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AN INVESTIGATION OF THE WHISTLE REGISTER
IN THE FEMALE VOICE

DISSERTATION

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By

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The purpose of the study was concerned with specific elements of the portion of the female voice commonly referred to as whistle or flute register. Three elements of vocal production were chosen for which past research has demonstrated relationships to source function. These elements included spectral characteristics, airflow rates, and perceptual identification.

The research compared what the singer-subjects perceived as being whistle register phonations with that which they perceived as being head register phonations. A comparative technique was utilized where pitch, intensity and phonemic category were held relatively constant, register, therefore, being the only variable. Spectral characteristics and airflow rates of the two subject-determined registers were compared. In addition, an attempt was made to determine if the whistle register could be perceptually differentiated on the basis of voice quality.

The results of the study indicated that significant differences in the spectral nature of the two

subject-determined registers did exist. Overall, whistle register phonations exhibited fewer harmonics than did head register phonations. While head register phonations were characteristically "symmetrical" in their spectral form, whistle register phonations were often characterized by an asymmetrical form. One frequently noted structural peculiarity of whistle register phonations was a spectral form characterized by a subordinate second harmonic.

Significant differences in mean airflow rates were also found to exist between the two subject-determined registers. The airflow rates were found to be significantly less during whistle register phonation with three of the four singer-subjects investigated during this portion of the research. With one subject, however, mean flow rates of the whistle register phonations were significantly higher than those of the head register phonations.

Finally, the results indicated that the whistle register was a perceptual identifiable entity, in that auditors were able to discriminate between head register phonations and whistle register phonations at a level significantly above chance.

From the results, the conclusion was drawn that it is a logical hypothesis that what the singer-subjects

perceive as being whistle register is a true vocal register that stems from a distinct adjustment of the larynx.

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CHAPTER I

INTRODUCTION

Registers in the singing voice have been recognized since at least the 13th century, and for most of that duration have been a source of confusion and debate among singing teachers. Early examples of the recognition of registers in the singing voice may be found in the writings of medieval theorists such as John of Garland (c. 1193 - c. 1270) and Jerome of Moravia (c. 1250). The medieval theorists classified the registers according to what was then considered their place of origin: the chest, the throat, and the head.¹ Masters of the 17th- and 18th-century Italian "bel canto" school of singing also spoke of registers in the voice. Sources such as Tosi and Mancini spoke of the chest, head and falsetto registers.²

The original concept of vocal registers was based upon the subjective vibratory sensations singers felt

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¹Michael Kent Warren, "Theories of Vocal Registers in Singing," doctoral dissertation, University of Maryland, 1977.

²John Large, "Towards an Integrated Physiologic-Acoustic Theory of Vocal Registers," The NATS Bulletin, (February/March, 1972), p. 19.

during the production of tones at different pitch levels. In the case of the chest, throat, and head registers, it was assumed, because of sympathetic vibrations in these areas during phonation, that those "cavities" were in fact the areas where the registers were produced.

It was Manuel Garcia (1805-1906), the famed pedagogue and inventor of the laryngoscope, who offered the first empirically-based understanding of registers. Garcia's explanation emphasized laryngeal adjustment determinants.

A register is a series of consecutive homogeneous sounds produced by one mechanism, differing essentially from another series of sounds equally homogeneous produced by another mechanism, whatever modifications of timbre and of strength they may offer. Each of the three registers has its own extent and sonority, which varies according to the sex of the individual, and the nature of the organ.³

Since Garcia, speculation has flourished regarding the physiological as well as the acoustical aspects of vocal registers. Even though much more is known today about the physiological and acoustical function of the vocal mechanism, there are still many areas of disagreement; some of the disagreement is due to a lack of needed data, while other conflicts may be due to problems of semantics. Still, in view of the confusion, some

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³Manuel Garcia, Hints on Singing (New York, 1894), p. 8.

degree of agreement might be reached by a broad definition of the term. (Register--an adjustment of the larynx which produces phonations of a particular quality for a particular frequency range.)

In light of all this, research seems to indicate a two-register hypothesis if the human voice is considered in its basic form. That is to say that all people, singers and non-singers alike, exhibit two registers which can be defined as a result of laryngeal adjustment. In the western cultural evolution of vocal training, however, many 'gray' areas become evident. It is with trained singers that the ambiguity arises in the understanding of registers.

Perhaps the crux of the problem is that even the slightest modification in a singer's technique is often labeled a register transition. J. B. Van Diense recently studied this problem. He described a theory in which two "orders" of registers are recognized: (1) first-order registers consisting in males of chest and falsetto, and in female of chest, head, and whistle registers, and (2) second-order registers which occur during the involvement of the cricothyroid to assist in the production of the highest tones in the male chest and falsetto and in the female head registers.

Van Diense draws a parallel between second-order registers and what teachers of singing commonly refer to as "covering."⁴

Due to the ambiguity which arises from the use of varied register terminology, Hollien et al. have suggested discarding the traditional metaphoric register terminology in favor of the term "modal" referring to the lower primary register, and "loft" referring to the upper primary register.⁵ At the present, however, authors continue to use a potpourri of terms in reference to the same frequency areas. Figure 1 shows the most commonly used register terminology with the corresponding frequency ranges.

Research indicates the existence of the two primary registers. Both of these registers are due to a change in laryngeal configuration as well as vibratory pattern. (Müller, Garcia, Zimmerman, Pressman, Luchsinger, Arnold, Vennard, Hirano, Van den Berg, Hollien, Appleman, Large, et al.)

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⁴J. B. Van Diense, "Registers," Folia Phoniatrica, XXXIII (1981), pp. 37-50.

⁵Harry Hollien, "On Vocal Registers," Journal of Phonetics 2 (1974), pp. 125-143.

Figure 1--Common Register Terms and Corresponding Frequency Ranges

modal-----loft
 lower-----upper
 chest-----head/falsetto
 heavy mechanism-----light mechanism

Figure 2--Common Terms Referring to
 the Primary Registers

The strohbass and whistle or flute registers have been referred to as auxiliary registers used by some singers. Proof of their existence, however, is inconclusive. Regarding the so-called "middle register" of the female voice, it is postulated that it is not a laryngeal register at all, but instead a result of an acoustical phenomenon occurring within the vocal tract.

Glottal fry (a popping sound made by the vocal folds at very low frequencies) is ordinarily not used in song; however, it has been demonstrated to be characterized by a distinct vibratory pattern of the vocal folds.

Rationale

The idea that the upper tones of the soprano voice are produced by a whistle or flute type of laryngeal production has been in the literature of vocal pedagogy and performance for quite some time.

In order to explain this hypothetical register phenomenon, a parallel has been drawn between laryngeal function and actual labial whistling. It has been postulated that the vocal folds actually stop vibrating (approximating), and instead are tensed to such a degree that the glottis remains open in a sharp-edged oval shape. Thus, air passing through the orifice produces a "whistle tone."

Leopold Mozart (the father of Wolfgang Amadeus Mozart) was reportedly the first to describe and name this extended soprano range. Mozart named it the flageolet (whistle) register. The register was described by Mozart in a letter addressed to his wife dated March 24, 1770:

It was impossible for me to believe that she (Lucrezia Aguari) was capable of singing up to sopra acuto (C7), but my ears convinced me. The arias sung by her contained all the runs that Wolfgang composed. She sang them a little more softly than the lower notes, but she sang them beautifully, like the fluted sounds of an organ.⁶

According to Luchsinger and Arnold (1965), the whistle register begins above the soprano "high C"

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⁶M. Nadoleczny-Millioud and R. Zimmerman, "Categories et Registres de la voix," Rev. fr. Phoniat, XXIII (1938), pp. 21-31.

(C6, 1047Hz) and extends to C7 (2093Hz) or D7 (2349Hz). They also report that in young children very high whistle tones may be heard extending up to E7 (2637Hz) or even G7 (3136Hz).⁷

In the past, many descriptive terms have been applied to this frequency area of the female voice. M. Morner offers the following list of terms which various authors have applied to the frequency range of B5 (988Hz) to C7 (2093Hz).

1. Delregister (Forchhammer V.)
2. Falsett (Luchsinger, Van den Berg, Rubin H., M. Mackenzie)
3. Fistlestimme (Preissler, Merkel, Luchsinger, Nadoleczny, Winckel, Muschold, NHR Bleggrad)
4. Flageolette (L. Mozart, Tarneaud)
5. Flojtestimme (S. Schmidt)
6. Flute (Van den Berg)
7. Grenzoktave (Hartlieb)
8. Highest range (Mörner)
9. Hochstes Gebeit (Mörner)
10. Högsta (höjd) omrad (Mörner, Rubin H., S. Fex, Sällström F.)
11. Kortregister (Forchhammer V., S. Schmidt, NHR Bleggrad)
12. Partialstimme (Forchhammer V.)
13. Petit registre (Garde)
14. Pfeiffregister (L. Mozart, Preissler, Barth, P. Lohmann)
15. Pipe register (van den Berg)
16. Rayon eleve (Mörner)
17. Voix do sifflet (Garde, Tarneaud)
18. Whistle register (Van den Berg)⁸

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⁷ Richard Luchsinger and Godfrey Arnold, Voice-Speech-Language (Belmont, 1965), p. 95.

⁸ John Large, "Introduction," Janua Linguarum, Series Minor, 164 (1973), p. 14.

In addition to the terms offered by Mörner, other terms used in the literature include bell register, piccolo range, echo voice, voce di campanello, Pfeifestimme, hohe Quinta and Zweite Höhe.⁹ In contemporary usage, "whistle register" is the most common term employed in reference to this frequency area of the soprano voice. That term will therefore be used throughout this investigation.

It should be noted that an early theory of human sound production basically adhered to an open glottis schema. According to Van den Berg, Dodard (1700) developed a complex hypothesis which attempted to explain everything by means of eddies generated in the glottis. Ferrein (1741), the first to use isolated larynges, those of dogs, to determine whether the larynges should be classified as instruments "a cordes" or "a vent" (i.e., stringed or wind instruments), determined that the larynges should be classified as "a cordes et a vent." Thus, Ferrein's hypothesis was that the laryngeal

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⁹Richard Miller, English, French, German and Italian Techniques of Singing (Metuchen, 1977), p. 120.

mechanism was actuated by airflow, but that the vibration of the vocal folds were also essential to sound production.¹⁰

The whistle register is recognized and used pedagogically by teachers throughout Europe and America. It is especially important for the soprano techniques of the Italian and French schools of pedagogy.

...a range of notes referred to as the bell register, lying above high d3 (D6 1174Hz) for the soprano. In producing notes within the compass of this range, the French and Italian schools often find a key to the brilliant development of the upper voice. The shape of the mouth is drastically altered by extensive buccal closure, exaggerated smile and elevated maxillaries. There is a heavy concentration of upper partials, and unless modified, the sound becomes brittle and dry. This sound then is brought down into the neighboring tones of the upper register. This practice is not common among German teachers nor among teachers of the English school.¹¹

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¹⁰ Janwillem Van den Berg, "Sound Production in Isolated Human Larynges," Ann. New York Academy of Science, CLV (1968), p. 18.

¹¹ Richard Miller, English, French, German and Italian Schools of Singing (Metuchen, 1977), p. 135.

In the Italian school of pedagogy, Miller equated the use of the bell or "campanello" register with the Italian national tonal preference for brilliance in the coloratura voice. Miller claimed the register to be excessively high in upper partials in contrast to much of the research literature which reports sinusoidal characteristics or limited wave complexity.¹²

The French school, according to Miller, is even more fond of the whistle register than the Italian. All types of French sopranos vocalize rather extensively in the whistle register.¹³

In contrast, Miller stated that the German School seeks an "ethereal flute quality" in this range. The problem of semantics here becomes obvious; however, the confusion seems more related to perceptual timbre than to that of registration.

The coloratura trained by typically Germanic techniques is characterized by the flute-like quality of her velocity passages, nearly devoid of vibrato in both legato and staccato melismas except for those occasional notes of longer duration. This quality of straight tone is especially in evidence at pianissimo level and

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¹²Ibid., p. 146.

¹³Ibid., p. 147.

in that area of the voice termed Pfeifestimme (the zweite Höhe) by some teachers. She opens the mouth vertically as opposed to the horizontal smile posture of some schools; minimal consonantal articulation takes place. The timbre which results from this buccal posture has about it much of the character of disembodiment to be found in the male feigned voice voce finta. Some German teachers believe it to be the female falsetto.¹⁴

Since Garcia and the resulting advent of modern pedagogy, authors within the field tend to align themselves with one of two schools of thought. One school avoids the analysis of mechanistic details and believes that the voice is best developed through the building of self-confidence and positive mental concept. This school of "inspirational" or "holistic" pedagogy normally denies the existence of register; therefore, any mention of a whistle register will not be found in the literature of this school.

The other school is that of "mechanistic" pedagogy. Within this school, the idea of voice registers is generally accepted; however, the origin, number and pedagogical implications of registers

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¹⁴Ibid., p. 143.

in the voice vary greatly. Often, any mention of the whistle register is cursory at best. An open-glottis mechanism is frequently implied without being actually stated, whereas in the descriptive and research literature the theory is frequently described. Some authors have given this hypothetical register a great deal of pedagogical credibility, while others dismiss its use completely.

Garcia (1894) listed the whistle register range and merely stated that the fifth from D6 to A6 is very rare and should not be attempted unless it occurs spontaneously.¹⁵ In The Child Voice in Singing, Howard (1895) spoke of the importance of the pure, flute-like sounds produced when the higher head tones are sung.¹⁶ H. Holbrook Curtis (1901) described this upper range of the female voice as an "extreme bird-like register sometimes found in the altissimo of women's voices."¹⁷

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¹⁵Manuel Garcia, op. cit., p. 11

¹⁶Frances Howard, The Child Voice in Singing (New York, 1895), p. 28.

¹⁷Henry Holbrook Curtis, Voice Building and Tone Placing (New York, 1901), p. 43.

Proschowsky (1923) referred to the whistle register as the "falsetto or open glottis method." Proschowsky stated:

...the chords do not meet, thereby causing the emitted tone to resemble that of a flute or eventually that of a ventriloquist. Such a production will never develop volume nor possess artistic value. This open-glottis voice can, at best, be used only as a substitute for pianissimo and cannot be united with any other voice unless change of timbre, break or hiccough follows. Female voices, notably German sopranos, using this so-called head tone, invariably sing off the key.¹⁸

The eminent author and teacher, Douglas Stanley, was even more critical than Proschowsky of the use of this mechanism. Stanley dismissed the whistle register as that of a "squeak voice" and "silly tricks." Stanley condemned the use of this register based on his assumption that the vocal cords are extremely short and that control is based entirely on constriction.¹⁹

Kate Emil-Behnke (1945), daughter of Emil Behnke who described the open-glottis mechanism in 1880, spoke of the whistle register in a more positive pedagogical vein. Emil-Behnke referred to the whistle register as

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¹⁸ Franz Proschowsky, The Way to Sing (Boston, 1923), p. 37.

¹⁹ Douglas Stanley, Your Voice: Applied Science of Vocal Art (New York, 1945), p. 198.

"alt" and gives it a frequency range from C6 upwards. As with Garcia, she stressed the importance of spontaneity in the development of this part of the soprano voice and suggested practicing the upper head register softly and delicately in order to blend it with the notes in "alt." Emil-Behnke claimed the register was usually needed only by the coloratura soprano.²⁰

Husler and Rodd-Marling (1964) noted that many teachers and singers recognize the "flageolet" register above the falsetto/head register. The authors claimed that the register was useful for pedagogical purposes and the correction of certain vocal disorders; however, they felt the timbre quality of the register to be of little "aesthetic value." Furthermore, the authors noted the whistle register is based upon a "fairly vague hypothesis."

It can be assumed that the flageolet belongs to the same tonal and functional type as the 'collapsed falsetto' (mainly failure of the suspensory mechanism), though here the action of the posticus is very weak as well. The pyramid cartilages are drawn forwards, the vocal folds themselves and the chink of the glottis are shortened. The larynx is drawn strongly upwards. The vocal apparatus as a whole becomes, as it were, very much smaller.

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²⁰Kate Emil-Behnke, The Technique of Singing (London, 1945), p. 117.

Husler and Rodd-Marling go on to state that every healthy voice has a flageolet register even if never used. They related the inability to produce tones in this register with poor, "insufficiently unlocked" vocal production.²¹

One of the most prominent names in vocal pedagogy since 1950 is that of William Vennard. In adherence to some of the early stroboscopic investigations, Vennard basically dismissed the existence of an open-glottis mechanism as a legitimate singing register. In Singing: The Mechanism and the Technic (1967), Vennard stated that on rare occasions a whistle register may exist due to a chink existing between the arytenoid cartilages; however, it was not useful for singing.²²

Gerda Nielsen (1975), a proponent of the anti-register philosophy of Lilli Lehman, referred to the importance of "flute-like tones" in this part of the female voice.²²

²¹Frederick Husler and Yvonne Rodd-Marling, Singing: The Physical Nature of the Vocal Organ--A Guide to the Unlocking of the Singing Voice (London, 1964).

²²William Vennard, Singing: The Mechanism and the Technic (New York, 1967), p. 347.

²³Gerda Nielsen, A New Guide to Good Singing (Ontario, 1975), p. 51.

A current author in the field of vocal pedagogy, Meribeth Bunch, included the whistle register in her discussion of vocal registration.

Current thinking includes a concept in which there are three basic registers: the glottal fry (or a gentle popping sound made by the vocal folds on a low pitch); a large area of regular or modal voice (including middle and head); falsetto and the flute and whistle registers at the extreme top.²⁴

The open glottis theory of the whistle register has been both demonstrated and refuted through stroboscopic/laryngoscopic investigation. Research done with excised larynges has also demonstrated the existence of such a register. The validity of instrumentation utilizing the stroboscope has long been problematically viewed.²⁵ Early investigations by Behnke, Proschowsky, and others were hampered by the fact that when the larynx is vibrating at high frequencies it may not have time to open or close fully in each vibratory cycle. The result will appear to the unaided eye as an open-glottis mechanism through which a sort of "whistling" might be taking place. Furthermore, the limitations of

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²⁴Meribeth Bunch, Dynamics of the Singing Voice (Wein, Austria, 1982), p. 70.

²⁵Minoru Hirano, Clinical Examination of Voice (Wein, Austria, 1981), p. 49.

drawing any conclusions from the investigation of excised larynges are obvious. Therefore, there exists a continuing need to examine this frequency range of the female voice. Two possible investigative tools would be electromyography and fiber optics laryngoscopes. Unfortunately, both of these tools have limited applicability to this study. EMG requires electrode implants in the intrinsic musculature of the larynx which, due to the constant motion of the larynx itself and the possibility of physical injury, is not a viable alternative with live singer-subjects. On the other hand, the fiber optics laryngoscope has been demonstrated to the author to be limited by a) the gag reflex and b) the constriction of the pharyngeal wall as a singer ascends in pitch.

Reports of sinusoidal as well as complex wave forms have been reported in acoustical investigations of the female voice at this approximate frequency range. Other than these limited observations, very little is known about the acoustical and perceptual nature of these high pitches in the female voice.

Acoustical analysis of vocal phenomena has long been considered a primary tool in voice research. Acoustic analysis may furnish objective, quantitative data

concerning vocal function while allowing experimental procedure which is non-invasive for the singer-subject.²⁶

Since Wheatstone and Helmholtz, it has been known that vocal sound is the result of a complex glottal wave form which is then modified by the highly variable properties of the vocal tract. It therefore stands to reason that any significant change in laryngeal function as well as significant change in the physical structure of the vocal tract will result in some variation of the sound spectrum.

Peaks of acoustic energy observed in the sound spectrum which are a result of the resonances of the vocal tract are referred to as formants. Every vowel is formed by two or more formant ranges, which are determined by the pharyngeal and oral cavity adjustments required for the production of the vowel.

In the "trained" singing voice, other fixed formant areas are often mentioned in the literature which relate to the desirable vocal characteristics typical of western culture. Sources will generally speak of two "singer formant" areas (Bartholomew, Stanley, Rzhevkin, Sundberg, Large, et al.). One area lies at approximately 800 Hz and is credited with the subjective sensation of

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²⁶Ibid., pp. 66-78.

"warmth" or "darkness" in the voice. The other area is reported at approximately 2800 Hz to 3200 Hz and is said to be responsible for the subjective sensation of "ring" or "brilliance" in the singing voice.

Spectral analysis has also been used to study the primary registers in the singing voice (Katzenstein, 1911; Sokolowsky, 1912; Winckel, 1952/53; Bjørkland, 1962; Luchsinger and Arnold, 1965; Sonninen, 1962; Large, 1968; Large and Shipp, 1969; Colton, 1972; Large, 1973; Large, 1974; Russo, 1978). Reports vary, but generally phonations produced in the lower (modal/chest) register are said to be characterized by spectra in which the partials are both more numerous and stronger in acoustical energy than phonations produced in the upper (falsetto/head) register. Likewise, the fundamental is reported to be stronger in the upper register than in the lower.

A change in the laryngeal function, or more specifically a change in the mode of vibration of the vocal folds will manifest itself spectrally in some fashion. In other words, a change in the source function should demonstrate itself in spectral analysis. However, one cannot assume in the investigation of registers that if a spectral change occurs between tones of the same pitch/fundamental frequency sound pressure level and

phonemic category, that a register transition has taken place. If we accept the laryngeal adjustment theory of vocal registers, we must be aware that spectral variation may occur merely because of a change in the size and/or shape of the vocal tract. Spectral variation may or may not indicate register variation.

Another tool used to assess phonatory function is the measurement of airflow rates (Garcia, 1855; Merkel, 1863; Katzenstein, 1911; Nadoleczny, 1923; Luchsinger and Arnold, 1965; Isshiki, 1965; Rubin, LeCover and Vannard, 1967; Van den Berg, 1968; Hirano, Miyahara, Hirose, Kiritani and Fujimura, 1970; Large 1970/1972; and McGlone, 1970). Reports vary regarding airflow rate interaction with other variables such as intensity, frequency, subglottal pressure, register, and so on; however, significant differences have been demonstrated between the airflow rates of the primary registers. Also, there has been some agreement that airflow rates in the frequency range under investigation tend to be relatively small (Luchsinger and Dubois, 1956; Van den Berg, 1963, et al.). Significant airflow variation between tones of the same pitch/fundamental frequency, sound pressure level and phonemic category could logically indicate some change in source

function; that is, a change in the mode of vibration of the vocal folds.

It could therefore be assumed that significant and related changes in airflow and spectral characteristics would in all probability indicate that a variation in the mode of phonation is occurring. If substantial variations did occur, it would suggest that a register transition may be occurring.

Auditory perception of the primary registers have also been investigated (Mcglone and Brown, 1969; Large and Shipp, 1969; Colton and Hollien, 1973; Large, 1974; Hollien and Schoenhard, 1982). These studies have indicated that auditors are able to identify vocal registers.

In the approximate frequency range of the whistle register researchers have reported complex to sinusoidal forms in spectral investigations, airflow rates have been reported to be relatively small, and no research has been reported regarding the perceptual nature of the frequency area. Therefore, there existed a further need to investigate this area of the female voice.

Purpose

The purpose of this study was to investigate specific elements of the portion of the female voice commonly referred to as whistle or flute register.

Problems

The problems of the present study are as follows:

1. To investigate the spectral characteristics of phonations which the singer-subjects believed to be produced in whistle register;
2. To investigate the airflow rates of phonations which the singer-subjects believed to be produced in whistle register; and,
3. To determine if the phonations which the singer-subjects felt were produced in whistle register could be perceptually identified on the basis of voice quality alone.

CHAPTER II

RELATED LITERATURE

Perceptual Studies Dealing with Register Areas Other Than the Whistle Register

The perceptual study of vocal registration is a rather recent phenomenon. A discussion of vocal registers in both the singing and speaking voices will more often than not include voice "quality" differences. Researchers have therefore reasoned that if registers are to be operationally understood, then perceptual elements, as well as other elements, must be defined. To date, most research in this area has dealt with the ability of auditors to identify the two primary registers, the chest register, often referred to as modal or lower register, and the head register which is often termed loft, falsetto or upper register. Other register areas such as the whistle register and vocal fry have also received some attention. Studies dealing specifically with the perceptual analysis of the whistle register will be found in a later section of this chapter. The following research reports deal with other register areas in both the male and female voices.

In 1969, McGlone and Brown investigated the ability of auditors to identify the point where speakers indicated that a shift had occurred between the primary registers (modal and falsetto). The speakers had no formal voice training. As well, the auditors were referred to as "naive" in their formal training to make such evaluations. The results of the study indicated the speakers' own self-judgments to be more consistent than the judgments by the auditors listening to the recording. Also, the trend was noted that males were slightly more variable in self-judgment of their shift between registers than were females.¹

Large et al., 1969a, 1969b, 1973 and 1974, in the course of several related studies investigated spectral and perceptual characteristics of the "chest" and "middle" registers in the female voice. A paired-tone technique was developed where fundamental frequency, sound pressure level and phonemic category were held constant with differences in register being the only variable. Large referred to these as "isoparametric tones."² In the initial studies, isoparametric tones in

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¹Robert McGlone and William J. Brown, "Identification of the 'Shift' Between Vocal Registers," Journal of the Acoustical Society of America, XLVI, No. 4, Part 2 (1962), 1033-1036.

²John Large and Thomas Shipp, "The Effects of Certain Parameters on the Perception of Vocal Registers," The NATS Bulletin (October, 1969), 12-17.

which there were "audible differences" in register timbre were used. However, as Large pointed out, a primary concern of many schools of Western vocal pedagogy is that of "fusing or merging two overlapping but dissimilar sections of the vocal range into a continuous whole, so that the two sections shade invensibly into each other with no perceptible line of demarcation between them (Fields, 1948)."³ For this reason, the researcher found it necessary in the later studies to also examine isoparametric tones where an attempt had been made by the singer-subject to "equalize" or "blend" the phonations in the two different registers. In the concluding study (1974), a paired-comparison technique was utilized with female subjects performing tone-pairs in chest and middle registers. The tone-pairs varied in degree of audible timbre difference or equalization. Twelve expert auditors (professional voice teachers) judged the tone-pairs for register identification. The auditors also rated the tone-pairs for how well they were blended or "equalized." The auditors' judgments were compared to spectral analysis of the tone-pairs. The spectra for the tone-pairs

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³ John Large, "Acoustical-Perceptual Evaluation of Register Equalization," The NATS Bulletin (October, 1974), p. 20.

judged to be "best equalized" were also compared to the spectra of the tone-pairs judged to be "least equalized"

Large summarized his findings as follows.

- 1) Register identification judgments by expert listeners agree remarkably well (92% of the time) with the intentions of singer-subjects producing paired tones (tones of the same fundamental frequency, phonemic category and sound level) in female chest and middle registers at 300 Hz., with the vowel /a/, at comfortable but equal sound level--except when the singer-subject produces paired tones that are judged to be well 'equalized.'
- 2) The order of presentation of register pairs, either by duplication or reversed order within an item, does not appear to affect register judgments.
- 3) Certain singers appear to be able to produce at will paired register tones both (a) with obvious register-timbre differences and (b) with subtle register-timbre differences.
- 4) Register judgments do not appear to be vowel-dependent.
- 5) Perceived register-timbre differences do appear to be correlated at least in part, with different distributions of energy in the spectral envelope. Chest register in this study (for a given fundamental frequency of 330 Hz) is characterized by greater energy in the harmonics above the 3rd partial, especially numbers 4 and 5. Middle register appears to have a stronger fundamental and third partial--but not markedly.
- 6) The differences described in item 5 appear to be minimized when two different register tones are judged to be 'equalized.'
- 7) These findings are compatible with the theory that differences in register timbre between female chest and middle registers are a result of different source (vocal fold) waveforms.⁴

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⁴Ibid., p. 27.

Overall, Large's data supported his conclusions. The register identification judgments tended to be greater than in other studies of this nature. This was probably due to the nature of his auditors who were experienced voice teachers. One might anticipate that experienced auditors would be better able to perceive registers than naive or student/singer groups.

The conclusion that register judgments do not appear to be vowel-related may be a bit premature. The singer-subjects were asked to perform the tasks on the vowel /a/; however, vowel evaluation by a trained phonetician indicated that actual vowel quality included /a/, /ɔ/, and /ʌ/.⁵ Acoustically, these vowels are quite similar and do not provide enough variation in vowel quality to support the above premise. Large, however, does point out this discrepancy in his discussion.

Lerman and Duffy (1970) conducted an investigation to determine if falsetto (the male falsetto) could be distinguished from modal register in the male voice as well as "normal" female production and "normal" childrens' production. Lerman and Duffy were referring to the speaking voice (the modal/chest register) when

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⁵Ibid., pp. 23-24.

they spoke of "normal" production. The results indicated that the auditors were able to identify male falsetto tones seventy per cent of the time. The most easily identified production was the childrens' voices. Ninety-four per cent of the child/voice samples were identified correctly. The "normal" male samples had the lowest percentage of correct identification at fifty-eight per cent.

Normal female production was correctly identified sixty-six per cent of the time. Due to the obvious timbre difference between male modal and falsetto registers, one must question the ability of the subjects used in this study to maintain a modal/chest register production on the frequencies which were investigated.⁶

Colton and Hollien (1973) investigated the perceptual differentiation of the primary registers (modal and falsetto) in an approach similar to Lerman and Duffy (1970) and Large (1968/69). That is, paired tones were evaluated for register perception where fundamental frequency, sound level and phonemic category are held constant. Subjects consisted of five singers and five non-singers. According to the researchers, the subjects produced the vowel /a/ in each of the two

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⁶J. W. Lerman and R. J. Duffy, "Recognition of Falsetto Voice Quality," Folia Phoniatrica, XXII (1970), pp. 21-27.

registers at 208 Hz, 262 Hz, and 330 Hz, which represented the 25th, 50th and 75th percentage points of the range of frequency overlap between the modal and falsetto registers for all ten subjects. The vocal intensity level was determined by that which was most comfortable for the subject.

Three procedures to measure perceptual differentiation were used. Discrimination ability was measured by the utilization of a paired comparison procedure where observers were asked to label each pair as similar or different in voice quality. Categorization ability was measured by two procedures. The first, a forced-choice procedure, required the observers to divide the phonations equally into two undefined voice quality groups. Secondly, a free-choice procedure allowed the observers to place any number of phonations into either of the two quality groups. In the last procedure, each phonation was presented individually and phonations were intermixed with regard to fundamental frequency.

In the discrimination and forced-choice categorization procedure, two observer groups were utilized. The first group consisted of fifteen college students with no formal training in voice, speech or singing. The second group consisted of fifteen trained observers

equally divided into three professional subgroups: voice students/singers, experimental phoneticians, and speech pathologists and therapists. In the free-choice categorization procedure, thirteen naive observers were used.

The discrimination procedure was designed to test the ability of observers to perceive differences or similarities between paired tones. The two categorization procedures were designed to investigate "the ability of observers to abstract the commonalities of voice qualities among all phonations..."⁷

The discrimination procedure demonstrated that observers were able to discriminate register variation (between modal and falsetto) with a high degree of accuracy. An analysis of variance demonstrated no statistically significant differences among the sub-groups of the experienced observers or between the experienced and inexperienced observer groups. After a pooling of the data from individual observer groups, the researchers reported:

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⁷R. H. Colton and H. Hollien, "Perceptual Differentiation of the Modal and Falsetto Registers," Folia Phoniatrica, Volume 25 (1973), p. 273.

Further analysis revealed statistically significant differences between the proportion of correct discriminations for (1) the two subject groups ($F=81.86$)*, and (2) the three frequency levels ($F=68.15$)*. In addition, an interaction term involving subject groups and frequencies was significant ($F=21.91$)*.⁸

*(--df-1,14; $F_{0.05}=4.60$)

This information demonstrated that the proportion of correct responses to the singer-subject phonations varied less than those of the non-singer-subjects in regard to the fundamental frequency at which it was produced. The researchers concluded that this was due to the singer-subjects producing a more consistent voice quality at each of the three frequencies investigated.

For the forced-choice categorization procedure, an estimate of observer group reliability was tested. The researchers reasoned that a high number of identical responses to two presentations of the phonations would indicate observed consistency. Identical responses were tabulated in the form of a contingency table for each observer group. ϕ -coefficients were computed for each and were statistically significant at the 0.05 level; hence, the researchers concluded that the different groups were consistent in their rating of the identical stimuli and the responses were pooled.

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⁸Ibid., p. 273.

Again with the forced-choice categorization procedure, an analysis of variance revealed no statistically significant differences between the three experienced sub-groups of observers. After a pooling of the three experienced sub-groups, further statistical tests demonstrated no significant differences between "(1) the two groups of observers, (2) the two subject groups, and (3) the three frequencies at which the phonations were produced."⁹

The proportion of correct responses was not as high as in the discrimination procedure (.83-.98) but was still greater than the hypothesized chance level. ($P=.50$). Since the ANOVA revealed no significant differences among the subject groups or fundamental frequencies, all the data were pooled to reveal an overall proportion of correct responses in the forced choice categorization procedure of 0.64.

Free-choice categorization used only naive observers. They were free to place the phonations in the two (unnamed) quality groups as they wished. A Q -coefficient of .46 was calculated for the free

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⁹Ibid., p. 275.

choice category observer group which is significant at the .05 level. The researchers claim this measure indicated within-group consistency in the rating of the stimuli.

The ANOVA for the free-choice categorization data demonstrated a significant main effect for the vocal registers and significant interaction between register and fundamental frequency. The researchers determined again that the observers were able to differentiate the registers; however, the only conditions which were significantly above chance ($p=.50$) were the low frequency modal phonations and the high frequency falsetto phonations. The hypothesis was made that both voice quality and pitch affect the perception of register differentiation.

In summation, Colton and Hollien concluded that each of the primary registers exhibit an "identifiable voice quality."¹⁰ The researchers noted that auditors were very successful at discriminating the timbre qualities of the two registers "if they are permitted to attend only to that attribute,"¹¹ and that auditors were able to sort

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¹⁰ Ibid., p. 279.

¹¹ Ibid., p. 278.

phonations into register categories, but not at the level demonstrated with the discrimination task.

The research design set up by Colton and Hollien was the most rigorous of the perceptual studies reviewed by this author. Their conclusions were generally supported by data, especially within the realm of discrimination. A possible problem with the categorization procedures was observer (auditor) reliability. Even though the statistic used (Q -coefficient) is suited to this type of data and is not comparable to Pearson or any other correlation figure,¹² the reliability figures ($Q=.25-.46$), though significant at the .05 level, seem somewhat low. However, the discussion and conclusions are guarded and well stated in regard to categorization abilities.

Beard (1980) investigated the ability of auditors to identify isoparametric tones (tones of the same fundamental frequency, sound pressure level and phonemic category sung in different registers) in the male/tenor chest, head, and falsetto registers. In the background section of the report, Beard discusses the problem of the male "operatic head register" in regard to whether it is

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¹²Sidney Siegel, Non-Parametric Statistics for the Behavioral Sciences (New York, 1956).

a distinct laryngeal register, an acoustical phenomenon, or a modification of one or both of the two primary registers.

The report indicated that the auditors (university-level voice teachers) were in agreement with the intentions of the singers fifty-eight per cent of the time. The agreement-percentage breakdown for the three registers investigated were as follows: chest sixty per cent, falsetto fifty-nine per cent and head fifty-four per cent. Beard claimed chi-square analysis of the agreement percentage demonstrated significance at the .01 level.

Beard also explored the possibility that auditors would be more accurate in identifying registers of a tenor if they could hear two or three registers in an item rather than only one. This allowed for a comparison of timbres. Beard found that auditors were able to improve their identification accuracy when allowed to compare two or three registers in each item. In this breakdown of the data, Beard reported an accuracy rate of fifty per cent (chance level thirty-three per cent) when only one register was presented per item. However, when two registers were compared, the accuracy of the auditors jumped to fifty-eight per cent, and with all three registers within an item, the accuracy level went to

sixty-one per cent. Again, Beard reported that chi-square analysis revealed that the number of registers in an item had a significant effect (.01) on auditor accuracy.¹³

A recent perceptual study of registration was conducted by Schoenhard and Hollien (1982). They chose to use eight accomplished female singers as their subjects. Three "registers" were examined: "low (also could be labeled modal, chest, heavy registration); mid (mixed, head, Garcia's falsetto); and high (falsetto, head, Vennard's light registration)."¹⁴

As in other studies of this nature, fundamental frequency, intensity and vowel production were controlled insofar as possible. Subjects produced samples of each register at the frequency G4, 392 Hz, on the vowel /a/ at approximately equal intensity levels. According to the authors, though frequency and vowel were easily controlled, vocal intensity (due to the nature of the tasks) varied occasionally from the desired level. When this would occur, the liberty was taken to manipulate the recorder gain control in order to equalize the

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¹³Charles Beard, "Recognition of Chest, Head and Falsetto Isoparametric Tones," Transcripts of the Ninth Symposium: Care of the Professional Voice, Part I, Physical Factors, Vocal Function and Control, Van Lawrence ed. (New York, 1980), pp. 116-123.

¹⁴Carol Schoenhard and Harry Hollien, "A Perceptual Study of Registration in Female Singers," The NATS Bulletin, Volume 39, No. 1 (September/October, 1982), p. 24.

intensity of the recorded samples. The tasks were designed in order to assist the singer-subjects in correctly producing the three different registers at the same fundamental frequency.¹⁵

Figure 3--Phonatory Approaches to the Production of the Frequency 392 Hz (G4) in the Three Registers of Interest

Three groups of auditors were selected. One group consisted of nine singers and/or singing teachers. The second group was made up of ten phoneticians while the final group (control group) was made up of ten naive listeners. Register judgments were made by the auditors in both a three-way (low-mid-high) procedure and a two-way (low-high) procedure. The judges were asked to sort the samples into categories on the basis of quality

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¹⁵Ibid., p. 24.

and timbre. The categories were labeled A, B, and C with no reference to any register or quality terminology. The procedure thereby forced the auditors to make their own categorization criteria. Three playings of the tape were allowed so that the auditors could check their choices.

The basic data were summarized by the authors in the following table.¹⁶

TABLE I

SCHOENHARD & HOLLIEN IDENTIFICATION LEVELS OF INTENDED REGISTERS BY THREE LISTENER GROUPS--PERCENT "CORRECT"

Listener Group	Three-Way Register Judgments (%)					Two-Way Register Judgments (%)		
	<u>N</u>	<u>Low</u>	<u>Mid</u>	<u>High</u>	<u>Mean</u>	<u>Low</u>	<u>High</u>	<u>Mean</u>
Singers	9	66	49	76	64	75	92	84
Phoneticians	10	61	42	54	52	70	84	77
Controls	10	55	51	56	54	72	85	76
Mean		51	47	62	57	72	85	79

The singer/singing teacher group demonstrated the highest level of correct responses. The authors reported that chi-square analysis indicated that the difference

¹⁶Ibid., p. 25.

was significant for the three-way procedure.¹⁷ Also, as shown in Table I, the two-way judgments were considerably more accurate than the three-way judgments. In the two-way judgment procedure, auditors placed the samples into the intended categories seventy-nine per cent of the time. Chi-square analysis demonstrated the significance of this data at the .05 level.¹⁸

The three-way judgments were also found to be significant.¹⁹ However, the authors pointed out the relatively low scores for the mid-register judgments. In fact, the mid-register samples were placed in the other two categories over half of the time. Mid-register judgments were confused with upper register thirty-three per cent of the time and with lower register nineteen per cent of the time. The authors state:

Indeed, when the data for the high and low registers are compared statistically, it is found that they are similar with respect to both their 'strength' and their patterning. Such is not the case when the mid-register is compared with either of the other two.²⁰

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¹⁷Ibid., p. 25.

¹⁸Ibid., p. 25.

¹⁹Ibid., p. 25.

²⁰Ibid., p. 25.

Schoenhard and Hollien conclude that their data supports the existence of the two primary registers in the female voice. They do, however, question the existence of a mid-register in the classical sense: ". . .it is not a laryngeal register at all but rather a vocal tract phenomenon--and one that is overlaid upon one or both of the two laryngeally produced registers (Hollien, et al., 1976; Vennard, 1967)."21

Acoustical Studies Dealing with Register Areas
Other than the Whistle Register

Any change in laryngeal and/or vocal tract function during phonation will most likely manifest itself spectrally in some way. According to Hirano, "Acoustic analysis of the voice signal may be one of the most attractive methods for assessing phonatory function or laryngeal pathology because it is non-invasive and provides objective and quantitative data."22 Spectral analysis, especially when correlated with the analysis of other parameters, has added much to the understanding of vocal registers.

As an adjunct to a study of vocal fold paratasis, Sonninen (1961) analyzed the spectral characteristics

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21Ibid., p. 26.

22Minoru Hirano, Clinical Examination of Voice (Wien, Austria, 1981), p. 66.

of some of the voice samples recorded during a roentgenographic investigation. Sonninen indicated that an "open voice habit" was richer in overtones than the "covered voice habit." Also, he noted that as the pitch ascended, partial tones tended to decrease in all habits (qualities). In chest register the maximum number of overtones reported was thirty. In head voice, the number of partial tones varied from three to five. It should be noted that Sonninen's study used only one subject: a middle-aged actress who was interested in singing.²³

Van den Berg (1963, 1968a, and 1968b), in his experiments with excised human larynges, measured the spectra of pure glottal sound (sound unaffected by the properties of the vocal tract). Van den Berg reported rich harmonic activity in the chest register, intermediate activity in the middle register and sparse activity in the falsetto.²⁴ He basically discovered the same trend reported by other researchers who had analyzed the spectra of post vocal tract phonation. It is

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²³A. Sonninen, "Paratasis-gram of the Vocal Cords and the Dimensions of the Voice," Contributions of Voice Research to Singing, edited by John Large (Houston, 1980), pp. 134-144.

²⁴J. W. Van den Berg, "Register Problems," Annals of the New York Academy of Science (1968), p. 133.

important to note that even though it is known that vocal tract configuration affects spectral characteristics, the trend of decreasing harmonics with increasing pitch holds true in spite of vocal tract influence. This obviously strengthens the relationship of laryngeal function and spectral activity.

Large (1968) investigated spectral characteristics of so-called "isoparametric" tones in the female chest and middle registers. Isoparametric tones refer to tones of the same fundamental frequency, sound level and phonemic category in different vocal registers. Large found the middle register to be characterized by less energy in the higher partials than in the chest register. Also, it was discovered that the middle register has a stronger fundamental than that of the chest register. Just as important were Large's findings regarding the register transition itself. The researcher noted that register transitions (the spectral analysis of the point in time where the singer-subject is changing from one register to the other while maintaining fundamental frequency) were usually characterized by both frequency and vibrato perturbation.²⁵

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²⁵John Large, "An Acoustical Study of Isoparametric Tones in the Female Chest and Middle Registers in Singing," The NATS Bulletin (December, 1968), pp. 12-15.

Large claimed the data supports the laryngeal adjustment theory of vocal registers. Indeed, the combination of spectral variance and pitch/vibrato perturbation does indicate a change in source function thereby lending credence to the laryngeal adjustment theory.

Spectral characteristics of the primary registers (modal and falsetto) were investigated by Colton in 1972. Ten young adult males were used in the study. Five were voice students at the college level while the remaining five possessed no previous vocal training. The number of partials occurring in the phonations was highly variable; however, an analysis of variance demonstrated a significant difference between the number of partials in each vocal register.

Confirming the findings of Sonninen (1962), Van den Berg (1962), and Large (1968), Colton found modal phonations to exhibit a greater number of partials than falsetto phonations. The investigation demonstrated no statistically significant differences between the two subject groups. Colton's results are presented in Table II.²⁶

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²⁶R. H. Colton, "Spectral Characteristics of the Modal and Falsetto Registers," Folia Phoniatrica, Volume 24 (1972), p. 341.

TABLE II

COLTON'S RESULTS (THE MEDIAN NUMBER OF PARTIALS IN
MODAL AND FALSETTO REGISTER PHONATIONS PRODUCED
AT THREE FUNDAMENTAL FREQUENCIES BY
SINGER AND NON-SINGER GROUPS

	Median Number of Partial					
	208 Hz		262 Hz		330 Hz	
	modal	falsetto	modal	falsetto	modal	falsetto
non-singers	18	12	14	10	13	11
singers	20	11	16	11	15	11

Airflow Studies Dealing with Register Areas Other Than the Whistle Register

According to the mypelastic-aerodynamic theory of voice production, transglottic airflow is necessary to initiate and maintain phonation (Ferrein, 1741; Müller, 1847; Behnke, 1880; Garcia, 1840 and 1894; Stanley, 1945; Van den Berg, 1958; Luchsinger and Arnold, 1962; Son-ninen, 1962; Appleman, 1967; Vennard, 1968; Hollien and Colton, 1970; Large, 1972; Bunch, 1982). Many researchers have investigated the relationship of airflow to other observable parameteers of phonation such as fundamental frequency, intensity, sub-glottal pressure and registration. The relationship of airflow to fundamental frequency is not clearly understood. It would seem that airflow would increase with a rise in fundamental frequency; however, Kunze (1964) and Rubin, Vennard and Lecover (1967) found

no significant change in airflow rates associated with a change in the fundamental frequency. There does appear to be some relationship between airflow and intensity. Basically, researchers have found that an increase in intensity is accompanied by an increase in airflow; however, the relationship tends to be variable and unpredictable (Vogesanger, 1954; Kunze, 1964; Rubin et al., 1967; McGlone, 1970).

It stands to reason that glottal resistance (i.e. the degree to which the vocal folds resist subglottal pressure during phonation) is the complicating factor in these relationships. In fact, Rubin et al. (1967) hypothesized that glottal resistance is far more important in supporting a tone of increasing loudness than is airflow. The problem may arise through looking at these parameters in too dynamic a setting. For example, it would follow that if other variables are held constant, a change in register would result in a change in airflow. Indeed, as early as 1900, Roudet found airflow rates to be almost four times greater in falsetto than in chest voice. In 1967, McGlone found airflow rates in vocal fry to be significantly lower than those in the modal/chest register.²⁷ The same author investigated

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²⁷R. E. McGlone, "Airflow During Vocal Fry Phonation," Journal of Speech Research, X (1967), pp. 299-304.

airflow rates in the female upper register in 1970. Confirming Rubin et al. (1967), no relationship was found between airflow and fundamental frequency; yet, an increase in vocal intensity was accompanied by an increase in airflow rate. McGlone reported that an ANOVA of the data revealed the relationship between airflow and intensity to be significant at the .01 level.²⁸

A study directly relating air flow rates with registration was conducted by Large, Iwata and Von Leden in 1970. The researchers conducted an airflow study of isoparametric tones (same fundamental frequency, intensity and vowel) in the female chest and middle registers. Five adult female voice students were used in the investigation. Mean flow rates were determined for the isoparametric tones by the use of a pneumotachographic system. All five subjects demonstrated an increase in airflow rates from chest to middle register. Five samples were obtained from each subject and data was summarized as shown in Table III.

According to the authors, an ANOVA of the data demonstrated that the difference in airflow rates between the two registers was statistically significant

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²⁸R. E. McGlone, "Airflow in the Upper Register," Folia Phoniatrica, Volume 22 (1970), pp. 231-238.

at the .05 level. Also noted was the marked variability in airflow rates between subjects in both registers.²⁹

TABLE III

LARGE, IWATA, AND VON LEDEN'S RESULTS
MEANS AND STANDARD DEVIATIONS OF THE AIRFLOW RATES
(ML/SEC) IN FEMALE CHEST AND MIDDLE REGISTERS

Subject	Chest Register		Middle Register	
	Mean Values	SD	Mean Values	SD
1	141	18.5	316	17.5
2	74	9.7	269	32.8
3	79	8.0	248	30.4
4	136	15.3	175	23.4
5	188	16.9	257	23.8

A Review of the Literature Dealing Specifically With the Whistle Register

Physiological and acoustical descriptions of the frequency range encompassing the so-called whistle register may be traced to the nineteenth century. Emil Behnke, a contemporary of Garcia and a renowned English voice teacher, used the laryngoscope in his investigation of vocal mechanics. In The Mechanism of the Human Voice (1880), Behnke describes an open-glottis mechanism which closely resembles the modern concept of the

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²⁹John Large, S. Iwata and H. Von Leden, "The Primary Female Register Transition in Singing," Folia Phoniatrica, Volume 22 (1970), pp. 385-396.

whistle register. Behnke referred to the upper tones of the soprano range as the "small register." He theorized this register to belong almost exclusively to the soprano voice and claimed the register represented the series of tones above F5 or F#5. Through laryngoscopic observation, Behnke observed the following:

With the (F#5) the vocal ligaments suddenly closed firmly together to their middle, with their fine edges one over the other. This closing appeared as a fine red line extending from the pyramids (arytenoid cartilages) at the back, forward to the middle of the vocal ligaments, and leaving free only a third part of the whole glottis, immediately under the lid, to the front wall of the voice box...

The foremost part of the glottis formed an oval orifice, which, with every higher tone, seemed to contract more and more, and so became smaller and rounder. The fine edges of the vocal ligaments which formed this orifice were alone vibrating.³⁰

Behnke goes on to state that the raising of pitch within this register was produced by a contraction of the vocal ligaments.

The basic concept as presented by Behnke was also illustrated in laryngeal image drawings by Shakespeare (1898), and Proschowsky (1923).³¹ It should be noted

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³⁰Emil Behnke, The Mechanism of the Human Voice (1880), p. 102.

³¹William Vennard, Singing: The Mechanism and the Technic (New York, 1968), p. 67.

that laryngoscopic viewing of vocal fold vibrations at such high frequencies (740 Hz and up) may appear to the unaided eye as a puckered opening through which a type of "whistling" production may be taking place. Indeed, the lower frequencies at which Behnke reported the "small register" to exist (F#5 to B5) would in all probability be due to this phenomenon. Also, any frequencies above the B5 which were observed in such a manner to be produced by an open-glottis mechanism would necessarily be viewed with suspicion.

M. Nadoleczny (1923), in a survey of exceptional vocal ranges, reportedly recorded laryngeal whistle tones in young children as high as G7, 3136 Hz. The highest tone reached by a coloratura soprano was E7, 2637 Hz.³²

In 1937, M. Nadoleczny-Millioud and R. Zimmerman reported their findings concerning voice categories and registers to the Fifth Congress of the French Society of Phoniatriy. They confirmed the findings of P. Schulz (1902) that it is very likely that the larynx functions in this case much like a true labial whistle. It was reported that in observations of the glottis during singing, no vibrations (i.e., approximations of the vocal

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³²R. Luchsinger and G. Arnold, Voice-Speech-Language (California, 1965), p. 100.

folds) were seen in the "registre de sifflet" (whistle register). The report also mentioned Katzenstein's findings regarding airflow. By means of pneumographic techniques, it was reported that the quantity of air is greatest in the chest voice. For the whistle register, it is considered to be the smallest.³³

Preissler (1939), in an investigation of ranges and registers of the human voice found the highest frequencies to be those of children in the production of what he termed "laryngeal Pfeiftöne." He found an upper limit of 3100 Hz. or approximately G7. Preissler also claims to have observed "laryngeal Pfeiftöne" in a sample of 205 sopranos. The population consisted of students, opera singers, concert singers, amateurs, and church choir singers. Of the 205 subjects, the researcher reported sixty-nine of them to have an upper range limit of F6 (1397 Hz) to C#7 (2217Hz). Preissler claims the whistle register can begin from D6 to F6 depending on the individual. "Pfeiftöne" were reported having occurred eleven times out of the total number of soprano subjects. Assumedly based on his own aural perception of the subjects, Preissler listed the

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³³M. Nadoleczny-Millioud and L. Zimmerman, "Categories et registries de la voix," Rev. Fr. Phoniat (1938), pp. 155-162.

following occurrences of "Pfeiftöne" along with the corresponding ranges.³⁴

<u>Number of "Pfeiftöne"</u> <u>Occurrences</u>	<u>Range at Which</u> <u>"Pfeiftöne"</u> <u>Occurred</u>
3	E6-C7
2	E6-B6
2	E6-F6
1	F6-G6
2	D6-F6
1	D6-E6

The first strobolaryngoscopic study dealing specifically with the whistle register was that of E. G. Garde (1951). Garde, an advocate of Husson's neurochronaxic theory of voice production, concluded the "whistle voice" would only deserve its name metaphorically. Garde claimed to have seen vocal cord vibration on F6 (1397 Hz) and G6 (1568 Hz). Consequently, he proposed to replace the term whistle voice (voix de sifflet) with that of small register (voix de petit registre).

Several problems arise in the review of Garde's research. Stroboscopic photography does not demonstrate the actual details of each vibratory cycle as does ultra high speed photography, but it merely shows a facsimile of the vibratory pattern averaged over many

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³⁴W. Preissler, "Stimmumfang und Gattungen der Menschlichen Stimme," Archiv. Sprach - u. Stimmphysiologie, Volume 3 (1939), pp. 65-85.

successive cycles. Also, stroboscopic observations are limited by the necessity of subjective evaluations by the examiner.³⁵

Garde viewed the voice of the great coloratura soprano, Mado Robin, on two different occasions. On the first occasion, he reported that the real frequency of the stroboscope was the quarter of the fundamental frequency of the note observed.

Example: Stroboscope setting: 300 p.s.

Observed Frequency: Eb6 1200 Hz

Task (arpeggio) 600 Hz Eb5--750 Hz G5--900 Hz Bb5--1200 Hz Eb6

This task was repeated with the same calibration at a top frequency up to 1700 Hz A6.³⁶

In these conditions, Garde reported that one does not see the cords vibrate. However, Garde saw the problem as being one of too much variance between the frequency of vibration (Hz) and the stroboscope setting (p.s.).

We know indeed that if the gap between the frequency of the vocal sound emitted and the one of the stroboscope goes beyond 20 p.m., the eye of the observer no longer registers vibrations because of the after image. In order for the vibrations of the vocal cords emitting a sol 5 (1550 Hz) to be visible, one must create between them and the apparatus a

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³⁵M. Hirano, Clinical Examination of Voice (1981), pp. 66-68.

³⁶E. J. Garde, "Observation stroboscopique de la vibration des cordes vocales dans le 'petit registre' (ou registre 'de sifflet') des sopranis suraigus," Folia Phoniatrica, Volume 3 (1951), pp. 248-249.

tune of less than 20/1500, or less than 1.3/100. This wasn't possible with a stroboscope tuned on the 'quarter of the fundamental' and it is besides, in all hypotheses, at the limit of the regularity of recurring nervous influxes.³⁷

Garde's second observation was done with an apparatus which allowed the stroboscope to give exactly the fundamental of the note sung at the beginning of the arpeggio with a top frequency of approximately F6 or G6. Garde explained, "...the vocal cords are caught (in the process of) vibrating a very short time interval. One must necessarily conclude that they vibrate on the other sung high frequencies."³⁸

The data presented and the use of only one subject do not seem adequate to support Garde's conclusion.

Garde goes on to speculate:

Let's finally add that it is not by breath effort, but thanks to a particularly developed and tiring auditory mental concentration that Mrs. Mado Robin starts and maintains the emission of her voice at such vertiginous sound heights. This particularity, formally recognized by the artist, constitutes one more objection against the myo-elastic theory, a supplementary fact in favor of the theses exposed by R. Husson who faces, as we do, the vibration of the vocal cords as being an effect of the rhythmic activity of the nervous centers.³⁹

³⁷Ibid., p. 249.

³⁸Ibid., p. 249.

³⁹Ibid., p. 250.

Such obvious bias forces one to question further Garde's conclusion based on the given data. Neuro-chronaxic theory, of course, has been disclaimed by countless researchers. Garde seemed to be going to any length to promote Husson's thesis.

The neuro-chronaxic theory of voice production (Husson, Goerttler, Laget, Portmann, Garde, Piquet et al.) states that vibration of the vocal cords is due to clonic contractions of the vocalis muscles in response to successive stimuli from the central nervous system; in other words, a neuromuscular concept of vocal production versus the classical myoelastic-aerodynamic theory (Van den Berg, Negus, von Leden, Faaborg-Andersen, Vennard) which depends on breath pressure and muscular tension to explain phonation. Since motor nerves cannot be stimulated at a speed which would allow for phonation frequencies above 500 Hz, Husson postulated a polyphase theory of conduction in the recurrent laryngeal nerves for all frequencies above 500 Hz. From 500 to 1000 Hz the fibers of the vocalis muscle and recurrent laryngeal nerve would be functionally divided into two parts with a resultant biphasic response. One thousand to 1500 Hz, would require a "triphasic response" and at even higher frequencies a quadriphasic response was assumed.⁴⁰

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⁴⁰H. von Leden, "The Mechanism of Phonation," Arch. Otolaryng (1961), pp. 101-102.

In 1954, Belussi and Cerciello conducted spectrographic experiments with a recording of the voice of the famous South American singer Yma Sumac. During sustained phonation at 1550 Hz (G6), the investigators demonstrated four partial tones with noticeable vacillations in pitch.⁴¹

Luchsinger and Dubois (1956) investigated the voice of Jennifer Johnson, who reportedly could reach pitches as high as 2794 Hz (F7). The researchers investigated her voice phonetically as well as stroboscopically and radiologically.

According to the investigators, and undoubtedly the singers on perception, the register transition (to the whistle register) was said to have occurred at D6 (1174 Hz). Like M. Robin (Garde, 1951), Johnson claimed that for the highest notes, she needed a "mental auditive attitude" which was very tiring.

The researchers investigated the voice stroboscopically as high as 2069 Hz, C7. Their apparatus reportedly allowed a half-way setting at this frequency (1035 p.s.). Although no detailed description of the procedure is discussed, the investigators claimed that

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⁴¹G. Belussi and P. Cerciello, "Alcune considerazioni a proposito di un singolare Fenomeno yocale, La voce di Yma Sumac," Boll. Soc. Ital. Fon (1954).

vibrations of the vocal cords could be observed, thus confirming Garde's (1951) earlier hypothesis.

Radiological investigation resulted in tomograms typically showing considerable laryngeal contraction. It is with the acoustical investigation, however, that Luchsinger and Dubois appear to deviate from Garde as to their speculation of what is actually occurring.

When harmonic partials can no longer be shown for the highest selected singing notes (F#6), then we must be speaking of a pipe mechanism, as must be assumed for high falsetto notes. The fact that th tone showed a strong vibrato showed above all that the vibrations of the system in this high register as well are very labile and are more clearly dependent⁴² on pressure velocity than in falsetto.

At approximately C6 (1024Hz), the investigators reported a first overtone of about six per cent of the amplitude of the fundamental, a second overtone of about four per cent, and a fourth overtone of about six per cent. By F6 (1397 Hz), only an extremely weak component of the fourth partial could be observed. With the highest two tones observed, C7 (2093 Hz) and F7 (2793 Hz), acoustic analysis appeared to be purely sinusoidal; that is, only the fundamental was demonstrated.

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⁴²R. Luchsinger and C. Dubois, "Phonetische und stroboskopische Untersuchungen an einem Stimmphänomen," Folia Phoniatica (1966), p. 206.

These facts led the authors to believe that these very highest tones lacking in any harmonic partials were indeed "pipe notes," and produced in a manner similar to the tones of a labial pipe such as the piccolo or the ocarina.

It is possible that the air stream which flows through the narrow vocal cord receives a stimulus for edge wind vibrations⁴³ on the tautly drawn pocket folds.

This leads to the view that these very high notes, formed in a staccato manner and sounding like pipe-notes, are edge tones, in producing which the larynx is⁴⁴ blown upon rather like an ocarina.

The investigators added that the volume of air used for this mechanism is apparently very small. With one young coloratura soprano, the airflow ms. for C6 (1047Hz) was 12 cc per second.

The same criticism of stroboscopic technique made with Garde (1951) must be applied here. The use of only one subject in the bulk of the study is not adequate to support any suppositions.

In an investigation of the falsetto (i.e., the higher of the two primary registers) utilizing high speed photography of laryngeal activity, H. Rubin and C. Hirt (196)

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⁴³Ibid., p. 208.

⁴⁴Ibid., p. 210.

described three types of falsetto, one of which shares similar characteristics with the hypothetical whistle register. Using a Wollensak Fastax camera capable of indirect laryngoscopy at 6000-8000 frames per second, the researchers, by the use of 500 foot rolls of film, were able to record three-and-one-half to four-second sequences of phonation. One pattern of vibratory activity identified was that of the "open-chink" mechanism, which is characterized by vibrations in which the vocal cords touch each other infrequently or not at all. The comparison with the whistle register theory is obvious. However, it is unfortunate to note that the researchers do not give the frequencies at which the mechanism was viewed. The open-chink mechanism was reported to occur at "soft to moderate" intensities.⁴⁵

Arnold (1961) also claimed the existence of an "open-chink" falsetto in coloratura voices.

. . .in falsetto the vibrations are limited to the inner cord margins, and the glottis remains constantly open as a spindle-shaped slit. These marginal vibrations for the highest coloratura tones were seen as far as F3 (1397 Hz) and G3 (1568 Hz).⁴⁶

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⁴⁵H. Rubin and C. Hirt, "The Falsetto, A High Speed Cinematographic Study," Laryngoscope (1960), pp. 1350-1324.

⁴⁶G. Arnold, "Physiology and Pathology of the Cricothyroid Ms.," Laryngoscope (1961), pp. 687-753.

Arnold speculated that above this frequency area there may be a "flageolet" register in the highest coloratura voices.

Excised human larynges have been used extensively in the physiological voice research of the eminent Janwillen Van den Berg (1958, 1963, 1968). In his experimental method, temperature, moisture content and resulting tissue viscosity of the apparatus were controlled to approximate as closely as possible the conditions of a living larynx. Subglottal system dimensions were also designed in proportion to that of a living subject. Subglottal pressure was subject to direct control. The three primary factors determining pitch and vibrational pattern according to classical myoelastic-aerodynamic theory were also subject to control. These factors are (1) longitudinal tension (cricothyroid ms.), (2) adduction (interarytenoid ms.) , and (3) medial compression (lateral cricoarytenoid ms.).

Van den Berg reported that when only medial compression was applied to the larynx, that is, when the lateral cricoarytenoids are active but the interarytenoids are inactive, the glottis closes, but a small triangular opening is seen between the arytenoid cartilages. Stated another way, the vocal processes of the arytenoid cartilages will approximate while the posterior parts at

the apex will not come in contact. It was this physiological adjustment which Van den Berg speculated is used for the whistle register. Of course, the aforementioned mechanism is only possible while paratasis is not occurring (inactive cricothyroid ms.).

The resultant tone is not a result of vibration of the vocal folds as with the other registers, but instead is produced by the formation of eddies (backward-circling currents of air) in the triangular opening and subsequent cavity resonance. Van den Berg reported that phonation in this adjustment is characterized by very high tones (up to 2500 Hz), small airflow rates (75 cm³/sec.), and small subglottic pressures (up to 3 cm. water).

Van den Berg further demonstrated this hypothesis by showing that when a gas with a higher velocity of sound than that of air was used, the pitch was proportional to this velocity.

The tone originates by the formation of eddies in the triangular opening and subsequent cavity resonance, as the author proved by experiments in which gas with a higher velocity of sound than that in air was used, as the pitch was proportional to this velocity. At large flows the subglottic pressure increases to the extent that the vocal folds are thrown into vibration. . . the transition to falsetto was difficult. This is an additional argument to prove that the very high whistle register is not an extreme of the high falsetto register, but an entirely different register, which is found in some female voices.⁴⁷

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⁴⁷Ibid., p. 154.

TABLE IV
VAN DEN BERG'S GENERALIZED SCHEME OF REGISTERS⁴⁸

Contraction of:	Stroh bass	Chest	Mid	Falsetto	Whistle
Interarytenoids	weak	weak	medium	strong	---
Laterals	---	weak	medium	strong	medium
Longit. tension in:					
vocal muscles	small	large	medium	---	---
vocal ligaments	---	---	medium	large	---
Amplitude of vocal folds	large	large	medium	small	---
Closure time	small	large	medium	---	---
Number of partials	small	large	medium	small	---
Effect of increasing					
contr. of interaryten:					
pitch	increase	increase	increase	---	decrease
register, eventual	chest	---	---	---	chest
Contr. of laterals:					
pitch	increase	increase	increase	increase	decrease
register, eventual	chest	---	chest	mid	---
Effect of increasing					
long. tens. voc. muscles:					
pitch	increase	increase	increase	decrease	increase
register, eventual	stop	---	chest	mid	stop
Effect of increasing long.					
tens. voc. ligaments:					
pitch	increase	increase	increase	increase	increase
register, eventual	stop	mid	falsetto	---	stop
Effect of increasing flow:					
pitch	increase	increase	increase	increase	decrease
register, eventual	chest	---	chest	mid	chest

⁴⁸J. Van den Berg, "Vocal Ligaments Vs. Vocal Registers," Contributions of Voice Research to Singing, edited by J. Large (1980), p. 162.

Van den Berg also noted that an increase of airflow and subglottic pressure would eventually reach a point where the vocal folds would be thrown into vibration. The resulting adjustment would be very much like chest voice. On the other hand, transition into falsetto was very difficult and required laryngeal adjustment. Relative muscular activity as it relates to registration is demonstrated in Table IV. As well, the structural adjustments of the larynx as viewed by Van den Berg may be found in Figure 4.

Figure 4--Schemes of the Adjustment of the Larynx at Zero Flow⁴⁹

⁴⁹J. Van den Berg, "Vocal Ligaments Vs. Vocal Registers," Contributions of Voice Research to Singing, edited by J. Large (1980), p. 152.

Hollien (1979), assumedly based on self-auditory-perception, found the flute register evident among non-singers. In a survey of sixty-five pre-adolescent boys, seven of them could produce tones in flute register. In a survey of thirty-one adult women, four of them could produce flute register tones.⁵⁰

Van Deinse (1979) hypothesized the existence of two registers within the frequency range under investigation. From 1000 Hz (approximately C6) to 1500 Hz (approximately G6), Van Deinse calls the "little register" (Garde, 1951). From 1500 Hz (G6) to 2000 Hz (C7), he calls the whistle register. Both of these registers were categorized by the researcher as "first-order registers." That is, they are produced by the coordination of the muscles with the airflow, the specific action of the vocalis muscle itself, and "the coupling mechanism resonator-vocal folds."⁵¹ Van Deinse did not offer a precise physiological description of the two previously-mentioned registers.

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⁵⁰Transcripts of the Eighth Symposium: Care of the Professional Voice, Part I: Physical Factors in Production, The Voice Foundation, (June, 1979), p. 115.

⁵¹J. B. Van Deinse, "Registers," Folia Phoniatica (1981), p. 38.

Warren (1979) traced the development of vocal register theory in singing. Regarding the whistle register, Warren stated:

In this aspect, the cords are completely adducted except for the posterior end, the glottal chink. Since this area is relatively stiff (because of the vocal processes of the arytenoids) the cords themselves cannot vibrate. Phonation takes place instead by the production of eddies of air which does not depend on cord vibration. This is not considered to be a legitimate type of tone production by most voice teachers.⁵²

Rothman et al. (1980) investigated the perceptual and acoustical characteristics of different voice tonal qualities which "can represent variations in the use of the laryngeal mechanism or the vocal tract resonating system or an interactive syngerism among the two systems."⁵³ The following qualities were investigated: open tone, covered tone, whistle or flageolet tone, pure or collapsed falsetto tone, and coordinated or supported falsetto tone. The following description of the whistle tone was included in the report:

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⁵²M. K. Warren, "Theories of Vocal Registers in Singing," doctoral dissertation, University of Maryland, 1977.

⁵³Howard Rothman, Kenneth Neilsen and James Hicks, "Perceptual and Acoustical Analysis of Vocal Tones," Transcripts of the Ninth Symposium: Care of the Professional Voice, Part I: Physical Factors, Vocal Function and Control, Van Lawrence, ed., The Voice Foundation, New York (1980), p. 85.

The whistle, or flageolet, tone is related to the pure falsetto and is heard in the very highest pitches produced by the human voice. When producing whistle tone the larynx appears to be very highly elevated. The arytenoid cartilages are said to be drawn forward, the vocal folds are shortened, and the glottal chink is reduced. It is also said that the larynx is made smaller or compacted, possibly due to contraction of the inferior constrictors.⁵⁴

Rothman et al. collected fifteen sung samples of the different qualities from recordings of prominent vocal artists. Five repetitions of each sample were put on the experimental tape. Judgments were made by forty-one auditors (vocal pedagogues, professional singers, and voice scientists).

Of the five qualities investigated, the samples of whistle tone received the highest per cent agreement. Three samples of whistle tone were included on the experimental tape at frequencies of 1620 Hz (G#6), 1820 Hz (A#6), and 2160 Hz (C#7). The agreement percentages for the whistle tone samples were seventy-seven per cent, eighty-four per cent, and eighty-nine per cent; however, the authors did not indicate which frequency sample the agreement percentages applied to. Acoustical analysis of the whistle tones demonstrated only five harmonics. Each sample was characterized by a very strong fundamental (29dB-43dB)

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⁵⁴ Ibid., p. 85.

stronger than the second harmonic). Also, two of the samples contained very weak fourth harmonics. Spectrographic amplitude displays were characterized by irregular modulations ranging from 6-21dB. This, according to the authors, was due to "a lack of control and extreme tension possibly due to laryngeal constriction."⁵⁵

Rothman, Neilsen, and Hicks offered the only combined perceptual analyses of several different types of tonal qualities. Because of this, the control of fundamental frequency, vowel and intensity were not feasible. Therefore, the judgments made by the auditors in this study are based not only on timbre, but also on fundamental frequency intensity and perhaps vowel quality. It is not to say that this invalidates the researchers' data; however, caution must be used in comparing the agreement percentages of this study with the percentages of other studies where variables other than tonal quality were controlled. For example, it is the opinion of this author that the high agreement percentages for the whistle tone samples were in all probability due to the very high fundamental frequency of the samples.

From the related literature reviewed in this chapter, the following generalities may be made:

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⁵⁵Ibid., p. 87.

1. Spectral, airflow and perceptual analysis have been demonstrated to be useful in the investigation of vocal registers.

2. Three theoretical physiological descriptions of the whistle register may be found in the literature: (a) the early descriptions of Behnke (1880) and others which seem to describe what we would now consider to be the falsetto/loft register where the damping phenomenon is occurring; (b) the most common description of the whistle register (Van den Berg, 1968; Warren, 1978) which claims the phonation results from a glottal chink at the extreme posterior part of the glottis (between the arytenoid cartilages); and, (c) the description used by Husler-Rod-Marling (1978) and Rothman et al. (1980) which states the whistle register is falsetto related and characterized by an elevated larynx and overall laryngeal constriction.

3. Auditors can identify the whistle register in single tone identification tasks where, in all probability, fundamental frequency is the primary distinguishing characteristic.

4. Sound spectra of phonations in this frequency range reportedly vary from complex wave forms of approximately five harmonics to sinusoidal forms.

5. Airflow rates in this frequency range tend to be relatively small based on the very limited data available.

6. A systematic investigation of the three parameters of this study, to the knowledge of this author, does not exist.

CHAPTER III

METHODOLOGY

Introduction

Since Garcia's postulate, vocal registers have, for the most part, been viewed as being distinct "laryngeal" mechanisms. It therefore stands to reason that physiological description is the most objective and scientific element involved in register definition. In fact, in the strictest sense of register definition it is the only element involved. However, the author of this dissertation supports Schoenhard and Hollien (1982) that if registers of the voice are to be understood, they "must be operationally defined with respect to their perceptual, acoustic, physiological, aerodynamic and neurological elements/bases for both non-singers and singers as well as with respect to their laryngeal and vocal tract components."¹ In the same vein, Titze (1980) pointed out:

You need to describe the entire production process at as many levels as you can possibly do, starting all the way from the neuromuscular level to the biomechanical level,

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¹Carol Schoenhard and Harry Hollien, "A Perceptual Study of Registration in Female Singers," The NATS Bulletin, XXXIX (September/October, 1982), p. 23.

to the kinematic level, where you observe motion, and to the aerodynamic and to the acoustic levels, and finally, to the perceptual level.²

No single investigation can hope to address all of the elements previously cited. This investigation described three parameters of vocal production by comparing what the subjects believed to be whistle register with what the subjects believed to be head register. The technique used was one where pitch, phonemic category and intensity were held as constant as possible; register, therefore, was the only variable. This comparative technique was used to describe the spectral characteristics, the airflow rates and the ability of auditors to perceive the two subject-determined registers. It was determined that each parameter could feasibly be determined by source function. Thus, significant variations between the subject-determined head and whistle register phonations in the three observed parameters would support the hypothesis that a register (which is described as an actual change in

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²Ingo Titze, "Have We Learned Anything About Registers?" (panel discussion), Transcripts of the Ninth Symposium: Care of the Professional Voice, Part I: Physical Factors, Vocal Function and Control, edited by Van Lawrence, New York, The Voice Foundation, (1980), p. 130.

source function) was occurring.³ Conversely, insignificant variations between the two subject-determined registers would support the idea that a register does not exist in this part of the soprano voice.⁴ Another possible scenario would be the observation of significant variations in spectra coupled with positive auditor discrimination of the two register qualities contrasted with no or insignificant variation in airflow rates. These possible findings would seem to support the idea that the whistle register is not a true register (an actual change in source function) but instead an acoustical phenomenon probably in vocal tract configuration.

The factor reported as fundamental frequency in previous research reports was reported in this investigation as pitch. It is well known that as a singer produces an intoned phonation, there is often a degree of frequency perturbation. If this perturbation is regular and periodic it may be perceived as vibrato.

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³J. W. Van den Berg, Sound Production in Isolated Human Larynges, "Annals of the New York Academy of Science," CLV (1968), pp. 18-27.

⁴William Vennard, Singing: The Mechanism and the Technique, New York, Carl Fischer, (1968), p. 67.

As well, in a basically straight-tone production, the fundamental frequency may vary slightly over the duration of the phonation. In any case, seldom when a singer intones a phonation is the fundamental frequency held numerically constant. And, because the term fundamental frequency does imply a numerically consistent frequency, it was decided that a less precise term such as "pitch" would be a better choice. In this investigation, therefore, the term "pitch" was applied to intoned phonations which though perceptually identified as being distinct intonations, may vary somewhat in fundamental frequency. The phonations that were investigated ranged from approximately 987 Hz (B9) to 1588 Hz (G6).

The phonemic category factor should also be considered as it applied to this investigation. Phonemic/vowel potential is greatly diminished in this general frequency range of the soprano voice (987Hz to 1588Hz). It was, therefore, more easily controlled than at lower frequency areas. It is generally accepted that "recognizable vowels cannot be produced with a fundamental frequency appreciably higher than the frequency

of the first formant."⁵ Table V represents the approximate characteristic vowel formant areas for the five cardinal vowels. Reported formant areas vary somewhat (Crandall, 1924; Liddell, 1924; Paget, 1930; Peterson and Barney, 1952; and Howie and Delattre, 1962); however, the differences are not great. Table V is an "average" of reported formant areas.

TABLE V
APPROXIMATE AREAS OF CHARACTERISTIC VOWEL
FORMANTS FOR THE FIVE CARDINAL VOWELS

	/i/	/e/	/a/	/o/	/u/
Upper Formant	2500 Hz	2200 Hz	1200 Hz	850 Hz	750 Hz
Lower Formant	250 Hz	350 Hz	650 Hz	350 Hz	250 Hz

Whereas vowel consistency was crucial to the research environment in the investigation of the primary registers (approximately 261 Hz to 440 Hz), with this investigation all phonation samples are well above the lower characteristic vowel formants. It was, therefore, easier to control the variability

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⁵J. Howie and P. Delattre, "An Experimental Study of the Effect of Pitch on the Intelligibility of Vowels," The NATS Bulletin (May, 1962), pp. 6-9.

of phonemic category. Furthermore, it was reasoned that because lower vowel formants would not be a factor, variations in harmonic components would more likely be related to other (non-vowel determining) changes in vocal tract configuration and/or laryngeal function.

The intensity factor as reported in this investigation referred to relative sound pressure levels (measured in + or - decibels) above or below a mean level individually calibrated for each singer-subject.

Research Problem I Spectral Analysis

Subjects

In all, ten female volunteer singer-subjects were used. All but one of the subjects considered themselves to be coloratura sopranos. The one subject considered herself a dramatic soprano. Because the coloratura classification occurs less frequently than other soprano types, some difficulty was encountered in finding enough subjects. Each subject was an accomplished female (soprano) vocalist who, by her own admission, believed that she possessed and could isolate whistle register phonations at the prescribed pitch levels. All subjects were either professional singers or advanced graduate-level voice students.

Three of the subjects who volunteered had great difficulty in isolating the registers during the recording sessions. By their own admission, were never exactly sure which register they were in. The method of this research necessitates subject determination of the register they are supposedly in during each phonation. Because of this, it was impossible to utilize the phonation samples of these three subjects. Therefore, only seven of the original ten subjects were used in the analysis.

Collection of Tone-Pair Samples

Tone-pair samples were taken at the following pitches when possible: B5, C6, C#6, D6, D#6, E6, F6, F#6, and G6. The number of samples taken from each subject was determined by how many pitches the subject could comfortably sing at the time the samples were taken. The tone-pair samples consisted of two different phonations. One was what the subject considered to be upper/head/loft/falsetto registration; that is, the same registration she would normally use in the octave below the frequency range being investigated. The other phonation was one which the subject considered to be whistle/flute/bell register. Pitch was held

relatively constant for each tone-pair sample. In addition, the subjects were asked to match the intensity levels of the tone-pair phonations as closely as possible (sound pressure level was monitored). At this frequency range, a great deal of vowel "neutralization" had occurred because the frequencies under investigation were all well above the lower characteristic vowel formants. However, an effort to control vowel quality was made by having the subjects perform the tasks as closely as possible to the vowel /a/. This resulted in a very consistent "open vowel" production from each singer-subject. Through a pilot study investigation of five subjects, a task had been designed to help the subjects correctly produce what they considered to be the two different registers. This task is shown in Figure 5.

Figure 5 --Task (A) for Register Isolation
(Head/Loft Register vs. Whistle/Flute Register)

Tone-pair samples were collected as shown in Figure 5. Also, subjects were asked to isolate the two registers by merely singing the prescribed pitch without the aid of task (A) as shown in Figure 6, Task B.

Figure 6--Task (B) for Register Isolation
(Head/Loft Register vs. Whistle/Flute Register)

Tone-pair samples were used only when the subject felt that she was able to produce the tone pair in two different registers. The number of pitches a given subject could produce in what she considered to be the two different registers varied from subject to subject.

Samples were recorded with a studio-quality Ampex reel-to-reel recorder using a Teac Model ME-50 microphone at a flat response setting. Samples were recorded on Ampex Grand Master audio tape (1.5 mil, 1/4 inch). An acoustically-treated room provided a very favorable recording environment. A sound pressure meter was used

to assist the subjects in maintaining consistent intensity levels between the head and whistle register phonations. Pitches were given to the singer-subjects on a conventional chromatic pitch instrument.

Analysis of the Tone-Pair Samples

Spectral displays, as well as signal displays, were made of each of the tone pair samples with the aid of the acoustical analyzing functions of the Synclavier Unit of the School of Music at North Texas State University. A doctoral student in music composition at North Texas State University, expert in the functions of the Synclavier Unit, assisted in the production of all the spectral and signal displays. Samples of the spectra were taken via a Hanning window which samples a portion of the tone .020480 seconds in duration. In each case, it was the intent of the investigators to sample enough "pieces" of each phonation to get an overall picture of the spectral nature of that particular phonation. Through trial and error, it was discovered that the number of spectral displays needed to demonstrate the spectral nature of the phonations varied from approximately 5 to 15 per phonation according to the length of the phonation as well as the overall complexity of the signal. With each sample, spectral

displays were taken of the attack, the steady-state, and the decay portions of the phonations. Where substantial amplitude perturbation existed, it was determined that taking spectral samples of adjacent amplitude peaks and valleys would also be advantageous in obtaining a true idea of the spectral characteristics.

The spectral analyses were displayed on a video monitor. Hard copy was obtained by photographing the spectral and signal analyses displayed on the video monitor. Photographs were made using a Nikon 35 mm camera model FG-20. The camera was set on a tripod approximately one foot from the video screen. The close-up photography was facilitated by the use of Samigon 52 mm micro-lenses. With the shutter speed set on the automatic position, it was possible to make the photographs using only the light available from the video monitor screen. The lens aperture was set at 5.6 and 200-speed Kodak film was used.

The spectral characteristics of the individual phonations supposedly produced in the head and whistle registers were compared by observation of the following parameters: 1) the total number of harmonics present in each sample, 2) the highest harmonic present in each sample, 3) the characteristic shape of the spectrum, and 4) the relative amplitudes presented in the signal displays of each tone pair.

Research Problem II Airflow Analysis

One aspect of phonation is that of aerodynamics. Four quantifiable parameters of vocal aerodynamics are subglottal pressure (P_{sub}), supraglottal pressure (P_{sup}), glottal resistance (GR), and mean flow rate (MFR). The four parameters are related as shown below:

$$P_{sub} - P_{sup} = MFR \times GR^6$$

With open vowels, when phonation occurs with an open tract, supra glottal pressure is equal to the atmospheric pressure. With this condition, P_{sup} is not a factor. Therefore:

$$P_{sub} = MFR \times GR^7$$

Measurements of these parameters are often used in the assessment of vocal function. Measurement of subglottal pressure requires invasive methods which carry with them the possibility of complications (i.e., tracheal puncture, esophageal balloon and transglottal catheter). The measurement of mean flow rate is a non-invasive technique often used in research and clinical settings. MFR may be measured by three

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⁶Ibid., p. 25.

⁷Ibid., p. 25.

apparatus: the pneumotachograph, the spirometer, and the hot-wire anemometer. Glottal resistance is determined mathematically and cannot be measured directly.⁸

Only differences in MFR have been consistently demonstrated to be related to variation in vocal register. MFR is obtained by dividing the total volume of air used during a maximum sustained phonation or a pre-determined period of phonation divided by the phonation duration. Normal values of MFR range from 89 to 141 ml/sec among adult subjects phonating in modal/chest register at habitual pitch and loudness.⁹ The relationships of MFR to variations in vocal register were reported in Chapter II.

The airflow analysis for this study was conducted at the cardiopulmonary laboratory of Westgate Hospital in Denton, Texas. Technical assistance for this part of the research was provided by Westgate Hospital. Four of the seven subjects used in the spectral analysis were also able to volunteer for airflow rate measurements.

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⁸Ibid., p. 39.

⁹Ibid., p. 27.

In order to obtain mean flow rates, it was necessary to observe two variables: 1) the total volume of air used during the phonation, and 2) the duration of the phonation. The subjects were asked to perform Task (B) into a mouthpiece which in turn was coupled to a Pulmo-Lab Spirometer Series 4000. Air used during the phonation passed through the mouthpiece and into the connecting spirometer which displayed the volume of air exhaled. Volumes were graphically displayed and measured by caliper. All volume displays were measured by the registered respiratory therapist assisting with the research.

The durations of the phonations were timed electronically so as to insure accurate mean flow rate readings. The digital time counter used in the procedure was set to measure in hundredths of a second. The counter was a manually-activated (push-button) type. It was soon discovered that activation of the time counter was best performed by the subjects themselves. Each subject was trained prior to the procedure how to use the apparatus. With the use of a metronome, each subject was trained to sing phonations of approximately four seconds in duration as well as to accurately stop and start the time counter. In addition, each

subject was trained to glottally stop the flow of breath after each phonation so that the volume of air measured was only that of the phonation and not that of an expiratory breath after the phonation. Each subject was allowed as many trial runs as necessary to feel comfortable with the apparatus.

The mechanical lapse time required to stop and start the digital time counter was estimated at less than .25 seconds. Because of the comparative nature of this part of the study, however, it was not viewed as a problem in the research procedure. Though somewhat affecting the accuracy of the MFR readings themselves, because the variable would be the same in both the head and whistle register phonations, it therefore would not affect comparison of MFR between the registers.

Sound pressure levels were observed during the procedure to determine whether or not the subjects were successfully matching intensity levels. A microphone contacting the spirometer mouthpiece was connected to a sound pressure meter which measured in decibels relative to a calibrated average sound pressure level. The sound pressure meter was calibrated for each

individual subject. Readings were in + or - decibels above or below the point of calibration for each phonation sample.

The mean flow rates of the individual phonations supposedly produced in head and whistle registers (according to the subjects' own perceptions) were calculated and compared. Differences in the mean flow rates between head and whistle register phonations were tested for significance. As well, the observed relative sound pressure levels for the whistle and head register phonations were compared. Differences in sound pressure levels between the whistle and head register phonations were tested for significance.

Research Problem III Perceptual Analysis

It was the purpose of this parameter of the study to determine whether or not the whistle and head registers could be perceptually discriminated by both expert and naive auditor groups on the basis of voice quality alone. The auditors consisted of two groups. Group (1) was made up of seventeen university/college level vocal music instructors. Group (2) served as a control group and consisted of twenty naive auditors. The naive auditor group consisted of non-music major

students who volunteered from the student population at East Central University, Ada, Oklahoma. The expert group consisted of vocal music teachers from various colleges and universities.

The ability of auditors to discriminate between the two subject-determined registers was tested. From the recordings made during the sample collection process, forty tone pairs produced at varying pitch levels were extracted. Based upon the subjects' determination, the phonations were ordered according to register in the following fashion: whistle/whistle, head/head, whistle/head, head/whistle. The total number of samples (40) were broken down into ten of each of the above categories. The liberty was taken to electronically equalize sound pressure levels when there existed a notable difference. This was to prevent any judgments being made by attending to intensity rather than timbre/sound quality.

The tone pairs were presented to the auditors by means of a studio quality sound reproduction system. During the instructions prior to the testing, register terminology was not used in order to minimize any bias effect toward the hypothetical register being investigated. Auditors were asked merely to judge the tone

pairs as same or different in regard to timbre and tone quality.

The forty-item test was administered twice in order to obtain an estimate of auditor reliability. It was reasoned that a percentage of identical responses significantly above chance would suggest that the auditors were consistent in the discrimination of the two register qualities.

Agreement and reliability percentages were calculated and tested for significance. In addition, the discrimination abilities of the two auditor groups were compared.

CHAPTER IV

RESULTS

Research Problem I Spectral Analysis

Photographs of the video displays of the spectral analyses were made. In all, there were four hundred seventy photographs made of twenty-four tone pairs produced by the seven subjects at seven different frequency levels. During the analysis, the following parameters were observed: 1) the total number of harmonics present in each sample, 2) the highest harmonic present in each sample, 3) the characteristic shape of the spectrum (i.e., the relationship of a particular harmonic to those surrounding it, missing harmonics, or the relationship of the partials to the fundamental), and 4) the relative amplitudes presented in the signal displays of each tone pair. Only the steady-state portions of the phonation samples were used in the analysis. Spectrograms of the attack and decay portions of the tone were taken with each phonation sample; however, no structural consistencies were observed. Spectra of the attack and decay portions of the phonations tended to be asymmetrical and highly variable, both within and between subjects.

Description of the Acoustical Displays*

The signal displays are merely a compression of the entire sound wave. For the purposes of this investigation, they were used to compare the relative amplitude of the head and whistle register phonations in each pair. As well, they allowed the comparison of relative amplitude perturbation.

The spectral displays allowed for the analysis of the complex waveform. The Synclavier spectral analysis package computed and displayed the frequency components of a sample of the waveform via a spectral window. The Synclavier provided a choice of three window shapes: 1) rectangular or boxcar, 2) Hanning or half cosine bell, and 3) Hamming, a slight modification of the Hanning window. The boxcar window normally allows a severe amount of spectral energy leakage from a frequency component into other frequencies of the spectrum. Hanning and Hamming windows, however, produce a spectral display which corresponds very closely to the spectrum of the waveform being sampled. Therefore, the Hanning window was chosen for this investigation. The Hanning window extracts a sample of the sound .020480 seconds in duration.

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*See Appendix I.

The vertical scales on the displays are logarithmic spectral density scales. This scale correlates to decibels and was useful in comparing relative amplitudes (i.e., comparison of the relative strengths of the harmonics to the fundamental).

The horizontal scale is the frequency scale. It demonstrates the harmonic components of the sound in kilohertz. This scale could be adjusted up or down in order to obtain maximum visual clarity. For example, if the frequency scale were set at an upper limit of 20 kHz, yet no demonstrable harmonics were apparent past 10 kHz, then the scale would be moved back to an upper limit of 10 kHz, thereby magnifying and enhancing the visual clarity of the display.

Quantification of Harmonic Components

The mean number of harmonics for each phonation was determined by adding all the harmonics observed in each spectral display and then dividing that sum by the total number of displays.

Overall, head register phonations were characterized by a larger number of harmonics than were the whistle register phonations. Table VI presents the mean number of harmonics observed per subject and pitch.

TABLE VI
MEAN NUMBER OF OBSERVED HARMONICS PER SUBJECT
AND PITCH

<u>Head Register</u>							
<u>Pitch</u>	<u>Subject</u>						
	1	2	3	4	5	6	7
B5			13	7.5			10.25
C6	10.4		13.6		8.1	9	10.28
C#6	10.2		12.3	6.4	7.8		9.24
D6		11.4	12.5		9.5		10.23
D#6	8		13.3		8		8.75
E6			11		8		9.5
F6	11				8.5	9.8	9.77
	9.9	11.4	12.62	6.9	8.32	9.4	8.58

<u>Whistle Register</u>							
<u>Pitch</u>	<u>Subject</u>						
	1	2	3	4	5	6	7
B5			9.25	4.4			6.83
C6	9		10.2		9	5	8.3
C#6	8.2		8.6	4.2	7.6		7.22
D6		8.4	9.3		9.2		8.25
D#6	7.5		10.3		8.6		6.7
E6			8.4		8.8		8.6
F6	7.4				6.8	6.2	6.8
	8.03	8.4	9.34	4.3	8.33	5.6	7.48

It is indicated in Table VI that in both registers the number of observed harmonics was relatively consistent within subjects, but quite variable between subjects. Between-subject variability ranged from 12.62-6.9 observed harmonics per phonation in the head register to 6.9-4.3 harmonics per phonation in the whistle register. On the other hand, the number of harmonics per specific pitch was somewhat less variable (head, 10.29-9.24; whistle, 8.79-6.8). In addition, each subject, except Subject 5, exhibited more harmonics in the head register phonations than in the whistle register phonations. With Subject 5, however, the mean number of harmonics were practically identical with the head register having an average of 8.32 harmonics per phonation while the average whistle register phonation exhibited 8.33 harmonics.

The data from all the subjects was combined for further analysis. As demonstrated in Table VII the analysis of the combined data showed the overall mean number of harmonics present in head register to be greater than the overall mean number of harmonics present in whistle register. Furthermore, an analysis of variance demonstrated this difference to be significant.

TABLE VII
OVERALL MEAN OF HARMONICS OBSERVED IN
HEAD AND WHISTLE REGISTER PHONATIONS

Register	Mean	Standard Deviation
Head	9.69	2.07
Whistle	7.87	1.64

TABLE VIII
ANALYSIS OF VARIANCE OF THE NUMBER OF
OBSERVED HARMONICS PRESENT IN HEAD
AND WHISTLE REGISTERS

Source of Variation	Sum of Squares	df	Mean 5 Square	F
Between group	37.19	1	37.19	9.377*
Within group	182.44	46	3.97	
Total	219.63	47		

*p<.05

The highest observed or "ultimate" harmonic was determined for each phonation by locating the last (highest in frequency) demonstrable harmonic in the spectral display samples. Overall, head register phonations were characterized by a greater ultimate harmonic than were the whistle register phonations. Table IX lists the highest observed harmonic per subject and pitch.

Again, it was noted that variability between subjects was somewhat greater than variability between pitches. As well, each subject, except Subject 5, exhibited a higher average ultimate harmonic in the head register phonations than in the whistle register phonations. With Subject 5, the average ultimate harmonic was identical. As can be expected, the data compares closely to the data regarding the mean number of harmonics.

A pooling of the data from all subjects exhibited an overall mean highest observed harmonic of 12.46 in the head register, while the overall mean highest observed harmonic in whistle register was 10.42. An analysis of variance (presented in Table X) demonstrated this difference to be significant.

TABLE IX
HIGHEST OBSERVED HARMONIC PER SUBJECT
AND PITCH

<u>Head Register</u>							
<u>Pitch</u>	<u>Subject</u>						
	1	2	3	4	5	6	7
B5			16	10			13
C6	12		18		14	10	13.5
C#6	15		17	8	11		12.4
D6		15	14		10		9
D#6	10		15		11		12
E6			15*		11		13
F6	12				12	11	11.67
	12.75	15	15.8	9	11.5	10.5	10.66

<u>Whistle Register</u>							
<u>Pitch</u>	<u>Subject</u>						
	1	2	3	4	5	6	7
B5			10	7			8.5
C6	11		17		12	6	11.5
C#6	11		10	6	11		11
D6		10	13		14		10
D#6	9		11		13		9
E6			13		11		12
F6	9				8	8	8.33
	10	10	12.3	6.5	11.5	7	10

*See Appendix I, p. 166. Head Register Display showing the highest harmonic observed at approximately 20,000 Hz.

TABLE X
ANALYSIS OF VARIANCE OF THE HIGHEST OBSERVED HARMONICS
IN WHISTLE REGISTER AND HEAD REGISTER PHONATION

Source of Variation	Sum of Squares	df	Mean Square	F
Between group	50.02	1	50.02	7.380*
Within group	311.79	46	6.78	
Total	361.81	47		

* $p < .05$

Observation of the Spectra

Characteristic shape of the spectrum required a more subjective evaluation. Because of the individual spectral nature of each singer-subject, evaluation of this parameter was best treated on an individual basis. As well, measurements of amplitude as demonstrated by the signal displays were subject to variability despite the fact that factors such as distance from the microphone and recording level were controlled as carefully as possible.

Subject 1 (C6, C#6, D#6, F6)
Acoustical Displays 1-7*

This subject exhibited a typical stair-step spectral display on all four head register phonations. Head register phonations were also characterized by a very strong fundamental relative to the partials.

During the C6 and C#6 whistle register phonations, a subordinate fourth harmonic was evident; however, this characteristic was not observed during the phonations produced on D#6 and F6. Head register phonations were generally greater in amplitude than those in the whistle register.

Subject 2 (D6)
Acoustical Displays 8-9

The whistle register phonation was characterized by a slight subordination of the second harmonic. The head register phonation was displayed in the typical stair-step pattern. During the whistle register phonation, the signal display demonstrated an unusual amount of amplitude perturbation while the two phonations were very similar in regard to peak amplitude.

Subject 3 (B6, C6, C#6, D6, D#6, E6)
Acoustical Displays 10-18

Head register phonations tended to be more symmetrical (stair-step) than did the whistle register phonations.

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*See Appendix I for displays.

No consistent pattern was found during the whistle register phonations; however, a subordinate second harmonic was found periodically during the production of both registers. All samples were relatively close in amplitude except for the sample produced on B6. As with the other subjects, Subject 3 found it very difficult to produce a whistle register phonation with anything other than a very "soft" production. Though observed amplitude peaks were very similar, there was a greater degree of amplitude perturbation during the production of the whistle register phonations.

Subject 4 (B5, C#6)
Acoustical Displays 19-22

The whistle register phonation exhibited a slight subordination of the second harmonic while the head register phonation was symmetrical (stair-step) during the B5 tone-pair. Typically, the amplitude was very low on the whistle register sample. Amplitudes were much closer on the C#6 sample though both tones were basically asymmetrical with no notable structural trends.

Subject 5 (C6, C#6, D6, D#6, E6, F6)
Acoustical Displays 23-31

During the analysis of subject 5, a very distinct pattern emerged. While the six head register phonations were typically stair-step in their spectral structure,

the whistle register phonations were all typified by a consistent subordination of the second harmonic. In addition, the relationship of the partials to the fundamental was consistently stronger in head register phonations than in whistle register phonations. As well, peak amplitude and amplitude perturbation was more pronounced in the head register phonations.

Subject 6 (C6, F6)
Acoustical Displays 32-33

The analysis of Subject 6 demonstrated symmetrical stair-step patterns in both register phonations, the only noticeable variation being the previously cited numerical differences. The head register phonations were typically stronger in amplitude on the C6 sample while amplitudes were well equalized on the F6 sample.

Subject 7 (C#6, D6, D#6)

As with Subject 5, a very consistent pattern of a subordinate second harmonic was again in evidence. Whistle register phonations were characterized by a very consistent subordination of the second harmonic while the head register phonations were symmetrical. Peak amplitude and amplitude perturbation was somewhat less pronounced in the whistle register phonations.

Table XI presents an overview of the comparisons made during the acoustical analysis.

TABLE XI

SUMMARY OF COMPARISONS: ACOUSTICAL ANALYSIS
OF TONE PAIRS, WHISTLE VS. HEAD

Subject	Number of Observed Harmonics	Highest Observed Harmonic	Peak Amplitude	Amplitude Perturbation	Structural Characteristic	
					$\underline{W}$	$\underline{H}$
1	$W < H$	$W < H$	$W < H$	$W = H$	Subordinate Fourth Harmonic	Stair- Step
2	$W < H$	$W < H$	$W = H$	$W > H$	Subordinate Second Harmonic	Stair- Step
3	$W < H$	$W < H$	$W = H$	$W > H$	Asymmetrical	Stair- Step
4	$W < H$	$W < H$	$W < H$	$W = H$	No Trend	No Trend
5	$W = H$	$W = H$	$W < H$	$W < H$	Subordinate	
6	$W < H$	$W < H$	$W < H$	$W < H$	Second Harmonic	Stair- Step
7	$W < H$	$W < H$	$W < H$	$W < H$	Stair- Step Subordinate Second Harmonic	Stair- Step Stair- Step

Spectral analysis of the tone pairs demonstrated the following trends:

1) Head voice phonations generally have a greater number of harmonics than do whistle register phonations (9.69 head vs. 7.87 whistle). An ANOVA demonstrated this difference to be significant. Only Subject 5 varied from this trend, and with her, the mean number of harmonics were practically the same (8.32 head vs. 8.33 whistle).

2) Head voice phonations generally have a higher "ultimate" harmonic than do whistle register phonations. The mean highest observed harmonic of all the head register phonations was 12.46, while the mean of the highest observed harmonic of the whistle register phonations was 10.42. An ANOVA demonstrated this difference to be significant. Only Subject 5 varied from this trend, and with her, the mean highest harmonics were equal.

3) Whistle voice phonations tended to be less in amplitude as demonstrated by the total signal displays. This trend was most obvious in the lower frequencies sampled. Amplitude tended to equalize in the mid to upper frequency samples. Amplitude perturbation was highly variable.

4) Symmetrical stair-stepped displays were more common in head register phonations than in whistle register phonations.

5) The relative strength of the partials to the fundamental tended to be higher in head register phonations.

6) A distinct pattern of a subordinate second harmonic occurring in the whistle register phonation was noted consistently with two of the subjects and was sporadically demonstrated elsewhere.

Research Problem II Airflow Analysis

Sixty-two tone pairs produced by four of the singer-subjects were investigated. Each frequency pair investigated was measured whenever possible so as to insure an accurate MFR reading. As demonstrated in Table XII, Mean Flow Rates varied significantly in all four subjects. With three of the subjects, the MFR was greatest during the head register phonation. With one subject, the MFR was greatest during the whistle register phonations.

TABLE XII

SUMMARY OF CORRELATED t-TEST FOR HEAD REGISTER PHONATIONS
AND WHISTLE REGISTER PHONATIONS

Subject	M(Head) Mean Flow Rate in ml/sec	SD	M(Whistle) Mean Flow Rate in ml/sec	SD	df	t
1	129	19.52	143.74	20.43	19	-4.703*
3	156.38	21.26	119	11.73	16	6.023*
4	352.94	28.39	246.5	40.84	16	9.224*
7	353.73	47.13	202.61	29.67	9	7.987*

*p .05.

All four subjects, including Subject 1 who had the negative variance, had difficulty qualizing sound pressure levels under the research condition. Though relatively insignificant in regard to perceptable loudness, mean sound pressure levels revealed a significant positive difference with each subject, as demonstrated in Table XIII.

TABLE XIII

SUMMARY OF CORRELATED t-TEST FOR HEAD REGISTER PHONATION
AND WHISTLE REGISTER PHONATION SOUND PRESSURE LEVELS

Subject	M(Head) Sound Pressure Level	SD	M(Whistle) Sound Pressure Level	SD	df	t
	+ or - db		+ or - db			
1	2.21	1.81	.63	1.92	19	3.75*
3	5.94	2.02	3	1.83	16	6.031*
4	5.69	3.16	1.75	4.65	16	5.331*
7	3.37	1.01	2.11	.782	9	5.291*

*p<.05

With this evidence, it was necessary to consider the possibility of the variance in amplitude being directly related to the variance in MFR. An item-by-item analysis of the data, however, revealed ten tone-pair samples in which the sound pressure levels of the whistle register phonations were equal to or greater in decibels than the head register phonations. Yet, in none of these instances were the differences in MFR also equal or reversed in order.** In addition to this was the situation involving Subject 1. As pointed out earlier, Subject 1 was the only subject to produce

**See Appendix II.

phonations in which the whistle register MFRs were greater than those of the head register phonations. Yet, the analysis of the sound pressure levels showed the head register phonations to be significantly greater, which, of course, was in agreement with the other singer-subjects. These factors caused this researcher to disregard the possibility of a cause-and-effect relationship between the two variables.

Investigation of airflow rates revealed the following trends:

1) A significant change in airflow occurred between head register phonations and whistle register phonations in all subjects.

2) In three of the four subjects, mean flow rate was greater in the head register phonations than in the whistle register phonations.

3) Airflow rates were consistent within each subject but highly variable between subjects.

Research Problem III Perceptual Analysis

The ability of auditors to discriminate between the two subject-determined registers was tested. Table XIV presents the proportion of correct responses (i.e., agreement with the intentions of the singer-subjects) obtained

for the procedure in which the two auditor groups judged the similarity or dissimilarity of voice quality for the paired phonations. The expert and naive auditor groups were compared to a hypothesized chance agreement percentage of 50. Both auditor groups were able to agree with the intentions of the singer-subjects at a level significantly above chance. It was obvious from these data that both the expert and naive auditor groups were able to discriminate between the two subject-determined registers (head and whistle) with a high degree of accuracy.

TABLE XIV
SUMMARY OF INDEPENDENT t-TEST AUDITOR
GROUP DISCRIMINATION

Auditor Group	Mean Agreement Percentage	Range	SD	Hypothesized Mean	df	t
Expert	82.16	65-91.25	7.56	50	16	4.136*
Naive	75.52	61.25-88.75	7.18	50	19	3.469*

* $p < .05$

The forty-item test was administered twice in order to obtain an estimate of auditor reliability. It was reasoned that a percentage of identical responses

significantly above chance would suggest that the auditors were consistent in their discrimination of the two register qualities. Further analysis did demonstrate that both auditor groups were reliable with their discriminations. Table XV represents an independent t-test demonstrating that the actual proportion of identical responses of both auditor groups was significantly higher than the hypothesized identical response proportion of 50.

TABLE XV
SUMMARY OF INDEPENDENT t-TEST AUDITOR
GROUP RELIABILITY

Auditor Group	Mean	Range	SD	Hypothese-	df	t
	Reliability Percentage			sized Mean		
Expert	79.06	70-92.5	9.89	50	16	2.855*
Naive	72.5	55-82.5	7.74	50	19	2.838*

* $p < .05$

Also, as demonstrated in Table XVI, an analysis of variance revealed a significant difference between the expert and naive auditor groups in regard to discrimination ability. This led to the obvious conclusion that training

does have an effect on the ability to discriminate these register quality differences.

TABLE XVI
ANALYSIS OF VARIANCE OF DISCRIMINATION ABILITIES
FOR EXPERT AND CONTROL AUDITOR GROUPS

Source of Variation	Sum of Squares	df	Mean Square	F
Between treatment	404.75	1	404.75	7.482*
Within treatment	1,893.35	35	54.10	
Total	2,298.11	36		

* $p < .05$

Mean agreement percentages were tabulated for each individual subject as well as for each pitch. As seen in Table XVII, Subject 4 had the highest agreement percentage at ninety per cent while Subject 1 had the lowest at sixty-six per cent. Likewise, the pitch with the highest agreement percentage was E6 at ninety-three per cent, while the lowest agreement percentage was seventy-six per cent only on half step lower at D#6.

TABLE XVII
MEAN AGREEMENT PERCENTAGES FOR SUBJECT
AND PITCH

Subject	Mean	Pitch	Mean
1	66	B5	87
2	76	C6	83.5
3	83	C#6	81
4	90	D6	82
5	88	D#6	76
6	79	E6	93
7	82	F6	77

The results of the perceptual analysis were summarized as follows:

- 1) Auditors were able to discriminate between the two subject-determined registers.
- 2) Auditors were consistent in their discrimination of the two register qualities.
- 3) The expert auditor group was able to discriminate the register quality differences at a rate significantly higher than the control auditor group.
- 4) The data indicated that the head and whistle registers are perceptually identifiable entities.

CHAPTER V

CONCLUSIONS

Summary

Since the writings of the medieval theorists, a great deal of misinformation has been disseminated regarding the existence, source and pedagogical implications of vocal registers. Indeed, the derivations of many of the common register terms in contemporary usage, such as chest register and head register, are products of this misinformation. However, recent advances in the understanding of vocal production have led informed individuals within the profession to general agreement as to what constitutes a register in the human voice.

Register--an adjustment of the larynx which produces phonations of a particular quality for a particular frequency range

Singers and non-singers alike exhibit at least two registers which are determined by laryngeal adjustment. These two different mechanical modes of production may be thought of as the primary registers, and have for some time been a primary

component of the myoelastic-aerodynamic theory of voice production (Muller, Garcia, Zimmerman, Pressman, Luchsinger, Arnold, Vennard, Van den Berg, Appleman, Large, Hirano, Hollien, et al.). However, it is with the singing voice that many gray areas become evident. One such area is the so-called whistle register of the soprano voice.

The most complete physiological description of the hypothetical register was offered by Van den Berg. Basically, Van den Berg described an adjustment of the larynx where the lateral cricoarytenoids are active while the interarytenoids and the cricothyroid are inactive. Stated another way, medial compression alone occurs without the forces of primary adduction or paratasis. The adjustment supposedly results in a small triangular opening occurring at the posterior part of the glottis between the arytenoid cartilages through which a sort of labial whistle occurs instead of regular cordal vibration.¹

The whistle register hypothesis had been both demonstrated and refuted through laryngoscopic/stroboscopic investigation. Early investigations by

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¹J. W. Van den Berg, "Vocal Ligaments vs. Vocal Registers," The NATS Bulletin, XXXI (December 1963), pp. 16-21.

Behnke, Proschowsky and others were hampered by the fact that when the larynx is vibrating at high frequencies, it may appear to the unaided eye as an open-glottis mechanism through which a sort of "whistling" might be taking place. And, as discussed in the review of related literature, the validity of instrumentation using the stroboscope has long been problematically viewed. Furthermore, research done with excised larynges has demonstrated the existence of such a register; however, the limitations of drawing any conclusions from the investigation of excised larynges are obvious. In any case, there existed a continuing need to examine this frequency range of the female singing voice.

Two obvious investigative tools which could have directly investigated this hypothesis were found to have limited applicability to this study. Electro-myography is an invasive technique requiring the implantation of electrodes into the intrinsic musculature of the larynx. This, of course, was not a viable alternative for live singer-subjects. The second consideration was fiber optics laryngoscopy and high speed photography. At the present, however, technological limitations render this tool ineffective. Because of the difficulties of directly investigating

this hypothesized register adjustment in live singer-subjects at this time, it was determined to investigate three parameters of vocal production which have proven to be useful in operationally defining the primary registers.

The purpose of this study was to investigate specific elements of the portion of the female voice commonly referred to as whistle or flute register. Three problems were included in this investigation.

The first problem was to investigate the spectral characteristics of phonations which the singer-subjects believed to be produced in whistle register. Sonninen (1961), Van den Berg, (1968), Colton (1972), and Large (1974) found significant spectral differences between the two primary registers. For this study, it was determined to compare the spectral characteristics of subject-determined head and whistle register phonations to ascertain if differences in the spectral characteristics of the two registers existed. Investigation of these possible differences was implemented by using a paired-tone technique where pitch (fundamental frequency), intensity and phonemic category were all held relatively constant; register, therefore, was the only variable. A change in register would obviously result in a change of spectra. However, a

change in the spectral characteristics may be a result of a change in vocal tract configuration. In other words, spectral variation may or may not indicate register variation.

It was decided, therefore, to include the second problem: to investigate the airflow rates of phonations which the singer-subjects believed to be produced in whistle register. Roudet (1900), McGlone (1970), and Large (1970) et al. found differences to exist in mean flow rates between the primary registers as well as between glottal fry and modal register. If other variables are held constant, a change in register should result in a change in airflow.

The third problem was to determine if the phonations which the singer-subjects felt were produced in whistle register could be perceptually identified on the basis of voice quality alone. Findings of previous studies had indicated that auditors were able to identify other register areas on the basis of voice quality alone (McGlone and Brown, 1969; Lerman and Duffy, 1970; Colton and Hollien, 1973; Large, 1974; Beard, 1980; and Schoenhard and Hollien, 1982).

Spectral Analysis

The spectral analysis clearly exhibited two differences. First, the number of harmonics evident in whistle register phonations was found to be less than the number evident in head register phonations. Secondly, the highest observed harmonic was found to be lower in the whistle register phonations and higher in the head register phonations. Past research has reported the spectra of tones produced in this frequency range to be characterized by wave forms of sinusoidal nature to approximately five harmonics (Belussi and Cerciello, 1954; Luchsinger and Dubois, 1956; Rothman et al., 1980). In contrast, this research found phonations in this frequency range in the subject-determined head register to be characterized by a mean of 9.69 harmonics while phonations in the subject-determined whistle register were characterized by a mean of 7.78 harmonics.

In addition, in one sample of head register phonation at the pitch D#6, a total of fifteen harmonics was observed. As well, on the pitch G6, which was the highest frequency observed in this investigation, one particular whistle register phonation

contained a sample exhibiting eleven harmonics.* Further contrasting with past research, in no instance was a phonation observed exhibiting a sinusoidal form.

A third spectral variation between head and whistle register phonations was less clearly defined, but evident none the less. The characteristic shape of the spectra often denoted the register in which the subject believed herself to be singing; however, with only two subjects was this "spectral signature" consistent, that being the subordinate second harmonic discussed in the results. Other than the subordinate second harmonic, it was generalized that the head register phonations tended to be more symmetrical (the typical stair-step shape) than those of the whistle register, and that the relative strength of the partials to the fundamental tended to be less in the whistle register phonations and greater in the head register phonations.

Airflow Rates

As with the spectral differences, the differences in mean flow rate were clearly defined. A significant

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*See Appendix I, #42, p. 166.

change in mean flow rate occurred between the head register and whistle register phonations with all subjects. Only one anomaly occurred. While three of the subjects investigated typically demonstrated greater mean flow rates in the head register phonations, one subject (Subject 1) reversed the trend and demonstrated greater mean flow rates in the whistle register phonations. As reported in past research, mean flow rates were found to be consistent within subjects but highly variable between subjects.²

The Problem of Intensity

The ideal situation in a comparative study of vocal registration, such as this, was to maintain a research environment where pitch, phonemic category, and sound pressure level are all held constant, register therefore being the only variable. Pitch and vowel quality were easily controlled by the singer-subjects; however, it was soon discovered that maintaining a constant sound pressure level between the different registers at frequencies this

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²John Large, et al., "The Primary Female Register Transition in Singing," Folia Phoniatrica, XXII (1970), pp. 385-396.

high was an arduous task indeed for the singer-subjects. Past research at lower frequency levels of vocal production had indicated that both harmonic structure and airflow are affected by vocal intensity (Large, 1968; McGlone, 1970; Large, et al., 1970; and Colton, 1972). At any rate, a causal relationship had to be investigated.

Careful investigation of the data revealed that in the subjects' attempts to equalize intensity levels, enough "equalized" tone-pair samples were evident to determine whether or not sound pressure level was significantly influencing differences in mean flow rate and sound spectra. It was determined that invariably, significant differences in both the airflow and spectral characteristics existed sample for sample, whether the sound pressure variable was held constant or not. For example, if a causal relationship existed in the research procedure between mean flow rate and sound pressure level, then it would stand to reason that as sound pressure level in the whistle register phonations equalized or became greater than those in the head register phonations, mean flow rates in the whistle register would also equalize or become greater. However, in

no instance did this happen. This was not to say that more extreme variations in intensity would not influence mean flow rate; however, it did demonstrate that the slight, though numerically significant, differences in sound pressure levels had no causal relationship to the observed mean flow rates.

In addition was the situation with Subject 1 who exhibited mean flow rates greater in the whistle register phonations. If there was a cause and effect relationship, sound pressure levels would also be greater in whistle register. This, of course, as the data showed, was not the case. Indeed, the sound pressure levels were found to be significantly greater in the head register phonations than in the whistle register phonations.

Perceptual Discrimination

Perception is an auditory manifestation of the harmonic components of a phonation. It therefore stands to reason that if the spectral variation which existed between the whistle and head register phonations was vigorous enough, auditors should be able to perceive that variation. Indeed, the ability of auditors to discriminate the register qualities was verified.

Both expert and naive auditor groups were able to agree with the intentions of the singer-subjects at a level significantly above chance, thus inferring that what the subjects believed to be whistle register was indeed a perceptually identifiable entity.

The Problem with Subject 1

During the analysis of the perceptual data, it became clear that phonations produced by Subject 1 were more difficult to discriminate than those of the other six subjects (sixty-six per cent compared to a mean of eighty-two per cent). Subject 1 was also the only subject whose variance in mean flow rates was reversed, or in other words, the only subject whose whistle register mean flow rates were greater than the head register mean flow rates. As well, spectral variations were exhibited, but not as markedly as with some of the other subjects. In any event, it became difficult not to speculate as to whether or not Subject 1 was indeed experiencing the same "transition" as the other six subjects.

Speculation

The whistle register was an identifiable entity based upon the three research parameters of this study.

It does exist, but is it a "true register" in the laryngeal/physiological sense? It was not the intent of this research to set out to prove or disprove the existence of a true laryngeal register in this area of the female voice; however, one must consider the inference which the data presented. It is true that spectral variation may or may not indicate register variation. Spectral variation could be the result of a change in laryngeal or vocal tract components. And, because perception is merely an aural manifestation of the acoustical properties of the tone, it too may or may not indicate register variation. Variation in airflow does not necessarily indicate variation in register; however, it does indicate that some change occurred at the source level. This change could be a change in register, or it could be the result of a change of production within a particular laryngeal register adjustment (i.e., a breathy modal voice production vs. a well-adducted modal voice production). Still, it seemed that airflow data probably had the most inferential power of the three research parameters. In any case, the significant changes in spectra and airflow coupled with the auditor's ability to discriminate the two

qualities did indicate that a variation in the mode of production could likely be occurring. In other words, the results of this research did make the existence of the whistle register a logical hypothesis.

Need for Further Study

Further investigation of these parameters as well as other parameters of vocal production in an attempt to better define this possible register area is needed. Because of the complexity of an investigation such as this, the population sample, for reasons of practicality, must be relatively small. It therefore stands to reason that replications of this study as well as studies of a similar nature are needed. Many studies of the primary registers have been conducted using the same basic parameters and procedures as utilized by this investigation. It is this compilation of data that has been important in operationally defining the primary registers. It therefore follows that similar studies in the area of the whistle register should also be conducted.

In addition, other possible avenues of research might include perceptual analysis by categorization and the comparative study of vibrato. Though not the

intent of this investigation, differences in perceived vibrato were observed. Investigation of this parameter would indeed be a logical next step.

APPENDIX I

SPECTRAL AND SIGNAL DISPLAYS

Subject 1   Signal Display   C6   Head Register

Subject 1   Signal Display   C6   Whistle Register

Subject 1 Spectral Display C6 Head Register

Subject 1 Spectral Display C6 Whistle Register

Subject 1 Spectral Display C#6 Head Register

Subject 1 Spectral Display C#6 Whistle Register

Subject 1 Signal Display D#6 Head Register

Subject 1 Signal Display D#6 Whistle Register

Subject 1 Spectral Display D#6 Head Register

Subject 1 Spectral Display D#6 Whistle Register

Subject 1 Signal Display F6 Head Register

Subject 1 Signal Display F6 Whistle Register

Subject 1 Spectral Display F6 Head Register

Subject 1 Spectral Display F6 Whistle Register

Subject 2 Signal Display D6 Head Register

Subject 2 Signal Display D6 Whistle Register

Subject 2 Spectral Display D6 Head Register

Subject 2 Spectral Display D6 Whistle Register

Subject 3 Spectral Display B5 Head Register

Subject 3 Spectral Display B5 Whistle Register

Subject 3 Spectral Display C6 Head Register

Subject 3 Spectral Display C6 Whistle Register

Subject 3 Signal Display C#6 Head Register

Subject 3 Signal Display C#6 Whistle Register

Subject 3 Spectral Display C#6 Head Register

Subject 3 Spectral Display C#6 Whistle Register

Subject 3 Signal Display D6 Head Register

Subject 3 Signal Display D6 Whistle Register

Subject 3 Spectral Display D6 Head Register

Subject 3 Spectral Display D6 Whistle Register

Subject 3 Spectral Display D#6 Head Register

Subject 3 Spectral Display D#6 Whistle Register

Subject 3 Signal Display E6 Head Register

Subject 3 Signal Display E6 Whistle Register

Subject 3 Spectral Display E6 head Register

This display demonstrates highest observed harmonic.

Subject 3 Spectral Display E6 Whistle Register

Subject 4 Signal Display B5 Head Register

Subject 4 Signal Display B5 Whistle Register

Subject 4 Spectral Display B5 Head Register

Subject 4 Spectral Display B5 Whistle Register

Subject 4 Signal Display C#6 Head Register

Subject 4 Signal Display C#6 Whistle Register

Subject 4 Spectral Display C#6 Head Register

Subject 4 Spectral Display C#6 Whistle Register

Subject 5 Signal Display C6 Head Register

Subject 5 Signal Display C6 Whistle Register

Subject 5   Spectral Display   C6   Head Register

Subject 5   Spectral Display   C6   Whistle Register

Subject 5 Spectral Display C# head Register

Subject 5 Spectral Display C# Whistle Register

Subject 5 Spectral Display D6 Head Register

Subject 5 Spectral Display D6 Whistle Register

Signal Display:

Extracted data

File OD0MDSE (50.000 kHz)
 Length: 2.747 100 Sec.
 Cursor: 0.000 000 Sec.
 Level: Volts

(Compressed)

Subject 5 Signal Display D#6 Head Register

File OD0MDSE (50.000 kHz)
 Length: 3.830 000 Sec.
 Cursor: 0.000 000 Sec.
 Level: Volts

(Com

Subject 5 Signal Display D#6 Whistle Register

Subject 5 Spectral Display D#6 Head Register

Subject 5 Spectral Display D#6 Whistle Register

Subject 5 Spectral Display D#6 Head Register

Subject 5 Spectral Display D#6 Whistle Register

Subject 5 Spectral Display E6 Head Register

Subject 5 Spectral Display E6 Whistle Register

Subject 5 Spectral Display F6 Head Register

Subject 5 Spectral Display F6 Whistle Register

Subject 6 Spectral Display C6 Head Register

Subject 6 Spectral Display C6 Whistle Register

Subject 6 Spectral Display F6 Head Register

Subject 6 Spectral Display F6 Whistle Register

Signal Display:

Extracted data

File WHITCSE (50.000 kHz)
 Length: 3.873 400 Sec.
 Cursor: 3.350 000 Sec.
 Level: Volts

(Compressed)

Subject 7 Signal Display C#6 Head Register

Signal Display:

Extracted data

File WHITCSE (50.000 kHz)
 Length: 4.288 960 Sec.
 Cursor: 0.000 000 Sec.
 Level: Volts

(Compressed)

Subject 7 Signal Display C#6 Whistle Register

Subject 7 Spectral Display C#6 Head Register

Subject 7 Spectral Display C#6 Whistle Register

Subject 7 Signal Display D6 Head Register

Subject 7 Signal Display D6 Whistle Register

Subject 7 Spectral Display D6 Head Register

Subject 7 Spectral Display D6 Whistle Register

Subject 7 Spectral Display D6 Head Register

Subject 7 Spectral Display D6 Whistle Register

Subject 7 Spectral Display D#6 Head Register

Subject 7 Spectral Display D#6 Whistle Register

Subject 7 Spectral Display D#6 Head Register

Subject 7 Spectral Display D#6 Whistle Register

Subject 7 Spectral Display D#6 Head Register

Subject 7 Spectral Display D#6 Whistle Register

Subject 3 Spectral Display G6 Whistle Register

This was the highest pitch observed--
even at this frequency there were 11
harmonics.

APPENDIX II

AIRFLOW DATA

AIRFLOW DATA
Subject 1

<u>Fo.</u>	<u>Head</u>				<u>Whistle</u>			
	<u>Vol/ml</u>	<u>duration</u>	<u>s.p.</u>	<u>MFR</u>	<u>Vol/ml</u>	<u>duration</u>	<u>s.p.</u>	<u>MFR</u>
C	690	4.20	+6	164	640	4.25	+3	151
C	725	4.46	+2	164	800	4.85	+1	165
C	490	3.59	+1	136	610	3.99	+1	153
C	520	4.19	+2	124	610	4.31	+1	142
C#	650	4.37	+6	149	900	5.25	+2	171
C#	560	4.49	+4	125	610	4.15	+1	147
C#	690	4.30	+2	160	700	4.57	0	197
C3	510	4.18	+2	122	670	4.70	0	143
D	550	4.59	+1	120	625	4.29	+2	146
D	150	4.56	+2	112	600	3.96	+3	152
D	490	4.14	+2	118	600	4.71	+4	127
D	425	4.54	+2	94	510	4.43	+2	115
E	400	3.76	0	106	450	4.07	-2	111
E	500	4.15	+3	120	625	4.28	0	146
E	475	4.25	0	112	577	4.57	-2	126
F	500	4.12	0	121	600	4.56	0	132
F	510	3.90	+4	131	650	4.86	0	134
F	580	4.49	0	129	500	4.09	-4	122
G#	590	4.09	+3	144	575	3.82	0	151

AIRFLOW DATA
Subject 3

<u>Fo.</u>	<u>Vol/ml</u>	<u>Head</u>			<u>Vol/ml</u>	<u>Whistle</u>		
		<u>duration</u>	<u>s.p.</u>	<u>MFR</u>		<u>duration</u>	<u>s.p.</u>	<u>MFR</u>
C	880	4.56	+3	193	610	4.91	+1	124
C	995	4.98	+5	200	520	4.49	0	116
C	875	5.22	+4	168	550	4.85	0	113
C	790	5.15	+4	153	600	4.52	+1	133
C#	670	4.36	+6	154	500	4.87	+1	103
C#	650	4.42	+8	147	550	4.54	+3	121
C#	670	4.60	+4	146	500	4.45	+3	112
C#	625	4.69	+4	133	525	4.74	+5	111
D	720	4.42	+8	163	580	5.34	+5	109
D	700	4.44	+5	158	400	4.15	+5	96
D	600	4.83	+5	124	575	4.37	+3	132
D	630	4.67	+6	135	640	5.36	+4	119
D#	800	4.62	+10	173	540	4.50	+4	120
D#	610	4.37	+8	140	620	4.68	+4	132
D#	710	4.09	+8	174	680	4.85	+4	140
D#	625	4.43	+7	141	625	5.10	+5	123

AIRFLOW DATA
Subject 4

<u>Fo.</u>	<u>Vol/ml</u>	<u>Head</u>				<u>Whistle</u>		
		<u>duration</u>	<u>s.p.</u>	<u>MFR</u>		<u>duration</u>	<u>s.p.</u>	<u>MFR</u>
C	1380	4.49	+3	307	800	4.32	-2	185
C	1375	4.46	+3	308	750	4.35	-2	172
C	1550	4.05	+4	382	1000	4.42	-4	226
C	1680	4.36	-1	385	900	4.31	-6	208
C#	1370	4.28	0	320	1250	4.16	-4	300
C#	1575	4.32	+4	365	980	4.35	0	225
C#	1690	4.32	+8	391	1000	4.17	0	240
C#	1620	4.91	+9	330	1150	4.32	+2	266
D	1590	4.32	+8	368	930	4.35	+8	214
D	1510	4.17	+8	362	1340	4.24	+6	316
D	1600	4.32	+8	370	1090	4.28	+8	255
D	1400	4.09	+9	342	1275	4.29	+4	297
D#	1375	4.29	+6	321	1080	4.46	+2	242
D#	1400	4.04	+8	347	1050	4.19	+2	251
D#	1580	4.33	+7	365	1150	4.14	+8	277
D#	1290	3.36	+7	384	1125	4.16	+9	270

AIRFLOW DATA
Subject 7

Fo.	Vol/ml	Head				Whistle		
		duration	s.p.	MFR		Vol/ml	duration	s.p.
C#	1150	3.47	+3	331	990	4.52	+2	219
C#	1460	4.29	+3	340	980	4.50	+1	217
C#	1400	4.10	+5	341	1000	4.32	+3	231
D	1575	3.82	+3	412	715	4.40	+2	162.5
D	1480	3.84	+2	385	780	4.52	+1	173
D	1910	4.19	+5	456	900	4.48	+3	201
D	1590	4.46	+3	357	1040	4.11	+3	253
D#	1230	3.78	+5	325	870	4.69	+2	185
D#	1425	4.29	+4	332	830	4.54	+2	182
D#	1220	4.24	+4	288				
D#	1400	4.32	+4	324				

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