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A Study Of The Relative Contributions Of Orally And Nasally Emitted Signals To Hyper-Nasal Speech.

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A STUDY OF THE RELATIVE CONTRIBUTIONS OF ORALLY AND NASALLY EMITTED SIGNALS TO HYPERNASAL SPEECH
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A STUDY OF THE RELATIVE CONTRIBUTIONS OF ORALLY AND NASALLY EMITTED SIGNALS TO HYPERNASAL SPEECH

BY
MILO ELLIS BISHOP
B.S., University of Utah, 1966

THESIS

Submitted in Partial Fulfillment of the
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in the Graduate School of
The University of New Mexico
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To My Mother

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A STUDY OF THE RELATIVE CONTRIBUTIONS OF ORALLY AND NASALLY EMITTED SIGNALS TO HYPERNASAL SPEECH

BY
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ABSTRACT OF THESIS

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ABSTRACT

The validity of The Oral Nasal Acoustic Ratio (Tonar) System as a means of obtaining data relevant to perceived nasality was established by comparing forward and backward play scale values with nasal/oral acoustic ratios computed by Tonar.

The acoustic characteristics of orally and nasally emitted signals and their relative contributions to the total speech signal were analyzed and considered within the framework of oral and nasal acoustic masking.

A passage free of nasal phonemes was read by 20 subjects with surgically repaired palatal clefts. A specially designed instrumentation system (Tonar) was used to separate the signals emerging from the oral and nasal tracts for recording on a two-channel tape recorder. The separate identity of the signals was maintained as they were amplified and analyzed by interlocked frequency and intensity analyzers set to cover frequencies from 250 to 2750. The signals thus analyzed were channeled into an analog ratio computer where the voltage levels representing the nasal and oral signals were compared and the acoustic ratio computed. The continuously computed ratios were then displayed on oscillographic paper from which digital data were derived. To analyze the acoustic contributions of orally and nasally emitted signals, 6 of the 21 recorded speech samples were selected for further analysis. A sample phrase, arbitrarily chosen from the passage, was subjected to detailed frequency analysis by Tonar. To gain a general impression of relative nasality, a 2000 Hz frequency band covering frequencies from 250 Hz to 2250 Hz was used to measure nasal and oral intensities and to compute ratios for each of the six subjects. A 200 Hz bandwidth was used to examine the Tonar ratio as a function of frequency. All frequencies between 150 Hz and 3250 Hz of the same sample were analyzed and the nasal-to-oral acoustic ratios for each of the 16 pass bands were computed.

The data revealed: (1) Narrowband nasal/oral ratios varied as a function of frequency and appeared to be the result of a variety of interactions between oral and nasal intensities. (2) Oral and nasal energy concentrations were centered around a frequency of 500 Hz. (3) Narrowband acoustic ratios for central frequencies of 350, 550, and 750 were the principal contributors to the wideband ratio.

It was concluded that the potential for oral or nasal masking was present. It was further suggested that perceived nasality may be the result of variable nasal masking of the underlying oral signal. Conversely, nasality may be present but undetected as a result of oral masking.

Should nasal masking of the oral signal be a reality, it could mean that nasality, in addition to being a distractive quality, may be covering (masking) acoustic cues vital to phonemic disciminations.

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CHAPTER I

INTRODUCTION

Nasality is commonly defined as a quality of speech which results from resonation of the phonic stream in the nasopharynx and nasal cavities (Dunn, 1950; McDonald and Baker, 1951; Fant, 1952; Stevens, et al., 1953). House and Stevens (1956) in an analog study of vowel nasalization stated that: ". . . nasality in speech sounds is produced most characteristically by coupling the nose and nasopharynx to the oral cavity." The acoustic effect of this coupling of nasal and oral cavities is described rather succinctly by Hattori, et al. (1958):

> It is reasonably assumed that the function of the nasal passage is more like that of a damped channel rather than that of a resonant chamber as far as higher frequency regions are concerned. It is also reasonable to expect, however, that there would be some dull and complex resonances which are due to the higher vibration modes of the nasal cavity, when the spectra of nasalized vowels or nasal consonants are examined more closely. Presumably, those should be the same for all the nasalized vowels and nasal consonants if the nasal cavity itself is not altered.

Efficient management decisions for speakers displaying hypernasality are contingent upon accurate assessment of the problem. Traditionally, such assessments have been made by having listeners subjectively judge the severity of nasality. Recently, attempts have been made to arrive at an objective method of measuring and quantifying the parameters affecting perceived nasality. They have included studies of nasality as a function of nasal air flow (Quigley, *et al*. 1963), velopharyngeal orifice size (Warren, 1964), and oral-nasal relative intensity (Wiess, 1954). The acoustics of nasal speech also have been studied using analogs and spectrographic analysis (House and Stevens, 1956). The subsequent discussions of these ways of assessing nasality (Hattori, *et al*., 1958) might be facilitated by a basic review of: (a) the anatomy and physiology of the pharyngeal area and, (b) the processes of generating speech.

Anatomy and Physiology of the Pharyngeal Area

Soft Palate

Critical to the study of nasality is the soft palate, or velum. In this text, the term "soft palate" will be used except in those situations where reference is being made to articulation between the palate and pharyngeal wall. In such cases the terms velopharyngeal or palatopharyngeal closure may be used interchangeably. Podvinec (1952) described the soft palate in the following manner:

> The soft palate is a muscular palate which is firmly attached to the posterior edge of the bony palate by means of the anterior part of its sponeurotic structure. The posterior edge of the soft palate takes the shape of an arch. It is free and moves easily. Muscles enter into the palate only from right and left, thus each pair of muscles forms a sling, which opens either in an upward or downward direction. With their concavity directed upward we encounter, one behind the other, the tensor, the levator, and upper constrictor muscle sling. With their concavity downwards we find the glossopalatine muscle sling in front, and the pharyngo-palatine sling behind.

Due to its strategic placement between the oral and nasal cavities, the soft palate serves multiple functions.

However, the primary concern of this thesis is its function in regulating air flow through the nasopharynx and nasal cavities.

When discussing nasal air flow as related to nasality, it is significant to note that dynamic modifications occur in palatal relationships within the pharynx until early adulthood. During this time, soft palate growth patterns are reflected in two different dimensions--consistent lengthening and thickening (Subtelny, 1957). Bosma and Fletcher (1961) stated:

> With maturation, the pharynx in general becomes more mobile, and the palate more mobile within it. . . .
>
> The mobility of the palate increases even more than does that of the pharynx. This is made possible by expansion of the cavity of the upper pharynx, and also reflects the change in cephalocaudal alignment of the palatal extrinsic musculature. This mobility is reminiscent of that acquired by the tongue within the correspondingly and simultaneously expanded oral cavity, though movement of the palate occurs only in a median plane, without lateral deflection.

Tongue and Adenoids

In addition to the soft palate, two other soft-tissue structures are enclosed within the oral cavity and pharynx which significantly influence air flow--the tongue and adenoids. Brodie (1941) reported that in the infant, the tongue fills the entire oral cavity and is second only to the brain in closeness to adult size. Fletcher (1966) pointed out that with maturation, the internal space of the oral cavity increases as a result of tongue, mandible, and hyoid bone growth which is in a forward and downward direction. Growth in the depth of the nasopharynx similarly increases.

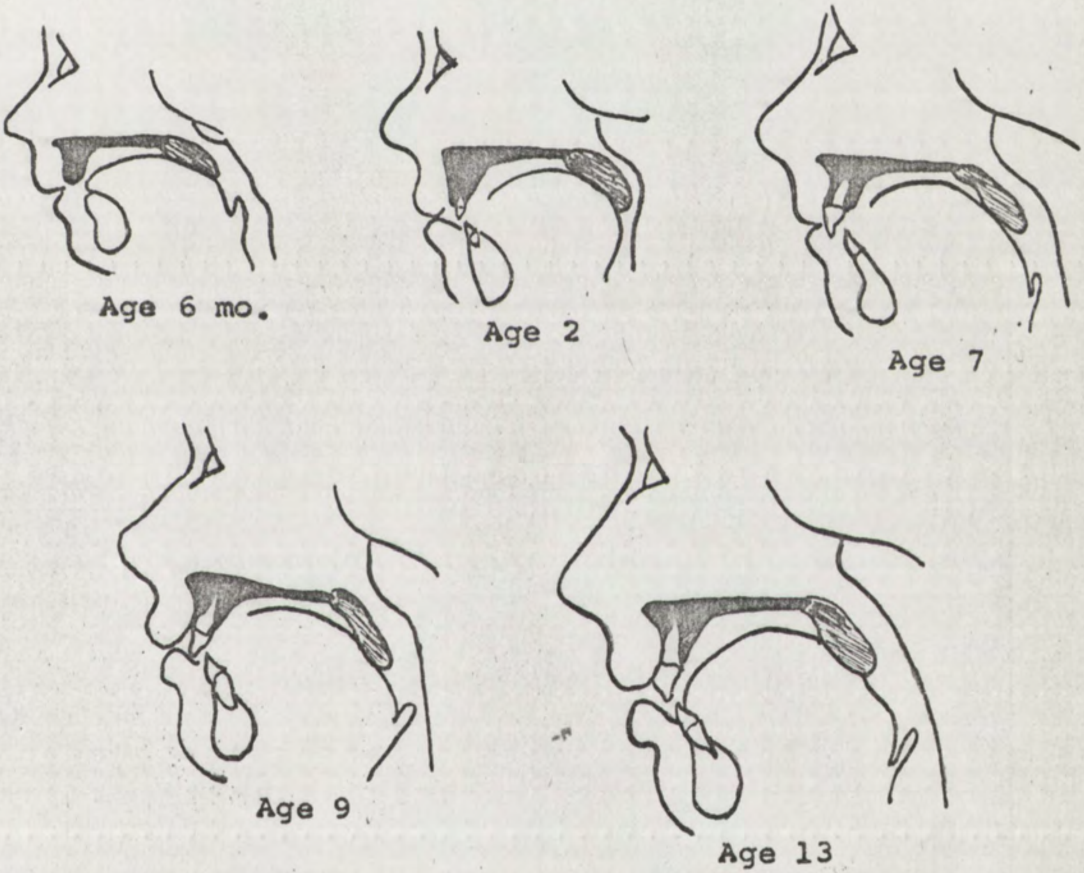
The average vertical dimension of the nasopharynx doubles from infancy to adulthood, increasing most rapidly during the first 18 months of life. Fletcher (1959) also emphasized that during this maturational period from infancy to adulthood, not only do the dimensions undergo change, but the relative position of the nasopharynx during rest is also dynamic. The palate re-aligns itself from being nearly parallel to the pharyngeal roof to a position parallel to the posterior pharyngeal wall. Figure 1 schematizes growth patterns of the nasopharynx from infancy to adolescence.

The adenoids, if large, may play a significant role in providing bulk to compensate for hypoplasia (the shortage of tissue) in achieving an adequate velopharyngeal closure. The adenoids exhibit minimal growth during infancy. Until two years of age such growth is downward and forward. After age 2 its growth is downward until adult size is attained at approximately 15 years of age (Subtelny and Koepp-Baker, 1953).

Pharynx

The pharynx itself communicates inferiorly with the laryngeal cavity and superiorly with the oral and nasal cavities. It is subclassified as the nasopharynx (epipharynx), oropharynx (mesopharynx), and the laryngopharynx (hypopharynx). The nasopharynx is bounded superiorly by the cranial base, inferiorly by the soft palate, anteriorly by the posterior nares and the nasal cavities, and posteriorly by the first and second cervical vertebrae. Pendergrass, et al. (1948, pg. 26) have described the pharyngeal area as follows:

GROWTH OF PHARYNGEAL AREA



Age 6 mo.

Age 2

Age 7

Age 9

Age 13

FIGURE 1

TRACINGS OF THE CEPHALOMETRIC X-RAYS OF THE SAME INDIVIDUAL DEPICTING PHARYNGEAL GROWTH FROM INFANCY TO ADOLESCENCE

> The lumen of the pharynx is widest in the nasal portion, where the bony walls keep the pharyngeal cavity permanently open for respiratory purposes; elsewhere, the ventral and dorsal folds, because of lack of osseus support, are closely approximated, especially in the laryngeal pharynx. Although the nasal pharynx is moderately roomy, there is a definite constriction at the isthmus, where the nasal pharynx goes over into the oral pharynx.

The nasopharynx always remains patent (Grey, 1954; Zemlin, 1968; Fletcher, 1957; Judson and Weaver, 1942).

The oropharynx extends from the soft palate inferiorly to the hyoid bone. It communicates anteriorly with the oral cavity through the pillars of fauces. Unlike the nasopharynx, the oropharyngeal boundaries are relatively dynamic due to the mobility of the soft palate and the root of the tongue. The largyngopharynx extends from the hyoid bone inferiorly to the level of the sixth cervical vertebra, where it communicates with the laryngeal additus of the larynx and the esophageal sphincter (Grey, 1954; Zemlin, 1968).

Muscles of the Pharyngeal Area

Pharyngeal musculature consists of the three paired constrictor muscles (superior, middle, and inferior) as well as stylopharyngeus, palatpharyngeus, levator veli palatini, and salphingopharyngeus. The muscle fibers of the constrictors are circularly directed and overlap each other forming part of the pharyngeal wall. The pharyngeal muscles are longitudinally oriented. The anatomy and physiology of the upper pharyngeal region have been comprehensively reviewed by Bosma and Fletcher (1961, 1962).

Much controversy has been created by attempts to describe and explain the physiological action of the soft palate and the pharyngeal walls during velopharyngeal closure (Wardill, 1928; Wood-Jones, 1940; Harrington, 1944; Hydes, 1953; Flëtcher, 1957, 1958; Warren, 1961; Fletcher and Bosma, 1961, 1962). This controversy has centered around the action of the pharyngeal wall in palatopharyngeal closure. Passavant's pad, which protrudes on the posterior wall of the pharynx at the level of the palate, in certain individuals may assist in velopharyngeal closure. However, anterior movement of the posterior pharyngeal wall during velopharyngeal closures has been well documented. (Fletcher, 1957; Warren, 1961; Hynes, 1953; Moll, 1965). Astly (1958), using cineradiography, reported a pronounced inward (medial) shift of the lateral pharyngeal wall during phonation of the phoneme /ɑ/. Hixon and Miniffie (1968) reported lateral pharyngeal wall movement during speech. This was documented by use of pulsed ultrasonic techniques.

Opinions also differ as to the musculature involved in velopharyngeal closures and the relative contribution of each. Bosma and Fletcher (1961) have stated:

> The direction and extent of palatal valving necessary for normal voice quality varies among different individuals. Normal speech in the mature person can result either from palate-pharynx approximation or from palate-pharynx apposition. This variability led to the term "physiological closure," in which the principal criterion is absence of unusual nasal resonance, rather than presence of anatomic contact of palate to pharynx. Thus, anatomic abnormality is significant only when the requisite limits of physiologic closure are exceeded and defective speech results.

For the scope of this study, it is sufficient to note that currently it is thought that in addition to the superior and posterior movement of the soft palate, there is significant anterior movement of the posterior pharyngeal wall and some medial movement of the lateral pharyngeal wall. Whatever physiological phenomena is responsible for bringing the soft palate and pharyngeal walls into approximation, the fact remains that together they have a principal role in controlling the direction of air flow, a control vital to intelligible speech.

Processes of Generating and Transforming Speech

Fundamental to analyzing and quantifying nasality is an understanding of the processes by which phonemically meaningful sounds are generated. The underlying energy for speech is provided by the flow of air. Physiological modifications of the expiratory airflow may be acoustically reflected, providing the air stream is affected in such a way as to alter, vary, and/or regulate its flow (Potter, *et al*., 1947). Four types of physiological interferences can accomplish this: (1) periodic, (2) impulse, (3) frictional, and (4) cavity modulation. Periodic interference may be accomplished by forcing the air stream through a constricted glottis which acts as a flutter valve. The resulting periodic pulsations of air carry the imbedded acoustic characteristic of speech called voicing. The counterpart to voicing, namely voiceless, is not subjected to periodic interference. The resultant phonic stream whether voiced or voiceless, must be affected by at least one--possibly all--of the three remaining physiological interferences in order to be phonemically meaningful. Impulse interference stops and starts the flow of air and is critical in the production of stop-plosive phonemes. Impulsive interference may occur at any point in the vocal tract where a complete constriction is physiologically possible. It is characterized by a pseudo-silence period resulting from a complete constriction and is followed by a transient burst as the constriction is released. Frictional interference, like impulse interference, is a result of constricting the diameter of the vocal tract. The critical parameter differentiating these types of interference is the degree of constriction. Frictional interference requires a constriction of sufficient magnitude as to create a turbulance in the air passing through the constriction. It is this turbulance or noise which is critical in the production of the fricative phonemes. The fourth type, cavity modulation, unlike the other types does not modulate the air stream in such a way as to generate sound. Rather, the effect of cavity modulation is to modulate the sounds generated by the other interference types in such a manner as to redistribute their energy concentration, thus affecting their quality. It is this quality change that is critical in the perception of nasality.

Whether listening to sound or viewing its visible counterpart through spectographic analysis, interpretation requires identifying its acoustic components i.e., time, frequency, and intensity. The values of these components are determined by the volume-velocity or air flow and the type and degree of interference or modulation acting upon that outward flowing air.

When a tone is generated at the glottis by periodic interference, it produces a fundamental frequency (f_o) plus an infinite number of overtones (f_x). Each overtone is a multiple of the fundamental. The relative energy possessed by each overtone is contingent upon its distance from f_o. The closer the frequency of a given f_x to f_o, the greater its energy. Thus distant overtones, while existing, may not be perceived because of their low energy level. This is an important aspect of cavity modulation, since its effectiveness is restricted by the energy level of the overtone it is modulating.

Cavity modulation occurs principally in the coupling cavities of the throat, mouth, and nose, and acts on the overtones produced by the noise generators. These coupled cavities suppress some of the overtones, while reinforcing others. In other words, these cavities have the property of selective transmission and radiation. The frequency regions in which the overtones appear to be reinforced are referred to as vocal resonances (Potter, et al., 1947). Selection of the frequency regions to be amplified is determined by the resonant characteristics of the cavity. These characteristics are contingent upon the cavity length, shape, surface texture, impedance offered by the resonaters, and the propogation constant. Thus each cavity is endowed with unique resonant characteristics which mold the intensity of the overtones. However, due to the intercoupling of cavities, each cavity modulates an already-modulated signal. Hence, the unique characteristics of each cavity are not retained in the final emitted signal (Fant, 1960). Any cavity through which the sound passes may be considered a potential cavity modulator. However, like low-energy overtones, modulations by the smaller cavities, while present, do not significantly affect the final emitted signal.

Speech then is the summation of the acoustic vibrations which are imbedded within the air stream and pass through a system of interlocking cavities, each possessing unique filter and resonant characteristics. Collectively, these resonating cavities are referred to as the vocal tract. The vocal tract is constructed such that it provides a common channel from the glottis to the oropharynx. At the oropharynx it divides into two channels, oral and nasal. The relative distribution of the phonic stream between these two channels may be explained by the electrical principles stated in Ohm's Law--I $\frac{E}{R}$; where I equals air flow volume-velocity, E equals energy, and R equals resistance. Ohm's law specifies that as resistance decreases, the volume-velocity of air flow will increase. In other words, the flow of air will follow the path of least resistance. Absolute resistance into the nasal channel is the result of the anatomical morphology of the velopharyngeal isthmus and the synergistic action of muscles involved regulating velopharyngeal closure. However, more important than absolute resistance is the relative resistance which defines the functional relationship between resistance of the oral and nasal cavities.

CHAPTER II

REVIEW OF THE LITERATURE

Assessment of Nasality: Physiological Parameters

As previously noted, velopharyngeal closure is a critical parameter in determining the amount of air which will pass through the nasal channel. This is significant in studies of nasality when one recalls that the acoustic characteristics of speech are imbedded in the air stream, and any portion of that stream passing through the nasal cavity will be modified according to the resonant characteristics of the nasal cavity. The interrelationships between velopharyngeal closure, air flow, and nasality have been the topic of numerous studies.

As early as 1934 it was suspected that velopharyngeal closure was influenced by actions within the oral cavity. Norris (1934), Nusbaum, *et al*. (1935), Harrington (1944), and Bloomer (1953) all conjectured that the precision of the velopharyngeal closure may systematically vary with the production of the vowels.

McDonald and Koepp-Baker (1951) hypothesized that a critical point exists at which a characteristic balance or ratio is established between oral and nasal resonance, and if this point is not reached, nasality will occur. They further stated that this balance is related to the degree of closure of the nasopharynx as well as tongue and mandible positions.

House and Stevens (1956) in an analog study of vowel nasalization, verified the supposition that velopharyngeal closure is systematically varied with the production of vowels. They further reported that a complete velopharyngeal closure is not necessary for the production of all "American vowels".

Bjork (1961) hypothesized that there exists a minimal velopharyngeal orifice opening which is necessary for speech to be perceived as nasal. Using cinefluorographic techniques from a lateral projection, he reported a 4 mm opening as being the minimum opening. Subtelny, *et al*. (1961), also using cinefluorographic techniques, reported that for cleft palate speakers velopharyngeal openings ranging from 3.5 to 7 mm were associated with speech which was low in intelligibility and poor in quality.

Warren (1964a) recognized a relationship between air flow and velopharyngeal sphincter size and reported a technique for measuring pressure-flow through the nasal cavity which employed the Theoretical Hydralic Principle (Lilly, 1950; Glorin and Glorin, 1951). By using this technique to measure the differential pressure across the velopharyngeal orifice simultaneously with the air flow through it, Warren was able to calculate the area of the velopharyngeal orifice. Utilizing this approach, Warren (1964b) studied pressure-flow patterns in normal speech and reported the following conclusions:

> Variations in pressure amplitude among consonants are not due to variations in the velopharyngeal orifice size. The normative data suggest that the differences are due to variations in the lung output and glottal impedance.
>
> Oropharyngeal pressure diminishes rapidly when the orifice size exceeds 10 mm^2. A non-linear, possibly exponential relationship, exists between pressure and area. It appears possible that velopharyngeal insufficiency may begin at this 10 to 20 mm^2 range.

Warren further concluded that articulation positions and phonetic content will influence the pressure amplitude of consonants during continuous speech, with phonetic content being the main factor. As expected, nasal phonemes displayed high nasal air flow and low oral air flow, while oral phonemes displayed high oral and low nasal air flow. Quigly, et al. (1963) reported on an instrument (the anemometer) which was designed to quantify oral-nasal air flow in normal and cleft palate speakers. They found that cleft palate speakers demonstrated greater nasal air flow rates than did the normals.

Warren (1964c) again looked to velopharyngeal sphincter size as a means of objectively assessing nasality. He reported that rehabilitated cleft palate speakers having velopharyngeal sphincter openings up to 10 mm^2 were judged as having acceptable voice quality, while nasal speakers generally exceeded an opening of 20 mm^2. Thus it appeared that velopharyngeal orifice size may be the parameter by which nasality could be objectively assessed. Andrew (1967) used a variable aperture prosthesis, to correlate velopharyngeal orifice size, the intensity of the oral and nasal signals, and perceived nasality. He concluded:

> Current theory should be modified to state that at small degrees of coupling, nasality probably is based on the distorted oral output, but that as coupling increases, sound is emitted from the nose which may increase the degree of severity of nasality.

A subsequent study by Warren (1967) revealed: ". . . all ranges of velopharyngeal incompetency cannot be reliably estimated from measures of nasal emission of air. The correlation between the two parameters decreases in strength as sphincter inadequacy increases in magnitude." The validity of this approach was further challenged by Isshiki, et al. (1968). They studied the effects of velopharyngeal incompetence upon speech by using a polyvinyl tube to create an incompetency in normal speakers. They reported:

> There is no definite point of velopharyngeal dimension where speech suddenly changes from normal to abnormal. To determine the critical point of velopharyngeal closure for acceptable speech is therefore directly connected with what we judge acceptable speech.

However, they did report a positive correlation between velopharyngeal opening and perceived nasality. Velopharyngeal orifice size, while not the only determinant regulating nasal air flow, nevertheless, is an important variable.

As previously pointed out, the percentage of the phonic stream which will enter the nasal cavity is also contingent upon the relative impedance of the oral and nasal cavities. While the nasopharynx and nasal cavities remain patent, the size, shape, and coupling characteristics of the oral cavity during speech production are constantly varying. Isshiki, et al. (1968) stated: ". . . it is evident that the degree of nasality depends not only on the size of the velopharynx but also on other factors, such as mouth opening and the position of the tongue." Fletcher (1966), focusing on a related source of variability, reported: "Since the diameter of the oral cavity as a route of exit for the phonic stream is markedly increased with age, complete palatopharyngeal closure is less critical in the adult /than in infants/."

It is apparent from the review of the literature that velopharyngeal orifice size, while important, is not the only parameter determining phonic flow through the nasal channel. The efficiency of a given velopharyngeal closure is contingent upon such factors as age, oral resistance, and phonetic content.

Andrews (1967), in view of inconsistent findings associated with nasality, sought to determine the contribution, if any, of nasally-emitted sound to the perception of nasality. He fit normal speakers with a variable aperture prosthesis, thus enabling control of nasal air flow as a function of velopharyngeal orifice size. Using modifications of Weiss' (1954) recording techniques, Andrews made a four-foot lead cylinder with a microphone located 8" from the speaker's nose, with another microphone outside the cylinder positioned 8" from the speaker's mouth; thus, separate and simultaneous recordings of the oral and nasal signals were permitted. Three judges rated the speech samples in three conditions: nasal and oral combined, nasal only, and oral only. Andrew (1967) concluded: ". . . the nasal signal was, in fact, adding to perceived nasality." His data also indicated that as nasal coupling increased, perception of nasality also increased. Andrews' findings lead to a fundamental question: What acoustic parameters or combinations of parameters precipitate this rise in perceived nasality?

Assessment of Nasality: Acoustical Parameters

As previously discussed, the oral and nasal cavities possess resonant characteristics which are unique to their size, shape, and surface texture. A signal entering either of these cavities will be acoustically modified as it travels through that cavity. Coupling the oral and nasal tracts so that the phonic stream is divided between the two channels results in an acoustic output possessing spectral characteristics which are different than those produced by either the oral or nasal cavities alone. Such spectral changes may be manifest as: (1) a shift in the harmonic frequency containing energy concentrations and, (2) a change in the relative intensity of the signals emitted from the oral and nasal passages. Several studies have been conducted to examine the effects of nasal coupling on the spectral characteristic of the speech envelope. Such studies, using sound spectrographic techniques, have added considerable data critical to formulating an acoustical description of nasality.

House and Stevens (1956) in an analog study of acoustical changes in vowel spectra resulting from the nasal passage participation, reported:

> . . . the general effect of increasing and coupling is to broaden and flatten the peaks of the vowel spectra. The most pronounced spectral changes occur in the region of the first formant, and hence it is reasonable to assume that these changes may be of primary importance in the

> description of nasality. . . . As the /nasal/ coupling is introduced, the first formant drops in amplitude, increases in band width and rises in frequency. Concurrent with these changes there are modifications in the structure of the higher formants, and a spectral prominance appears to be developing in the vicinity of 1000 cps.

The authors cited personal communication with Delattre in which he reported the results of his experiments were in complete agreement with their findings.

Hattori, et al. (1958), in disagreement with the above data, reported a general intensity reinforcement in the region around 250 Hz and a weakening of intensity around 500 Hz with increased nasal coupling. They further noted weak and diffused components between vowel formants especially around 1000 Hz to 2500 Hz. In addition to the shift in frequency distribution reported by House and Stevens (1956), Dickson (1962) found three spectral alterations in frequency of "some nasal speakers": (1) an increase in the formant band width, (2) an increase or decrease in the formant frequency, and (3) a rise in the fundamental frequency. Schwartz (1968) reported finding similar shifts in the formant frequency of nasal speakers during vowel production.

Hockett (1955) is said by House and Stevens (1956) to have reported an increase in the intensity of the third formant. House and Stevens, finding a decrease in this formant, suggested:

> The present data indicate that during the transition from a non-nasal to a nasalized vowel the third formant deteriorates and it is possible, therefore, that the spectral prominance being labeled F_3 in a nasal vowel is actually the fourth resonance of the vocal tract.

Dickson (1962), in agreement with House and Stevens, also reported an intensity drop in the third formant. In addition, he reported a separate region of resonance just above the first formant, as well as a shift in the formant frequency. Curry (1940), Potter, et al. (1947), Peterson (1961), and Coleman (1963) have all reported "extra" components between formants in the spectra of nasal speech.

House and Stevens (1956) observed a general decrease in voltage intensity with an increase in nasal coupling and said that the greatest changes in intensity should occur in the frequency range where impedance differences are greatest, which is in the vicinity of the first formant. They also reported that for any particular vowel configuration, the maximum intensity reduction ranges from 5 to 9.5 dB. These findings agree with the results reported by Cotton (1940) and Weiss (1954). Hattori, et al. (1958) and Dickson (1958) reported the presence of "anti-formants or anti-resonance" which are consistent with Fant's (1960) theory of the effect of nasal pole-zero pairs on vowel resonance.

Concurrent with studies examining spectral changes of nasal cavity participation were studies examining the intensity of nasal and oral sounds emitted during oral-nasal cavity intercoupling.

Weiss (1954), using a probe microphone in the nares, measured the sound pressure level (SPL) of the acoustic signal traveling through the nasal channel of hypernasal speakers. He compared the SPL values taken at the nose to ones obtained with a microphone positioned to pick up the mixed oral and nasal signal. Using the scaling method of paired comparisons, Weiss studied perceived nasality and the SPL differences between the two microphones. The Pearson's Product Movement correlation coefficient was 0.948. Pierce (1962), as cited by Shelton, et al. (1967) compared listener judgement of nasality in sentences with SPL differences for vowels in isolation, syllables, and words. He found correlations similar to those reported by Weiss.

Bryan (1963) also examined the relationship between perceived nasality and SPL measurements. He found much lower correlation coefficients between median nasality ratings for vowels and sentences, and mean nasal oral sound pressure differences, than did Weiss and Pierce.

Shelton, et al. (1967), in a partial replication of the Weiss study, examined the relationship between nasality ratings and SPL measurements obtained from the nose and mouth of cleft palate speakers. He reported smaller correlation coefficients than Weiss or Bryan. However, they were still statistically significant.

The review of the literature has revealed that four spectral changes seem to be related to increased nasal coupling.

1. There appears to be a change in intensity in the low frequency regions.
2. There seems to be a general decrease in the overall intensity of the signal.
3. The intensity seems to decrease in the region of 2000 Hz.
4. Areas of anti-resonance tend to become prominent.

Which of these spectral changes that occur with increased nasal coupling are related to the perception of nasality, and to what degree they are related, has not yet been demonstrated. However, the studies examining relative oral-nasal intensities and perceived nasality have provided data which indicate the need to examine in more detail the influence of relative intensity on nasality.

Fletcher (1969) hypothesized that acoustic masking is a critical factor in the perception of nasality in that a signal emerging from the oral or the nasal tract is potentially capable of masking a signal emerging from the other. It has been well documented that one acoustic signal is capable of masking a second signal of similar frequency if: (a) the intensity of the first is sufficiently increased or, (b) the intensity of the second is sufficiently decreased. What constitutes sufficient intensity alterations is contingent upon such factors as the relative intensities of the paired signals and their frequency differences. All other factors remaining constant, the closer the frequency of the masking signal to that of the masked signal, the more efficient the masking signal.

As previously discussed, the phonic stream, in its course through the vocal tract, must pass through the oral and/or nasal channel. Acoustic masking can be a factor only in those speech situations where the phonic streams from the oral and nasal channels are mixed; otherwise, the masking criterion, that of having competing acoustic signals, is not met. Warren and Hoffman (1961) and others found simultaneous leakage of the phonic stream into the nasal channel during the production of oral phonemes judged free of nasality. Thus from their findings it would seem that there are, in fact, two potentially competing signals. Whether the lack of perceived nasality in such situations is due to oral masking of the nasal signal or simply due to a lack of nasal energy cannot be ascertained from their data.

In order to determine if masking is related to the presence or absence of perceived nasality, the following questions relative to the four previously stated spectral changes should be examined.

1. What is the average oral-nasal intensity relationship of normal and nasal speech?
2. Does this oral-nasal intensity relationship vary as a function of frequency?
3. If this relationship varies with frequency, which frequencies are most influential in determining the overall relationship?
4. Are the frequencies of the oral and nasal energy concentrations close enough to permit efficient masking?

Fletcher (1969) has reported an instrumentation system which has the necessary flexibility for providing data pertinent to these questions. This system, the Oral Nasal Acoustic Ratio (Tonar), is similar to the instruments used by Weiss (1954), Shelton, _et_ _al_. (1967) and Andrews (1967) in that it makes use of the separated oral and nasal signals as they emerge from their respective channels. However, unlike these instruments, Tonar has the capability to analyze these signals within specific frequencies and provides electronically computed analog ratios. Thus, Tonar can provide an analog equivalent of the intensity of the emerging oral and nasal signals, plus their acoustic ratio, within experimentally controlled frequency bands.

As previously discussed, before Tonar or any other objective instrument can be used to gain meaningful information about the acoustic nature of nasality, it must first be shown to analyze parameters which are in fact related to perceived nasality. One way of accomplishing this is by examining the relationships between psychophysical scaling of speech samples from nasal speakers and the analog ratio values computed by Tonar. Since other instruments using the same general approach as Tonar have demonstrated significant positive correlations with psychophysical scaling of nasality, it is likely that Tonar measurements will be similarly related to listener ratings of nasality.

STATEMENT OF THE PROBLEM

Information presented earlier in this thesis indicates that nasality is the result of numerous physiological interactions which permit the phonic stream access to the nasal and/or oral channels. Studies have indicated that the presence of some nasal flow during the production of oral phonemes is not abnormal and seems to have little effect on the final acoustic signal. However, with increased nasal coupling the final emitted signal undergoes acoustic changes which are perceptually and spectrographically noticeable.

Fletcher (1969) hypothesized that acoustic masking has considerable relevance to perception of hypernasal speech in that as changes in oral-nasal relative intensities occur, their capacity to mask one another also changes. Acceptance or rejection of this hypothesis is contingent upon the independent and relative contribution of oral and nasal signals to the total speech envelope. Acoustic studies of nasality, while contributing valuable information about the characteristics of nasality, have provided little concrete data describing the individual characteristics and contributions of the oral and nasal signals to the entire signal.

The purpose of this study is to examine the acoustic characteristics of orally and nasally emitted signals and their relative contributions to the total acoustic signal, thereby providing data with which to consider acoustic masking theory in relation to the perception of hypernasal speech.

Since Tonar is capable of separately analyzing the intensity characteristics of the oral and nasal signals within desired frequency bands, it should be able to provide data pertinent to the objectives of the study. However, since it has not been experimentally established that Tonar analyzes parameters which are related to the perception of nasality, this must first be examined. This study has two main objectives: (1) to establish the validity of using Tonar in obtaining information about the acoustic nature of nasality and, (2) to provide data using Tonar which describes the acoustic characteristics of orally and nasally emitted signals and their relative contributions to the total speech signal.

In order to get data pertinent to the objectives, an experimental design was formulated to answer the following questions:

1. Do Tonar's ratios correlate well with perception of relative nasality, thereby establishing that Tonar is analyzing parameters which are related to perceived nasality?
2. Are oral-nasal ratio differences between individuals the result of systematic oral and/or nasal intensity variations?
3. Are the frequencies of the oral and nasal energy concentrations close enough for potential acoustic masking?
4. Does the average oral-nasal intensity relationship vary as a function of frequency?
5. If this relationship varies with frequency, which frequencies are most influential in determining the overall relationship?

CHAPTER III

PROCEDURES

Methodological Design

The principal intent of this study, as previously stated, was to determine the validity of Tonar in measuring the acoustic characteristics of nasality in speech. To investigate this, psychophysical judgements of perceived nasality were compared to oral-nasal acoustic ratios computed by Tonar.

A passage free of nasal phonemes (Appendix A) was read by 20 subjects with surgically repaired palatal clefts. Specially designed instrumentation was used to separate the signals emerging from the oral and nasal tracts for recording on a two-channel tape recorder. The separate identity of the signals was maintained as they were amplified and then analyzed by interlocked frequency and intensity analyzers. The signals thus analyzed were channeled into an analog ratio computer where the voltage levels representing the nasal and oral signals were compared and the acoustic ratio computed. The continuously computed ratios were then displayed on oscillographic paper from which digital data were derived.

A second recording of the same speech materials was obtained for each subject, this time using traditional sound field recording procedures. These speech samples were scaled for severity of nasality by ten trained observers using a modified direct magnitude estimation procedure. Listener judgements were made twice for each speech sample--once for the sample played forward and backward. Mean perceived nasality scores were then compared with mean acoustic ratios to determine the relationship of listener judgements of nasality to the measured acoustical parameters.

A second objective of this study was to analyze the acoustic characteristics of nasal speech. To study this relationship, six of the 21 recorded speech samples were selected for further analysis. A sample phrase, arbitrarily chosen from the passage, was subjected to detailed frequency analysis by Tonar. To gain a general impression of relative nasality, a 2000 Hz frequency band covering frequencies from 250 Hz to 2250 Hz was used to measure nasal and oral intensities and to compute ratios for each of the six subjects. A 200 Hz bandwidth was used to examine the Tonar ratio as a function of frequency. All frequencies between 150 Hz and 3250 Hz of the same sample were analyzed and the nasal-to-oral acoustic ratios for each of the 16 pass bands were computed. As a check on the validity of the automatically computed ratios, the intensities of the oral and nasal signals were also examined and ratios were manually computed. With this overview, the instrumentation and procedures will now be discussed in detail.

Instrumentation

Tonar

The Oral Nasal Acoustic Ratio (Tonar) is the name given to an instrument system capable of separately but simultaneously recording and analyzing sounds being emitted from the oral and nasal channels. Figure II is a block diagram showing the general components of the system. The separate recordings are accomplished by two matched B & K D150 E 200 microphones suspended in fiberglass and housed within lead chambers cut to fit facial contours. An inter-microphone attenuation of 40 dB is realized in the sound separator. See Figures 3a and 3b. The sound separator may be singularly and vertically adjusted to provide maximum comfort for the subject. Separated signals detected by the oral and nasal microphones are relayed to a Sony stereophonic tape recorder, Model 600, where they are recorded on separate channels. For acoustical analysis the separated signals are played back, passing through a Monacur stereophonic amplifier, Model SA-300, then to Models 305 (master) and 1305 (slave) Quantech tracking wave and spectrum analyzers. The absolute acoustic intensity of the two signals is electrically reflected by the wave analyzers as voltage. These analyzers are inter-connected so as to form a dual-channel, phase and frequency locked, master-slave system possessing liberal frequency scanning flexibility. By setting the variable gain control to calibrate, the meter may be read directly in millivolts to multiplying the

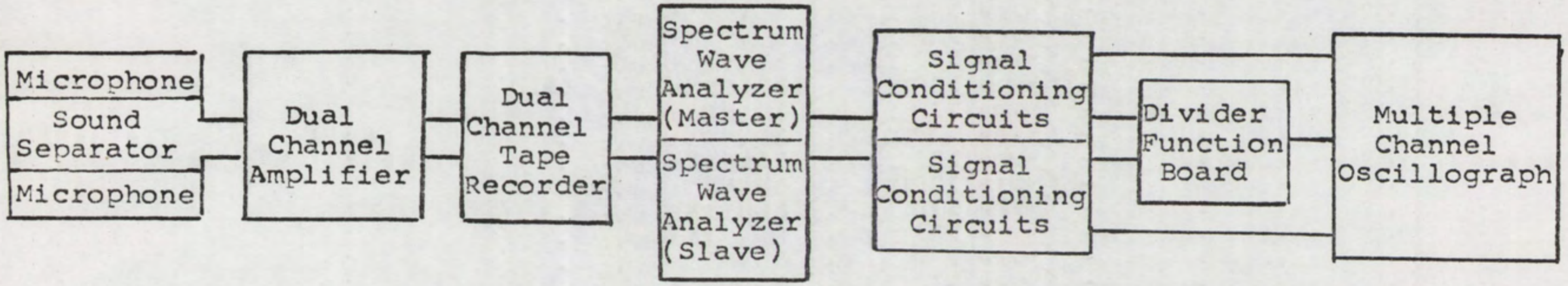


FIGURE 2

BLOCK DIAGRAM OF THE ORAL NASAL
ACOUSTIC RATIO (TONAR) SYSTEM

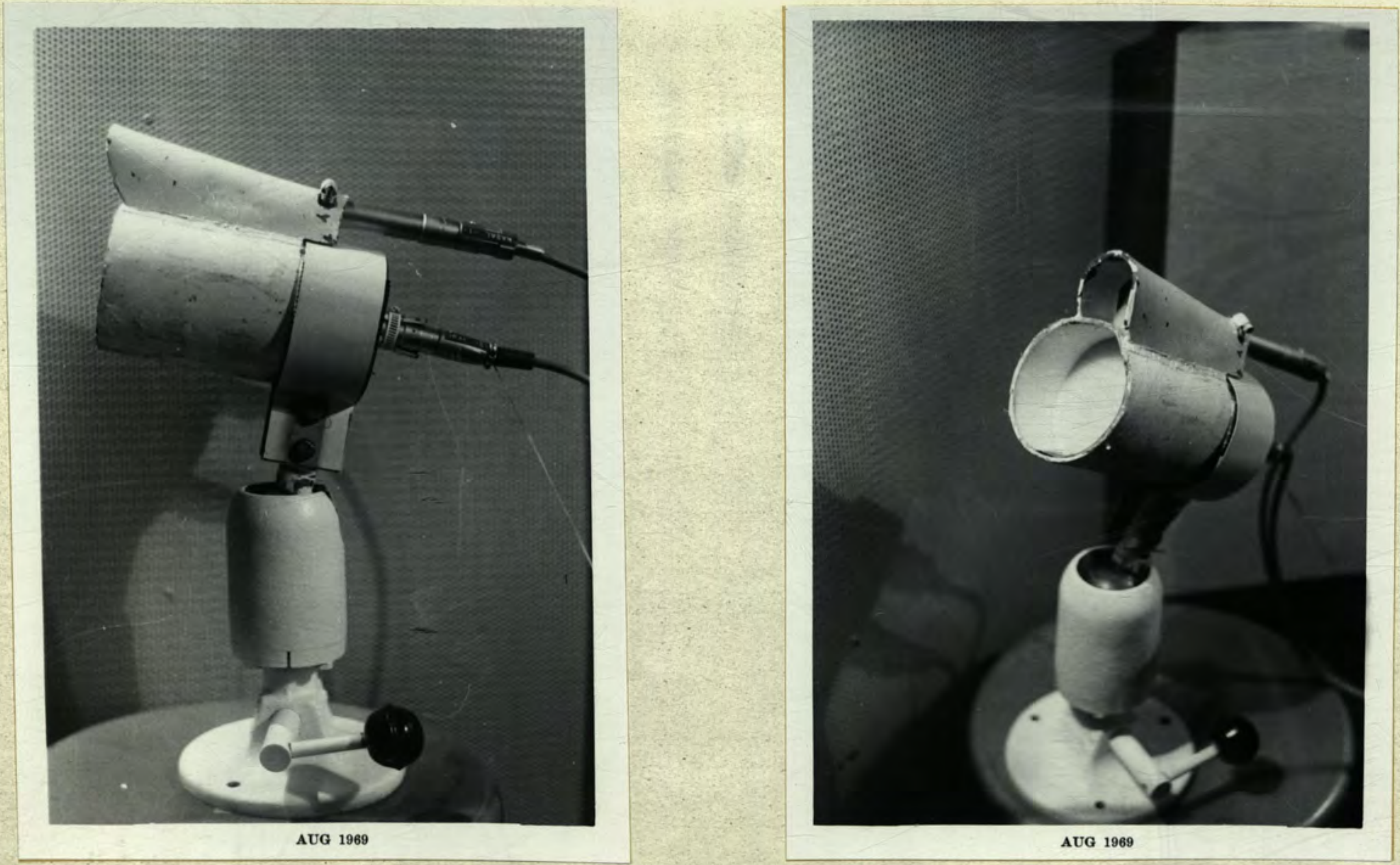


FIGURE 3

THE ORAL NASAL ACOUSTIC RATIO (TONAR) SEPARATOR millivolt reading and the meter multiplier. The averaging time of the analyzers is controlled by the meter time constant. The meter time constant control may be set at averaging times of less than 0.1, 1, and 10 seconds. For example, at a time constant setting of 10 seconds the intensity reading at any given time is the average intensity of the preceding 10 seconds.

Frequency selectivity of the overall pass bands of the system is controlled by the bandwidth switch which may be set to half-band ranges of 10 Hz, 100 Hz, 1 KHz, or 65 KHz. Thus a bandwidth setting of 100 Hz results in a pass band of 200 Hz. Likewise, a bandwidth setting of 1 KHz will result in a pass band of 2 KHz.

The emerging D.C. voltages from the two wave analyzers are divided without a voltage loss. One set of signals is fed to a Consolidated Electrodynamics Corporation galvanometer-driver amplifier, type 1-162A, and then to a Consolidated Electrodynamics Corporation oscillographic recorder, Model 5-124 for visual display. The equivalent set of signals is conducted to an analog computer system for further processing before recording on the oscillograph.

The ratio computer system developed for Tonar utilizes an Industrial Scientific Research divider function board, Model 1041A, as its central component. Operating as an electric slide rule, the ratio computer provides continuous computations of the nasal (E_1) to oral (E_2) intensity ratio as they are received from the wave analyzers. This ratio is amplified before being displayed on the oscillograph.

Sound Field Recording System

A Sony Stereophonic Tape Recorder, Model 600, with an Electro Voice microphone, Model 67, was used to record the speech samples taken in sound field conditions.

Calibration

Since it was necessary to maintain the relative intensity of the signals emitted from the oral and nasal channels, it was vital that the processing systems be calibrated. To accomplish this, the sound separator was placed eight inches in front of a ten inch speaker connected to a Hewlett and Packard ABR Audio Oscillator, Model 200 (see Figure 4). The oscillator was set to generate a frequency of 1000 Hz at an intensity of 65 dB SPL. This signal was recorded at equal VU levels on both channels of the tape recorder. It was determined that within the required limits, the two record level controls on the tape recorder remained calibrated when moved synchronously. Thus it was possible to record speech at comfortable loudness levels without affecting their natural speaking level.

The playback and analyzing systems were calibrated jointly using the 1000 Hz tone recorded earlier. The wave and spectrum analyzers were calibrated for frequency and intensity then set at a central frequency of 1000 Hz with half-band setting of 100 Hz. The time constant was set at one second and the full scale meter was set at 100 millivolts. The 1000 Hz calibration tone was used to adjust the playback intensity controls on the tape recorder to

FIGURE 4

TONAR SEPARATOR: POSITIONING FOR RECORDING 1000 Hz CALIBRATION SIGNAL approximate 0.6 millivolts reading on the voltage meter. Discrete balance and intensity changes were then made on the stereo amplifier such that a voltage of precisely 0.6 millivolts was registered by both analyzers.

By calibrating the oscillographic recorder such that a baseline represents zero and each of ten progressive line deflections reflects a ratio change of 0.1, the analog ratio was converted to digital form. Interpolations between lines could be made since the total deflection was essentially linear for ratios from 0 to 1.5. A ratio of 1.0 represents those situations where the intensity of the two signals was equal. During the recording and analyzing sessions, calibration checks were made on the system after every three speakers or three hours, whichever occurred first.

Subjects

Thirty-five subjects were chosen from a population of 250 children with surgically repaired cleft palates. Names of potential subjects were drawn randomly from clinical files. Only subjects free of sensory or mental impairment were accepted. Of the original 35 chosen, 11 were out of town during the test period or could not be contacted and four indicated nasal congestion due to colds or hay fever and so were not included in the study. The remaining 20 children, those who served as subjects for the study, ranged in age from five years to 19 years. The median age was eight years and the mean age ten years.

Speech Recording

Fletcher's phonemically balanced non-nasal passage was used as the speech sample (Appendix A). This passage was recorded both in a sound field and through the sound separator. All recordings of the speech sample were made with the subject, the microphones, and the sound separator in an Industrial Acoustics Company Sound Control Room, Model 1202. The microphones were connected through a jack panel to other instrumentation outside the chamber.

For sound field recordings, the subject was positioned in the sound control room so that his lips were four to five inches from the microphone. The subject was then instructed to read the passage until familiar with all the words. Those subjects unable to read the passage were instructed to repeat the sentences as they were read to them through earphones. During the actual recording, each subject prefaced the passage with a number previously assigned him. The record level of the tape recorder was adjusted to a comfortable loudness level.

Tape recordings for Tonar were accomplished by positioning the subject in the sound control room such that he could speak into the sound separator without discomfort. Care was exercised to assure that a tight seal was maintained between the oral and nasal cylinders, and that sound from the nares was not restricted by the lead separation plate. This condition was contingent upon head positioning and adjustment angle of the separator (Figure 5). The remainder

FIGURE 5

SUBJECT POSITIONING FOR RECORDING SPEECH
THROUGH TONAR SEPARATOR

of the recording procedure was identical to that previously described in Sound Field Recording.

Psychophysical Scaling of Nasality

Observers

Ten observers were used to scale perceived nasality. Eight observers, graduate students in Speech Pathology at the University of New Mexico, were enrolled in a Cleft Palate Seminar at the time of the scaling sessions. The two remaining observers were members of the speech pathology staff, both of whom had considerable experience with hypernasality.

Scaling Sessions

The initial attempt to scale perceived nasality was conducted using a paired comparison procedure with backward play. However, due to gross inconsistencies between observers, it was deemed necessary to alter the procedure. This initial scaling experience was used as a training session for backward play scaling. Formal scaling of nasality was accomplished in two sessions using backward play and forward play separated by a ten-minute rest interval.

Observers were seated in a large observation room and asked to rate each of the stimuli using a modified direct magnitude estimation procedure (Stevens, 1956). The observers were instructed to assign values between 0 and 100 to the experimental stimuli using the first stimulus as the standard, with subsequent stimuli being compared. Stevens stated that by not using an imposed standard value, the observer is not influenced by the experimenter's judgements of a given stimulus, hence a more valid scaling is secured. A total of 30 stimuli presentations were made to the observers in both sessions. As a check for test-retest reliability of observers, 10 of the 30 presentations were replicas. At least 15 stimuli were interposed between the initial presentation and the replica.

Analysis

To derive the overall acoustic ratios with which to correlate the psychophysically scaled values, the previously recorded separated speech samples were analyzed at central frequencies of 1250 Hz and 1750 Hz with the half bandwidth set at 1 KHz. This range thus covered all frequencies between 250 Hz and 2750 Hz. This full scale meter was 100 millivolts with a time constant of 10 seconds. The analog ratio computer was set to provide a nasal to oral ratio (E_2/E_1). The paper speed of the oscillographic recorder was 0.5 inches per second. The time marker was set at one mark per second.

To examine the relative intensity of the oral and nasal signals plus their acoustic ratio as a function of frequency, a second acoustic analysis was conducted using six subjects with varying amounts of nasality. The segment of the passage used in this analysis was: "We hear that straw covers the floor of cages to keep the chill away." A 100 Hz half-bandwidth tone was used with a time constant of one second. Measurements were first taken at a central frequency of 250 Hz. Subsequent readings were taken at 200 Hz intervals starting at 350 Hz and ending at 3150 Hz. The full scale setting used at each frequency band was contingent upon the energy within that band.

Conversion from the analog tracings on the oscillographic paper to their digital counterpart was relatively simple. It will be recalled that the oscillographic amplifiers had previously been calibrated so that a deflection of 10 lines on the paper represented a digital ratio of 1.0. Hence, digital values in excess of 1.0 were recorded in those situations where the nasal intensity was greater than the oral intensity. Mean ratio values were obtained by counting the line deflections at each one second time marker and calculating their mean value.

As previously stated, this study is concerned with the relative intensity of the nasal and oral signals within selected frequency bands as well as their acoustic ratio. Since relative rather than an absolute value was needed, no attempt was made to convert the voltage values representing oral and nasal intensities into their corresponding decible values. Rather, their voltages were obtained from the calibrated oscillographic record.

CHAPTER IV

RESULTS AND DISCUSSION

In the statement of the problem, a number of questions were posed which pertain to the assessment of the acoustic characteristics of nasality. Data relevant to these questions are presented and examined statistically and descriptively in the following sections of this chapter. These questions, as originally stated, are listed below:

1. Do Tonar's ratios correlate well with perception of relative nasality, thereby establishing that Tonar is analyzing parameters which are related to perceived nasality?
2. Are oral-nasal ratio differences between individuals the result of systematic oral and/or nasal intensity variations?
3. Are the frequencies of the oral and nasal energy concentrations close enough for potential acoustic masking?
4. Does the average oral-nasal intensity relationship vary as a function of frequency?
5. If this relationship varies with frequency, which frequencies are most influential in determining the overall relationship?

Tonar's Acoustic Ratio and Perceived Nasality

Speech samples from 20 cleft palate subjects were perceptually and acoustically studied for nasal characteristics. Each sample was scaled twice by ten observers: (1) while listening to forward play, and (2) while listening to backward play. A modified direct magnitude estimation procedure having a 0 to 100 scale was used. A mean value for each subject was derived by averaging the direct magnitude values assigned by the observers. Acoustical data were obtained using Tonar. Tonar, while set to scan frequencies from 250 to 2250 Hz, computed continuous nasal-to-oral acoustic ratios for the complete passage. The mean ratio value for each subject was determined by averaging ratio values at each one-second interval. Correlation procedures were used to study inter- and intra-test relationships between forward and backward play and relationships between Tonar's mean ratios and scaled values.

Psychophysical Scaling of Nasality

The mean values assigned each stimulus during backward (Appendix B) and forward (Appendix C) play and their rank order are presented in Table I. The mean values for backward play ranged from 25.0 to 76.5 with an average score of 58.9. For forward play the values varied from 2.9 to 87.0 with an average score of 35.4. A cursory inspection of the data revealed that values assigned the stimuli during forward play had a greater scale spread and were generally lower than the values assigned during backward play. In only two instances were the mean scores of a stimulus lower in backward play scaling than the corresponding score for forward play. Inspite of this disparity between mean values for forward and backward play, a Spearman rho coefficient of 0.835 reflected a strong relationship between the rank

TABLE I

MEAN PSYCHOPHYSICAL SCALING VALUES AND RANK ORDERS FOR FORWARD AND BACKWARD PLAY PROCEDURES

Subject	Mean Scores: Backward Play	Rank Order	Mean Scores: Forward Play	Rank Order
1	75.1	19	87.0	20
2	57.0	8	13.2	4
3	60.9	11	25.6	11
4	56.4	7	8.9	2
5	76.5	20	33.3	13
6	55.1	6	19.5	9
7	63.5	14	39.4	14
8	61.5	12	15.8	5
9	53.6	4	18.3	7
10	60.5	10	21.0	10
11	70.5	17	48.3	15
12	54.9	5	18.4	8
13	40.5	3	16.3	6
14	34.2	2	12.1	3
15	25.0	1	2.9	1
16	71.6	18	84.7	19
17	60.0	9	29.0	12
18	67.0	15	70.5	17
19	67.5	16	60.2	16
20	63.3	13	82.8	18

NOTE: The Spearman rho correlation coefficient of 0.835 was significant at the 0.01 level.

ordering of stimuli using the two procedures. This coefficient was statistically significant at the 0.01 level. Thus it seems perception of relative nasality is comparatively unaffected by forward and backward play procedures, although the magnitude of perceived nasality is affected. The implications of this will be discussed later in conjunction with its relationship to ratios computed by Tonar.

Using a procedure outlined by Guilford (1954, p. 395), average rank order correlations among listener ratings were calculated for both forward and backward play. Correlation coefficients of 0.826 and 0.816 for forward and backward play respectively indicated that average intercorrelations among individual judges were not significantly different.

Table II displays the mean test, retest values (Appendix D) and their rank order for backward play. The scores for the ten test stimuli ranged from 25.0 to 71.6. Retest values ranged from 41.6 to 76.0. A Spearman rho correlation coefficient of 0.600 was obtained between the two sets of data. This was significant at the 0.05 level.

The mean test, retest scores (Appendix E) and their rank order for forward play are presented in Table III. Test scores ranged from 2.9 to 84.7. Retest scores extended from 4.9 to 85.2. Test, retest reliability for scaling values assigned stimuli during forward play was extremely high as indicated by a rho coefficient of 0.939.

Tonar's Ratios vs. Perceived Nasality

Table IV presents the mean acoustic ratios computed by Tonar, the mean scaled values for backward play, and the

TABLE II

BACKWARD PLAY MEAN TEST VALUES, RETEST VALUES WITH RANK ORDERS

Subject	Test Mean	Rank Order	Retest Mean	Rank Order
17	71.6	10	76.0	10
16	25.0	1	43.2	3
15	34.2	2	46.7	5
14	40.5	3	46.3	4
13	54.9	5	41.6	1
12	70.5	9	53.3	6
11	60.5	6	63.0	2
10	53.6	4	55.4	7
9	61.5	7	57.4	8
8	63.5	8	65.2	9

NOTE: The Spearman rho correlation coefficient of 0.600 was significant at the 0.05 level.

TABLE III

FORWARD PLAY MEAN TEST VALUES, RETEST VALUES WITH RANK ORDERS

Subject	Test Mean	Rank Order	Retest Mean	Rank Order
11	21.0	7	25.8	7
12	48.3	9	43.0	8
13	18.4	5	13.2	3
7	19.5	6	25.5	6
8	39.4	8	44.8	9
9	15.8	3	21.6	5
10	18.3	4	16.3	4
15	12.1	2	11.7	2
16	2.9	1	4.9	1
17	84.7	10	85.2	10

NOTE: The Spearman rho correlation coefficient of 0.939 was significant at the 0.01 level.

TABLE IV

MEAN SCALING VALUES FOR BACKWARD PLAY AND MEAN TONAR RATIOS WITH RANK ORDERING

Subject	Backward Play	Rank Order	Tonar Ratio	Rank Order
1	75.1	19	1.341	20
2	57.0	8	.006	4
3	60.9	11	.096	5
4	56.4	7	.100	6
5	76.5	20	.491	12
6	55.1	6	.001	2
7	63.5	14	.918	17
8	61.5	12	.272	10
9	53.6	4	.823	15
10	60.5	10	.362	11
11	70.5	17	.937	18
12	54.9	5	.663	13
13	40.5	3	.213	7
14	34.2	2	.001	2
15	25.0	1	.001	2
16	71.6	18	.788	14
17	60.0	9	.241	9
18	67.0	15	1.245	19
19	67.5	16	.235	8
20	63.3	13	.825	16

NOTE: The Spearman rho correlation coefficient of 0.702 was significant at the 0.01 level.

rank orders for each. The nasal-to- oral acoustic ratios varied from 0.001 (no nasality) to 1.341 (more nasal than oral intensity). The average ratio values for the 20 speech samples was 0.431. A rho correlation coefficient of 0.702 revealed a statistically significant relationship between the rank order of stimuli using Tonar's ratio and backward play scores. This correlation was significant at the 0.01 level. Six of the 20 speech samples had acoustic ratios of 0.100 or less. The scaled scores for these same stimuli ranged from 25.0 to 60.9. Thus, magnitude estimations from backward play ratings of the same subject were much higher than ratios found with Tonar. The rho coefficient established between Tonar's ratios and forward play scaling was 0.742. The mean ratios and scaled values along with their rank order are displayed in Table V. Forward play values assigned the six stimuli displaying acoustic ratios of 0.100 or less ranged from 2.9 to 25.6.

Tonar's acoustic ratios, when rank ordered, correlated equally well with the rankings from either forward or backward play procedures. Thus, it may be concluded that Tonar does, in fact, analyze parameters which are involved in the perception of nasality. This indicates that Tonar is a valid instrument for measuring nasality as perceived in speech.

Having established Tonar's validity in the acoustic measurement of nasality, it is interesting to note the proximity of mean values assigned by listeners and acoustic ratios as computed by Tonar. A Pearson's Product Moment correlation coefficient was computed between the mean values

TABLE V

MEAN SCALING VALUES FOR FORWARD PLAY AND MEAN TONAR RATIOS WITH RANK ORDERING

Subject	Forward Play	Rank Order	Tonar Ratio	Rank Order
1	87.0	20	1.341	20
2	13.2	4	.006	4
3	25.6	11	.096	5
4	8.9	2	.100	6
5	33.3	13	.491	12
6	19.5	9	.001	2
7	39.4	14	.918	17
8	15.8	5	.272	10
9	18.3	7	.823	15
10	21.0	10	.362	11
11	48.3	15	.937	18
12	18.4	8	.663	13
13	16.3	6	.213	7
14	12.1	3	.001	2
15	2.9	1	.001	2
16	84.7	19	.788	14
17	29.0	12	.241	9
18	70.5	17	1.245	19
19	60.2	16	.235	8
20	82.8	18	.825	16

NOTE: The Spearman rho correlation coefficient of 0.742 was significant at the 0.01 level.

for forward play and ratios from Tonar. The resultant coefficient shown in Table VI was 0.616. This coefficient was statistically significant at the 0.01 level and reflected a positive correlation between the magnitude of perceived nasality and nasal-to-oral acoustic ratios. For backward play the correlation coefficient was 0.401. It was not statistically significant. This suggests that the high nasal magnitudes perceived, using backward play, may have been related to factors other than the relative intensity of the oral and nasal signals.

In contrast with the above data Sherman (1954), speaking of backward play, reported that speech free of nasal phonemes was judged less nasal than in forward play. Conversely, speech loaded with nasal phonemes was judged as more nasal using backward play than it was using forward play. Sherman's explanation for this phonomenon was that judgements made while listening to forward play are influenced by a "halo effect." The "halo effect" is the contamination of judgements by such irrelevant factors as pitch, articulation defects, and duration. Whether or not these factors are relevant to the perception of nasality seems conjectural. Whatever the case, Sherman concluded that nasality judgements using backward play are "more valid."

Colton and Cooker (1968), using backward play procedures, reported: ". . . all of the normal speakers were judged to be more nasal when they spoke in a slower tempo than when they spoke in their normal tempo." They suggested this increase in perceived nasality might have been

TABLE VI

PRODUCT MOMENT AND RHO COEFFICIENTS SHOWING CORRELATIONS BETWEEN TONAR'S RATIOS AND FORWARD AND BACKWARD PLAY MEAN SCALING VALUES

	Backward Play		Forward Play	
	Product Moment	Rho	Product Moment	Rho
Tonar Ratio	.401	.702*	.616*	.742*

*Significant at 0.01 level.

precipitated by physiological changes in the palatopharyngeal isthmus resulting from a reduction in tempo. However, it is also possible that a change in the tempo affected the perception rather than the production of nasality. It may be that the so-called "halo factors" are very relevant to the perception of nasality, and removal of the speech signal from its perceptual environment by using backward play may have emphasized these factors. In fact it might have been that backward play introduced a "halo effect" of its own. One thing seems apparent; that is, the relative merits of forward and backward play procedures for judging perceived nasality need additional experimental scrutiny.

Tonar's Acoustic Information As Related to Frequency

Intensities and Ratios: A Function of a Wide Frequency Band

As previously stated, the relationship of acoustic masking to perception of nasality is contingent upon the independent and relative contributions of the oral and nasal signals within the total speech envelope. To examine these factors, speech samples of six subjects displaying ratios spread along the continuum were selected for additional analyses.

The phrase: "We hear that straw covers the floor of cages to keep the chill away. . ." was selected as the criterion stimulus for an intensity analysis by frequency. Comparisons of oral-nasal intensities and ratios were made within: (1) a wideband frequency range of 250 to 2250 Hz (broadband data) and (2) narrow bandwidths of 200 Hz between 150 and 3350 Hz limits (narrowband data).

Table VII displays the broadband data. Broadband ratios ranged from 0.03 to 1.00. Subjects number five and ten displayed nasal intensities of 35 and 33 respectively, but acoustic ratios were 0.75 and 0.31. On the other hand, subjects nine and ten had essentially the same oral intensity with grossly different acoustic ratios. Thus nasality as measured by Tonar could be the resultant of stable oral levels with variability in the nasal referent or from stable nasal signals with variability in the oral referent or from a variety of interactions expressed in the composite total. Perceived nasality may therefore be the result of variable nasal masking of an underlying oral signal. Conversely, nasality may be present but undetected as a result of oral masking.

Intensities and Ratios: A Function of Selected Frequencies

Table VIII displayed oral and nasal intensity scores in millivolts and their computed ratios for each 200 Hz bandwidth between 250 Hz and 2550 Hz. Frequencies between 2550 and 3250 Hz were also analyzed, but their intensity outputs were too weak to produce measurable oscillographic deflections. Inspection of the tabular data reveals that oral and nasal intensities, as well as the acoustic ratios, vary as a function of frequency. Caution should be exercised in comparing absolute intensities between individuals since

TABLE VII

COMPOSITE ORAL AND NASAL INTENSITIES WITH TONAR COMPUTED RATIOS FOR THE NON-NASAL PHRASE

Subject	Voltage Intensities In Millivolts		Tonar's Broadband Ratio
	Oral	Nasal	
5	47	35	.75
8	140	75	.53
4	79	10	.12
15	94	03	.03
9	105	105	1.00
10	106	33	.31

TABLE VIII

MEAN ORAL AND NASAL INTENSITIES*AND THEIR TONAR COMPUTED RATIOS FOR SELECTED CENTRAL FREQUENCIES WHILE USING A 200 Hz BANDWIDTH

Subject		250	350	550	750	950	1150	1350	1550	1750	1950	2150	2350	2550
5	N	-	84	9	14	26	3	-	1	-	-	-	-	-
	O	-	230	6	24	21	-	2	1	-	-	-	-	-
	R	-	.38	1.23	.54	1.23	.34	.21	.44	.43	.38	.44	.28	.32
8	N	-	34	10	11	9	1	1	-	-	-	-	-	-
	O	-	195	9	13	20	3	2	-	-	-	-	-	-
	R	-	.08	.88	.82	.42	.32	.50	.32	.34	.52	.45	.29	.18
4	O	7	5	5	2	1	1	-	-	-	-	-	-	-
	N	21	70	11	3	1	1	1	-	-	-	-	-	-
	R	.27	.00	.20	.18	.20	.22	.02	.00	.40	.39	.18	.24	.11
15	O	10	4	3	1	-	-	-	-	-	-	-	-	-
	R	250	170	30	6	4	2	-	-	-	-	-	-	-
	N	.00	.00	.05	.04	.00	.00	.13	.16	.15	.15	.08	.08	.03
9	O	15	100	80	25	27	6	2	1	1	1	1	1	-
	N	70	250	54	13	27	6	2	3	2	2	2	1	-
	R	.22	.19	1.28	1.78	1.00	.90	.60	.43	.50	.36	.25	.38	.54
10	O	5	60	6	15	8	3	2	-	-	-	-	-	-
	N	40	300	30	24	18	8	3	-	-	-	-	-	-
	R	.05	.13	.19	.66	.45	.33	.27	.27	.19	.10	.14	.10	.10

NOTE: N - nasal, O - oral, R - ratio.

*Oral and nasal values as listed are in millivolts which are converted to relative intensities in the ratio scores. Discrepancies between voltage level and ratios are the result of voltage values being instantaneous measurements, while ratio scores were averaged over a one second interval.

the record level on the tape recorder was adjusted for some speakers.

Relative intensity patterns are presented in Figures 6a-6f, which graphically displays mean oral and nasal intensities at varying frequencies for the six subjects. The intensity values are expressed in millivolts. As might be expected, energy concentrations are focused in the low frequencies. The intensity curves for the oral and nasal signals have very similar configurations. Both reflected energy peaks around 500 Hz then gradually sloped downward until intensities of less than one millivolt were reached at approximately 1350 Hz. This pattern was consistent among the six subjects.

It is evident from the data that the central frequencies of oral and nasal energy concentrations are close enough for potential acoustic masking.

Inspection of the broadband data presented in Table VIII reveals that acoustic ratios vary considerably from frequency to frequency. Within subject ratios ranged as much as 0.19 to 1.78 (subject 9) and as little as 0.00 to 0.16 (subject 15). Figures 7a-7f are graphic reflections of the ratio data presented in Table VIII. Unlike the intensity curves, configurations of the ratio curves are highly variable. It is therefore logically asked how these differences between ratios from narrowband analyses are reconciled with the broadband ratios representing the total spectrum. Does each component ratio contribute equally to

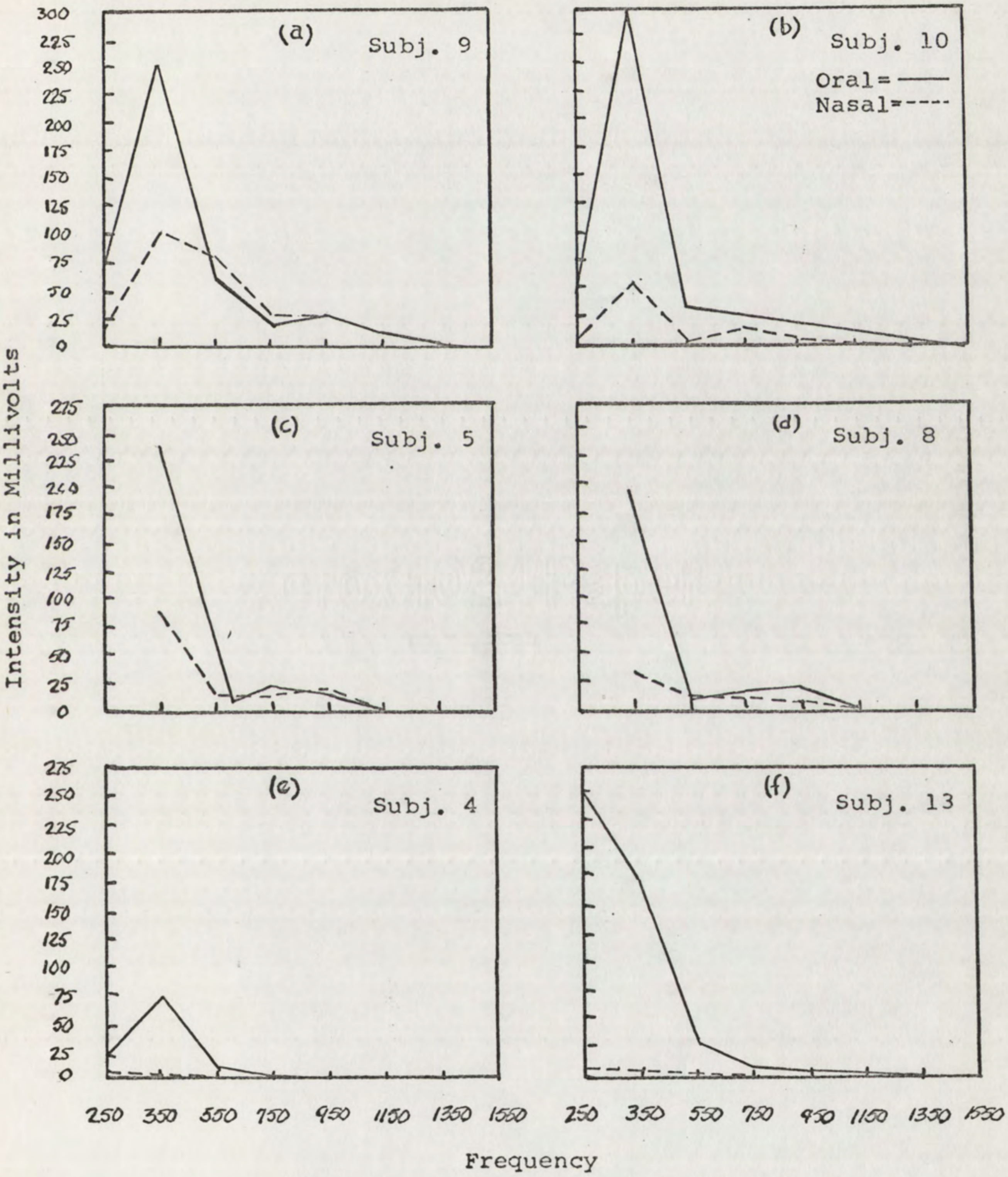


FIGURE 6

ORAL AND NASAL INTENSITIES:
A FUNCTION OF FREQUENCY

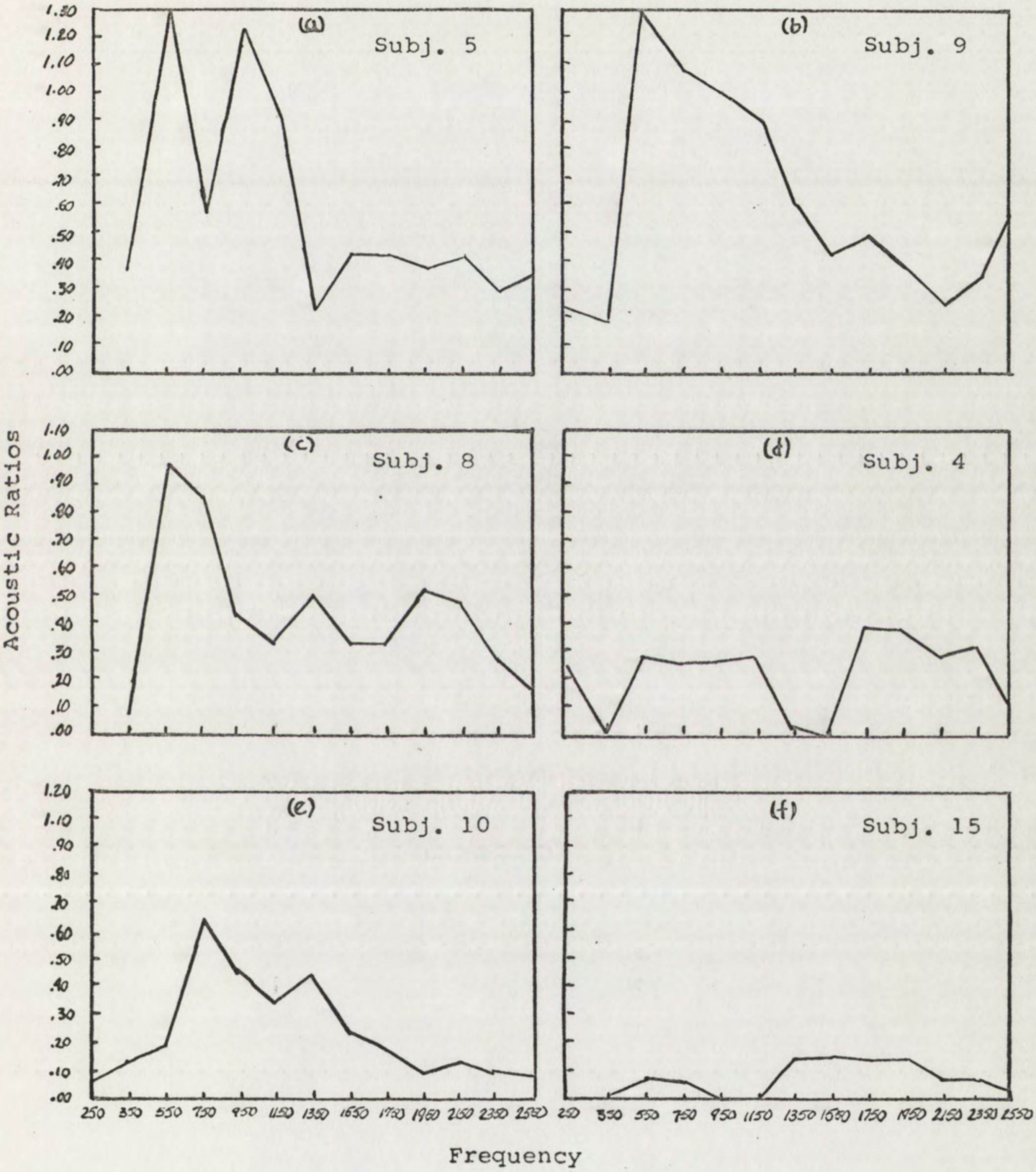


FIGURE 7

NASAL/ORAL ACOUSTIC RATIOS:
A FUNCTION OF FREQUENCY

the composite ratio, or are selected ratios more influential than others?

Table IX presents the mean for ratio at 350 Hz, 550 Hz, and 750 Hz, the composite ratio, and the difference between the two for each subject. A maximum difference of 0.059 was noted between any of the paired ratios.

It is concluded from this data that acoustic ratios for central frequencies of 350 Hz, 550 Hz, and 750 Hz are the principal contributors to the broadband ratio.

TABLE IX

AVERAGE OF NARROWBAND RATIOS FOR 350, 550, AND 750 Hz, WIDEBAND RATIOS 250 - 2250 Hz AND THEIR DIFFERENCES

Subject	Narrowband Ratios	Broadband Ratios	Differences
15	.030	.030	----
4	.127	.120	.007
10	.323	.314	.009
8	.592	.533	.059
5	.713	.747	.034
9	1.085	1.000	.015

CHAPTER V

SUMMARY AND CONCLUSIONS

A review of the previous research dealing with hypernasality indicates that nasality is the result of physiological interactions regulating distribution of the phonic stream between the nasal and oral channels. The presence of some nasal flow during the production of oral phonemes is not abnormal and seems to have little effect on the final acoustic signal. However, with increased nasal coupling, the final emitted signal undergoes acoustic changes which may be perceptually detrimental to the intelligibility and acceptability of the message the speaker is attempting to transmit.

Previous acoustic studies of nasality, while contributing valuable information about the characteristics of nasality, have provided little concrete data describing the individual characteristics and contributions of the oral and nasal signals to the entire signal. Fletcher (1969) reported an instrumentation system (Tonar) with the necessary flexibility for providing pertinent data.

The purpose of this study was to examine: (a) the validity of Tonar as a means of obtaining data relevant to perceived nasality, and (b) the acoustic characteristics of orally and nasally emitted signals and their relative contributions to the total acoustic signal, thereby providing data with which to consider acoustic masking theory in relation to the perception of hypernasal speech.

Procedures

To investigate the validity of Tonar, psychophysical judgements of perceived nasality were compared to oral-nasal acoustic ratios computed by Tonar. A passage free of nasal phonemes was read by 21 subjects with surgically repaired palatal clefts. For scaling of nasality, speech recordings were made using tradition sound field recording procedures. These speech samples were scaled for severity of nasality by ten trained observers using a modified direct magnitude estimation procedure. Listener judgements were made twice for each speech sample--once for the sample played forward and backward. As a check on correlations between the relative values assigned the stimuli during the two listening conditions, mean scores from each procedure were rank ordered and a Spearman rho correlation coefficient computed.

Using components of the Tonar system, signals emerging from the oral and nasal tracts were separately recorded as subjects read the experimental passage. The separate identities of the signals were maintained as they were amplified and then analyzed by interlocked frequency and intensity analyzers. The signals thus analyzed were channeled into an analog ratio computer where the voltage levels representing the nasal and oral signals were compared and the acoustic ratio computed. The continuously computed ratios were then displayed on oscillographic paper. Forward and backward play rank orders were then individually compared with the rank order of the mean acoustic ratios from Tonar. The rational for this analysis being: If the acoustic parameters which Tonar analyzes are significantly related to the perception of nasality, it is expected that while absolute perceptual and acoustical scaling magnitudes need not demonstrate significant correlations, the rank ordering of the values should.

A second objective of this study was to analyze the acoustic characteristics of nasal speech, specifically examining oral and nasal intensities and ratios as a function of frequency.

To study these relationships, 6 of the 21 recorded speech samples were selected for further analysis. A sample phrase arbitrarily chosen from the passage was subjected to detailed intensity of frequency analysis by Tonar. To gain a general impression of relative nasality, a 2000 Hz frequency band covering frequencies from 250 Hz to 2250 Hz was used to measure nasal and oral intensities and to compute ratios for each of the six subjects. A 200 Hz bandwidth was used to examine the Tonar ratio as a function of frequency. All frequencies between 150 Hz and 3250 Hz of the same sample were analyzed and the nasal-to-oral acoustic ratios for each of the 16 pass bands were computed. As a check on the validity of the automatically computed ratios, the intensities of the oral and nasal signals were also examined and ratios were manually computed. Discrepancies between manually computed and Tonar computed ratios never exceeded 0.05 (Appendix F).

Results

The following major findings were forthcoming from the analysis of the data obtained in this investigation.

1. Psychophysical scale values from backward playback ratings of the 21 responses averaged from the ten listeners ranged from 25 to 76.5 with a mean of 58.9. Corresponding scale values from ratings of the forward playback responses ranged from 8.9 to 87.0 with a mean of 36.6. In each case the lower score indicates a rating of less nasality. Rho correlation coefficients between psychophysical scale values of the backward playback samples and the forward playback samples was 0.835.
2. Tonar's mean acoustic ratios when rank ordered correlated equally well with rankings of mean perceptive values for forward and backward play as indicated by rho coefficients of 0.742 and 0.702 respectively.
3. Tonar's mean acoustic ratios when correlated with mean perceptive values of forward and backward play demonstrated Pearson's Product Moment coefficients of 0.616 and 0.401 respectively.
4. Broadband ratios ranged from 0.03 to 1.00 and were interpreted to be the result of a variety of interactions between oral and nasal intensities.
5. Energy concentrations for oral and nasal signals displayed energy peaks around 500 Hz which gradually decrease to less than one millivolt at approximately 1350 Hz.
6. Narrowband acoustic ratios for central frequencies of 350, 550, and 750 Hz were the principal contributors to the wideband ratio.

Conclusions

Considering possible limitations imposed by experimental design or analysis procedures, the following conclusions seemed warranted:

1. Tonar does in fact measure acoustic phenomena that are also inherent in perception of nasality. The absolute magnitude of ratios computed by Tonar may or may not reflect the total functions underlying perception of nasality.

2. Scaling nasality may be expected to vary widely from listener to listener; whereas instrumental measurements, by definition, are stable. In this study clear superiority for neither backward nor forward play was demonstrated for purposes of scaling nasality.

3. Oral and nasal energy concentrations have overlapping frequency ranges; therefore, oral or nasal masking is potentially present.

4. Nasal-to-oral acoustic ratios vary as a function of frequency, with the average of ratios from central frequencies of 350, 550, and 750 being closely related to the composite ratio.

5. Oral-nasal acoustic ratios are equally affected by intensity changes in the oral or nasal signal. Hence nasality, as measured by Tonar, could be the resultant of stable oral levels with variability in the nasal referent or from stable nasal signals with variability in the oral referent or from a variety of interactions expressed in the composite signal.

6. Potential acoustic masking of the oral or nasal signal is present. And as previously suggested perceived nasality may be the result of variable nasal masking of an underlying oral signal. Conversely, nasality may be present but undetected as a result of oral masking. Should nasal masking of the oral signal be a reality, it could mean that nasality in addition to being a distracting quality may be covering (masking) acoustic cues vital to phonemic discriminations.

Limitations of the Study

Generalizations or conclusions from the data obtained from this investigation should allow for the following limitations: (1) Acoustical data were collected from a small number of cleft palate subjects. (2) The selected phrase used for the detailed acoustical analysis was loaded with phonemes conducive to high nasality. (3) Listener judgements were highly variable.

APPENDIX

APPENDIX A

FLETCHER'S NON-NASAL PASSAGE

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

APPENDIX B

RAW SCALE SCORES OF NASALITY USING BACKWARD PLAY

Subject	Observers										Mean Score
	A	B	C	D	E	F	G	H	I	J	
1	90	70	25	60	100	75	90	89	85	67	75
2	60	50	30	50	70	80	85	57	35	53	57
3	70	30	60	80	30	65	80	73	60	61	61
4	45	50	10	90	40	45	70	68	70	76	56
5	85	60	55	100	100	60	70	80	85	70	77
6	50	30	50	90	100	30	50	63	40	48	55
7	65	40	75	100	60	70	40	40	80	65	63
8	70	60	65	90	75	25	60	60	55	55	62
9	50	40	20	85	100	40	50	70	35	46	54
10	60	30	75	85	90	25	80	65	50	45	61
11	80	70	80	75	100	75	50	70	45	60	71
12	70	60	15	50	80	65	70	45	45	48	55
13	50	30	25	40	65	60	40	30	20	40	41
14	40	25	25	50	60	30	50	35	0	27	34
15	60	25	20	25	15	25	40	10	10	25	25
16	75	70	70	75	100	75	90	51	60	50	72
17	40	70	25	60	85	80	70	77	15	82	60
18	80	40	55	80	100	80	50	89	15	81	67
19	80	60	60	75	75	80	60	50	55	80	68
20	75	70	10	70	100	60	85	43	70	50	63

APPENDIX C

RAW SCALE SCORES OF NASALITY USING FORWARD PLAY

Subject	Observers										Mean Score
	A	B	C	D	E	F	G	H	I	J	
1	70	70	85	80	100	100	90	100	85	90	87
2	40	10	10	10	20	20	0	2	5	15	13
3	35	10	30	25	25	65	25	1	30	10	26
4	30	10	0	20	10	0	5	4	10	0	9
5	40	40	35	25	50	60	40	20	20	3	33
6	30	15	15	15	25	40	10	30	10	5	20
7	35	10	60	40	40	70	40	40	50	9	39
8	45	10	11	35	40	15	5	0	20	6	16
9	40	10	15	40	15	55	0	2	8	8	18
10	35	20	0	10	10	30	5	40	10	0	21
11	50	40	20	50	30	65	60	43	45	25	48
12	35	10	20	5	15	60	10	0	35	4	18
13	0	10	25	20	5	35	30	30	5	3	16
14	0	5	30	25	0	40	10	5	0	1	12
15	5	10	2	5	0	0	0	0	5	2	3
16	80	70	80	90	100	60	98	80	90	99	85
17	32	10	20	20	35	65	30	50	20	8	29
18	70	10	60	75	100	90	90	60	75	75	71
19	65	5	30	50	100	80	70	92	50	60	60
20	85	30	75	100	100	70	95	100	88	85	83

APPENDIX D

TEST, RETEST SCORES USING BACKWARD PLAY

Subject	Observers										Mean Score
	A	B	C	D	E	F	G	H	I	J	
Test											
16	75	70	70	75	100	75	90	51	60	50	72
15	60	25	20	25	15	20	40	10	10	25	25
14	40	25	25	50	60	30	50	35	0	27	34
13	50	30	25	40	65	60	40	30	25	40	41
12	70	60	15	50	80	65	70	45	45	48	55
11	80	70	80	75	100	75	50	70	45	60	71
10	60	30	75	85	90	25	80	65	50	45	61
9	50	40	20	85	100	40	50	70	35	46	54
8	70	60	65	90	75	25	60	60	55	55	62
7	65	40	75	100	60	70	40	40	80	65	63
Retest											
16	75	80	70	90	100	60	90	85	60	50	76
15	50	40	30	40	40	30	80	63	15	44	43
14	45	50	15	50	85	30	70	75	0	47	47
13	50	40	20	30	100	65	50	35	30	43	46
12	60	30	15	60	10	40	70	51	45	35	42
11	70	25	30	75	25	60	80	64	50	54	53
10	75	60	50	90	90	30	70	72	70	23	63
9	50	60	45	90	80	30	75	60	35	29	53
8	80	30	20	50	100	25	70	70	80	49	57
7	55	40	70	80	100	60	70	39	70	68	65

APPENDIX E

TEST, RETEST SCORES USING FORWARD PLAY

Subject	Observers										Mean Score
	A	B	C	D	E	F	G	H	I	J	
Test											
11	35	20	0	10	60	30	5	40	10	0	21
12	50	40	20	50	85	65	60	43	45	25	48
13	35	10	20	5	5	60	10	0	35	4	18
7	30	15	15	15	25	40	10	30	10	5	20
8	35	10	60	40	40	70	40	40	50	9	39
9	45	10	11	35	10	15	5	0	20	6	16
10	40	10	15	40	5	55	0	2	8	8	18
15	0	5	30	25	5	40	10	5	0	1	12
16	0	10	2	5	0	0	0	0	5	2	3
17	80	70	80	90	100	60	98	80	90	99	85
Retest											
11	45	40	30	30	10	65	10	0	15	13	26
12	40	30	50	75	30	75	60	10	30	30	43
13	40	10	25	10	15	15	5	0	10	2	13
7	35	20	20	75	25	55	10	30	15	20	26
8	45	15	65	50	40	65	30	57	50	31	45
9	40	10	42	20	15	55	5	10	5	14	22
10	35	10	10	25	10	55	5	0	10	3	16
15	0	10	15	15	0	70	10	40	5	2	12
16	5	10	5	5	0	0	0	10	10	4	5
17	80	70	85	100	100	65	98	70	85	99	85

APPENDIX F

DISCREPANCIES BETWEEN TONAR COMPUTED AND MANUALLY COMPUTED RATIOS

Manual Ratios	Tonar Ratios	Differences
0.18	0.18	0.00
0.17	0.16	0.01
0.13	0.12	0.01
0.13	0.09	0.04
0.13	0.08	0.05
0.18	0.17	0.01
0.21	0.20	0.01
0.14	0.13	0.01
0.18	0.14	0.04
0.62	0.65	0.03
0.53	0.49	0.04
0.81	0.79	0.02
0.98	0.97	0.01

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