VOICE SCIENCE: AN EVALUATION
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INTRODUCTION

Serious scientific investigation into the mechanics of voice began with the invention of the laryngoscope in 1854. Since that time voice science has made great strides in the field of voice pathology. However, taking into consideration the numerous scientific articles devoted to the study of the human voice, it is imperative to question the extent to which the results of these investigations have been useful to the teacher of singing. When an evaluation is made concerning the impact of these studies, one discovers that some of the information is useful, but in general contain little value when judged in terms of their practical application.

There are three phases essential to a scientific enquiry into vocal mechanics. First, is a need to properly identify the laryngeal muscular systems comprising the vocal mechanism; second, to explain its mechanical action; and third, to discover an operative principle capable of demonstrating how the vocal mechanism can be induced to function more efficiently. The first two requirements have long since been met, but up to the present, the third and most important of these objectives has for all intents and purposes been overlooked. What accounts for this failure to identify an operative principle?

In large part, it can be explained because of the misconceptions accepted as fact by the majority of scientific investigators. The purpose of this article is to expose some of these misconceptions and the false conclusions to which they inevitably lead.

THE FIRST MISCONCEPTION

It has long been assumed by voice scientists that humans possess a vocal organ as part of their anatomical make-up. To the contrary, according to Webster's Third International Dictionary, an organ is, "A differentiated structure (as in heart, kidney, leaf or stem) in an animal or plant made up of various cells and tissues and adapted for the performance of some specific function and grouped with other structures sharing a common function into systems." Thus, sung tonal qualities are not produced by an organ, but by a vocal mechanism comprised of parts of two separate organic systems, the respiratory and the deglutative.

The specific laryngeal muscular elements of the respiratory system being adapted to the production of singing tonal qualities are the arytenoids (whose natural function is to open and close the glottis). The muscle system associated with deglutition, or swallowing, is the cricothyroid (whose tension is directly influenced by peristaltic movement). The natural tendency of these organic systems is not to combine, but to function independently. Nevertheless, their interactive potential enables them to function at a high level of efficiency as a musical instrument; varying degrees of arytenoid activity thickening, relaxing and/or occluding the vocal folds, an action opposed by the cricothyroids, whose shifting ratios of tension regulate pitch.

The above-mentioned activities represent the core of the sound-making machinery itself and are indispensable elements of the phonative process. Viewed from this perspective, singing is an overlaid function that finds two nominally antagonistic organic systems combining to perform tasks beyond the province of their primary organic design and purpose.

Making this distinction is important. An organ performs a life-sustaining function and does not have to be trained. To produce singing tonal qualities, however, the cricothyroids and the arytenoids must enter into a coordinate relationship. This presents a difficulty. Since these muscle systems are not disposed by nature to function as a unit, they seldom cooperate efficiently. A more natural tendency of both the mechanical activities and the tonal product is to divide into two parts.

In its elemental condition, one part of the tonal product is perceived as legitimate, the other as false. This fact has been taken into account in preceding centuries dating back to the fourteenth, where two separate tone qualities were commonly recognized as the vox ficta, or false voice and the vox integra, or natural voice. Were the vocal mechanism to be an organ, there would be no such division of qualities.

During this adaptive process, the vocal mechanism must be governed by rules and regulations that induce these two separate parts to interact harmoniously, yet without violating their natural movement potential. Achievement of this objective is further complicated by the fact that during phonation, the arytenoids not only participate in an agonist/antagonist relationship with the cricothyroids, but with themselves as well. The basic activity involved in this secondary relationship is to alternately open and close the glottis. Making this conversion from inherently natural functions to the production of singing tonal qualities comprises the very essence of the pedagogic problem.

That there is no such thing as a vocal organ is indisputable. Evidence of this assessment is found in a statement written by Gray and Wise that reads:

> The vital life-sustaining functions of breathing and taking food are more comprehensible, because the reflex arcs [the travel of a nerve impulse from the point of stimulus, to the nerve center, to a muscle or gland] connected with them are natively established; but the function of speech [and singing] being in a sense overlaid or superimposed upon the musculature of these primitive functions and being forced to use borrowed mechanisms, represent acquired or learned adjustments, adaptations, and coordinations nothing short of miraculous.[1]

Clearly, the vocal mechanism cannot be considered a self-contained organ designed for speech and singing. Failure to recognize the division of the vocal mechanism into two separate and distinct parts is responsible for the confusions within both the scientific and the teaching profession. Were there to be a vocal organ it would be of simple design and, under normal conditions of health, function by nature at a high level of efficiency.

THE SECOND MISCONCEPTION

Another mistaken belief is to consider the cricothyroids to be part of the intrinsic muscles of the larynx. They are so named because of their attachment to the cricoid and thyroid cartilages. It is customary to label any muscle attached to the cartilages of the larynx as “intrinsic.” This argument is specious. The cricothyroids are located on the *lateral* and *outer* aspect of the larynx. They arise from the *external* surface of the arch of the cricoid cartilage, with the anterior portion inserting on the lower border of the thyroid cartilage.

Most of the anterior portion of the cricothyroid muscles attach to the *outer* surface of the thyroid cartilage with only *some* of the more posterior fibers finding their attachment to the inner surface. Therefore, as contended by Luchsinger, Arnold, and other authorities, the cricothyroids should be considered extrinsic.

While one could possibly argue that the attachment of the cricothyroids to the inner surface of the thyroid cartilage would validate the position that the cricothyroids are intrinsic, the strength of this opinion is diminished by the fact that only a *small* number of fibers are attached to this surface. This arrangement does not justify including the cricothyroids among the intrinsic muscles of the larynx. To do so would be similar to considering a man hanging outside a window with his hands grasping the windowsill to be inside the room.

The intrinsic muscles of the larynx, the arytenoids, are exclusively associated with the respiratory system, and their basic function is to open and close the glottal space. They therefore remain passive during the act of swallowing. The cricothyroids do not participate in respiration and are connected to the swallowing process. Since when swallowing we do not breathe, and vice versa, this makes for an important separation of the intrinsic and extrinsic muscles of the larynx. Were the cricothyroids to be intrinsic and lie within the laryngeal structure, they would be unable to act as antagonists to the arytenoids and stretch the vocal folds to regulate pitch.

The natural antagonism of the cricothyroids and arytenoids finds support neurologically. Branches of the vagus nerve innervate all laryngeal muscles. As a branch of that nerve, the recurrent laryngeal nerve serves all of the intrinsic (arytenoid) muscles of the larynx. However, many of the recurrent laryngeal nerve motor fibers supplying the larynx actually arise from the spinal accessory nerve. By contrast, the cricothyroids are innervated by the external branch of the superior laryngeal nerve, but have no connection to the spinal accessory nerve.

Surely, from a neurological perspective alone, the cricothyroids cannot be considered intrinsic muscles of the larynx. They form a separate and distinct entity, and it is because of this separation that they are disinclined by their very nature to participate in a coordinate relationship with the arytenoids, or to function efficiently as an indispensable part of a singing instrument. Indeed, it is because of this neurological separation of the cricothyroids (and their connection to the swallowing system) that throat constriction is a continuing vocal problem.

Since the cricothyroids and arytenoids can be factually proven to be parts of two separate organic systems, both muscularly and neurologically, the belief entertained by a majority of voice scientists that the cricothyroids are part of the intrinsic musculature of the larynx is flawed.

THE THIRD MISCONCEPTION

Yet another mistaken and generally accepted belief is that a dimensional setting of the vocal folds represents the mechanical source of a vocal register. The foundation for such a belief can be traced to Manuel Garcia's invention of the laryngoscope (1854) at which time it was observed that the physical dimensions of the vocal folds varied with pitch and intensity. Garcia's contemporary, Sir Morell MacKenzie, a prominent laryngologist and advisor to many of the great singers of his era, commented upon the results of these observations in *The Hygiene of the Vocal Organs* (1887). In an appendix entitled *Critical Observations on the Various Theories as to the Mechanism of the Registers*, he voiced this opinion:

> The immediate effect of the invention of the laryngoscope was to throw the whole subject into almost hopeless confusion by the introduction of all sorts of errors of observation, each claiming to be founded on ocular proof, and believed in with corresponding obstinacy.[2]

What Garcia, MacKenzie, and others saw reflected in the laryngoscopic mirror were divisions of the vocal folds into clearly distinguishable parts, the exact number varying with different observers. By common agreement, these divisions were referred to as "registers." From that time to the present, the vast majority of voice scientists have left this assumption unchallenged.

There are several reasons why this assumption lacks credence. First among them is the inconsistency with regard to the number of registers recognized by voice scientists, ranging from two to as many as six. This cannot be. If, except for size, all vocal mechanisms, male and female alike, are anatomically identical, then each and every individual and voice type must without exception have the same number of registers. Unquestionably, if a register is to be physiologically based, this difference in the number of registers cannot be justified.

Another objection to a register being associated with vocal fold dimensions is that their physical configuration is subject to the limitations imposed by a mathematical law. In substance, this law states that the length, mass and tension of a vibrator are equivalent to the rate of its frequency of vibration, or pitch. This law is immutable. In conformity with this law, and regardless of whether the vocal mechanism is used well or badly, a given dimensional setting of the vocal folds will inevitably correspond to the rate of its vibrational pattern.

For example, if the strings of a piano are in tune, whether the instrument is in good or bad condition, the A above middle C will be equal to 440 Hz (vibrations per second). If the vocal folds are vibrating at this frequency, whether the tone is sung well or badly, or whether the qualitative property corresponds to a chest voice or a head voice, the pitch will likewise be perceived as A above middle C. Being subject to the rigorous discipline of a law, vocal fold vibrations or configurations can neither regulate themselves efficiently, nor can they contain an operative principle capable of fulfilling either the physical or acoustic requirements necessary to define or identify a vocal register.

Yet another reason for discounting a registrational theory based on vocal fold dimensions is that in a seamless voice, no accounting can be made for the apparent disappearance of a register or registers; nor does this theory explain the presence and cause of break points in the tonal range. When the voice is seamless, does the number of vocal fold divisions remain intact? If so, what fills in the seams? When there is a “hole” in the vocal range, what happened to cause the missing register to disappear, and how is it to be replaced when those dimensions are ruled by law and not by a mechanical principle? Surely, if a registrational theory is to claim authenticity, one must search elsewhere to find suitable answers to this pedagogic conundrum.

It has long been common knowledge that vocal fold dimensions are regulated through opposing tension supplied by the cricothyroid and arytenoid muscle systems. Logically, since this fact is indisputable, concepts related to basic register mechanics must be explained through the activity of these two systems; in other words, the vocal folds are not the regulators, *but the regulated*. While the frequency of vocal fold vibration is fixed by a mathematical law, the relative amounts of arytenoid and cricothyroid tension are not. In other words, the same pitch can be sung with varying amounts of tension distributed between these two systems.

Beyond question, the proportional amounts of tension distributed between the cricothyroid and arytenoid muscle systems constitute the defining factor in vocal registration. This mechanical action is subject to regulation and innervation by an operative principle; that is to say, a procedure upon which the function of an organic system or mechanical contrivance is structured. This understanding puts an entirely different face on register mechanics.

For this principle to become operative there must be a catalyst. This catalyst is a musical figure consisting of pitch, intensity and vowel, whose use in various combinations impinges directly on the formation of vocal fold dimensions, as these dimensions are controlled through the activity of the cricothyroid and arytenoid muscle systems. When formed into a vocal exercise, particular patterns of these three tonal elements stimulate the laryngeal musculature through an act of will, so as to affect the balance of tension distributed between the cricothyroids and the arytenoids.

This interactive potential will, in effect, dictate the character of the tonal response, and in general exercise a special type of mechanical control over an involuntary laryngeal muscular system. In certain arrangements this practice will open up a “break” in the voice, in other arrangements close it, the result being the production of varying types of falsetto or legitimate tonal qualities.

It is evident, therefore, that a register must possess within itself a utilitarian purpose and properties capable of revitalizing the vocal mechanism as a whole. Unless a means is available for regulating and controlling the laryngeal musculature by way of the vocal registers, the subject of registration would have no greater significance than the arbitrary assignment of a name to identify a tone quality in association with certain glottal dimensions located within a particular pitch range.

THE FOURTH MISCONCEPTION

In addition to the preceding misconceptions, rules and techniques applicable to speech norms have been introduced to assist in clarifying theories and to overcome technical problems related to singing. Thus, speech and singing are studied conjunctively as though their dynamics were the same. In fact, the only common denominator (apart from using the larynx and vocal tract) is the use of vowels and consonants, as these are employed to create language.

Among the fundamental differences between vocal mechanics as they are used in singing as compared to speech are these:

1. A conceptual pre-setting of the vocal tract to initiate phonation by means of prephonatory tuning is required for singing, but not for speech. Prephonatory tuning is a reflexive approximation of the vocal folds and the vocal tract that occur in response to neurological stimuli before any movement of the air below the glottis has taken place. In effect, it is a tuning process essential to a precise initiation of a particular pitch, intensity and vowel pattern.
2. Accuracy of intonation is not a factor in speech, whereas in singing it is of the highest priority.
3. Speech requires a minimal amount of cricothyroid tension to regulate pitch, a responsibility being largely reliant on arytenoid activity. However, cricothyroid tension is a factor of inestimable importance to a correct singing technique, since without its ability to regulate pitch efficiently, all other aspects of laryngeal muscular coordination will be thrown out of sync.
4. In speech, the balance of tension between the cricothyroids and the arytenoids need only be approximate, whereas in singing those adjustments must be precise.
5. Singing demands a high level of motility among the participating laryngeal muscular elements, whereas speech does not.
6. Speech does not demand a fine-tuning of the resonating system, nor a gradual swelling and diminishing of intensity on either a sustained pitch or melodic pattern.
7. An important adjunct of a correct singing technique is the need to energize what science refers to as “the singer’s

formant" (a frequency range extending from 2800 to approximately 3400 Hz, which causes the voice to "ring"), a requirement well beyond the scope of speech norms.

8. Speech is not dependent on either a consistent periodicity of vibration nor an ability to increase and decrease the amplitude of vibration perceived as a vibrato, especially as these increases and decreases relate to intensity.
9. Speech does not require the sustaining of vowel qualities over a broad pitch range at widely variant levels of intensity, a critical factor in singing.

Because of these differences (physiologic, acoustic and conceptual) speech and singing must be considered fundamentally different disciplines.

It is of further interest to note that only marginal improvement can be brought about in the production of singing tonal qualities through speech mechanics alone, whereas through the study of singing, dramatic improvement in the speaking voice will be almost inevitable. The reason is plain: Even though the two disciplines are different, the same vocal muscles are used, but exercised more vigorously and with greater precision in singing than in speech. As a result, an improvement in laryngeal muscular activity is generally, but not always, carried over into speech habits.

THE FIFTH MISCONCEPTION

An additional misconception is the treatment accorded consonants and vowels. Increasingly, pedagogic emphasis has been placed on vowel categories described as front, back, high-back, open, closed, tense and lax, together with consonants categorized as voiced and unvoiced. As they relate to the singing voice, these concepts simply do not apply, and when incorporated into a training program, generally prove to be counterproductive.

Although this position represents a radical departure from conventional thinking, it is easily verifiable. With respect to sung vowels, and with the possible exception of the term "back," all qualitative descriptions listed above are both physiologically and acoustically irrelevant. Vowels are sounds created by vibrational patterns originating at the sound source (vocal folds) and conditioned qualitatively by a shaping of the vocal tract. The cavities of the vocal tract, however, possess no energy of their own, and are dependent on a vibratory source before they are able to act as a resonator. The responsibility of the vocal tract is to make the adjustments necessary to define and resonate the vowel, not to generate or supply energy.

Freedom of the vocal tract to adjust and act as a resonator, therefore, depends on and reflects the quality of the energy delivered from the sound source. Consequently, if the interactive potential of a complex laryngeal musculature is poorly coordinated, the friction created will adversely affect the singer's ability to tune the vocal tract to adequately define and resonate a variety of vowel qualities. In an ideal singing technique, these two areas of influence should be mutually complementary, the ultimate determinant of success being the efficiency of the physical events taking place at the generative source of sound, the larynx.

Until coordinative inequities have been corrected, the unavoidable consequence will be the production of impure and ineffectively resonated vowel qualities. Imbalances within the laryngeal musculature unavoidably engender undesirable throat, tongue and jaw tensions that inevitably interfere with the free articulation of consonants. Attempts to solve this problem through a dependency on vowel concepts (such as front, high-back, open, closed, tense and lax) obscure the issue. For a vowel to be described as pure, unblemished or well resonated, the acoustic (the shaping of the vocal tract) and the physiologic (the muscular interaction between the cricothyroids and arytenoids) must be in synchronicity. Of the two spheres of influence, tuning the vocal tract is important, but secondary to laryngeal mechanics.

Given the primacy of laryngeal mechanics, all vowels should be considered back vowels; that is to say, laryngeally oriented. This theory can be substantiated through the description of a standing wave, without whose presence tone production would be deficient. A standing wave develops when a special type of vibratory pattern generated at the sound source produces wave-forms that travel not only away from the source, but are reflected back to combine with the newly injected waves set in motion by the vocal folds. These two waves travel in opposite directions, yet share the same periodicity. The optimal point of amplitude of a standing wave is concentrated at the sound source, with the minimal point of amplitude located at the lip opening.

Johann Sundberg (1977) incorporated the concept of a standing wave in his acoustic explanation of the movement of sound waves through the vocal tract. He found this phenomenon to exert a profound influence on all aspects of singing, including the formant structure. Consequently, with the greatest amplitude of oscillation in a standing wave concentrated at the vibratory source, it follows that all vowels should be considered "back" vowels.

Until the past half century, singers and teachers of singing were well aware of the physical presence of a standing wave, since reference was made to "*inalare la voce*" (inhale the voice) or when used idiomatically in English, "drinking in the tone." An understanding of the acoustics of a standing wave as it affects the singing voice invalidates concepts related to front, lax or tense vowels, as well as efforts to direct the tone "forward" or to be resonated in the facial masque. The reason for this is because all such attempts direct both conceptual and physical energies away from the sound source.

Another problem area is the manner in which consonants are treated. Studies conducted in France by Nicole Scotto di Carlo (1979) refute the contention that strongly energized articulation is essential to a successful projection of the verbal text. According to di Carlo, and on the basis of evidence provided by most singers, the opposite seems true. An over-articulated text, especially in English, does not come clearly across the footlights. Therefore, something is obviously wrong with the theoretical propositions that have been put into practice. To quote di Carlo:

> We have shown in this research that articulation has particularly disrupting effects on the beauty of the vibrato, the continuity of the legato, the aesthetics of attacks, sustained phrases and releases, which are generally considered to play a considerable part in the quality of singing.
>
> The training methods based upon articulation or *consonantal emphasis* are therefore to be systematically avoided, as they are bound to endanger the precarious balance that the singer has to reach if he wants to preserve both the intelligibility of the text and the aesthetic value of the music.[3]

The issue for singers goes beyond consonantal emphasis or the use of consonants in general. There is also the problem of voiced and unvoiced consonants. As they apply to singing, all consonants should be treated as though they are unvoiced. This special treatment is necessary because, when a voiced consonant is articulated, it is usually preceded by a dull-sounding, neutral vowel. For example, an L or M is generally preceded by an ill-defined sound, so that one hears shadow or schwa vowels such as uh-La or mmm-Ma. The effect of this practice when singing a song or an aria is to inject an undesirable pre-tension throughout the entire vocal tract, which is especially noticeable on high pitches. Cultivation of this habit leads to slovenly and confused articulation and an impairment of textual clarity.

Given the constrictive nature of voiced consonants, the greater the amount of energy expended on their use, the greater the degree of vowel distortion. From the perspective of pure vocal mechanics, this practice creates imprecision rather than assisting in an accurate adjustment of vocal fold dimensions as phonation is initiated. Under these conditions, the two processes conflict rather than cooperate.

An equally important impediment to efficiently resonated vowel qualities is the association of the articulators with the act of swallowing. When over-energized, these muscles ensure the injection of constrictor tensions throughout the entire vocal tract, to the detriment of the vowel qualities being produced. Furthermore, this dispersal of energy makes it impossible for the singer to shape the vocal tract so as to encourage the formation of a standing wave.

There are circumstances, however, where unvoiced consonants can be stressed, provided the energy expended is not being simultaneously directed into the vowel quality. Although most unvoiced consonants are high frequency noises and possess no musical properties, they can be emphasized for dramatic effect. For example, in the word “strength,” the vowel quality of this word must be sounded after the stressing of the initial consonants has been completed. In general, however, one must be careful to avoid the overstressing and misdirected emphasis of all consonants.

Both in theory and practice, therefore, vowel qualities should be sounded without interfering with the free movement of the articulatory processes. Similarly, the articulation of consonants should be executed without interfering with the mechanical processes operative within the laryngeal area. Achievement of independence between tone and articulation without interfering with the melodic line is one of the primary objectives of technical training. Indeed, in a correct singing technique, tone and articulation are separate entities that nevertheless must be used conjunctively in a mutually compatible relationship.

THE SIXTH MISCONCEPTION

The decision to establish separate categories divided into trained and untrained singers for study and analysis, is apparently based on the mistaken assumption that trained singers have been well-trained and that untrained singers sing incorrectly. With respect to those who have been trained, it is evident that the findings are mainly of sociological value, since they have been based on current vocal fashions that are temporal, rather than an indication of a correct vocal technique. Fashions in singing change with time and place. Surely the singing style deemed acceptable in the early decades of the twentieth century differs widely from the accepted styles of the middle and later decades in terms of function, descriptive terminology and aesthetic taste.

As for the untrained singer category, Amelita Galli-Curci never received a voice lesson in her life, yet became one of the greatest coloratura sopranos of her era. Does this suggest that she should be classified as an untrained singer? To the contrary, it signifies that the objective of any scientific investigation is to establish the parameters of a physiologically healthy technique, whether achieved through training, instinct, intuition or a combination of these factors.

What can be said with assurance is that vocal skills are measurable. These skills find expression in an extensive vocal range, accuracy of intonation, an ability to produce pure vowel qualities, evenness of vibrato, flexibility, breath economy, singing without fatigue and apparent effort, and an ability to successfully execute the *messa di voce* (the art of swelling and diminishing on a single note) throughout the entire vocal range.

According to written accounts, the castrati, as well as other singers, achieved this goal of excellence during the eighteenth century. Since the vocal mechanism has not changed in any important respect since that time, their singing skills are potentially replicable in this century as well. Therefore, theories espoused that are based on studies conducted with singers of lesser skills than those mentioned above should be considered of questionable value.

THE SEVENTH MISCONCEPTION

Foremost among the numerous misconceptions related to vocal mechanics is the belief that the voice must be "supported." Generally associated with the term *appoggiare* (Italian, meaning to lean) its usefulness as a pedagogic tool has rarely been challenged. As defined by Sataloff, support is:

> Commonly used to refer to the power source of the voice. It includes the mechanism responsible for creating a vector force that results in efficient subglottic pressure. This includes the muscles of the abdomen and back, as well as the thorax and lungs; primarily the expiratory system.[4]

Sataloff reinforces this viewpoint with the following comment:

> Many of the muscles used for active expiration (forcing air out of the lungs) are also employed in "support" for singing and acting. Muscles of active expiration either raise the intra-abdominal pressure forcing the diaphragm upward, or lower the ribs or sternum to decrease the dimension of the thorax, or both.[5]

These descriptions have to do with the overt use of force that destabilizes the mechanism, rather than bringing it into a state of balanced tension or equilibrium. One reason for the ready acceptance of "support" and the forcing of air as a pedagogic tool is that, with the exception of the diaphragm, the respiratory muscles are largely subject to volitional control, whereas the musculature responsible for vocal fold tension and laryngeal stabilization is not. Without a means for stimulating an involuntary muscular system, especially when there is an obvious need to institute some kind of control to facilitate the learning process, "support" appears to offer a practical, if mechanistic, basis upon which vocal skills could be developed.

There are serious weaknesses, however, in the idea that the voice must be "supported." The vocal folds, while being asked to resist (through tension) the breath pressure directed against them (in which case the degree of tension would have to be directly proportional to the degree of pressure being exerted) are also being required to maintain their elasticity in order to accommodate quickly and easily to fluctuating melodic patterns. Another serious weakness is that the angulation of the vocal folds (which are shaped in the form of a Gothic arch) is not designed to effectively resist a vigorous pressure buildup from below without stiffening. This obvious conflict between resistance and motility cannot be properly resolved by an overt forcing of air through the vocal folds.

While it may be argued that "support" must be operative when the mechanism is limited in freedom because of imprecise muscular coordination, such a viewpoint does not hold true when the mechanism is in balanced tension. Clearly, a dependency upon "support" is either unnecessary, or a compensatory ploy for the energy dissipation which results because of technical limitations. It would seem, therefore, that the idea of "support" has been devised to accommodate the needs of the average singer, who, because of a poorly functioning instrument, finds his energy resources depleted too rapidly. These resources must be supplemented, the conventional solution being to press breath into the system, check it in some way by a special technique of breathing, and thereby control its expiratory flow.

The consequence is a superimposition of additional tensions, which serve to lock in those vocal faults already present, thus furthering the continuance of effortful, rather than natural, free vocalization. As a result, an effect – excessive expenditure of breath – has been substituted for the cause, *i.e.*, poor laryngeal muscular coordination. It is the energy loss that results from muscular interference that creates excessive demands upon the breathing apparatus – demands that cannot adequately be met.

The idea of "forcing" the air out of the lungs by means of breath pressure implies the use of overt effort. This concept should be replaced by the advantages provided by breath compression. With breath compression, the molecules contained in the oxygen are compacted in the lungs, and those compacted molecules act as a source of energy. Air trapped in a balloon is a perfect example of this type of compression. Once an opening at the neck of the balloon occurs, the air rushes out, without the necessity for the use of overt force.

Additionally, the oxygen inspired moves through the blood stream to stimulate the muscles being activated. This stimulation of itself releases energy – the question being one of efficient coordination among the systems involved during the performance of a given task. In turn, this combination of energies causes the laryngeal musculature to contain within itself a considerable amount of kinetic energy. The combined result of these two energy sources is sufficient to maintain vocal fold vibration over a broad range of pitch and intensity levels, independent of the use of force.

Unquestionably, singing requires the use of energy. But while there is energy contained in the application of a vector force associated with power, a different concept of energy use is required to sustain singing tonal qualities. Energy is work performed by a body to overcome inertia, as distinguished from power, which is required to forcefully move an object or body. The object of technical training is not to “support” the voice (voice merely being a moving column of air) but to bring all the muscle systems legitimately involved in phonation into a state of equilibrium, and an equilibrium is, by definition, self-supportive. Instead of associating singing with power and exertion, phonation should be initiated and sustained through a release of rhythmic energy.

CONSEQUENCES OF THE MISCONCEPTIONS

Burdened by the misconceptions outlined above, errors contained within procedures designed to explain vocal mechanics become inevitable. On closer examination it is clear that these misconceptions serve to undermine the structure upon which both the theory and practice of vocal pedagogy is dependent. The concepts most directly affected are the mechanics associated with the vocal registers.

VOICE SCIENCE AND REGISTERS

By the opening decades of the twentieth century, problems faced when uniting the falsetto with the chest voice were gradually shunted into the background, to be replaced by an overriding concern for singing *dans la masque*. In pursuit of this acoustic mirage, traditional register mechanics based upon many centuries of empirical observation (where two diverse qualitative properties were to be merged into a seamless scale) were supplanted by emphasizing localized sensations of vibrations experienced in different areas of the body and head.

Recognizing that sensations of vibration do not constitute a register, an effort was made to establish theories on a more scientific basis. As a result, registrational concepts have been variously defined as follows:

Robert T. Sataloff

> Registers: Weakly defined term for vocal qualities; often, register refers to a series of adjacent tones on the scale that sound similar and seem to be generated by the same type of vocal fold vibrations and vocal tract adjustments. Examples of register are vocal fry, modal and falsetto; but numerous other terms are also used.[6]
>
> Chest voice: Heavy registration with excessive resonance in the lower formants.[7]
>
> Creaky voice: The perceptual result of subharmonic or chaotic patterns in the glottal waveform. According to IR Titze, if a subharmonic is below about 70 Hz, creaky voice may be perceived as pulse register (vocal fry).[8]
>
> Falsetto: High, light register, applied primarily to men's voices singing in the soprano or alto range. Can also be applied to women's voices.[9]
>
> Loft: A suggested term for the highest (loftiest) register; usually referred to as *falsetto voice*.[10]
>
> Middle (or mixed): A mixture of qualities from various voice registers, cultivated in order to allow consistent quality throughout the frequency range.[11]
>
> Pulse register: The extreme low end of the phonatory range. Also known as *vocal fry* and *Strohbass*, characterized by a pattern of short glottal waves

alternating with larger and longer ones, and with a long closed phase.[12]

Strohbass (German): “Straw bass”; another term for *pulse register* or *vocal fry*.[13]

Vocal fry: A register with perceived temporal gaps; also known as *pulse register* and Strohbass.[14]

Whistle register: The highest of all registers (in pitch). It is observed only in females, extending the pitch range beyond F6.[15]

Registers are expressed as quality changes within an individual voice. From low to high, they may include vocal fry, chest, middle, head, falsetto, and whistle, although not everyone agrees that all categories exist. The term modal register, used most frequently in speech, refers to the voice quality generally used by healthy speakers, as opposed to a low, gravelly vocal fry or high falsetto.[16]

Ronald J. Baken

1. A Laryngeal register must reflect a specific and distinct mode of laryngeal action. Vocal tract contributions are irrelevant.

2. A laryngeal register is produced across a contiguous range of fundamental frequencies.

3. The F_0 range of any given laryngeal register has little overlap with the F_0 range of any other register.

With these restrictions, only three distinct laryngeal registers have been verified. To avoid problems due to prior – and, frankly, often confused – terminology, and to reduce the influence of connotations commonly associated with older names, Hollien has suggested that we adopt completely new designations for these narrowly defined registers.

1. *Modal register* describes the laryngeal function in the range of fundamental frequencies most commonly used by untrained speakers (from about 75 to about 450 Hz in men; 130 to 520 Hz in women). The name in fact, derives from the statistical term for "most common value/" This register may include the musical "chest," "head," or "low," "mid," and "high" registers, depending on how these are defined.

2. *Pulse register* occurs in the F_0 range at the low end of the frequency scale (25 to 80 Hz in men; 20 to 45 Hz in women). The laryngeal output is perceived as pulsatile in nature. The term is broadly synonymous with "vocal fry," "glottal fry," or the musical term "strohbass."

3. *Loft register* is employed at the upper end of the vocal continuum (275 to 620 Hz in men; 490 to 1,130 Hz in women). The name is intended to convey a sense of "upper reaches." In general, it corresponds to the older term "falsetto."

   Modal register phonation is implicitly accepted as the norm, and, in fact, the glottal cycle we have been considering is that which characterizes it. Pulse and loft differ from modal register in the shape and tension to which the vocal folds are adjusted.[17]

Johann Sundberg

> The most common description is that a register is a phonation frequency range in which all tones are perceived as being produced in a similar way and which possess a similar voice timbre.[18]
>
> A register covers a certain phonation frequency range, but the various registers overlap, so that a person may phonate at a given phonation frequency in different registers. The range of overlap between male modal and falsetto registers is in the vicinity of 200 to 350 Hz (pitches G3-F4, approximately). In the female voice, the ranges of overlap are found in the neighborhood of the

following phonation frequencies: chest-middle: 400 Hz (pitch G4), and middle-head: 660 Hz (pitch E5). These ranges of register overlap, and the register boundaries vary substantially among individuals.[19]

Harry Hollien

Hollien (1974) defines register in the following way: “a vocal register is a totally laryngeal event; it consists of a series or a range of consecutive voice frequencies which can be produced with nearly identical phonatory quality; . . . there will be little overlap in fundamental frequency and . . . the operational definition of a register must depend on supporting perceptual, acoustic, physiologic and aerodynamic evidence.”[20]

Willard Zemlin

A particular mode or pattern of vocal fold vibration is usually confined within a given pitch range, and when phonation is attempted outside the limits of this range, the mode of vibration will be altered appropriately to accommodate the succeeding range. This modification of the mode of vocal fold vibration may be regarded as an operational definition of voice register.[21]

Meribeth Bunch

The existence of registers has been argued over the years, but research of van den Berg (1968), Vennard (1972), Large (1968,1972,1972) and Hollien et al. (1969, 1971) has put this beyond dispute. 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); and falsetto and the flute and whistle registers at the extreme top. Glottal fry is not used in song, but some teachers use it as a way to release tension in the vocal folds. The real question perhaps is whether registration is purely a function of the vocal folds or a combination of factors including the supraglottic vocal tract. As yet, there are no satisfactory answers to this problem.[22]

Minoru Hirano

There are three major vocal registers: falsetto or light, modal or heavy, and vocal fry. Falsetto is characterized by the absence of complete glottal closure. The modal register is accompanied by complete glottal closure for each vibratory cycle, and it is traditionally subdivided into head, mid, and chest registers. Vocal fry is characterized by an extremely long closed phase relative to one vibratory cycle.[23]

Harry Hollien, Oren Brown, and Rudolf Weiss

Perhaps a less ambiguous definition might be that the term register refers to a portion of the frequency range, within the human voice, that is of similar quality and is so due to similar vocal fold activity throughout that range. In addition, there is little dispute that registers are physiologically created by operation of the larynx. Generally, they result from variations in the thickness, length and mass of the vocal folds (when they are vibrating) and to some extent (perceptually anyway) to the correlative richness of harmonic overtones. . . .

It is important to remember that vocal registers are not only "laryngeally" based, they are also frequency dependent. The "modal register" (often referred to as full register or "chest voice") constitutes more or less the middle frequency domain of the voice. It may, in some cases, not even overlap with the other (speaking) registers. In any case, it is the range in which most speaking and singing takes place (Colton and Hollien 1972, Hollien and Michel 1968). The "falsetto " or "head" or "loft" register is located above "modal." Other registers, save for the middle register, are rarely used in singing, hence are of only passing importance to this basic

> discussion. And even the middle register, when it is found to exist, appears to be a part of or overlaps the upper end of modal (Hollien 1982).[24]

Ingo Titze

> Registration is observed in both speaking and singing. Typical speaking registers are *pulse, modal,* and *falsetto* (Hollien 1974); typical singing registers are *chest, head,* and *falsetto*….It is generally assumed that modal (the normal, or mode) register and chest register (the one that produces vibratory sensations in the trachea and sternum) are similar, both being the typical male quality in speech and low pitched singing. Thus, there is considerable overlap between singing and speaking registers. For example, head register is sometimes described as a mixture between chest and falsetto. It is the typical male quality in high pitched singing and approximates the female quality in speech….Because physiologic and acoustic descriptions of vocal registers have been incomplete, there has been much room for debate over the number of identifiable registers, their names, their origins, and their pedagogical utility in voice training (Colton & Hollien, 1972).[25]

SOME CONTRADICTIONS

Obviously, when contemplating the significance of the definitions cited above, several questions suggest themselves. For example, how can these descriptions of a vocal register be of assistance to the practical teacher of voice, especially when considering the many contradictions as to their name, number and position in the musical scale? If, as Baken contends, a register reflects "a specific and distinct mode of laryngeal action," how can one register, the modal, include such diverse qualities (reflecting vastly different modes of laryngeal action) as "'chest,' 'head,' or 'low,' 'mid,' and 'high' registers?" Is it possible for a modal register to contain several other registers at one and the same time "depending on how these are defined?" This reflects an avoidance of the issue of registers as they relate to the singing voice.

Unlike Baken, who sub-divides the modal register into five parts, and Bunch, who recognizes two divisions, Hirano sub-divides the modal register into three parts. This highlights yet another inconsistency. If modal is generally accepted as a legitimate register, what is the difference among the modal registers as defined by Baken, Bunch and Hirano that their subdivisions should vary so widely?

Instead of dividing modal register into several parts, as do Baken, Bunch and Hirano, Titze associates it with the chest voice, as do Hollien, Brown and Weiss. Sataloff, on the other hand, defines modal as "The term. . . used most frequently in speech, [referring to] the voice quality generally used by healthy speakers." Again, one must ask, in what way do any of these formulations assist the teacher of voice in the construction of a utilitarian program based on scientific knowledge?

Zemlin's definition states that a register is the "modification of the mode of vocal fold vibration." However, Baken believes the modal register to embrace a pitch range extending "from about 75 to about 450 Hz in men; 130 to 520 Hz in women." Within the extensive pitch range of Baken's modal register, "the mode or pattern of vocal fold vibration" will undoubtedly be altered many times. Thus, according to Zemlin's definition, this pitch range should contain several different registers, an obvious contradiction.

By some feat of legerdomain, Bunch starts out claiming there to be three registers, but ends up with six. When she refers to "falsetto and the flute and whistle registers at the extreme top," it is not clear whether she considers the falsetto to be separate or part of the flute and whistle registers, or whether the flute and whistle registers are themselves separate entities. While Bunch considers the falsetto to be positioned at the extreme top of the voice, Sundberg places it within the lower pitch range of the male voice, specifically "in the vicinity of 200 to 350 Hz (pitches G3-F4, approximately)." If a register is based on "vocal fold vibrations" or "a range of consecutive voice frequencies," then how can the falsetto, which is considered a register, be positioned in such widely separated pitch ranges? Additionally, how can the pitch range of the falsetto, as outlined by Sundberg, share anything in common with the pitch range of the modal register as outlined by Baken? It is also interesting to note that Sundberg does not acknowledge the presence of a falsetto in connection with the female voice, while Baken appears to dismiss its importance altogether.

Hollien, Brown, and Weiss place "the 'falsetto' or 'head' or 'loft' register" in the pitch range lying above the modal register. Are these three different names for the same quality of sound, or are they three diverse qualities sharing the same pitch range? If the latter is true, what accounts for those differences? Moreover, this grouping of the falsetto with head and loft differs from Bunch's identification of the falsetto with the terms flute and whistle. Hollien, *et al.*, further confuse matters when they recognize the presence of a middle register that is separate from the modal register. However, this elusive register is thought to put in an appearance only sporadically.

Ingo Titze recognizes the confusions implicit in these definitions of register mechanics when he confesses, "physiologic and acoustic descriptions of vocal registers have been incomplete." This statement, a recurring theme among voice scientists in general, is not only scientifically unacceptable, but a dangerous intrusion into vocal pedagogy, both as to theory and practice. Surely, if concrete and provable theories are not provided (except for physiological and acoustic descriptions that are incomplete), voice science will have mainly succeeded in directing attention away from the real subject matter at hand, which is the development of procedures designed to improve individual singing skills.

Beyond question, the analyses presented by the authorities quoted above are physiologically and acoustically based. In most respects, their registrational concepts can be said to be similar, all being founded on a belief that the physical dimensions of the vocal folds constitute a register. The fundamental flaw, however, is a consistent failure to recognize that glottal dimensions, although indispensable to the production of singing tonal qualities, are but one of several elements in the complex agonist/antagonist muscular activities essential to tone production.

What is missing in all the definitions quoted above is the identification of a mechanical action, leading to knowledge of a control system capable of improving the interactive potential of an involuntary laryngeal muscular complex, whose activity accounts for diverse glottal dimensions. If the singing profession is to take voice science seriously, a mechanical theory cannot be based on loosely defined register terminologies.

THE OVERLAP PROBLEM
AND
REGISTER BLENDING

Another of the loose ends left dangling by voice science is the presence of overlapping qualities that involve neighboring registers. Baken's definition contends that any given laryngeal register has little overlap with any other register, whereas Sundberg recognizes an overlap extending little short of an octave. Unlike Sundberg, and in agreement with Baken, Hollein finds little overlap of fundamental frequencies. On the other hand, Sataloff (more in line with Sundberg) believes, "Overlap of frequency among registers routinely occurs."[26]

One thing is certain, however: as long as glottal dimensions and/or pitch ranges are thought to be a register, no reasonable accounting can be made for the appearance of such diverse qualities as a chest voice and a falsetto located within an identical pitch range (approximately 220 to 350 Hz) which, when blended, produce a third and distinctively different quality. Clearly, voice science has not been able to offer a rational and consistent explanation to account for this phenomenon. Another curious anomaly is the inclination to overlook facts proving that the successful amalgamation of the falsetto with the chest voice is a real possibility. One of the rare exceptions is van den Berg's identification of the physical processes necessary to effect a unification of the falsetto with the chest voice. As reported by James Stark in *Bel Canto, A History of Vocal Pedagogy*:

> Janwillem van den Berg theorized that the registers could be blended by a graduated change between active and passive longitudinal tension. 'This mixture between chest and falsetto may be called mid-voice.' He said that 'the mid-voice is not really an "independent" register but a "mixture" of chest and falsetto register'. Some voice teachers also maintain that the two modes of vibration associated with the primary registers can be blended. However, it is difficult to reconcile van den Berg's own

> assertion that the registers are caused by 'mutually exclusive adjustments of the larynx,' with his parallel theory that 'mid-voice' is a blending of those same exclusive adjustments.[27]

Reconciliation of van den Berg's two assertions is indeed possible if the mutually exclusive adjustments of the larynx are related to the cricothyroid and arytenoid muscle systems, acting as tensors of the vocal folds. If the chest voice is associated with aggressive thyroarytenoid (vocalis) tension, and the falsetto with an active increase in cricothyroid tension, then when these two muscular adjustments gradually shift to a state of balanced tension relative to the pitch-intensity pattern being sung, the resultant tonal product will undoubtedly become what van den Berg referred to as mid-voice. In accordance with nineteenth-century tradition, Manuel Garcia called this quality "medium," Francesco Lamperti, "mixed."

The disinclination of voice science to accept either the theoretical or practical utility of register blending is directly attributable to a misunderstanding of register mechanics. Donald G. Miller exemplifies this failure when he states:

> Simultaneous activation of 'chest' and 'falsetto' modes of vibration of the vocal folds, while experimentally feasible, is not applicable in singing, and even the ability to pass imperceptibly from one to the other is considered more an exceptional gift than a pedagogical goal. The skilful blending of registers remains an important characteristic of the well-trained voice, but it is effected by other means than a percentagewise blending of the 'chest' and 'falsetto' voice source.[28]

Achieving a proper coordination between the chest voice and the falsetto is an exceedingly difficult pedagogic challenge. However, techniques for combining these two "voices" had been an integral part of vocal pedagogy for a period of at least four centuries preceding the twentieth. To overlook or dismiss this process is to discard a theory of vocal mechanics that has proven to be functionally effective and indispensable to the development of optimal technical skills.

VOICE SCIENCE AND REGISTER UNIFICATION

Fulfillment of the developmental potential of the vocal mechanism requires solutions centering on problems associated with the unification of the falsetto with the chest voice. Factual knowledge concerning the physiology of this unification has long been known, as is evident from this statement by Ingo Titze:

> . . . an effective way to eliminate register breaks is to train the thyroarytenoid muscle to deactivate gradually, in coordination with increased cricothyroid (CT) activity. In their electromyographic investigations of laryngeal control, Hirano, Vennard, and Ohala (1970) showed that this was indeed the strategy employed by a well-trained singer. As the pitch was raised, TA activity decreased in relation to CT activity, and there was no abrupt release of TA activity. This differential control of two intrinsic laryngeal muscles is one of the most difficult tasks in all of voice training.[29]

With all recognized authorities in substantial agreement on this point, the question arises; why has this phase of vocal mechanics not been pursued with greater vigor? Indeed, to suggest a correct management of the unification process through the "differential control of two intrinsic laryngeal muscles" as "the strategy employed by a well-trained singer," states the problem and the training objective, but offers nothing in the way of concrete proposals essential to the acquisition of this skill.

To be sure, attempts have been made to solve problems related to register unification, but the wrong means have been adopted for this simple reason; *problems rooted in physiology cannot be solved through the application of acoustic laws*. Recourse to current remedies such as matching acoustic signals, the practice of covering (which inevitably leads to vowel distortion), breath support (which tends to destabilize the entire respiratory system) and similar solutions not only skirt the issue, but tend to worsen an already undesirable technical condition.

The solution to problems related to register unification, of course, is dependent on an understanding of the mechanics involved when unifying the falsetto with the chest voice. This process is precisely what Titze described when he spoke of the necessity for training "the thyroarytenoid muscle to deactivate gradually, in coordination with increased cricothyroid (CT) activity" as "an effective way to eliminate register breaks." However, frequently overlooked by Titze and his fellow scientists is the importance of the relationship between either thyroarytenoid (vocalis) activity and sounds perceived as a chest voice, or cricothyroid activity in connection with falsetto tone qualities.

By common agreement it has been observed that increased thyroarytenoid or vocalis tension causes a thickening and shortening of the vocal folds, thereby lowering the pitch. When accompanied by higher levels of intensity, this tension coincides with the appearance of a chest voice. Over and against this, falsetto tonal qualities have been shown to be products of increased cricothyroid activity, causing the vocal folds to become longer and thinner, consequently elevating the pitch. These physical processes admit the possibility of producing an infinite variety of interactions involving shifts of muscular balance, as these are related to their tonal equivalents.

The most important piece of the vocal puzzle overlooked by voice science is how a "differential control of two intrinsic laryngeal muscles" described as "one of the most difficult tasks in all of voice training" is to be attained. The only suitable procedure for performing this task is through the employment of appropriately arranged musical scales and exercises. Physiologically, the thrust of such exercises and their special design, should serve to balance the amounts of tension distributed between the cricothyroids and arytenoids, whose shifting ratios of tension determine the physical dimensions of the vocal folds. Depending on the particular balance of tension assumed by these two muscle systems the tonal product will emerge as a chest voice, a falsetto, or some combination resulting from a blending of these two qualities.

FROM THEORY TO PRACTICE

The knowledge gained through an understanding of the possibilities inherent in the approach outlined above can be used to achieve a successful bridging of the registers. The beginning of this process is subject to an aural recognition of qualities perceived as a chest voice and a falsetto. By employing registrational mechanics as they relate to pitch, intensity and vowel patterns, a blending of these two qualities becomes a real possibility.

Obviously, one cannot reasonably expect a pupil to decrease thyroarytenoid activity by an act of will. However, thyroarytenoid activity can be reduced when the student is requested to sing a chest voice quality at a lowered level of intensity. Similarly, instructing the student to sing in a falsetto will inevitably result in an increase of cricothyroid activity. These are but two examples among many that can be cited to indicate how indirect control over the involuntary musculature of the larynx can be obtained.

Before the mechanics of register unification or "bridging the *passaggio*" can be understood, two basic registrational facts require clarification. The first is the significance of the term *passaggio*. It has long been known that the voice commonly divides into two parts, creating a passage or bridge that must be negotiated. On one side of the separation the voice is robust and traditionally referred to as a chest voice. On the other side, the tone quality is weak and perceived as a falsetto.

Secondly, there is a considerable pitch range shared in common between these two qualities, known as the register overlap. What immediately strikes the attention when appraising these voices is their incompatibility, both as to quality and intensity. This incompatibility must not only be reconciled, but these two qualities must undergo a transformation. The solution is to reduce the intensity of the quality that is more robust, while building up the strength of the weaker.

To bridge the *passaggio*, therefore, the aggressive quality of the chest voice must be tempered throughout its range to produce what during the Bel Canto era was known as a *mezzo petto* (half chest). The next step is to maintain that quality without an appreciable increase in intensity as the pitch ascends up to and beyond the *passaggio*, so that the *mezzo petto* quality gradually merges into a *mezzo falso* (half false).

Once the tensor muscles adjusting glottal dimensions accommodate themselves to this balancing act, the next objective is to gradually increase the overall intensity level so that the *mezzo petto* and *mezzo falso* tone qualities merge and develop into the *voce piena* or full voice. After this amalgamation has been put into effect the art of the *messa di voce*, or the swelling and diminishing of a single tone, should be undertaken.

At the onset of the *messa di voce* the tone quality should be that of a soft, clear *mezzo falso*. As the intensity level is gradually increased the sound will modify and assume those qualitative aspects associated with the *mezzo petto*, to ultimately emerge as a *voce* *piena*. In the diminuendo phase of a *messa di voce*, these qualities reverse themselves, eventually returning to a clear *mezzo falso*.

So considered, the *messa di voce* is not only an artistic device, but a pedagogic exercise whose purpose is to prove that the two muscle systems acting as tensors of the vocal folds are precisely balanced and the chest voice and falsetto are fully integrated.

As a general rule, the exercises outlined above have traditionally been practiced while singing on an AH vowel, because this vowel invites more chest voice participation and therefore, at a reduced intensity level, encourages a smooth juncture with the falsetto. However, all vowels should be included in the developmental process.

An important factor to be taken into consideration when blending the falsetto with the chest voice is the individual's vocal condition. For example, the same exercises described above, when sung by a student with negative constricting tensions, will undoubtedly ensure a negative result. Another critical element is the need to bring both the chest voice and the falsetto up to optimal strength before the final stages of coordinative interaction take place. There is yet another factor to be considered. If the registers are incorrectly combined they must be *disengaged* before a unification process should be set in motion. However, this disengagement is essential only in extreme circumstances.

Overcoming the difficulties affecting the "differential control of two intrinsic laryngeal muscles" becomes a real possibility through the application of an operative principle involving the construct of an exercise using various combinations of pitch, intensity and vowel. These combinations can be specifically designed to regulate the behavior of the cricothyroid and arytenoid systems as their tension affects the configuration of the vocal folds. Because of this special type of interaction, it becomes possible to bring the chest voice and the falsetto into a "percentagewise blending," thereby molding the voice into a seamless scale. By this means, indirect control over involuntary muscular activities can be achieved, and register breaks effectively eliminated.

WHY ALL THE FUSS OVER REGISTERS?

A common point of agreement among voice scientists is that a complex of laryngeal muscles governs the events taking place at the sound source. It is also recognized that the sounds perceived as vocal registers are derived from this source, and are unquestionably laryngeally based. This points to the pedagogic importance of the vocal registers, and explains why they are fundamental to an understanding of vocal mechanics. Through knowledge of the vocal registers and the exercise patterns that prompt their emergence, indirect control over the involuntary laryngeal muscular systems can be gained, leading to the correction of a vast majority of vocal faults at their point of origin.

This insight raises an interesting question. Why, if this coordination of the laryngeal muscular systems is so important, has so little research been conducted in an attempt to discover what Frederick Hussler and Yvonne Rodd-Marling referred to as the "'unlocking' process"[30] involved in freeing the vocal mechanism? Instead, studies have concentrated almost exclusively on breathing, support, visual feedback, articulatory devices (such as the lip trill) and the acoustic influence of the vocal tract (formants) as primary control factors in the regulation of vocal mechanics. This raises yet another question. How is it possible for these practices to improve the shifting balances of laryngeal muscular tension necessary to the regulation of glottal activity?

What is being challenged here is whether current scientific investigations are capable of establishing principles that can provide solutions to such problems as an abbreviated vocal range, tonal unsteadiness, poor breath economy, impure vowels, throat stiffness, jaw and tongue tension, and other vocal maladies. Transparently, the answer is: they cannot.

SCIENCE AND ITS SELF-IMPOSED RESTRICTIONS

When reflecting on the wealth of information published by voice science, it becomes apparent that these studies content themselves with an accumulation of physiological and acoustic data gleaned from subjects whose vocal technique is questionable. Except in rare instances, experiments have not as yet been conducted whose purpose and aim is to indicate *how* vocal faults are to be corrected, or *how* the mechanism is to be developed so that its overall function becomes more efficient. Clearly, both the investigative and pedagogic focus should be directed toward the establishment of a means whereby the technical status of those vocally gifted can be brought to a level commensurate with their potential.

It is when confronted with the task of developing practical solutions to vocal problems that voice science stumbles badly. The reason can be traced to several sources. First among them is the amount of time wasted on frivolous studies. A list of such studies appears in an article written by Hollien, Brown and Weiss:

> Some investigators have studied how long an individual can hold a note (Ptacek, Sander, Manoley, and Jackson 1966), or how old a person sounds (Hollien and Shipp 1972, Huntley, Hollien, and Shipp 1987, Ptacek and Sander 1966, Shipp, Qi, Huntley, and Hollein 1992), or the highest and lowest frequency one can phonate (Gelfer 1989, Hollien, Dew, and Phillips 1971, Reich, Frederickson, and Schlauch 1990). . . dozens of studies can be combined to show that the speaking voices of men average out to about 115 Hz (i.e., vibrations or cycles per second), women to about 200 Hz and children even higher (Bennett 1983, Brown et al. 1991, Curry 1940, de Pinto and Hollien 1982, Duffy 1970, Hollien et al. 1994, 1997, Hollien and Jackson 1973, Hollien and Shipp 1972, Krook 1988, Linke 1973, Mysak 1959, Stoicheff 1981).[31]

It is further contended by these writers that, "Knowledge of these relationships is important if the pedagogue is to understand properly the laryngeal mechanism."[32] Clearly, there is no connection between these studies and a practical developmental program whose purpose is to improve the quality of laryngeal functioning.

On the positive side, certain procedures essential to the pursuit of a scientific methodology have been followed. Among these are data acquired through the availability of diagnostic machinery, the drawing of graphs and charts to record the information collected, together with abstract formulations expressed in terms of mathematical equations. However, this information is difficult, if not impossible, to implement and convert to a practical vocal pedagogy. In short, voice scientists know how the mechanism works. What they do not know is how to conduct the experiments leading to the discovery of an operative principle that, when properly applied, is capable of improving the workings of the vocal mechanism.

As a consequence of this limitation, students are led into practices that are in all essentials superficial. These include: 1) singing into a microphone for the purpose of matching the vibrational pattern displayed on a screen, 2) an overemphasis on the "singer's formant" (an adjustment that causes the voice to "ring") without making a distinction between genuine ringing tonal qualities, as opposed to those that are falsely brilliant (associated with throat constriction) and technically damaging, 3) a dependency on breathing techniques accompanied by an overemphasis on abdominal support, which creates bodily stiffness and leads to a disturbance of the equilibrium of the total system, thus making vocal forcing inevitable.

Why are these approaches superficial? Because not one of them addresses the most important aspect of vocal mechanics, which is the interplay between the cricothyroids and the arytenoids as they draw the vocal folds into tension. This muscular interaction forms the crux of the pedagogic problem, and unless a way can be found to induce these two muscle systems to respond efficiently, real technical progress cannot be made.

A typical example of the failure of scientific solutions to vocal problems is revealed in an article written by Donald G. Miller and James Doing entitled *Male Passaggio and the Upper Extension in the Light of Visual Feedback.* As its name suggests, visual feedback is used to enable the singer to "see" the changing acoustic signal of the voice during the act of singing. The purpose of this approach is to inform the singer where his voice is lacking with respect to a desired harmonic structure (referred to as the singer's formant) help direct him to match a pre-conceived ideal, and assist in bridging the *passaggio* successfully to attain greater freedom in accessing the higher pitch range.

As Miller and Doing reported in their article, an effort was made to smooth the *passaggio* and gain access to the high pitch range of a young tenor who had been unsuccessful in overcoming this difficulty. After several futile attempts had been made, no positive results were obtained, forcing this admission, ". . . we should report that this student, at least for the time being, is singing more comfortably and effectively in the baritone range. Perhaps at some future point, when he has established better habits in his approach to *passaggio*, he will once again claim the tenor range."[33] This raises the question as to how the visual feedback machine is to be of assistance in achieving a desirable technical status when it is not already present.

The acoustic analysis used in the above approach was applied to recordings of several famous tenors, each singing the high B-Flat at the end of the aria *Celeste Aida*. The present writer witnessed an exhibition of this procedure by Dr. Miller during the 1997 Congress of the Bundesverband Deutscher Gesangspädagogen (the German Singing Teacher's Association) in Munich, Germany. It is true that in the various recordings each tenor acoustically displayed a dominant singer's formant. However, it was never explained why Domingo only held the B-flat briefly and at one dynamic level, while Corelli not only sang the note with ease, but gradually diminished the sound to a pianissimo.

Clearly, something is lacking in the Miller/Doing formulation, since both Domingo and Corelli had been successful in exploiting the resources of the singer's formant, yet Corelli obviously possessed a freer vocal technique and sang with greater mechanical skill. Surely, there must be something of greater significance to the successful singing of high notes than the mere presence of the singer's formant.

The reason the experiments conducted by Miller and Doing failed of their purpose is because they chose the wrong venue. Of the two influences at work when attempts are made to regulate glottal behavior, first in importance are the muscle systems that adjust glottal dimensions, while the impact of the formant structure on those dimensions is secondary. Thus, in focusing on the formant structure, Miller and Doing erred because they chose to apply an acoustic law to solve a physiological problem.

Why is this an error? Because while acoustic laws to a degree affect glottal dimensions, and therefore laryngeal muscular activity, those laws contain within themselves neither a mechanical action nor an operative principle, and therefore supply an important, but not a complete answer to the problem of register unification.

Sundberg offered a clear picture of the primacy of laryngeal muscular activity over acoustic influences when in *The Science of the Singing Voice* he made the following observation in a section entitled *Control of Vocal Fold Vibration*; ". . . one has to give the main responsibility to the muscles manipulating the properties of the vocal folds."[34]

With the solutions proposed by Miller and Doing demonstrably unsatisfactory, others have sought elsewhere for answers. Hollien, Brown and Weiss avoid the issue entirely by shifting the responsibility to the individual instructor with this disclaimer, "How this is handled by the teacher depends on his or her skill and orientation."[35] Taking this position hardly falls within the rigorous disciplines associated with a scientific methodology.

Moving further away from both physiology and acoustics is a pedagogic device, whose mechanical legitimacy is defended by Ingo Titze, called the lip trill. He justifies its use with this "proof":

> As I ask singing teachers and the theater coaches (let's call them vocologists collectively) about the benefit of these exercises, there usually emerges an answer like this: "It's easy on the vocal folds, but gets the respiratory system going full steam." There is scientific validity in this. . . physical law dictates that the pressure across the lips plus the pressure across the vocal folds must equal the lung pressure.[36]

The first question to be raised in response to this extraordinary statement is why any voice scientist would seek the opinion of non-scientists with respect to the pedagogic value of any exercise or theory. Had Titze followed an accepted scientific methodology, he would have challenged the validity of the lip trill and its use as a viable pedagogic tool. In a scientific methodology, it is common practice to conduct experiments, not to prove, but to disprove a theoretical proposition.

What Titze overlooks here is the importance of the proportional amounts of laryngeal muscular tension required to adjust the vocal folds so that the total mechanism is brought into a state of equilibrium – the only fundamental objective of technical value. At best, therefore, the lip trill is a time-wasting tool; at worst, if accompanied by constrictor tensions, its use can be damaging.

Titze also employs the use of the term "twang." In his article, *Acoustic Interpretation of Resonant Voice*, he writes:

> A twang quality emerges from the ring quality when the pharynx is narrowed, and this twang can be nasalized when velar coupling is added, but nasalization is secondary to both ring and twang. It is quite unfortunate that ring and twang have been so strongly associated with nasality, because this association has led to much of the confusion about "placement" and "focus" of resonant voice.[37]

There are serious misconceptions contained in these statements. A genuine tonal ring is far removed from possessing "twang." To the discriminating ear, a beautiful tone quality has no association whatsoever with any aspect of this type of resonance. According to Sir Richard Paget, "twang" is associated with throat constriction. In his view:

> . . . if, while the reed was sounding, the tube was suitably pinched, near the opening from the reed . . . an appreciable twang was added to the vowel-sound. This experiment indicates that a part, at least, of the so-called nasal quality . . . is probably due to a constriction of some part of the pharynx."[38]

On the basis of this evidence, it is imperative that a distinction be made between a narrowing of the pharynx and negative pharyngeal constriction. Thus, while a narrowing of the pharyngeal aperture is desirable, the constriction associated with nasality and twang is not. How does one differentiate between these two conditions? Essentially, the difference is qualitatively reflected in the vowel. With a correct narrowing of the pharyngeal area the vowel quality will be pure, vibrant, and well-defined. By contrast, all aspects of "twang," being related to constrictor tensions, are reflected in a distortion of the vowel quality. Making this distinction requires trained listening of the highest order.

With technical skills in singing so dependent on the sensitivity of listening skills, the introduction of mechanistic solutions such as a volitional narrowing of the pharyngeal cavity, not only diverts attention from critical listening, but inevitably leads to throat constriction and the production of poorly resonated vowel qualities. It must be concluded, therefore, that any and all concepts related to "twang" are inappropriate, since this quality inevitably reflects the presence of mechanical deficiencies.

To seriously discuss the lip trill and twang within the confines of a scientific discipline points out the deficiencies and self-imposed restrictions inherent in current scientific thinking. If, according to Sataloff, "Interactions among the components of the voice are ultimately responsible for all the vocal characteristics we produce,"[39] solutions of the type mentioned above are bound to fail, because they do not attack vocal problems at their source; that is to say, the interactions among the diverse laryngeal musculatures. Ignoring the importance of these interactions is not only a serious scientific oversight, but one that often leads to disastrous and harmful consequences.

THE INVESTIGATIVE MYSTERY

A continuing mystery surrounding voice science is its failure to investigate theories of vocal mechanics predating the invention of the laryngoscope. The period of special interest is the eighteenth century, a time known for the extraordinary virtuosity of its singers. Built upon centuries of empirical observation and practical experience (the very cornerstone of all scientific experimentation), the lessons to be learned from this era are of inestimable value. Surely, therefore, the eighteenth century pedagogic scene and the sophisticated training programs in effect at that time are worthy of study, if not emulation.

Fortunately, a number of recognized eighteenth century authorities have left a record describing both the mechanical and artistic bases on which this period of vocal training was founded. The first to seriously comment on vocal mechanics as practiced prior to the invention of the laryngoscope was Pier. Francesco Tosi (1647-1727). In *Opinioni de' cantori antichi e moderni, o sieno osservazioni sopra il canto figurato*, Tosi's views represent what must be considered a consensus of vocal training, both as to theory and practice, prevalent during that era. The substance of these opinions can be summed up in the following remark, ". . . if the union [of the chest voice and the falsetto] is not perfect, the voice will be of more registers, and consequently will lose its beauty."[40] Tosi also noted that the area commonly known as the *passaggio* is the point in the tonal range ". . .where the difficulty of unification is located."[41]

A specific procedure for effecting this unification of the falsetto and chest voice has been left posterity by Vincenzo Manfredini (1737-1799). According to his report:

> ...it is necessary to unite these and those [notes in the head voice and notes in the chest voice] in such a way, that the voice seems to be of one register. . . This is done not by forcing the high notes of the chest, but rather by

> reinforcing the low notes of the falsetto; or doing the opposite, if the notes of the chest are weak and deficient and those of the falsetto are abundant and strong.[42]

Without exception, all eighteenth century authorities steeped in the Bel Canto tradition shared the opinions expressed by Tosi and Manfredini, and although the castrati were the vocal darlings of the time, these opinions contained a fundamental principle applicable without exception to all voice types. Proof of this assertion can be found by consulting many currently available sources, one of which appears in the writings of Domenico Corri (1746-1825). According to Corri:

> There are four sorts of Voices, Basso, Tenore, Contralto, and Soprano. . . that part above the Natural [voice] is called the feigned or falsetto Voice. . . After the Scholar has ascertained the compass of the Natural Voice, his great study should be to contrive to unite the Natural to the first Note of the Falsetto, to blend them with such nicety, that the union may be imperceptible.[43]

On the basis of the above comments alone, it is evident that the practice of blending the falsetto with the chest voice has a history covering at least five centuries, and comprised the building blocks of all pedagogic systems up to and including the final decades of the nineteenth.

Why then, one must ask, has voice science been reluctant to investigate and replicate theories and practices common to that period? Surely, the development and integration of the falsetto with the chest voice, studied with a view to discovering its value to contemporary pedagogic practice, should be of the highest priority!

The only conceivable answer to account for this oversight is that the development and integration of the falsetto with the chest voice cannot be measured, quantified or calculated through the use of diagnostic equipment, no matter how sophisticated those instruments may be. As reported by Sataloff, “These instruments are important, but clearly our best clinical tools remain our own eyes and ears.”[44]

Viewed from this perspective, experiments must be conducted through reliance on trial and error methods, coupled with studies based on cause and effect relationships, rather than a dependency on graphs and mathematical equations. Essential to this process is the cultivation of listening skills capable of recognizing and correctly evaluating different qualitative relationships involving the chest voice and the falsetto, together with an understanding of the special musical stimuli needed to prompt their emergence.

The processes necessary to develop and unify the falsetto with the chest voice are essential to an understanding of vocal mechanics that is provable, consistent, and applicable to all voice types, male and female. To attempt to answer questions regarding how the voice works and the means for improving its mechanical functioning, *without* including studies concerned with the unification of the chest voice and the falsetto, is to ensure that satisfactory answers to fundamental vocal mechanics uniting both theory and practice will forever lie beyond reach.

DODGING THE ISSUE

Although voice science has, over the years, chosen to ignore the pedagogic theories and practices extant prior to the invention of the laryngoscope, this gap has recently been filled by Richard Miller. The substance of his analyses of this period in vocal history is recorded in an article entitled *Historical Overview of Vocal Pedagogy*, included in a collection of essays compiled by Robert T. Sataloff under the heading *Vocal Health and Pedagogy* (1998).

According to Miller's interpretation of eighteenth century pedagogy, one is assured that, "Although singing technique may not have adhered to uniform instructional ideals endorsed by all, common technical threads run throughout early treatises."[45] However, Miller mistakenly claims that this commonality centers on breathing and enunciation, while ignoring the most important aspect agreed upon by all reputable authorities of the time, which is to unite the falsetto (or head voice) with the chest voice.

In his representation of Tosi's position, Miller has chosen to ignore the importance of this unification, being content to state that Tosi believed in the existence of two registers. Moreover, instead of dealing with the pedagogic substance of Tosi's writings, Miller emphasized superficialities such as, "Tosi was not happy with the existing status of the singing art."[46] What Miller has failed to bring to one's attention is that in Tosi's instruction, the subject of breathing was never emphasized and, indeed, barely mentioned. Left without comment in Miller's article is Tosi's insight into basic vocal mechanics which runs as follows:

> A diligent Instructor knowing that a soprano without falsetto must sing within the narrowness of a few notes, must not only attempt to obtain it [the falsetto] for him, but to leave no method untried in order to unite it [the falsetto] to the chest voice in such a manner that one cannot be distinguished from the other. . .[47]

One can only infer from Miller's avoidance of the intelligence communicated in this passage, is that the importance of this unification process does not fit comfortably within the parameters of current scientific thinking. Perhaps it is because Tosi left no specific instructions as to how this unification was to be accomplished. Undoubtedly, it was because in a creative vocal pedagogy, the processes of register unification are so complex as to preclude codification. In other words, a principle is being applied that requires flexibility, as opposed to the rigidity of static procedures.

Turning to a more detailed account of eighteenth century vocal mechanics, Miller quotes from Mancini's treatise *Pensieri, e riflessioni pratiche sopra il canto figurato* (1744). Here, Miller draws attention to what he considers to be the substance of Mancini's theory of vocal mechanics as follows:

> Much of his [Mancini's] pedagogic comment is directed to the resonator system, with particular attention to the maintenance of natural postures of the buccal cavity, and to the smiling posture as an adjustor of the vocal tract.[48]

Although it is true that Mancini entitled one of his articles, or chapters "*On the Position of the Mouth, or, on the Manner of Opening the Mouth*," what has been conveniently overlooked are the contents of two complete articles entirely devoted to the importance of the vocal registers, one entitled "*Of the Voice of the Chest and Head, or Falsetto*," and the other, "*Of the Union of the Two Registers, Portamento of the Voice, and of the Appoggiatura*."[49] This emphasis on register unification was not only fundamental to Mancini's beliefs, but unanimously endorsed by other eighteenth century authorities as well.

Just how fundamental this registrational conception was to Mancini's instruction is made clear by the following advice, to be observed before undertaking more advanced vocal studies such as ornamentation:

> . . . this study [agility] should not be undertaken until the master has succeeded in uniting the divided registers. . . If this essential point is overlooked. . . the passage will be unequal, and consequently defective, as much in the strength and the clarity of the voice, as in the proportion and unity of it.[50]

Ignoring this admonition and moving further away from concepts related to basic register mechanics, Miller focused on an opinion more compatible with current scientific thinking:

> Another Mancini pedagogic tenet was that in order to be distinct and executed with the greatest possible velocity, all runs and agility passages should be supported by a robust chest assisted by graduated breath energy, and with light "fauces" [the passage from the mouth into the pharynx].[51]

By elevating this belief to a position of special importance, Miller focuses on the comparatively superficial, rather than on fundamental vocal mechanics. Indeed, the use of the anatomical term "fauces" is at best an obscure reference, even among voice scientists. What Mancini probably had in mind when referring to a light "fauces" is the need to avoid throat constriction. This theoretical position is made clear in the following quotation:

> That which is called the defect of the throat or crude and suffocated occurs because the singer does not sustain the voice with the natural force of the chest, but believes to obtain good effect merely by tightening the fauces. He deceives himself, however, and must hold as true that this method is not only insufficient to correct the voice, but moreover, is absolutely harmful, the reason being that the fauces, as it was shown in Article III, are part of the organ of the voice, which is not able to emerge naturally and beautifully with the fauces found in a forced position and hindered from behaving naturally.[52]

To discount the importance of Mancini's emphasis on register unification (by stressing the setting of mouth position and avoidance of throat constriction by using a light "fauces") shows a misunderstanding of the basic fundamentals of eighteenth century pedagogy.

Continuing his exegesis, Miller turns to Domenico Corri, but digresses from the subject of the article, vocal pedagogy, to comment on the musical practices and extensive variations and cadenzas for which Corri was so well known. Again, Miller chooses to avoid the fundamental issue of register development and integration with this observation:

> However, he [Corri] does not offer significant advice to a reader searching for clues on how best to accomplish the technical complexities of the vocal literature considered.[53]

Miller ignores the key component upon which all vocal pedagogy was then structured, and with it, any suggestion as to the best means for dealing with technical complexities. The following statement made by Corri in *The Singer's Preceptor* contradicts Miller's contention that Corri failed to offer significant technical advice:

> After the Scholar has ascertained the compass of the Natural Voice, his great study should be to contrive to unite the Natural to the first Note of the Falsetto, to blend them with such nicety, that the union may be imperceptible.[54]

This blending process was fundamental to the teaching of all eighteenth century authorities. Only after this procedure had proved successful was attention shifted to more sophisticated areas of musical expertise. Given the primacy of the need to blend the two vocal registers, why has Miller, along with the majority of both voice teachers and voice scientists, chosen to ignore such an important pedagogic fundamental?

THE FALSETTO:
A CURIOUS OMISSION

When reflecting on Miller's reluctance to mention the falsetto and the necessity for uniting certain of its properties with those of the chest voice, one must ask the question; why this reluctance? Surely, one would think, this incompletely formed voice quality (so successfully incorporated into the teaching regimen of Tosi, Mancini, Corri, together with a host of other eighteenth and nineteenth century authorities) would qualify as an ideal area for investigation and testing. In large part, the reason for this omission is revealed in Miller's comment on a traditional terminology:

> Garcia devised register terminology with the designations Chest Voice, Falsetto Voice, and Head Voice, based on physiologic information and practical knowledge of then-current performance practice. These registration divisions are confusing to modern-day voice researchers.[55]

Confusing indeed! These terms have been in constant use for at least three centuries. Up to the immediate present, literally thousands of singers and voice teachers have found meaning in these terms, perceiving in their qualities an association between pitch range and localized sensations of vibrations. Clearly, for singers and teachers of singing, these terms possess much more meaning than those introduced by voice science, such as vocal fry, modal and loft, which confuse even those who have considered these terms to be more correct scientifically. Paradoxically, the term falsetto is the only term that has been carried over and left unchanged by contemporary science. The reason for this omission, to quote Ingo Titze, is because "It cannot be confused with much else."[56]

One explanation offered as to why modern-day voice researchers do not understand the significance of the terms chest voice, head voice, and particularly falsetto, is that they have interchanged the position in the pitch range where these qualities put in an appearance. Thus, in the new order, one finds the falsetto positioned above the head voice. As opposed to this, authorities of an earlier period were aware that the falsetto and the chest voices overlapped and shared several pitches in common (A below middle C to an octave and a minor third above) and it was on these pitches that the integrative process was to take place.

It is evident, therefore, that as long as voice scientists continue to position the falsetto above the head voice, the processes essential to a successful amalgamation of these two ‘voices’ can neither be understood theoretically nor successfully implemented technically.

Perhaps it is for this reason that in current research scant attention has been given the falsetto, its identification with a mechanical action or actions, agreement as to its location in the musical scale, and whether it is common to all voice types, male and female. A logical explanation for this confusion is that false tonal characteristics are difficult to explain due to the many qualities emergent during the process of register blending.

As a matter of history, different types of falsetto were commonly recognized by all authorities up to the final years of the nineteenth century. Those potentially capable of being successfully integrated with the chest voice were utilized, while qualities known to be incompatible with the blending process were rejected. Since it is impossible to describe, identify, or otherwise communicate the actual tonal qualities deemed potentially useful during the processes involved in uniting the falsetto with the chest voice, the sole recourse is to conduct experiments to discover which falsetto qualities are developable and which are not.

As previously mentioned, clues pointing the way to a successful integrative process are to be found in early terminologies. Among these are *mezzo falso* (half false), *mezzo petto* (half chest), *voce mista* or *voix mixte* (mixed voice), and *voce piena* (full voice) this last designation indicating a complete integration of the two registers.

To leave any of these progressive steps essential to register development and unification unexplored is to abort the investigative processes essential to an understanding of vocal mechanics. Beyond a shadow of doubt, ignoring the developmental potential of the falsetto succeeds mainly in watering down the vitality of concepts and procedures capable of exploiting the resources of this mechanism. One thing is certain: to impose modern-day pedagogic viewpoints when interpreting theories and pedagogic practices of a bygone era is neither good scholarship nor good science.

THE TESTING PROBLEM

Despite the amount of research conducted by voice science, satisfactory answers to problems related to the vocal mechanism and the operative principle that regulates its behavior have proven to be elusive. Missing in the investigative process is a connection between tone quality, the physiological events transpiring at the sound source, and the association of these events with specifically arranged combinations of pitch, intensity and vowel. Also overlooked are the dynamics involved in the above-mentioned relationships, how these dynamics provide a complete understanding of the vocal mechanism, how it works, and how it ensures the acquisition of indirect control over an involuntary laryngeal musculature.

The relationships outlined above have rarely, if ever, been tested by voice science. Failure to pursue this course can be directly related to a misunderstanding of falsetto mechanics and the means whereby this part of the vocal mechanism can be induced to enter into a full coordinate relationship with the chest voice. What stands forth loud and clear is this: voice scientists in general simply do not understand how the differential control of two opposed muscle systems, responsible for creating a division of the voice into two parts, can be successfully united and induced to function as an efficient physiological entity, without breaks and/or divisions being apparent to the listener.

Yet another aspect of this testing problem is the inaccessibility of the laryngeal musculature to overt control systems. Nevertheless, this difficulty can be successfully overcome. The behavior of the vocal mechanism can be modified and altered to a considerable extent by projecting an exercise designed to rearrange the coordinative response of these muscle systems. It is through these interactions that the behavior of a complex of involuntary laryngeal muscles can be brought under an environmental control system. Concepts related to chest voice and falsetto mechanics are key factors in this approach, and serve to open up a broad range of possibilities for altering the response capability of these muscle systems.

Clearly, none of the data accumulated by voice science leads to a successful pursuit of this course. Essentially, it is simply a compilation of information without relevance to problem solving. The pedagogic objective is to devise a means whereby the proportional amounts of cricothyroid and arytenoid tension can be properly regulated. A critical element to the success of such a project is the development of listening skills, without which a complete understanding of vocal mechanics will forever remain, if not a mystery, at least in practical terms, an unattainable goal.

THE SCIENTIFIC IMPASSE

What now becomes increasingly clear is that diagnostic machinery, upon which voice science depends, moves beyond its depth when vocal study based on an environmental control system is undertaken. No matter how sophisticated these machines may be, they cannot supplant the human ear and its potential listening skills.

Why is the listening ear more sensitive than the most efficient diagnostic machinery? Simply because machines record isolated elements of vocal mechanics, whereas the human listening faculty is able to hear comprehensively; that is to say, capable of analyzing the complex act of singing as a total experience. Thus, like the skilled conductor of a symphony orchestra, a singing teacher must instantly record a host of complex sound waves, both as separate and yet unified events.

That the human ear is far superior to the most sophisticated equipment in detecting not only the totality of the voice, but its subtle characteristics, is made clear in another statement by Sataloff:

> Subtle characteristics, however, still cannot be detected. For instance, in studies of voice fatigue in trained singers, the difference between a rested and tired voice is usually obvious to the ear, but significant changes cannot be detected consistently even with sophisticated equipment.[57]

In yet another article it is Sataloff's further contention that, "The best acoustic analyzers are still the human ear and brain. Unfortunately, they are still not very good at quantifying the information they perceive, and we cannot communicate it accurately."[58] The last part of this quote is revealing, the operative word being "quantifying." This exposes a basic limitation of science, since it is evident that human beings are not fixed equations and therefore cannot be quantified. Sataloff points out the difficulty of standardizing the analysis of the voice in the following quote:

> Because the human ear and brain are the most sensitive and complex analyzers of sound currently available, many researchers have tried to standardize and quantify psychoacoustic evaluation. Unfortunately, even definitions of basic terms such as hoarseness and

> breathiness are still controversial. Psychoacoustic evaluation protocols and interpretations are not standardized. Consequently, although subjective psychoacoustic analysis of voice is of great value to the individual skilled clinician, it remains generally unsatisfactory for comparing research among laboratories or for reporting clinical results.[59]

Here Sataloff is quite correct. Listening is purely an individual matter and that is what the training of the voice, whether it be for speech or singing, is and forever must remain, a one-on-one situation in which the teacher applies a fundamental principle whose purpose is to correct vocal faults. Success in this venture depends on the teacher's skill in correlating the tone qualities produced by the singer with deficiencies of coordinative skill among the laryngeal musculature that interfere with the free emission of the voice. No matter how sophisticated the equipment, voice science is incapable of providing the answer the voice teacher is looking for; that is, the development of a hearing sensitivity to tone quality that is able to lead the student to a mechanical functioning of the voice parts resulting in the production of beautiful tone qualities.

The essence of the process here defined involves those procedures that relate to the development and integration of the falsetto with the chest voice. In mechanical terms, this means that the teacher must learn to listen functionally as well as aesthetically. Beautiful tone quality is the ultimate goal, the processes employed to overcome technical flaws being dependent upon an understanding of vocal mechanics.

The essential difficulty confronted during the process of learning how to sing is that the ideal tonal quality sought after has not as yet been heard, nor have the physical sensations or kinestetic experiences associated with the singer's potential been sensed. Clearly, diagnostic machinery, however sophisticated, is inadequate as a means for achieving the singer's functional and artistic goals.

CONCLUSION

With an obvious dichotomy existent between the analytical dependency of voice science on mechanical contrivances, and the reliance of the teacher of singing on listening skills, it would appear that science and art operate in separate realms. Thus, the question arises as to whether a commonality exists between these two disciplines. In spite of obvious differences both in theory and practice, the encouraging fact is that a commonality does exist. Both the scientist and the voice teacher should share one objective in common – knowledge of the physical and acoustic nature of the vocal mechanism, the rules governing its mechanical action, and an understanding of an operative principle capable of regulating the behavior of these involuntary muscle systems when adapted to serve phonative needs.

On the basis of this reasoning, common ground can and must be discovered where science and art are able to work comfortably together. This compatibility exists in other areas such as engineering where both a theoretical and an applied science meet. Therefore the goal of both the voice scientist and the teacher of singing should be to bring this cooperative venture into being. It is on this foundation that the future of voice science must rest. It is also where the future of vocal training lies.

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