SPL difference measure and ratings of the severity of nasality may vary, even in experiments where vocal intensity is controlled, depending upon the vocal intensity levels employed. This possibility deserves further study.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of the present study was to investigate nasal-"oral" SPL differences of four selected vowels produced at four different intensity levels by a group of normal speakers and by a group of cleft palate speakers with presumed velopharyngeal incompetency. Sixteen cleft palate persons, eight male and eight female, and sixteen normal speakers, matched to them according to age and sex, served as subjects. To obtain a cleft palate sample with velopharyngeal incompetency, all cleft palate subjects were required to present oral breath-pressure ratios less than .75.

Each subject sustained each of the vowels /i/, /u/, /æ/, and /ɑ/ in isolation for four seconds at each of four intensity levels, 70, 75, 80, and 85 dB SPL, at a mouth-to-microphone distance of eight inches. The vowel samples of each subject were tape-recorded by means of a dual channel high-fidelity recording system, and subsequently analyzed by instrumentation that provided a graphic representation of "oral" and nasal sound pressure levels. The "oral" signal represented an overall signal since it was the sound pressure level measured using a microphone positioned in front of the speaker's lips. The nasal sound pressure levels were measured by a microphone equipped with a probe-tube which was placed approximately one-quarter inch inside the least-occluded nasal meatus. For each item of the speech sample, the arithmetic difference between the nasal and "oral" sound pressure levels was obtained and these difference measures provided the quantitative acoustic data of this experiment.

In order to evaluate the research data, an overall analysis of variance with a factorial arrangement of treatments was utilized in which the factors were condition, sex, vowels, and intensity. In addition, as a supplementary statistical analysis, individual analyses of variance were performed to examine the simple effects occurring within each condition - sex group. A significance level of .05 was selected for this investigation.

The results of the statistical analysis indicated that the condition, vowel, and intensity main effects as well as condition-by-vowel and condition-by-intensity interactions were significant. Within the limitations of this experiment, the following conclusions appear to be warranted:

1. No significant differences related to the sex of the speaker were revealed by the present experiment.

2. Mean SPL differences obtained for the cleft palate group, averaged over all vowels, significantly exceed those obtained for the normal group.

3. The difference between the mean SPL difference measures for the cleft palate and normal-speaking groups is greater when high vowels than when low vowels are compared.

4. Mean SPL differences obtained for the four vowels differ significantly for the cleft palate, but not for the normal-speaking group. For the cleft palate group, mean SPL differences for the high vowels /i/ and /u/ substantially exceed those for the low vowels /æ/ and /ɑ/. This relationship holds at each of the four intensity levels studied.

5. Mean SPL differences for both the normal and cleft palate groups show a significant decrease as vocal intensity is increased from 70 to 85 dB SPL. With 5 dB increments in "oral" intensity, there are small decrements (1.69 to 2.12 dB) in the SPL difference measure.

6. Mean SPL differences decrease to a significantly greater extent for the normal-speaking than for the cleft palate group as vocal intensity is increased from 70 to 85 dB SPL. That is, smaller decrements in the size of the SPL difference occur for the cleft palate than for the normal-speaking group as vocal intensity level is increased.

7. The differences between the mean SPL difference measures for the cleft palate and normal-speaking groups increases significantly as vocal intensity is increased from 70 to 85 dB SPL.

The experimental design of the present study might be altered profitably in future investigations of the relationship of vocal intensity and SPL difference measures for vowels in cleft palate and normal speakers. First, although an attempt was made to identify cleft palate subjects with velopharyngeal incompetency on the basis of their obtained oral breath-pressure ratios, the experiment would have been enhanced if the degree of oral-nasal coupling of each subject could have been specified more accurately. With this information available, the effect of specific degrees of nasal coupling on SPL difference measures in normal and cleft palate speakers could have been determined.

Second, the use of sustained, isolated vowels presents some limitations. It may be difficult to generalize about the effect of coupling and intensity level changes on SPL difference measures for connected speech from data obtained for isolated vowels. Evidence in support of this is provided by Bryan (4) who reports a relatively low correlation coefficient (.52) between SPL difference measures for vowels and SPL difference measures for sentences.

Third, it would be helpful to understand the amount of vocal effort that was expended by each subject in the production of each vowel at each of the intensity levels. An understanding of vocal effort exerted by these subjects would be enhanced if concomitant subglottal pressure and oral-nasal air flow data had been obtained with the measures taken in this study, particularly as they relate to the factor of glottal resistance. Since the intensity-changing mechanism for normal subjects appears to vary somewhat for different pitches (23), a simultaneous recording of fundamental frequency along with these other measures for cleft palate and normal speakers would be useful. In addition, a further understanding of the inter-relationship between SPL difference measures for vowels with intensity level changes would have been increased if information regarding the presence and nature of possible tongue position within the oral cavity, the size of the mouth opening, and the degree of posterior and lateral pharyngeal wall movement had been made available. The need for an understanding of the physiologic events that contribute to the acoustic end-product remains an essential area of further investigation.

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APPENDIX

TABLE 4

NASAL-"ORAL" SPL DIFFERENCE MEASURES FOR THE FOUR SUSTAINED VOWELS AT THE FOUR INTENSITY LEVELS PRODUCED BY EIGHT NORMAL FEMALE SPEAKERS

Subject Number	Intensity	Vowel /i/	/u/	/æ/	/ɑ/
1	70	37.5	23.0	28.5	30.5
	75	37.5	21.5	28.0	26.5
	80	37.5	20.5	26.5	28.0
	85	31.5	26.0	20.5	21.5
2	70	21.5	21.5	21.0	18.0
	75	23.0	21.5	18.0	16.0
	80	22.5	19.5	16.5	16.0
	85	23.5	25.0	13.5	15.5
3	70	30.0	25.0	23.0	18.0
	75	29.0	24.0	23.5	20.5
	80	25.0	21.5	26.0	18.0
	85	18.0	20.5	21.0	18.5
4	70	32.0	30.5	24.0	29.0
	75	32.5	20.0	23.5	25.0
	80	20.5	23.5	16.0	15.0
	85	20.5	22.0	12.5	13.5
5	70	27.5	26.5	31.0	31.0
	75	26.5	29.0	29.5	28.0
	80	29.5	29.0	15.0	25.0
	85	25.5	18.5	18.0	26.0
6	70	32.5	31.5	28.0	27.0
	75	28.0	22.0	28.5	27.5
	80	20.5	22.5	27.5	22.5
	85	22.5	18.0	21.0	21.5
7	70	36.5	42.5	35.5	37.0
	75	31.0	34.5	31.0	31.0
	80	29.5	22.5	24.5	33.5
	85	24.5	23.0	34.5	28.5
8	70	27.5	26.0	35.5	38.0
	75	24.5	29.5	24.5	28.0
	80	20.5	17.5	21.5	24.0
	85	24.5	21.0	19.0	17.0

TABLE 5

NASAL-"ORAL" SPL DIFFERENCE MEASURES FOR THE FOUR SUSTAINED VOWELS AT THE FOUR INTENSITY LEVELS PRODUCED BY EIGHT NORMAL MALE SPEAKERS

Subject Number	Intensity	Vowel /i/	/u/	/æ/	/ɑ/
1	70	26.5	28.0	21.0	16.0
	75	27.0	25.0	15.5	12.5
	80	25.5	21.5	14.0	12.5
	85	23.0	19.0	12.5	13.0
2	70	31.0	29.5	19.5	14.5
	75	29.0	26.5	18.0	16.0
	80	19.5	20.5	15.0	14.0
	85	18.5	17.5	11.0	13.0
3	70	24.5	26.5	31.5	30.5
	75	25.0	23.5	28.5	27.5
	80	25.5	23.5	30.0	26.5
	85	20.5	19.5	24.5	24.5
4	70	35.0	34.5	34.0	34.0
	75	32.0	32.0	29.5	31.5
	80	30.5	31.0	32.5	27.0
	85	28.5	29.0	23.0	28.5
5	70	23.0	19.5	30.0	29.0
	75	20.5	20.0	32.0	24.0
	80	17.0	18.0	26.0	17.5
	85	19.5	17.0	28.0	17.0
6	70	31.0	22.5	22.5	25.5
	75	27.0	24.0	20.0	19.5
	80	31.5	20.0	19.0	15.5
	85	24.0	21.5	19.5	20.5
7	70	32.0	36.0	35.0	23.5
	75	30.5	21.0	28.0	27.0
	80	33.5	26.0	20.5	22.0
	85	27.0	19.0	21.5	17.0
8	70	21.0	21.0	28.5	27.0
	75	20.5	20.0	24.0	20.5
	80	20.5	19.0	17.0	18.5
	85	18.5	19.0	18.5	17.5

TABLE 6

NASAL-"ORAL" SPL DIFFERENCE MEASURES FOR THE FOUR SUSTAINED VOWELS AT THE FOUR INTENSITY LEVELS PRODUCED BY EIGHT CLEFT PALATE FEMALE SPEAKERS

Subject Number	Intensity	Vowel /i/	/u/	/æ/	/a/
1	70	43.5	44.0	39.5	40.0
	75	42.0	41.0	37.5	41.0
	80	41.5	37.0	38.0	37.5
	85	41.0	35.5	32.5	32.5
2	70	36.5	34.0	33.0	32.5
	75	35.0	32.5	32.5	28.5
	80	36.0	31.5	24.5	20.5
	85	35.0	29.0	22.5	24.0
3	70	42.0	42.5	31.5	32.0
	75	43.0	39.5	31.5	32.0
	80	38.5	25.0	28.5	30.0
	85	35.5	38.5	30.0	27.0
4	70	42.0	41.5	39.0	36.0
	75	42.0	43.0	34.5	34.5
	80	41.5	42.5	31.0	35.0
	85	42.5	35.5	27.0	34.0
5	70	43.5	43.5	33.5	34.0
	75	43.0	44.0	34.5	31.5
	80	39.5	38.5	30.0	30.5
	85	35.5	35.5	33.0	31.0
6	70	38.0	33.5	25.5	24.5
	75	29.0	27.5	25.5	22.5
	80	30.0	37.5	28.0	22.5
	85	28.0	27.5	19.5	25.5
7	70	47.0	42.5	32.5	28.5
	75	43.5	43.5	28.0	32.0
	80	42.0	44.0	29.0	32.5
	85	41.0	39.5	31.0	33.0
8	70	36.0	34.0	28.5	28.5
	75	34.5	32.5	27.5	27.5
	80	36.0	32.0	27.5	29.0
	85	32.5	28.5	28.0	30.0

TABLE 7

NASAL "ORAL" SPL DIFFERENCE MEASURES FOR THE FOUR SUSTAINED VOWELS AT THE FOUR INTENSITY LEVELS PRODUCED BY EIGHT CLEFT PALATE MALE SPEAKERS

Subject Number	Intensity	Vowel /i/	/u/	/æ/	/a/
1	70	41.0	38.0	37.5	37.0
	75	36.0	35.0	34.5	32.5
	80	38.0	34.0	32.5	31.5
	85	33.5	31.0	30.0	29.5
2	70	35.5	39.5	33.5	38.5
	75	41.5	39.5	30.5	32.5
	80	36.5	36.5	33.5	28.5
	85	33.5	36.5	28.5	32.5
3	70	35.5	31.5	28.5	32.5
	75	33.5	34.0	31.0	34.0
	80	33.5	32.5	28.0	30.5
	85	32.5	30.5	28.5	31.0
4	70	39.5	39.5	33.5	31.5
	75	39.5	35.5	33.0	31.0
	80	39.5	36.0	27.0	30.0
	85	35.5	32.5	22.0	25.0
5	70	41.0	38.0	38.0	38.5
	75	36.5	37.0	39.5	37.0
	80	33.5	33.0	39.0	40.5
	85	35.5	29.5	39.5	31.5
6	70	40.0	39.0	38.0	37.0
	75	40.0	29.0	41.0	37.5
	80	41.0	42.0	42.0	39.0
	85	39.0	37.5	38.0	37.0
7	70	45.0	46.5	38.0	40.5
	75	45.0	44.0	42.5	40.0
	80	41.0	43.5	39.5	39.5
	85	41.0	40.0	37.0	34.5
8	70	36.0	34.5	30.5	28.5
	75	36.5	33.5	35.5	27.5
	80	34.0	25.5	30.5	25.0
	85	29.5	32.0	26.5	26.5