ABSTRACT

Title of Dissertation: TEACHING REGISTRATION IN THE MIXED CHORAL REHEARSAL: PHYSIOLOGICAL AND ACOUSTICAL CONSIDERATIONS

Nicole Aldrich, Doctor of Musical Arts, 2011

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One of the most challenging concepts of vocal technique is registration. In classical Western singing, noticeable changes of timbre over the course of a singer's vocal range are considered undesirable, and much effort is spent in learning how to eliminate these "breaks." Faults in vocal registration can cause unevenness of tone quality, lack of resonance, and instability of intonation. The choral conductor must learn how to address these problems in rehearsal in order to establish good choral sound.

Much literature exists which defines the physiological and acoustical adjustments required to create a well-blended, "one-register" voice; however, this literature is aimed at the individual singer or teacher of solo voice. Voice-training resources for choral conductors may mention registration and vowel modification but typically do not explain in any detail the science underlying the concepts. The choral conductor thus must adapt

the body of solo voice research for application to a group voice teaching setting. The primary goal of this paper is to propose and describe techniques for teaching registration and vowel modification concepts to choral singers.

The paper details the physiological factors at work in vocal registration, including the functions of the intrinsic laryngeal musculature. It also surveys the science of acoustics as it applies to the singing voice, including a discussion of vowel formants and the purposes and methods of formant tuning for male and female voices. This section will draw heavily on existing research in solo singing.

The next portion of the paper tailors this knowledge to the needs of the choral vocal teacher. The author describes signs of registration difficulties within an ensemble and their possible causes. Next the author provides a series of vocalises and other tools designed to help the conductor achieve two goals in rehearsal: first, to help both men and women develop the physiological adjustments necessary to reduce obvious registration shifts; and second, to assist singers of all voice types in discovering the vowel modifications which will produce a uniform tone quality throughout the range. Finally, the author explains how the conductor can identify potential registration problems during score study and preparation.

TEACHING REGISTRATION IN THE MIXED CHORAL REHEARSAL: PHYSIOLOGICAL AND ACOUSTICAL CONSIDERATIONS

by

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Introduction

One of the most challenging concepts of vocal technique is registration. In classical Western singing, noticeable changes of timbre over the course of a singer's vocal range are considered undesirable, and much effort is spent in vocal training learning how to eliminate these "breaks." In ensemble singing as well as solo work, faults in vocal registration can cause unevenness of tone quality, lack of resonance, and instability of intonation. These problems are magnified in a choral setting, because multiple singers may experience these difficulties at the same time. The choral conductor must learn how to address these problems in rehearsal in order to establish good choral sound.

Even a singer whose voice is perceived as seamless must make laryngeal and vocal tract adjustments over the complete vocal range; in fact, it is these adjustments themselves which produce the well-blended, "one-register" quality of such a voice.[1] Much literature exists which defines the physiological and acoustical factors underlying these efforts. Some of these resources provide general information, while others describe the separate challenges faced by male and female singers. Some provide vocalises which can be tailored to the individual singer to assist in developing proficiency in these technical areas; however, this literature is aimed at the individual singer or teacher of solo voice.

Voice-training resources for choral conductors may mention vocal registration but typically do not explain in any detail the science underlying the concepts. These resources usually include a variety of vocal exercises but do not always connect an

[1] Scott McCoy, *Your Voice: An Inside View* (Princeton, NJ: Inside View Press, 2004), 69.

exercise to a specific physiological or acoustical function, and often do not explain how to properly execute the vocalise to achieve maximum benefits. For example, one resource explains that to avoid register breaks, "elements of breath, timbre, and muscle coordination should be isolated and corrected."[2] The authors do not define what the elements are or how the conductor can address them. They propose four exercises to "blend" the registers[3], with suggested vowel sounds but no other information, such as recommended pitch levels for the exercises or how to explain the vocalises to the singers.

Some materials seem to be based on techniques that have been successful for the author of the resource, but they do not provide the factual foundation that would make the results repeatable by another conductor, or empower another conductor to develop his or her own voice-building techniques. Other resources simplify the facts so much that the reader may be left with a misunderstanding of how the vocal instrument works. An author's assertion that resonance is created by "amplification in the head and chest"[4] is strictly true, because the trachea is a resonator, and the vocal tract is found inside the head. In the absence of further explanation, however, the choral conductor may mistakenly assume that it is the solid materials of bone and tissue that create the amplification, not the air within the empty spaces. Without an understanding of the nature of vocal resonance, the choral director is ill-equipped to help his or her singers to develop it.

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[2] Brenda Smith and Robert Thayer Sataloff, *Choral Pedagogy* (San Diego: Singular Publishing, 2000), 132.

[3] *Ibid.*

[4] Frauke Haasemann and James M. Jordan, *Group Vocal Technique* (Chapel Hill, NC: Hinshaw Music, 1991), 67.

Resources for choral conductors may have incomplete information because they typically address a number of topics besides vocal instruction: recruitment, classroom management, performance practice, repertoire selection, and many other issues which are a part of the choral director's daily work. The most detailed information about the workings of the voice can be found in materials written for and by voice scientists and private voice teachers. The choral conductor is thus faced with the challenge of adapting the body of solo voice research for application to a group voice teaching setting.

In a group setting such as an ensemble rehearsal, time constraints are such that the conductor cannot work with problem voices one at a time. Nor can the conductor always work with one section at a time, helping sopranos learn to modify their vowels or tenors to navigate their *passaggio*, while the rest of the choir sits idle. Rather, the choral director must have at his or her disposal a range of teaching techniques that will help as many singers as possible in as short a time as possible. Proposing and describing these techniques is the primary goal of this paper.

The paper will first detail the physiological factors at work in vocal registration, to include descriptions and diagrams of the structure of the larynx and explanations of the functions of its intrinsic musculature. It will also survey the science of acoustics as it applies to the singing voice, including a discussion of vowel formants and the purposes of vowel modification for male and female voices. This section will draw heavily on existing research in solo singing.

The next portion of the paper will tailor this knowledge to the needs of the choral vocal teacher. The author will describe signs of registration difficulties within an ensemble and their possible causes. Next the author will provide a series of vocalises and other tools designed to help the conductor achieve two goals as efficiently as possible within the choral rehearsal: first, to help both men and women learn to navigate the physiological adjustments necessary to reduce obvious registration shifts; and second, to assist singers of all voice types in discovering the vowel modifications which are most effective in producing a uniform tone quality throughout each singer's range. Finally, the author will explain how the conductor can identify areas of potential registration problems during his or her score preparation.

I. The Larynx

The larynx, or voice box, is a small structure located in the throat, comprising bone, cartilage, muscle, ligaments, and membranes. In the adult male, it is about the size of a walnut. In the adult female, it is approximately 40 percent smaller.[5] The larynx is connected to the hyoid bone above it, and to the trachea below. The movement of structures within the larynx is responsible for phonation (the creation of sound through vocal fold vibration), pitch change, volume change, and to a certain extent vocal quality.

Cartilages

The main structure of the larynx consists of several cartilages: the thyroid, cricoid, and arytenoid cartilages and the epiglottis.

The thyroid cartilage is the largest cartilage in the larynx and is somewhat shield shaped. At the anterior (front) it has a notch at the top or superior point; just below that is the anterior commissure, the front attachment point of the vocal folds. The superior horns or cornu of the thyroid cartilage are two horn-like projections which extend upward from the posterior of the cartilage and are connected to the hyoid bone. Two inferior horns attach the thyroid cartilage to the cricoid cartilage below. See figures 1 and 2 on the next page.

The cricoid cartilage, the second largest cartilage in the larynx, forms a complete circle, with the posterior portion considerably wider than the anterior portion, rather like a signet ring. The cricoid cartilage is attached to the thyroid cartilage at the inferior horns

[5] Scott McCoy, *Your Voice: An Inside View* (Princeton, NJ: Inside View Press, 2004), 113.

via a synovial joint. The synovial joint allows the cartilages to both pivot and slide in relation to each other.

The arytenoid cartilages sit atop the cricoid cartilage at the posterior. They are roughly pyramid-shaped. The arytenoids are connected to the cricoid cartilage by synovial joint. They can slide together or apart, and can also rotate on the surface of the cricoid cartilage.   The arytenoids are the posterior point of attachment of the vocal folds and also serve as the connection point for all the muscles which open or close the glottis, the opening between the vocal folds.

At the top of the larynx is the epiglottis, a cartilage which folds over during swallowing to direct the swallowed material into the esophagus and keep it out of the airway. At the bottom of the larynx is the trachea, or windpipe, which divides into the two bronchial tubes leading to the lungs.

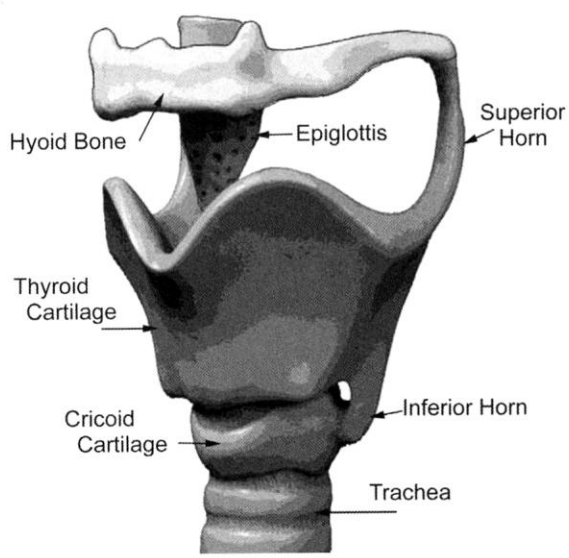

Figure 1. Cartilages of the larynx, anterior view.[6]

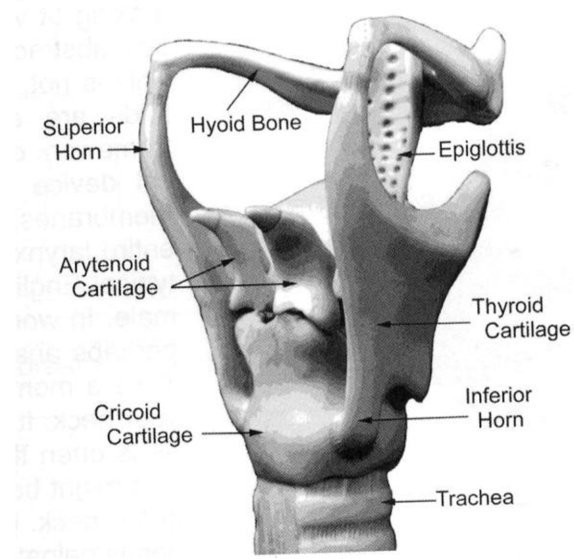

Figure 2. Cartilages of the larynx, posterior view.[7]

[6] McCoy, 113.

[7] McCoy, 114.

The vocal folds

The vocal folds are a pair of tissue folds within the larynx, running across the airway from front to back, from the anterior commissure of the thyroid cartilage to the arytenoid cartilages. The vocal folds in adult males range in length from approximately 15 to 20 millimeters when abducted, and in adult women from 9 to 13 millimeters.[8] At rest, the posterior portions of the two vocal folds are separate from each other, resembling the letter V when viewed from above (with the point of the V at the anterior, attached to the thyroid cartilage).

The myoelastic-aerodynamic theory of voice production describes the process of phonation as a combination of muscular and aerodynamic forces. One cycle of the phonatory process begins with the drawing together of the vocal folds by muscle activity. Air pressure beneath the closed vocal folds increases, causing the gradual opening of the glottis from bottom to top. As the vocal folds open, the high-pressure air begins to move through the opening. The velocity of the air must increase in order to move through the constriction created by the partially-open glottis. This increase in air speed causes a reduction in air pressure through the glottis. The lessening of air pressure (also known as the Bernoulli Effect), along with the stiffness or elasticity of the folds, causes the folds to close again, from bottom to top. The cycle then begins again. The cycle repeats as many times per second as the fundamental frequency of the pitch being sung: for example, for A_4, the A above middle C on the piano, this cycle is repeated 440 times in one second (440 Hertz or Hz). The chopping of the airstream resulting from the opening

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[8] Willard R. Zemlin, *Speech and Hearing Science: Anatomy and Physiology*, 2nd edition (Englewood Cliffs, NJ: Prentice-Hall, 1981), 193.

and closing of the glottis creates the air disturbance which the ear perceives (and the brain interprets) as sound.

The vocal folds have both a main body and a looser covering that can move independently of the body. The slippage of the cover over the body allows for free oscillation of the vocal fold. The cover moves in a ripple which is known as the mucosal wave. When inflammation such as laryngitis causes the cover to adhere tightly to the body, the mucosal wave is impeded, and phonation becomes more difficult or impossible.[9]

The cover of the vocal folds is known as the epithelium. It is made of a thin layer of skin cells and is constantly bathed in mucus, giving the area its common name, the mucosa of the vocal folds. The lamina propria forms a transition between the cover and the main body of the vocal folds. The lamina propria consists of three distinct layers, superficial, intermediate, and deep. The superficial lamina propria is the narrowest layer and also the least viscous. The intermediate layer, which is wider and more viscous than the superficial layer, forms the vocal ligament along with the deep layer. The deep lamina propria is the densest layer of all and rests closest to the body of the vocal fold. The main body of the vocal fold consists of the thyroarytenoid muscle, one of the intrinsic muscles of the larynx. These structures may be seen in figure 3.

[9] McCoy, 109.

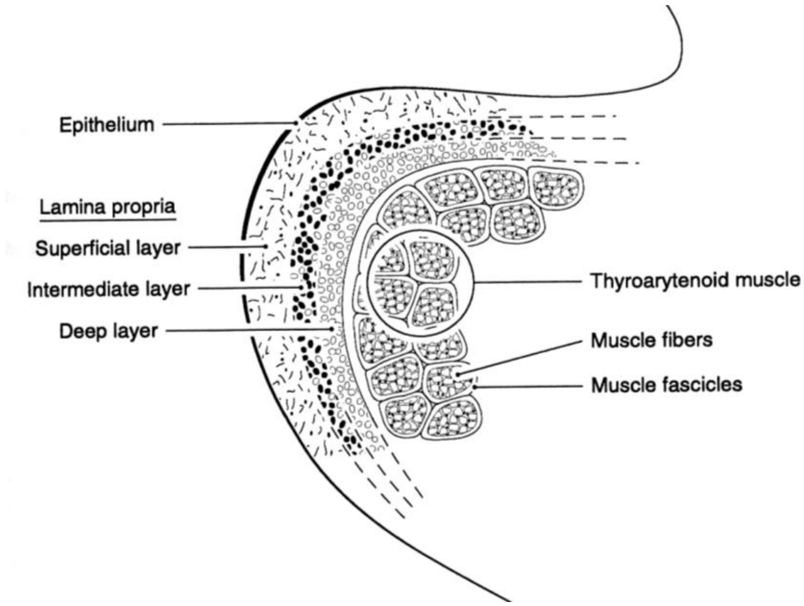

Figure 3. The structure of a vocal fold.[10]

Musculature

The intrinsic muscles of the larynx (those found entirely within the laryngeal structure) are responsible for phonation and pitch change. The actions of some muscles adduct or close the glottis, bringing the vocal folds together for vibration. Others open the glottis (abduction), separating the vocal folds for inhalation or to stop phonation. Still other muscles are responsible for changing the length of the vocal folds, stretching or shortening them and varying their thickness. Changes in length and thickness of the vocal folds are responsible for change in fundamental frequency (pitch).

The thyroarytenoid muscle forms the main body of the vocal fold. Each of the two thyroarytenoid muscles, often abbreviated "TA," originates at the anterior commissure of the thyroid cartilage and attaches to one of the arytenoid cartilages at a

[10] Ingo Titze, *Principles of Voice Production* (Iowa City: National Center for Voice and Speech, 2000), 116.

small protrusion called the vocal process. The main fibers of the thyroarytenoid muscle, known as the thyrovocalis, run parallel to the medial edge of the vocal fold, the edge closest to the airway. The other division of the TA, the thyromuscularis, runs slightly more laterally. These two portions of the thyroarytenoid muscle are shown in Figure 4. When the TA muscle contracts, it draws the arytenoids forward, closer to the thyroid cartilage, thus shortening the vocal fold. Shorter vocal folds result in a lowering of pitch. Contraction of the TA muscle also thickens the vocal folds, which can strengthen low pitches or add loudness to higher pitches by increasing the area of contact of the vocal folds during vibration.[11]

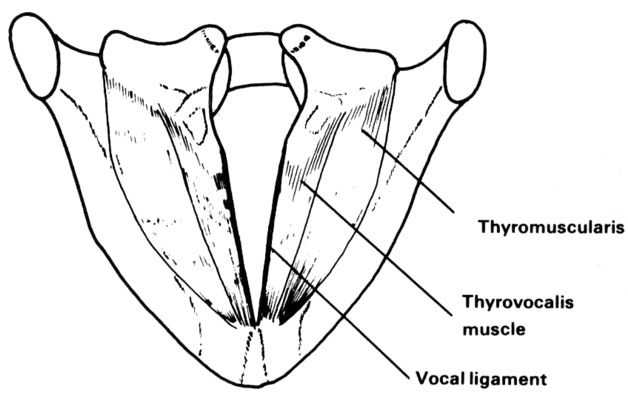

Figure 4. The main portions of the thyroarytenoid muscle, superior view. The thyroid cartilage forms the outer perimeter. The paired arytenoid cartilages, the posterior attachment point of the TA muscles, are at top center. The space between the vocal ligaments is the glottis.[12]

The pair of cricothyroid (CT) muscles originates on the external sides of the cricoid cartilage and inserts on the inside of the thyroid cartilage. The cricothyroid muscle has two portions, the pars recta and the pars obliqua. Contraction of the pars recta tilts the thyroid cartilage on the cricoid, pulling the thyroid and cricoid cartilages closer

[11] McCoy, 117.

[12] Johan Sundberg, *The Science of the Singing Voice* (DeKalb, IL: Northern Illinois University Press, 1987), 18.

together at the anterior. Contraction of the pars obliqua causes the thyroid cartilage to slide forward with respect to the cricoid cartilage. These different motions are possible because of the pivoting ability of the synovial joint which connects the cricoid and thyroid cartilages at the posterior. Either of these motions creates more distance between the anterior of the thyroid cartilage and the arytenoids. This causes the vocal folds (the edge of the TA muscle, which connects the thyroid and arytenoid cartilages) to lengthen and thin. The longer, thinner vocal folds are also under greater tension, producing higher pitches. The two different motions of the cricoid cartilage are shown in figure 5.

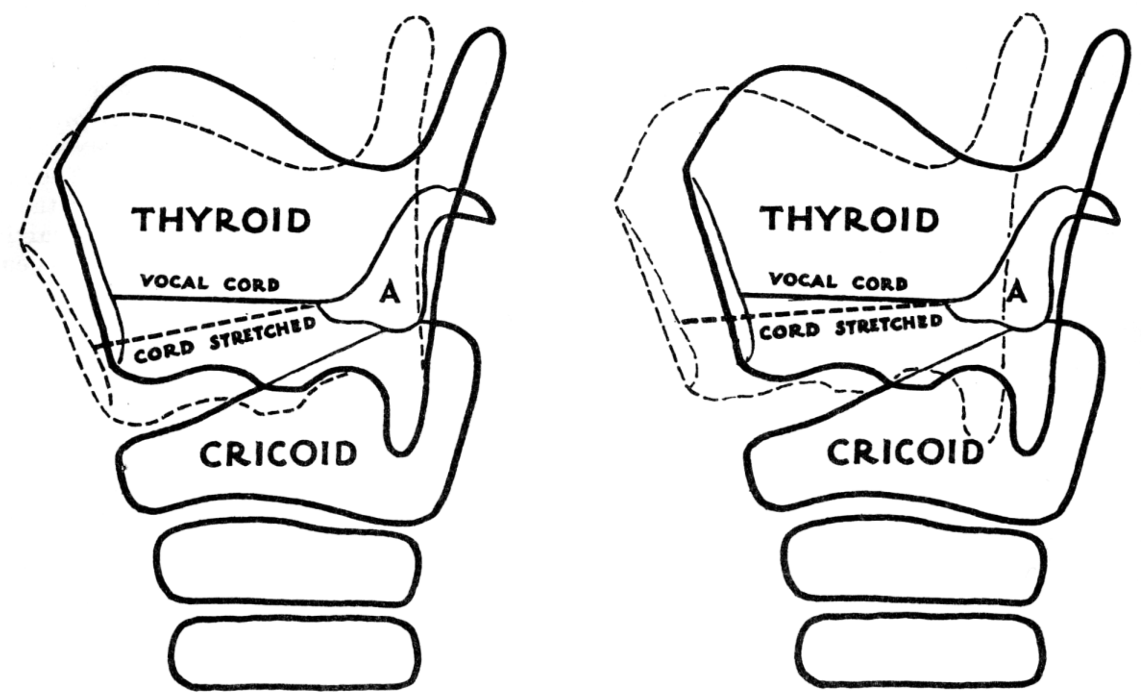

Figure 5. Contraction of the cricothyroid muscles. On the left, dotted lines show the tilted position of the thyroid cartilage caused by contraction of the pars recta. On the right, dotted lines show the sliding of the cartilage caused by contraction of the pars obliqua. The arytenoid cartilage is labeled "A." This drawing uses the older term "vocal cord."[13]

[13] William Vennard, *Singing: The Mechanism and the Technic*, rev. ed. (New York: Carl Fischer, 1967), 54.

Other intrinsic muscles of the larynx are responsible for adduction of the vocal folds. The pair of lateral cricoarytenoid (LCA) muscles connects the top of the cricoid to the muscular processes at the side of the arytenoid cartilages. Contraction of the LCA muscles rotates the arytenoid cartilages, bringing the vocal processes of the arytenoids together. Since the vocal processes are the posterior attachment point of the vocal folds, the contraction of the lateral cricoarytenoids partially adducts the vocal folds. An open gap remains at the posterior of the vocal folds, which can be closed completely by contraction of the interarytenoid muscles, which connect the two arytenoid cartilages to each other. See figure 6.

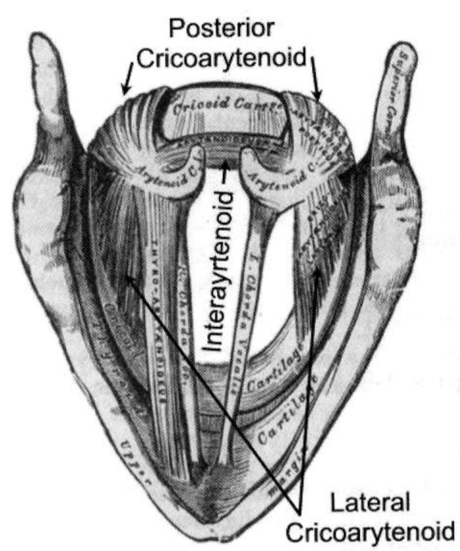

Figure 6. Muscles which adduct and abduct the vocal folds.[14]

The posterior cricoarytenoids are the only intrinsic muscles which abduct, or separate, the vocal folds, opening the glottis to stop phonation or for inhalation. These muscles originate at the posterior of the cricoid cartilage and also connect to the muscular processes of the arytenoids. The posterior cricoarytenoids connect the same cartilages as the lateral cricoarytenoids, but because of their different origination point, contraction of these muscles rotates the arytenoid cartilages in the opposite direction, thus opening the glottis. The remaining intrinsic muscles are used to prevent choking during swallowing:

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[14] McCoy, 118.

the aryepiglottic and thyroepiglottic muscles pull the epiglottis downward, covering the airway.

Phonation requires a complex coordination of nearly all of the intrinsic muscles of the larynx to act on the vocal folds: the lateral cricoarytenoids and interarytenoids to adduct them, the thyroarytenoids and cricothyroids to adjust their length and thickness, and the posterior cricoarytenoids to abduct the vocal folds when phonation is no longer required. Because of their action on the length, thickness, and tension of the vocal folds, the thyroarytenoid and cricothyroid muscles directly impact fundamental frequency and play a major role in vocal registration.

II. Registration

The classic definition of vocal registration comes from the esteemed nineteenth-century pedagogue Manuel Garcia: "a series of consecutive and homogenous sounds produced by the same mechanism, and differing essentially from other sounds originating in mechanical means of a different kind."[15]

This definition specifies the major characteristics of a vocal register: the tones are adjacent, as in a scale; the timbre within the register is uniform and similar; and all tones within that register are produced by the same "mechanism," or muscular activity. The definition also states that each individual vocal register will have its own characteristics, consistent within that register but quite different from the characteristics of another register.

Contemporary voice science researcher Ingo Titze offers a similar definition: registers are "perceptually distinct regions of vocal quality that can be maintained over some range of pitch and loudness."[16] William Vennard further explains that these different vocal qualities are caused by the action of the intrinsic musculature of the larynx on the vocal folds: "A wide variety of tones can emerge from the vibrator [that is, the vocal folds], depending on its adjustment alone and quite apart from any modification by the resonators which are above."[17]

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[15] Manuel Garcia, *Garcia's Treatise on the Art of Singing*. ed. Albert Garcia (London: Leonard and Company, 1924), 4, http://imslp.org/wiki/%C3%89cole_de_Garcia_(Garcia_Jr.,_Manuel) (accessed March 24, 2011).

[16] Titze, *Principles of Voice Production*, 282.

[17] Vennard, 52.

These definitions seem straightforward; however, vocal registers have long been a source of disagreement among voice pedagogues and between voice teachers and voice scientists. Opinions vary widely on the number of registers, their source, and what they should be called. Terminology has changed over the years, so that reading early treatises about registration can cause confusion. Voice scientists tend to describe registers in terms of the physical functions of the larynx, while singers and voice teachers usually speak of registers in terms of the sensations singers experience in other parts of the body. Complicating the issue further is the Western art music esthetic that finds audible changes of vocal timbre undesirable, except for particular artistic effects, so that a major goal of classical voice study is to reduce as much as possible the audience's perception of register shifts. A well-trained voice is thus described as having only one perceptible register.[18]

Terminology

As early as the thirteenth century, theorists such as John of Garland and Jerome of Moravia spoke of three divisions in the voice, which they called chest voice, throat voice, and head voice. In the pedagogical writings of the seventeenth and eighteenth centuries, at the dawn of the *bel canto* style of singing, the disagreements began, with Pier Francesco Tosi teaching three registers, chest, head and falsetto; while Giovanni Battista Mancini spoke of only two, chest and either head or falsetto.[19] In his descriptions of registers in the mid-nineteenth century, Garcia used the terms chest, head, and falsetto, as

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[18] Richard Miller, *The Structure of Singing: System and Art in Vocal Technique* (Boston: Schirmer, Cengage Learning,1996), 150.

[19] John Large, introduction to *Vocal Registers in Singing: Proceedings of a Symposium*, ed. John W. Large (The Hague: Mouton, 1973), 10.

many voice teachers do today, but the terminology he used in his early writings differed from today's in one important respect: he placed the falsetto register between chest and head, covering the range from A3 to C#5. The term "falsetto" was thus used for the highest tones in the male voice and also for the middle portion of the female voice, while head voice referred only to the highest notes in the female voice.[20]

Other names for the three-register system proposed since Garcia's time include low, middle, and high; thick, thin, and small (based on the conditions of the vibrating vocal folds when viewed by laryngoscope); and perhaps the simplest of all, one, two, and three.[21] Various adherents to a two-register system suggested long-reed and short-reed; lower and upper/falsetto; and heavy mechanism and light mechanism.[22] Some pedagogues spoke of a two-register system for men (chest and either head or falsetto) and a three-register system for women (with varied nomenclature). Garcia and others proposed two sub-registers each within the lowest and middle registers, creating in effect a five-register system.[23]

Some singers have access to extraordinarily high or low tones which fall beyond the boundaries of the typical range described by the above systems. Very high tones in the female voice, beginning around F6, are often said to belong to the "whistle" or "flageolet" register[24]. Very low tones in the male voice, such as those required for the

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[20] Manuel Garcia, "Observations on the Human Voice," *Proceedings of the Royal Society of London* 7 (1854-1855): 401.

[21] Gerard Mackworth-Young, *What Happens in Singing: A Short Manual of Vocal Mechanics and Technique* (New York: Pitman, 1953), 57-58.

[22] Large, 11-12.

[23] *Ibid.*

[24] Titze, *Principles of Voice Production*, 306.

bass parts in Russian choral music, are commonly termed the "vocal fry" register or "*Strohbass*" (German for "straw bass").

Voice science researchers generally recognize three distinct registers in the human voice: from lowest to highest, vocal fry, modal, and falsetto.[25] These divisions are recognized based on the behavior of the vocal folds, as explained by voice science researcher Minoru Hirano:

> 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.[26]

Falsetto as described here is typically used in the male voice when imitating a female voice. This definition could also possibly describe the female flageolet register. Vocal fry has been mentioned already as a technique for reaching extremely low pitches. Thus modal register, as described by Hirano, seems to refer to the main portion of the voice.

Voice pedagogue James McKinney has described the modal register as "the normal register for speaking and singing"[27] (though Johan Sundberg points out that it may well be "normal" for even male speakers to use the falsetto register in laughter or when surprised[28]). All of the most common repertoire for singers thus might be said to fall within the compass of the modal voice, and men and women both primarily sing in the modal register. In centuries of discussion of "registers," then, singers and voice

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[25] Minoru Hirano, "The Function of the Intrinsic Laryngeal Muscles in Singing," in *Vocal Fold Physiology*, ed. Kenneth N. Stevens and Minoru Hirano (Tokyo: University of Tokyo Press, 1980), 155; Paul B. Oncley, "Dual Concept of Singing Registers," in Large, 36.

[26] Hirano, 155-156.

[27] James McKinney, *The Diagnosis and Correction of Vocal Faults: A Manual for Teachers of Singing and for Choir Directors* (Nashville, TN: Genevox Music Group, 1994), 96

[28] Sundburg, *The Science of the Singing Voice*, 50.

pedagogues have been speaking primarily of perceived divisions within this “normal” voice. As voice teacher and researcher Paul Oncley notes, what voice teachers and singers are most interested in is “what the phoneticians would consider ‘sub-registers’ within the modal register.”[29] These sub-registers are related in part to the pitch-changing mechanisms of the intrinsic muscles of the larynx.

Function of the laryngeal musculature in frequency change

The concept of pitch is fairly complex; Titze explains that it is “the perceived ‘height’ of the voice either by a listener or by a vocalist. It correlates highly with F_0 [the fundamental frequency of vibration of the vocal folds] but is influenced by loudness and timbre.”[30] For example, a fundamental frequency such as A4, 440 Hz, might sound like a low pitch when sung softly by a soprano but like a high pitch when sung in full voice by a tenor. Therefore voice scientists usually refer to control of fundamental frequency, F_0, rather than pitch change.

Frequency change is effected by a change in breath pressure or in one or more dimensions of the vocal folds: length, mass, or stiffness.[31] Increase in breath pressure causes an increase in fundamental frequency, all other factors being equal. A decrease in mass, or depth of vibration in the vocal fold, will also contribute to an increase in fundamental frequency. Increase in length or stiffness (tension) of the vocal folds will also cause F_0 to rise. (Voice scientist Willard Zemlin has suggested that the increase in

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[29] Oncley, 36.

[30] Titze, *Principles of Voice Production,* 236.

[31] Raymond H. Colton, “Physiology of Phonation,” in *Vocal Arts Medicine: The Care and Prevention of Professional Voice Disorders*, ed. Michael Benninger, Barbara H. Jacobson, and Alex F. Johnson (New York: Thieme Medical Publishers, 1994), 39.

tension may be the most important agent in pitch raising, and that the change in length and vibrating mass may be the secondary response of the elastic vocal folds to the increased tension.[32])

At a very basic level, the vocal folds can be compared to simple oscillators such as strings or springs. Vocal fold stiffness can be increased by compression of the vocal folds in the medial-lateral direction, as with a spring, or by lengthening the vocal folds, as with a string. Titze explains that the natural frequencies of simple oscillators are determined by their elastic properties.[33]

The vocal folds are not simple oscillators, however, because the actions of the various intrinsic muscles of the larynx may cause the folds to experience both compression (increase in depth of vibration) and change of length simultaneously. Control of fundamental frequency in singing is therefore more complicated than with a simple oscillator like a string or spring, requiring precise coordination of several muscles. The primary muscles involved in change of F_0 are the cricothyroid and thyroarytenoid muscles.

The CT and TA muscles are responsible for changes in length of the vocal folds. Contraction of the TA shortens the vocal folds, while contraction of the CT lengthens them. The relationship between the two muscles can be simple: If the CT contracts but the TA does not, the folds will lengthen, their effective stiffness will increase, their mass will decrease, and consequently F_0 will increase. If the TA and CT muscles both contract in muscular antagonism so that the length of the vocal folds does not change at all, the stiffness of the vocal folds may still increase because of the tension in the TA muscle,

[32] Zemlin, 194.

[33] Titze, *Principles of Voice Production*, 213.

which forms the body of the vocal fold. This increase in stiffness would also cause a slight rise in fundamental frequency. In the situation where the TA muscle contracts and the CT muscle does not, the vocal folds will shorten, which typically would lower F_0, but given the increase in stiffness of the body of the vocal folds on contraction of the TA, this result is not guaranteed.[34]

Another example of this interaction of laryngeal musculature is described by voice researcher Raymond Colton. When an increase in vocal loudness is required, singers typically apply greater subglottal air pressure. Since greater breath pressure can cause fundamental frequency to increase, however, keeping F_0 constant requires another adjustment of laryngeal muscles. Under those circumstances, Colton notes, "singers increase activity in the…vocalis [portion of the TA] but hold constant or decrease activity in the cricothyroid." Colton hypothesizes that singers instinctively employ contraction of the TA to shorten the vocal folds, helping to counteract the pitch-raising effect of the extra breath pressure. A decrease in activity of the CT would also help keep pitch stable in response to the increase of breath pressure and lateral tension.[35]

These examples point to what Titze calls "the importance of *differential control* of the muscles in F_0 regulation, which means that the difference in activity between two muscles is more relevant than either of the absolute levels of activity."[36] Effective coordination of the different activity levels in the thyroarytenoid and cricothyroid muscles allows the singer to accurately produce the desired fundamental frequency and

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[34] Titze, *Principles of Voice Production*, 214.

[35] Colton, 58.

[36] Titze, *Principles of Voice Production*, 214-215.

also contributes to evenness of timbre (which is to say, the impression of unified registers) as F_0 changes.

Thyroarytenoid and cricothyroid muscle activity in vocal registers

As noted previously, singers and voice teachers have chosen names for the registers of the voice based on the parts of the body in which singers typically experience secondary vibrations while singing in those registers. Since the actions of the intrinsic muscles of the larynx are below the level of conscious control, these vibratory sensations are extremely useful to singers and teachers. The vibrations can help confirm for a singer which register he or she is using, and also aid the singer in reproducing a desired vocal result by attempting to create the same sensations again. It is these sensations that have given vocal pedagogy the terms *chest voice* and *head voice.*

Speech scientists can observe and measure the function of the laryngeal musculature and the acoustic spectrum of the voice through stroboscopy, electromyography, electroglottography, Fast Fourier Transform, and other means.[37] By the use of these tools, researchers have observed specific physiological and acoustical events associated with the chest register (or sub-register within modal voice, as speech scientists might term it). These characteristics are described by voice teacher Meribeth Bunch Dayme as follows:

> 1. thick vocal folds that close firmly for each vibratory cycle
> 2. a large amplitude of vibration (movement away from the midline)
> 3. closure and opening of the vocal folds beginning at their lower edges
> 4. a loud tone rich in harmonic partials (except for the very lowest notes).[38]

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[37] For further discussion of these analytical tools, see McCoy; Sundberg, *Science of the Singing Voice*; and Vennard.

[38] Meribeth Bunch Dayme, *Dynamics of the Singing Voice*, 5th ed. (New York: SpringerWienNewYork, 2009), 111.

The gradual transfer of the closing and opening action of the folds, from the lower edge of the vocal folds to the top, is known as vertical phase difference.

Because the above qualities, and the low pitches associated with them, are most strongly influenced by the contraction of the thyroarytenoid muscle, voice pedagogue Scott McCoy has termed singing in the chest register "thyroarytenoid-dominant production," or TDP.[39] This vocal approach has also been called "heavy mechanism."[40] McCoy further notes that in TDP, the glottis is closed more than 50 percent of the time, which contributes to the strong overtones present in the sound.[41]

Head voice, a higher register that causes many singers to experience vibrations in their head and face, has its own set of observable characteristics, as described by Dayme:

> 1. vocal folds that are stretched thin by the combined action of the cricothyroids and posterior crico-arytenoids, and at the highest pitches only the [mucosa and superficial layer of the] vocal ligaments are vibrating (falsetto)
> 2. glottal closure is brief and incomplete for each cycle because of the high tension in the vocal folds
> 3. the tone has fewer [harmonic] partials and is not as loud as that produced in heavy registration.[42]

This mode of production is also marked by the disappearance of the vertical phase difference. These qualities are what Vennard terms "light mechanism" and McCoy calls "cricothyroid-dominant production," or CDP.[43]

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[39] McCoy, 65.

[40] Vennard, 66.

[41] McCoy, 65.

[42] Dayme, 111.

[43] Vennard, *Singing: The Mechanism and the Technique*, 66; McCoy, 66.

McCoy notes that most women have a series of pitches they can produce in either TDP or CDP (heavy or light mechanism), while men use TDP as their main mode of vocal production, using CDP only for falsetto.[44] McCoy's terminology clarifies that what is typically called head voice in women is not produced by the same vocal technique as that which is called head voice in men. Female head voice more closely corresponds to the behavior of the vocal instrument in male falsetto (CDP), while "head voice" in the male singer is the upper, lightened portion of his modal voice (or chest, heavy mechanism, or TDP).

Pedagogue Richard Miller points out that the discussion of heavy and light mechanism, head voice and chest voice, or TDP and CDP, can be "pedagogically convenient," but it must be understood by singer and teacher that in good singing, the mechanisms are not truly separated, but are rather constantly engaged in "changing, dynamic balances."[45] If the relationship between the activity levels of the two mechanisms is not regularly adjusted, audible register shifts will occur.

Register shifts

Register shifts can be perceived when an abrupt change occurs from one mechanism of voice production to another. These are often heard during increases in fundamental frequency. As a singer ascends through his or her range, the cricothyroid muscles must contract, adding length and tension to the vocal folds in order to produce the higher fundamental frequencies. If the thyroarytenoid muscles continue their

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[44] McCoy, 68.

[45] Richard Miller, *The Structure of Singing*, 133.

contraction at the same rate, the muscles work in antagonism to each other until the TA reaches the limits of its strength, at which point the cricothyroids "win the tug-of-war," shifting the voice into cricothyroid-dominated production.[46] The sudden change of mode results in a new timbre which both singer and listener may notice.

In the Italian school of pedagogy, these breaking points are called *passaggi* (singular, *passaggio*). Pedagogue Richard Miller says that the first *passaggio* is the point at which a singer or speaker can no longer continue in chest voice without resorting to a "calling or yelling" voice quality, which is accomplished by a great increase in breath pressure and muscular effort of the thyroarytenoid. The second *passaggio* is the upper boundary of the "calling" voice, after which falsetto (male) or head voice (female) must take over.[47]

These register shifts occur at different points in different voice types (soprano, tenor, etc.), because of the slightly different size of laryngeal structures in each type. Even within a single voice type, individual voices vary somewhat, but a number of voice scientists and pedagogues have made note of a general trend of transition points for each voice type. Some suggest that the location of a singer's *passaggi* provides a more accurate voice categorization than timbre (since, for example, a heavy tenor voice may have a dark timbre resembling that of a baritone) or even usable range (since difficulty managing registration may result in an artificially limited vocal range). The *passaggi* can be located when the singer produces a long *glissando*, or vocal slide, from the lowest

[46] Vennard, 67.

[47] Miller, *English, French, German, and Italian Techniques of Singing: A Study in National Tone Preferences and How They Relate to Functional Efficiency* (Metuchen, NJ: The Scarecrow Press, 1977), 123. It should be noted that the words *passaggio* and *break* are used by some teachers and singers to mean all of the pitches found between the two shifting points, rather than the shifting points themselves. This paper will use the words to mean the shifting point.

pitches of the range to the highest, without making any effort to create a unified timbre. At a *passaggio* point, an audible change in quality or even a momentary cessation of phonation may occur.[48]

Voice teacher Karen Sell suggests the following passage points for voice classification:

	First *passaggio*	Second *passaggio*
Male voices		
Lyric tenor	D4	G4
Lyric baritone	B3	E4
Deep bass	A♭3 or G3	D4 or C4
Female voices		
Soprano	E♭4	F#5
Mezzo-soprano	E4 or F4	E5 or F5
Contralto	G4 or A♭4	D5

Note that in male voices, according to Sell, the interval between the two *passaggi* is approximately a fourth, while in all but the lowest of women's voices it is an octave or more.[49]

Richard Miller subdivides the vocal categories further, to recognize the various sizes and timbres of voice found in each voice type. He describes five types of tenor, two types each of baritone and bass, and light and dramatic sopranos. Like Karen Sell, he also finds an interval of approximately a fourth between the male passage points and an octave for women. In women's voices, he divides the long compass between the two *passaggi* into lower middle and upper middle voice. He also acknowledges a certain overlap of shifting points across vocal categories: for example, a dramatic (heavy)

[48] Jean Callaghan, *Singing and Voice Science* (San Diego: Singular Publishing Group, 2000), 89.

[49] Karen Sell, *The Disciplines of Vocal Pedagogy: Towards an Holistic Approach* (Burlington, VT: Ashgate Publishing, 2005), 106.

soprano might experience register shifts more similar to those of the mezzo-soprano than to those of the light soprano. He identifies the following register transition points[50]:

	First *passaggio*	Second *passaggio*
Male voices		
tenorino (little tenor)	F4	B♭4
tenore leggiero (light tenor)	E4 or E♭4	A4 or A♭4
tenore lirico (lyric tenor)	D4	G4
tenore spinto	D4 or C#4	G4 or F#4
tenore robusto or *drammatico*	C4 or C#4	F4 or F#4
baritono lirico	B3	E4
baritono drammatico	B♭3	E♭4
basso cantante ("singing" bass)	A3	D4
basso profondo	A♭3 or G3	D♭4 or C4
Female voices		
soprano	E♭4	F#5
mezzo-soprano	E4 or F4	E5 or F5
contralto	G4 or A♭4	D5

Voice teacher and researcher Brenda Smith and otolaryngologist Robert Thayer Sataloff propose another set of transition points in a chart detailing choral singing ranges and *passaggi*, shown in Figure 7. Since this chart details the singing ranges of choral singers rather than solo singers, it uses the common choral subdivisions of voice types into 1 (higher) and 2 (lower) rather than the descriptive words favored by Sell and Miller in their discussion of solo voices. It shows only a single passage area for soprano 1 and tenor 1, presumably under the assumption that the typical range expected of these voice types in a choral setting rarely passes into the lowest portion of the voice.

[50] Richard Miller, *Structure of Singing*, 117, 134-135.

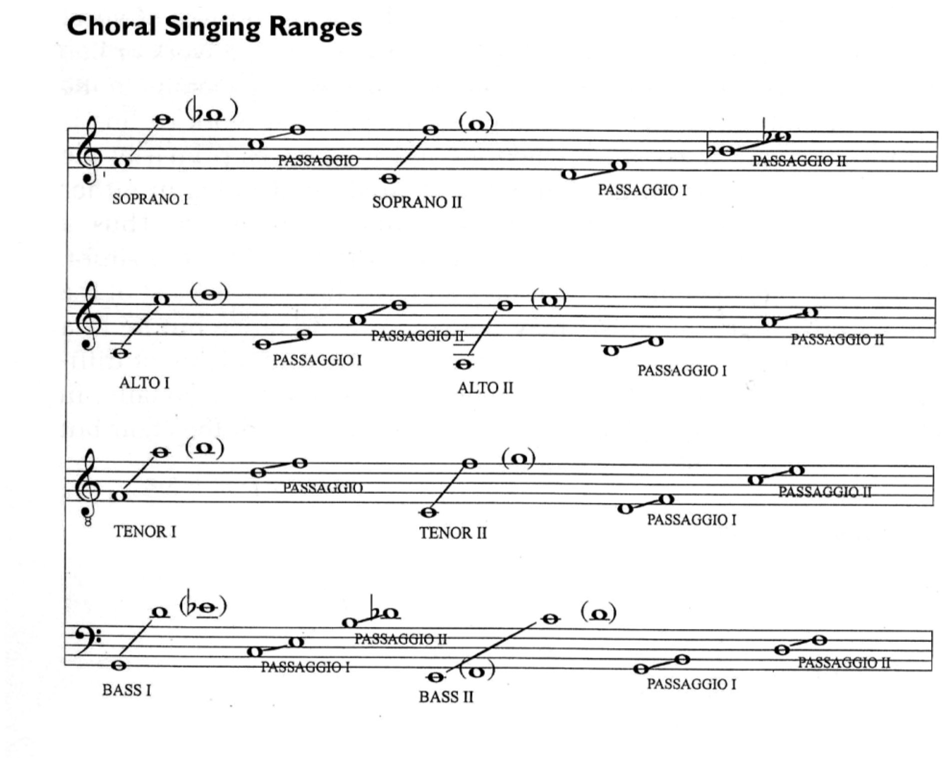

Figure 7. Choral singing ranges.[51]

Smith and Sataloff define *passaggio* or *break* as the area between two register transition points. They note that the pitches in these transitional ranges are usually somewhat unstable because they can be sung in either register.[52] A careful comparison of the Sell and Miller transition points with those noted by Smith and Sataloff reveals some similarities. All three charts agree that the baritone experiences a passage point at B3. For Smith and Sataloff this is the entrance to the second *passaggio* area, and for Sell and Miller it is the point at which chest voice needs a significant application of breath energy and strong TA contraction in order to continue upward. This same point for the lyric tenor or tenor 1 is located at D4 in all three charts. Smith and Sataloff have

[51] From *Choral Pedagogy*, 2nd ed. (p. 176) by B. Smith & R. T. Sataloff. Copyright © 2006 Plural Publishing, Inc. All rights reserved. Used with permission.

[52] Smith and Sataloff, 131-132.

transitional notes of F4 and E4 at the top of the first passage area for the choral soprano 2 and alto 1, respectively. This corresponds to Sell's and Miller's first transition point for the mezzo-soprano, the voice type which is most likely to sing soprano 2 or alto 1 in a choir.

There are some differences between the transition points noted by Smith and Sataloff and those identified by Sell and Miller, however. Some changes suggest that Smith and Sataloff are considering the particular requirements of choral singing in their chart. The lack of a lower passage area for soprano 1 and tenor 1 has already been noted. Smith and Sataloff also do not account for the male transition into falsetto, which is the second *passaggio* described by Sell and Miller, again probably because the choral bass or tenor rarely is asked to sing such high pitches (barbershop singing being a notable exception). In addition, the top notes of the upper passage points identified by Smith and Sataloff in the female voice types are lower than those noted by Sell and Miller, perhaps because choral singers often have shorter ranges than professional soloists.

Other differences do not seem to be related to choral phenomena. For example, in the soprano 1 voice, Smith and Sataloff identify a register shift beginning at C5 and concluding at F5, while Sell and Miller locate the register shift immediately above, at F#5. Similarly, according to Smith and Sataloff, the soprano 2 shift to the upper voice occurs between B♭4 and E♭5, while Sell and Miller mark the mezzo-soprano's upper *passaggio* at E5. Smith and Sataloff also identify register shifts in the bottom octave of alto 2, tenor 2, bass 1, and bass 2 voices, within what Sell and Miller would consider a single unified register. These differences seem to suggest that Smith and Sataloff may be using slightly different criteria for their transition points.

Pedagogues Sell and Miller (along with Vennard, McCoy, and others) identify register transition points based on the ratio of activity of the thyroarytenoid and cricothyroid muscles. These authors note *passaggi* at the areas where the behavior of the thyroarytenoid and cricothyroid muscles changes dramatically. By definition, these are points where an audible break exists. It is possible that the early transition ranges noted by Smith and Sataloff may relate to fine muscular adjustments made by the trained singer in an effort to disguise the true breaking point. These researchers may also be considering other factors beyond the activity of the intrinsic laryngeal muscles.

Pedagogue and researcher Paul Oncley points out that despite the physiological evidence supporting only two modes of normal vocal production (based on TA and CT muscle activity), there also exists "the more subjective evaluation of many respected singers and teachers who hear and feel various other register adjustments within the voice compass."[53] In particular singers may notice significant changes in resonance as they move through their full range. These acoustical phenomena and their relationship to registration will be discussed in chapter 3.

The "one-register" voice

It has already been noted that a primary goal in classical Western singing is a smooth, even timbre across the entirety of a singer's range. The obvious changes in voice quality which can occur at the transition points noted above are considered undesirable. As discussed previously, those changes in quality can be caused by the sudden disengagement of the thyroarytenoid muscle after reaching its point of maximum

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[53] Oncley, 39.

stress. Titze describes this as a "drastic rearrangement of tension" which can be avoided by gradually releasing the thyroarytenoid muscle at lower fundamental frequencies.[54]

Fundamental frequency can be raised by increasing either vocal fold length or stiffness. Contraction of the thyroarytenoid causes stiffness to increase, and as such can be used to increase fundamental frequency until the TA reaches its maximum contraction. Researcher Donald Proctor notes that it is possible instead to engage the cricothyroid muscles, which lengthen the vocal folds, at a fairly low point in the singer's range. In this way, as fundamental frequency rises, the responsibility for raising the pitch is transferred gradually from TA to CT. Constant readjustment of the ratio of activity of the two muscles creates "a smooth transition from increasing vocal fold tension to vocal fold lengthening" in the pitch-raising process.[55]

While the singer may still be aware of a transition point, this register-blending technique can disguise the shift points so that the listener does not perceive a change in quality. Under these circumstances, as Richard Miller notes, "there is no single, arbitrary pitch in the scale below which chest is sung and above which head predominates."[56] Rather, each note in the scale represents a new configuration of thyroarytenoid and cricothyroid muscle activity. In addition to creating a more uniform vocal quality in the full compass of the voice, differential control of the laryngeal muscles also affords the singer greater expressive potential, since it allows for a variety of timbres depending on emotional content or other factors.

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[54] Titze, *Principles of Voice Production*, 299-300.

[55] Donald Proctor, "Breath, the Power Source for the Voice," *The NATS Bulletin* 37, no. 2 (November/December 1980): 27.

[56] Miller, *Structure of Singing*, 117.

Learning to coordinate the actions of the pitch-changing muscles is a major goal of voice study, and is essential to the choral singer as well as the soloist. While choral music often calls for a smaller usable range than solo repertoire, most vocal music of any type will eventually cross at least one of the register transition points of the voice. Ensemble singers who experience registration difficulties will find themselves at odds with the rest of the ensemble when singing near the *passaggi*, either in intonation, dynamic level, or timbre. Vocalises designed to assist choral singers in acquiring and improving register transition techniques are detailed in chapter 6.

III. Acoustics of the Singing Voice

Sound

At its most basic level, sound can be described as a series of tiny, rapid variations of pressure within a medium, such as air, water, or a solid.[57] A sound source disturbs the medium, causing a compression of molecules within the medium. The compression is then followed by rarefaction, or depressurization, of the molecules. The movement of the compression is transferred from molecule to molecule, creating what is known as a sound wave. The sound wave continues until it runs out of energy or until it reaches the eardrum. If the ear receives the vibrations, it converts them to nerve impulses, which the brain interprets as sound. In singing, the sound source is usually the vibrating vocal folds. In unvoiced sounds such as the consonants [f] and [s], however, the vocal folds do not vibrate, and the sound source is instead the movement of air through the area of constriction which forms the consonant. The medium for the travel of the sound wave is usually air (though the sounds of singing can be also transferred underwater or through the walls of a practice room).

Musical sound has four properties, as described by McCoy:

- Frequency (objective measurement of pitch)
- Amplitude (objective measurement of loudness)
- Spectral envelope (objective measurement of timbre or tone color)
- Duration[58]

Frequency is measured in Hertz (Hz) and, for singers, denotes the number of cycles of glottal closure and opening per second. Amplitude is a measurement of the height of the compressions in the sound wave, perceived by the listener as loudness, and is typically

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[57] Sundberg, *Science of the Singing Voice*,18; McCoy, 16.

[58] McCoy,17.

measured in decibels (dB). The spectral envelope is a measurement of the relative strengths of the component frequencies within a complex sound, which will be discussed in more detail below. Duration is the length of time the sound is continued. The combination of these four factors gives the sung sound its unique identity.

Resonance

Perhaps the simplest definition of resonance comes from McCoy: "big vibrations that are induced by little vibrations."[59] A sound source provides relatively small vibrations, and a resonator receives them, increases their amplitude, and changes their quality. According to Sundberg, almost anything can be a resonator: "every system that can be compressed and that weighs something" has the required qualities.[60]

Resonance can be forced or free. Forced resonance is also known as conductive resonance and requires a direct connection between vibrator and resonator, such as between a piano string and the sounding board. Free resonance, or sympathetic resonance, relies on the movement of air molecules and the reflection of sound waves. It requires a hollow resonator which is open at one end, such as a trumpet or organ pipe.[61]

A singer experiences both forced and free resonance. Forced resonance includes the vibrations singers feel in the head and chest, because of the conductive qualities of the tissues connected to the larynx. This forced resonance does not increase the loudness of the sound from the listener's perspective, however, because these vibrations are damped

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[59] McCoy, 27.

[60] Johan Sundberg, "Vocal Tract Resonance in Singing," *The NATS Journal* 44, no. 4 (March/April 1988): 12.

[61] McCoy, 29.

by body tissues. Free resonance of the vocal sound source takes place in the air within the trachea, larynx, and vocal tract (the pharynx and mouth). Resonance in both the trachea and vocal tract can enhance or impede vocal fold vibration. Resonance in the vocal tract also plays a major role in the listener's perception of uniform loudness, tone quality, and vowel color across a singer's entire range.

Subglottal (tracheal) resonance

All resonators amplify certain frequencies and dampen others, and all will amplify one particular frequency more than any other. In a hollow resonator, this "resonance frequency" will vary depending on the following factors, as identified by pedagogue and researcher Barbara Doscher: the volume of the cavity; the size of the aperture (opening); the texture of the walls of the cavity; and, if the resonator is coupled to another, the interactions between the two cavities.[62]

The trachea, the passage from the larynx below to the bronchi, is a hollow resonator. (Resonance in the trachea is also called subglottal resonance, because it takes place below the glottis.) Its resonance frequency has been reported as 510 Hz.[63] Titze has shown that the acoustic pressures created by resonance in the trachea can either enhance or impede the vibration of the vocal folds, depending on the fundamental frequency of the vibration. He has mathematically demonstrated that vocal fold vibration is impeded when the fundamental frequency being sung is 204 Hz (approximately G#3)

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[62] Barbara Doscher, *The Functional Unity of the Singing Voice* (Metuchen, NJ: The Scarecrow Press, 1988), 86.

[63] Titze, *Principles of Voice Production*, 294.

or 510 Hz (approximately C5). When vocal fold vibration is impeded, an involuntary "break" may be heard.

Because the trachea has walls made of cartilage, its shape cannot be changed to alter its resonance frequency. The singer must make some other adjustments to counteract the impedance of vocal fold vibration when singing these pitches. These adjustments might be made by laryngeal musculature or by adjusting supraglottal resonance in some way. Titze notes that much is still unknown about the relationship between subglottal resonance and register shifts, and well-controlled experiments are needed to investigate possible connections and solutions.[64]

Resonance in the vocal tract

The vocal tract consists of the hollow spaces above the larynx: that is, the pharynx and the mouth. The pharynx is a cavity that extends from immediately above the larynx to behind the mouth and nose. It has three parts: the nasopharynx (the area closest to the nose), laryngopharynx (closest to the larynx), and oropharynx (closest to the mouth). The air in the vocal tract is the source of the free resonance which creates McCoy's "big vibrations" from the small vibrations produced by the vocal folds.

The pharynx contains a number of different muscles which can raise the larynx, lower the soft palate, raise the back of the tongue, or narrow the pharynx for swallowing.[65] These actions change the shape or length of the pharynx. Muscles which impact the shape of the mouth include those which control the soft palate, move the

[64] Titze, *Principles of Voice Production*, 298-299.

[65] McCoy, 148.

tongue, and move the lips and jaw. The movements of the tongue and lips in particular are responsible for creating the different vowel sounds needed for speech and singing.

Different vowel sounds are created by varying the location of the tongue (forward or back, high or low) and the degree of lip rounding. Each vowel has a distinct pattern of constrictions and open spaces in the mouth and pharynx. For example, in producing the vowel [i], the tongue pulls forward and is bunched high in the mouth. This creates a constriction at the front of the mouth, at the highest point of the tongue, and an open space at the oropharynx, behind the tongue constriction. The lips and jaw are neutral. In the vowel [u], the tongue is high as in [i], but its high point is farther back, resulting in a constriction at the oropharynx, and the lips are rounded greatly, creating another constriction at the front of the mouth. The neutral vowel [ə] is the most open vowel from larynx to lips.

A wide variety of vowels can be found in the languages commonly encountered in singing. Vennard lists a total of twenty-one common vowels, including the open and closed versions of the five cardinal vowels [a, e, i, o, u], the mixed vowels used in French and German, and vowels which are colored by the consonant [r][66]. Each of these vowels requires a slightly different combination of tongue position and lip rounding. Each distinct vowel, therefore, is created by a distinct shape and size of the vocal tract.

As noted above in the discussion of subglottal resonance, all resonators will amplify one particular frequency more than any other. In a hollow cavity, this "resonance frequency" is dependent on the volume of the cavity; the size of the opening; the texture of the walls of the cavity; and, if the resonator is coupled to another, the

[66] Vennard, *Science of the Singing Voice*, 136.

interactions between the two cavities.[67] It is possible to identify a single resonance frequency for the trachea (510 Hz), since its size, shape, and composition cannot be altered. In the case of the vocal tract, however, a number of resonance frequencies are possible, since the vocal tract can be altered in so many ways. Different configurations of the vocal tract, which create different vowels, also result in a new set of resonance frequencies. Each vowel thus possesses its own set of resonance frequencies. Resonances of the vocal tract are called formants.

Vowel formants

Vowels are identified by the relationship of two formants, F1 and F2, which are related to tongue position and degree of lip rounding.[68] Formants are identified by their frequencies, measured in Hz. The presence of these two frequencies, whether produced by a person, a bird, or a computer, results in the perception of that vowel by the listener. The formant frequencies are independent of the pitch being produced by the vibrating vocal folds. A sung or spoken vowel thus consists of the complex sound contributed by the vocal folds, plus the supraglottal resonances which result from the particular vocal tract shape required to form that vowel. How the glottal sound source and the vowel formants interact will be discussed below.

Berton Coffin proposed the following experiment to hear the relative frequencies of each formant: To hear F1, form the vowels [i, e, a, o, u] while using a finger to thump the base of the tongue under the jaw, with open mouth and closed glottis (permitting no

[67] Doscher, 86.

[68] Vocal tract resonance can include as many as five formants, but only the first two identify the vowel.

air to pass through). The pitch heard will rise and fall as the vowels are changed. To hear F2, whisper the same vowels. A steadily descending pitch can be heard.[69]

Typical formant frequencies of the five cardinal vowels are given in table 1. Because of the difference in size of the vocal tract in men and women, formant frequencies in women's voices are roughly ten to fifteen percent higher.[70]

Vowel	F1	F2
[i]	men: 270 Hz (C#4) women: 310 Hz (D#4)	men: 2,290 Hz (C#7) women: 2,790 Hz (F7)
[ɛ]	men: 530 Hz (C5) women: 610 Hz (D#5)	men: 1,840 Hz (A#6) women: 2,330 Hz (D7)
[ɑ]	men: 730 Hz (F#5) women: 850 Hz (G#5)	men: 1,090 Hz (C6) women: 1,200 Hz (D6)
[o]	men: 570 Hz (D5) women: 590 Hz (D5)	men: 840 Hz (G#5) women: 920 Hz (A#5)
[u]	men: 300 Hz (D4) women: 370 Hz (F#4)	men: 870 Hz (A5) women: 950 Hz (A#5)

Table 1. Formant frequencies of the cardinal vowels. [71]

These frequencies are only approximations or averages, since every human vocal tract possesses slightly different dimensions. Another way to view the formants is as a range of possible values for each formant, accounting for variances among individuals. When graphed, this range of values creates an area such as a circle or oval, rather than a single point. Vennard's chart, given in figure 8, shows such a graph. The first formant

[69] Berton Coffin, "The Singer's Diction," *The NATS Journal* 20, no. 3 (January/February 1964): 10.

[70] John Howie and Pierre Delattre, "An Experimental Study of the Effect of Pitch on the Intelligibility of Vowels," in *Contributions of Voice Research to Singing*, ed. John Large (Houston, TX: College-Hill Press, 1980), 388.

[71] McCoy, 44-45.

frequencies are shown on the horizontal axis, and the second formant frequencies are shown on the vertical axis. The [i] vowel, for example, is shown to have a range of possible first formant frequencies from roughly 200 to 350 Hz, and a range of possible second formant frequencies from roughly 1900 to nearly 4000 Hz. For reference, Vennard also plots these frequency ranges against a piano keyboard, with C4 denoted by the letter C on the key.

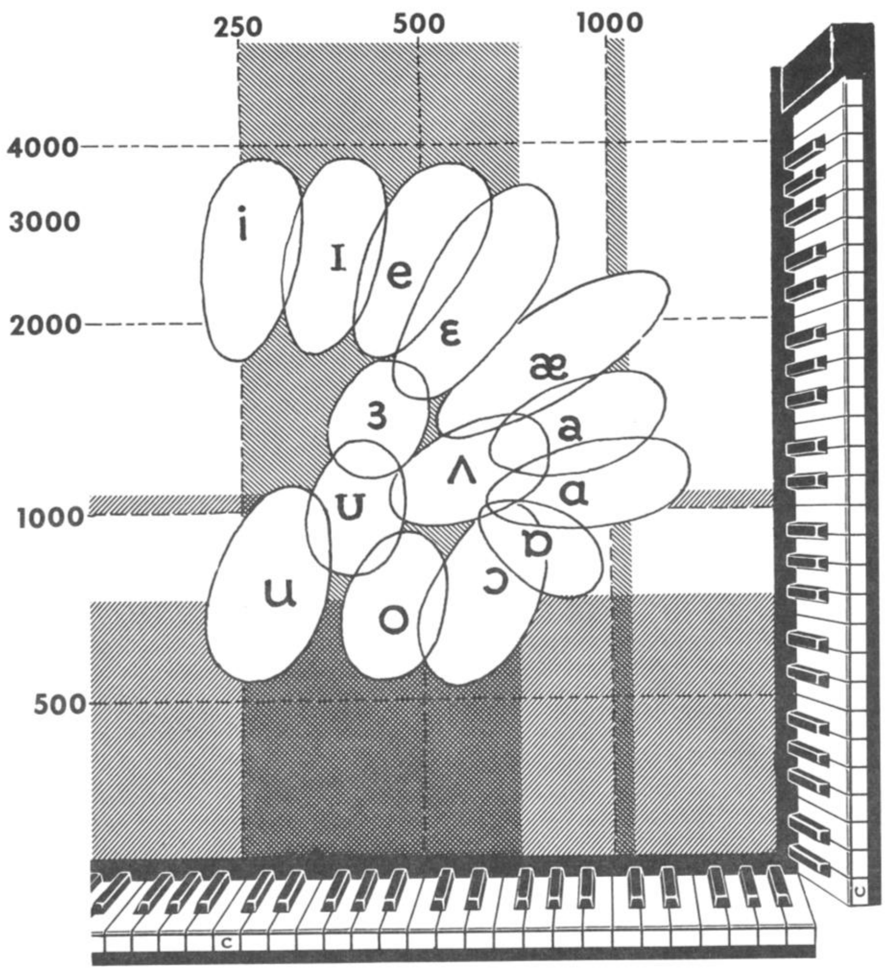

Figure 8. Average formant frequencies of English vowels.[72]

[72] Vennard, *Singing: The Mechanism and the Technique*, 137.

The source-filter theory

The function of a resonator in singing is to amplify the vibrations which are created by the vocal folds and change their timbre. The sound which is produced by the vibrating vocal folds is a complex one, consisting of a fundamental frequency F_0, which corresponds to the notated pitch, and its overtones (also sometimes called partials). The fundamental frequency is the lowest pitch in the complex sound, and the overtones have frequencies which are multiples of F_0. For example, for a fundamental frequency of 100 Hz, overtones have frequencies of 200 Hz, 300 Hz, 400 Hz, and so on. For a fundamental frequency of 400 Hz, the overtones have frequencies of 800 Hz, 1200 Hz, 1600 Hz, etc. Thus for higher fundamental frequencies, the harmonics are more widely spaced. (The term "harmonics" encompasses both the fundamental and its overtones, so that the first harmonic is the fundamental, and the second harmonic is the first overtone.)

Not all of the harmonics in a complex sound have equal amplitude (strength). The relative strengths of the various harmonics form what is called the spectral envelope. These relative strengths give each musical instrument its unique timbre. The clarinet, for instance, has a very strong fundamental and weak even-numbered harmonics ($2F_0$, $4F_0$, etc.). The spectral envelope of a cello consists of second and third harmonics which are stronger than the fundamental.[73] In the human voice (at the glottis, before the sound is resonated by the vocal tract), the fundamental is the strongest component of the sound, and the overtones gradually decrease in strength as their frequency rises. The degree at which the harmonics decrease in amplitude is known as the spectral slope.

The spectral slope in human voices is typically about 12dB per octave, though in breathy voices it may be as high as 20dB per octave, and in strong voices may be as little

[73] McCoy, 23-24.

as 6dB.[74] (An octave represents a doubling in frequency, so that for F_0 of 100 Hz, the second harmonic, 200 Hz, will typically be 12dB softer than the fundamental. The fourth harmonic, 400 Hz, will be 12dB softer than the second harmonic.) This produces a steady downward curve as the amplitudes of the harmonics are plotted on a graph, as shown in figure 9.

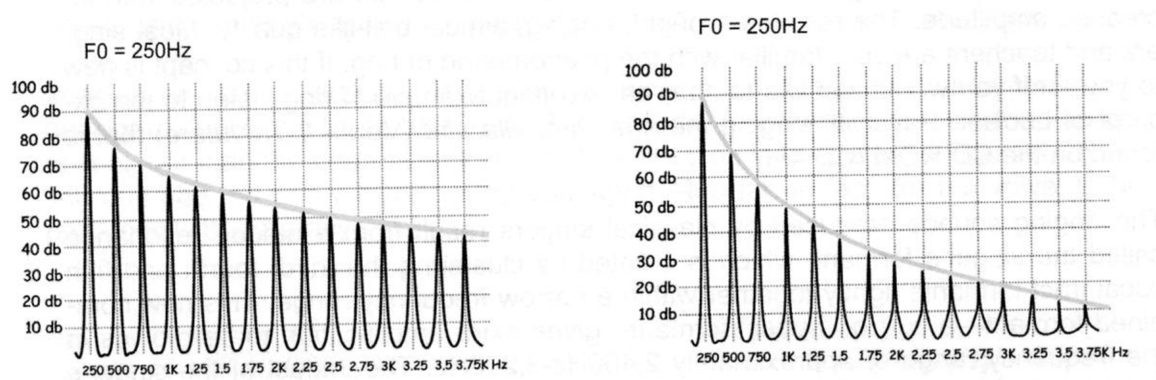

Figure 9. Spectral slope. Left, 12dB per octave. Right, 20dB per octave.[75]

A smaller spectral slope indicates that the high overtones lose strength more slowly, so that the sound will be “brassy.” A steeper spectral slope means that the high frequencies lose strength quickly, so that there are fewer high frequency components perceivable in the sound. This timbre has been described as “fluty.”[76]

In the source-filter theory of vocal production, the vocal tract receives the complex sound (fundamental frequency and overtones) from the glottal source and acts on it as a filter, reinforcing some of the frequencies in the sound and attenuating others. The filtering possibilities are as numerous as the possible configurations of the vocal tract,

[74] McCoy, 24.

[75] McCoy, 48.

[76] Titze, *Principles of Voice Production*, 131.

as voice teacher and researcher Thomas Cleveland explains: “As the vocal tract changes shape, its filter characteristics change also. As a result, different harmonics [including the fundamental] are amplified depending on the shape of the vocal tract.”[77]

As noted above, when the vocal tract is configured for a particular vowel, it produces resonance frequencies known as formants. If the fundamental frequency produced by the vocal folds is near one of those resonance frequencies, it will be amplified by the resonance of the vocal tract. The same is true of an overtone located near one of the resonance frequencies. Thus a particular vowel can reinforce certain fundamentals or particular overtones, while a different vowel would reinforce others. Figure 10 shows an example of this.

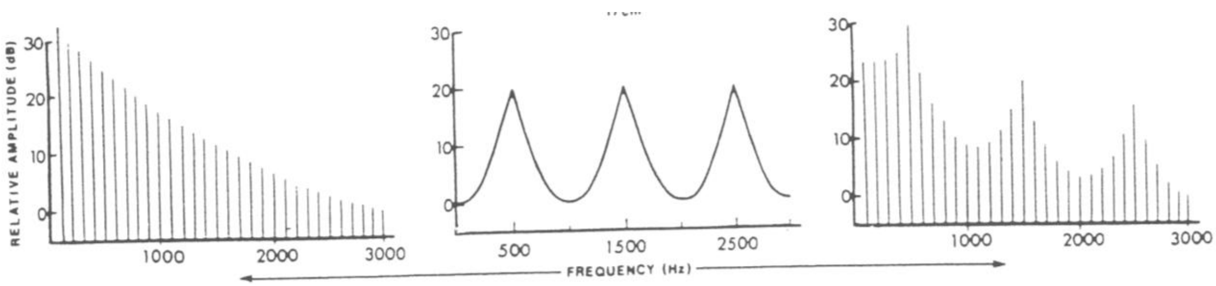

Figure 10. Source and filter. From left to right: Glottal source spectrum, resonance frequencies of the neutral vocal tract, and the resulting radiated sound.[78]

In each of the images in figure 10, frequency is mapped on the horizontal axis and amplitude in decibels is shown on the vertical. The image on the left shows the spectrum of the glottal source for a fundamental frequency of 100Hz, with the expected steady drop in amplitude as the frequency of the harmonics increases. The middle image shows the resonances of the vocal tract (formants) for a neutral configuration of the vocal tract.

[77] Thomas Cleveland, “A Closer Look at Formant Tracking,” *The NATS Journal* 50, no. 3 (Jan./Feb. 1994): 41.

[78] Gloria J. Borden and Katherine S. Harris, *Speech Science Primer: Physiology, Acoustics, and Perception of Speech* (Baltimore, MD: Williams & Wilkins, 1980), 100.

Formants are located at 500, 1500, and 2500 Hz. The final image shows the spectrum of the sound that is radiated from the mouth; that is, the result of source and filter taken together. The overtones of the source located at 500, 1500, and 2500 Hz receive a boost in amplitude, as do the overtones close by. (McCoy notes that "frequencies as much as 100 Hz higher or lower" than the formants can receive amplification from the vocal tract.[79]) These overtones are now louder than they would have been without the addition of the vocal tract. By contrast, the overtones which are farthest from the formants are attenuated, so that their amplitude is even less than it was at the glottis. The damping of these harmonics contributes to the distinct timbre of the radiated sound.

In this case, with a fundamental frequency of 100 Hz and a neutral configuration of the vocal tract (such as might be seen in the vowel [ə] or [ʌ]), the overall effect of the vocal tract is to increase the amplitude of vibrations which are radiated from the mouth. In other words, the listener hears a louder sound because of the resonance contributed by the vocal tract. A different vocal tract configuration and a different fundamental frequency could create very different results. Under some circumstances, the vocal tract might not be able to contribute much additional strength to the glottal source sound.

One such example is the vowel [u] on high pitches, such as a soprano might sing. For a fundamental frequency of 700 Hz, approximately F5, the overtones are found at 1400 Hz, 2800 Hz, 3500 Hz, and so on. Formants for the [u] vowel are located at 370 Hz and 950 Hz. Figure 11 on the next page shows the locations of the vowel formants relative to the harmonics of the sung pitch.

[79] McCoy, 71.

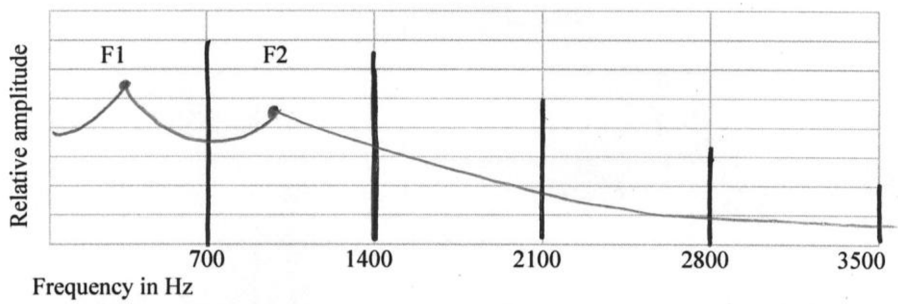

Figure 11. Harmonics for F_0 = 700 Hz, relative to formants 1 and 2 for the vowel [u].

In this case, none of the harmonics of the vocal source are located near a resonance peak for the [u] vowel, and in fact, the first formant at 370 Hz is actually lower than the fundamental frequency being sung (700 Hz). Two problems are created. First, the singer's sound will not receive much amplification, because the harmonics she is singing do not correspond to one of the vocal tract resonances (formants) for this vowel. Furthermore, the vowel will be unintelligible to the listener, since the formants identify the vowel for the listener, and the first resonance frequency of [u] is not activated at all by the vibrations from the glottal source.

Vocal tract resonance is thus a complicated issue, requiring an optimal, reinforcing relationship between vowel formants and the frequency components of the glottal sound source. In order to achieve the advantage of resonance at whatever pitch the composer requests, trained singers employ vowel modification.

IV. Vowel Modification

Basic principles

When vocal fold vibrations and vocal tract resonances are not optimally tuned to each other, significant changes in timbre or loudness can occur. In the case described above, with fundamental frequency of 700 Hz on the [u] vowel, no harmonics are near the vowel formants. Therefore the sound is not greatly amplified, and this pitch might have a sudden decrease in loudness compared with other notes in the musical phrase. In other cases, the filtering action of the vocal tract might create a sudden increase in loudness, or a dramatically brighter or darker timbre. In each of these cases, vowel modification can be used to create a more uniform quality throughout the voice range.

Vowel modification, also known as formant tuning, is the manipulation of vowel formants by changing the configuration of the vocal tract. The altered dimensions of the vocal tract will produce a different set of resonance frequencies. If the formants are adjusted correctly, the vocal tract can then filter the fundamental frequency and its overtones in a more advantageous way. Researcher and pedagogue John Nix describes the goals of vowel modification: "a unified quality throughout the entire range, smoother transition between registers, enhanced dynamic range and control, and improved intelligibility."[80]

There are two major approaches to vowel modification employed by singers and voice teachers. One method involves keeping the original vowel but altering its shape slightly so that one of the formants is changed to be nearer to one of the harmonics created by the vocal folds. The other method replaces the original vowel with another

[80] John Nix, "Vowel Modification Revisited," *Journal of Singing* 61, no. 2 (Nov/Dec 2004): 173.

vowel, resulting in all new formant frequencies. In this method, the correct replacement vowel is one that has a formant frequency matching one of the sung harmonics. Both approaches will be discussed below.

Vowel modification by shading

The formants of a particular vowel can be adjusted in a number of ways, as identified by McCoy:

- A constriction in the front of the vocal tract lowers F1 and raises F2.
- A constriction in the back of the vocal tract raises F1 and lowers F2.
- All formant frequencies lower uniformly when the vocal tract is lengthened.
- All formant frequencies rise uniformly when the vocal tract is shortened.
- All formant frequencies lower uniformly with lip rounding and increase with lip spreading.
- An increased mouth opening (dropping the jaw) raises F1.[81]

These changes can be very slight, resulting in only a small change in formants, or very great. The type and degree of modification required will vary depending on which fundamental frequency is being vibrated, and which vowel is being formed. In most cases the modification amounts to a shading or coloration of the original vowel, so that the original vowel can still be perceived within the modification.

In the case of high pitches, especially those sung by sopranos, the modified vowel may even be more intelligible to the listener than the unmodified vowel. Consider again the case of the soprano singing F5, 700 Hz, on the [u] vowel. The first formant of the [u] vowel is typically around 370 Hz for the female voice. Since F1 and F2 together identify the vowel for the listener, it could be said that the [u] vowel does not truly exist at this

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[81] McCoy, 43.

pitch. In order for the listener to be able to understand the vowel, the first formant must be raised so that it is included in the sound which is radiated from the mouth; in other words, it must be raised until it is above the fundamental being sung. According to the rules described above, the first formant can be raised by dropping the jaw. The soprano will still "think" the [u], and try to maintain the tongue position that creates the [u], but the raised F1 caused by the lowered jaw will aid in both resonance and intelligibility.

This modification, the raising of the first formant, must take place for any pitches which are higher than the normal first formant of the required vowel. This happens most often in the soprano voice and the upper notes of the alto voice. Table 2 shows the first formant frequencies of five vowels in the female voice, and the highest pitch at which this vowel can still be produced normally, without adjusting the first formant.

Vowel	**F1**	**Highest possible pitch**[82]
[i]	310 Hz	approximately D#4 (311 Hz)
[ɛ]	610 Hz	D5 (587 Hz)
[ɑ]	850	G#5 (830 Hz)
[o]	590	D5 (587 Hz)
[u]	370	F#4 (370 Hz)

Table 2. Highest possible pitch for vowel to be produced without modification.

John Howie and Pierre Delattre conducted an experiment that confirmed that when the fundamental is higher than the first formant, vowels become hard to differentiate. Table 3 shows the frequencies at which they found that vowels "start seriously losing intelligibility."

[82] Frequencies of pitches are based on A4=440 Hz and are from McCoy, p. 177.

Vowel	**F_0 at which intelligibility is lost**
[i, u, y]	350 Hz (approximately F4)
[e, o, ø]	450 Hz (approx. A4)
[ɛ, ɔ, œ]	600 Hz (approx. D5)
[æ, a, ɑ]	750 Hz (approx. G5)

Table 3. Howie and Delattre's vowel intelligibility results.[83]

For female singers, especially sopranos, many of the pitches they must sing will require some modification in the form of a lowered jaw to raise the first formant, thereby enhancing intelligibility of the vowel. Of course, as noted in chapter 3, by placing a formant in the vicinity of the fundamental, the singer also achieves an additional resonance boost.

As table 2 suggests, for pitches above the second *passaggio* for women (E5 to F#5, depending on voice type), the vowel most likely to resonate the fundamental is [ɑ], because its first formant is above the *passaggio* pitches. In effective vowel modification for these pitches, all sung vowels start to approach the [ɑ] vowel in their degree of jaw dropping, though the position of the tongue for the written vowel is maintained as much as possible. In the approach to the second *passaggio,* the most resonant vowel is [o], with a first formant near D5, or [ɔ], with a first formant near F5. A rounding and slight closing of vowels in this area, approaching the shape of the [o] or [ɔ], would take advantage of these resonances.

Rounding the vowels in the approach to the women's second *passaggio* also lowers the second formants of these vowels, which otherwise might over-amplify the

[83] Howie and Delattre, 393.

higher overtones in the sound. For example, a “pure” [ɛ] vowel has a second formant of approximately 2,330 Hz in the female voice (D7). If the singer attempts to sing an unmodified [ɛ] vowel on the pitch D5, the second formant matches exactly the fourth harmonic of the source spectrum. This exact match of a high harmonic can create a sound which is too bright and may also destabilize the vocal fold vibrations, as will be explained below. Rounding the vowels in this difficult area can prevent these problems.

At very high pitches, above C6, sopranos may not be able to lift the first formant any higher by jaw lowering. At this point they may make an adjustment that tunes the second formant closer to the fundamental, or even to the first overtone of the fundamental. Lip spreading can raise the second formant sufficiently to achieve this, which is why some singers seem to smile when singing in this pitch range.[84]

The first *passaggio* for women (ranging from E♭4 to A♭4 depending on voice type) can be smoothed out somewhat by modifying vowels in this range, as well. Formant tuning for women at the bottom of their voice range requires lowering the first formant for most vowels. According to the general principles noted above, this can be accomplished by greater lip-rounding or by more constriction at the front of the vocal tract. The vowels [u] and [i] have the lowest first formants because of their high degree of lip-rounding and front-of-mouth constriction, respectively. Lip-rounding can be used to lower the formants of “back” vowels such as [a]; increasing the height of the tongue at the front of the mouth will lower the formants of front vowels such as [e], [ɛ], [ɪ], and [æ]. This brings the first formant closer to either the fundamental or its first overtone.

[84] McCoy, 74.

These same pitches in male voices, which are above their first *passaggio*, need similar modification to avoid a too-bright, harsh or "white" sound. This is related to the strength of the upper harmonics in the sound. Below the first *passaggio*, where the fundamental being sung is less than 275 Hz, the male singer typically tunes the first formant to one of the overtones of the fundamental. This is because the overtones are much closer to the first formant than the fundamental is. (For example, for F3, approximately 175 Hz, the overtones are 350, 525, 700, and so on. The formants of most vowels are near one of these harmonics already.) At the first *passaggio*, a change in formant tuning is required to assure evenness of tone quality.

Above the first *passaggio* in the male voice, unless the singer switches to falsetto, all of the harmonics of the voice source are quite strong because of the firm glottal closure and relatively high closed quotient which characterize "full voice" at this pitch level. The upper harmonics can become so strong that the sound seems overly bright. When singing above the first *passaggio* on vowels with higher first formants, such as [ɛ] or [a], it is possible for F1 to further amplify the second harmonic to such an extent that the sound becomes harsh. If this spectral imbalance is combined with excess air pressure and muscular tension, the sound produced can be quite unrefined. The more open vowels in this pitch area should be modified to lower their first formants, so that the first formant will amplify the fundamental rather than an upper harmonic, helping to avoid this problem.

This technique is sometimes described as "covering." Richard Miller points out, however, that the word "cover" is used in some schools of pedagogy to mean not only vowel coloration, but also enlargement of pharyngeal space, increased air pressure, and depressed larynx. These physical changes can cause considerable muscular tension, especially if exaggerated. Miller suggests avoiding the term “cover” in favor of “vowel modification,” to avoid implying that these other physical changes are required.[85]

In summary, women make several different vowel modifications throughout their range:

- When crossing the lower *passaggio* downward into the bottom of the voice, open vowels should be closed slightly to lower the first formant.
- In middle voice, the jaw is gradually dropped as pitch ascends, especially on the more closed vowels such as [u] and [i], to keep the first formant above the fundamental.
- At the approach to the upper *passaggio*, beginning around B♭4 to C5, vowels should be rounded and closed somewhat.
- After crossing the upper *passaggio*, the jaw drops, as if for the vowel [ɑ], while tongue position remains as faithful to the position of the written vowel as possible.
- At extremely high pitches (above C6), sopranos may need to tune the *second* formant to the fundamental or the first overtone, which may require a more spread mouth position.

Men have a slightly different set of requirements:

- Below the first *passaggio*, vowels typically need little modification, because their first formants are generally near an overtone of the fundamental being sung.

[85] Miller, *Structure of Singing*, 151.

- Above the first *passaggio*, the target for formant tuning changes to avoid a too-bright, open sound. Open vowels are rounded and closed so that the first formant is lowered to the vicinity of the fundamental, rather than an overtone. In this way, the singer avoids over-amplification of the upper harmonics of the sound.
- Continuing above the second *passaggio* results in a change to falsetto, or cricothyroid-dominant production, in which the upper harmonics of the sound do not have as much strength, so "covering" is no longer essential. It would seem logical that beyond this point, men may tune the formants as women do in their own CDT.

Each of the vowel modification techniques above emphasize the need for gradual change of vowel color which corresponds to change in pitch. The result is an even-timbred sound for the listener, although the singer is quite conscious of multiple changes throughout the range. In this respect, vowel modification is very similar to the gradual change in relative activity of thyroarytenoid and cricothyroid muscles as pitch ascends. In order for the listener to perceive a uniform sound, the singer's production of the sound must be ever changing.

The vowel modification principles detailed above are understood as adjustments to the existing vowel. Their goal is to bring a formant within close range of a particular harmonic. Vowel substitution is another proposed method of formant tuning, aimed at finding an exact match of vowel formant and the frequency of a sung harmonic.

Vowel modification by substitution

Vowel substitution is the replacement of one vowel by another for the purposes of achieving maximum resonance and security of phonation. As practiced by several important pedagogues, the substitute vowel has a formant that exactly matches one of the harmonics being produced by the vibrating vocal folds. This approach is not without problems, however, which will be detailed below.

One pedagogue and researcher who advocated this technique is D. Ralph Appelman. He described a "stable pitch range" within which the vowels did not need modification, from C4 to B4 in the female voice, from C3 to B3 in the tenor voice, from A2 to A3 for baritones, and from F2 to G3 for low basses. In the highest parts of the voice, above E5 in women's voices, and above E4 in men (C4 for low basses), all vowels should be modified toward [ʌ] as in "up" or [ʊ] as in "foot." For the "first migration area," as he termed the compass between the stable pitch range and the highest range, Appelman proposed a vowel substitution system by which all vowels were changed to a "quality alternate vowel."[86]

According to Appelman, by substituting quality alternate vowels, the singer could produce resonance frequencies in the vocal tract that would match either the fundamental being sung or one of its overtones. He defined quality alternative vowels as those vowels that could be substituted with little impact on intelligibility, because they have a low percentage of recognition by a listener; that is, they are easily mistaken for another vowel.[87] (For example, the vowel [ɪ], as in "hid," is often mistaken for [i], as in "heed.")

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[86] D. Ralph Appelman, *The Science of Vocal Pedagogy* (Bloomington: Indiana University Press, 1967), 226.

[87] Appelman, 228.

Figure 12 shows Appelman's vowel migration chart.

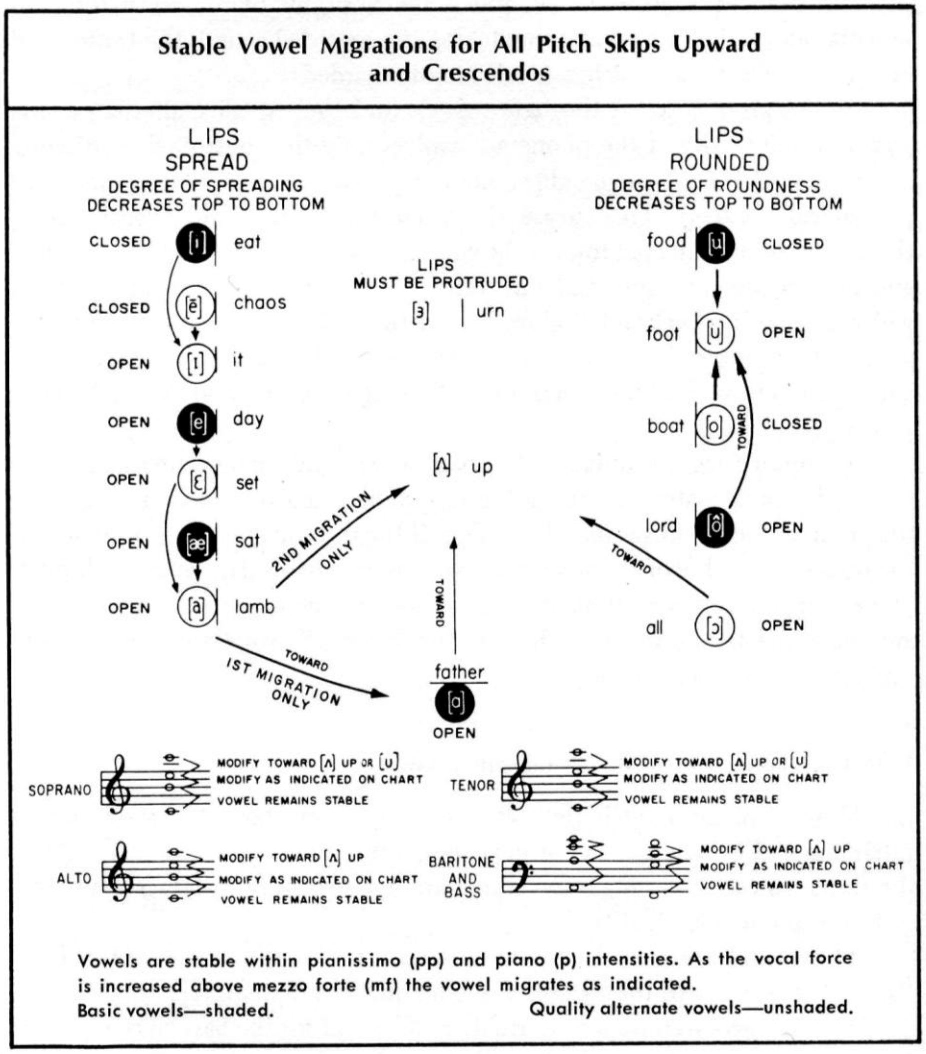

Figure 12. Appelman's vowel migration chart.[88]

According to the chart, in the first migration area, all vowels change to a more open vowel ([i] to [ɪ], [e] to [ɛ], etc.). He proposed identical vowel migrations for women's voices and men's voices, an octave apart (with the exception of low basses, who experience their first migration area a tenth lower than women). Appelman wrote

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[88] *Ibid.*, 234.

that effective use of the migration chart required both teacher and student to commit it to memory, and that the singer should always make vowel substitutions when singing in the migration areas.[89]

Pedagogue Berton Coffin proposed an even more detailed system. His “chromatic vowel chart” provided specific vowels for each pitch, chosen for their ability to provide “loudest resonance,” which according to Coffin occurs “when the vocal tract has a pitch which resonates a harmonic or fundamental of the sung tone.”[90] He wrote that this can be achieved “by shading (slightly opening or closing) the vowel, somewhat like focusing a camera.”[91] Coffin’s vowel chart proposed exact parameters for that shading, offering a replacement vowel when necessary to achieve loudest resonance. In order to match every fundamental that could be sung, Coffin added several “new” vowels by adjusting the lip position of common vowels, resulting in brighter or darker colors (with the attendant formant changes). His highly complex chart was designed to be placed behind the black keys of a piano keyboard for reference, and could be adapted for all voice types by placing it at different locations on the keyboard.

In a later pedagogical volume, Coffin also provided a numerical system for degree of mouth opening. The chromatic vowel chart and numerical system together could be applied to any passage in the singer’s repertoire, such as the example from Pamina’s aria in *Die Zauberflöte* shown in figure 13.

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[89] Appelman, 260, 227.

[90] Berton Coffin, “Chromatic Vowel Chart,” in *Coffin’s Sounds of Singing*, 2nd ed. (Metuchen, NJ: The Scarecrow Press, 1987), verso.

[91] *Ibid.*

Figure 13. Pamina's aria, marked with Coffin's suggested vowel substitutions and mouth openings.[92]

A similar approach is taken by Shirlee Emmons and Constance Chase in their book *Prescriptions for Choral Excellence*. Using information from Coffin's research, the authors provide charts for each voice type, proposing a substitute vowel as well as a numerical mouth opening for each pitch in the area of a register shift. Table 3 shows the chart for the soprano voice at the upper *passaggio*. The sections in bold type indicate the general location of the *passaggio*. Two choices of vowel for each pitch are given; the singer or conductor should choose the substitute vowel which is closest to the written vowel (for instance, [e] as a substitute for [i] or [ɪ], [ʌ] as a substitute for [a] or [o]). Parentheses around a vowel symbol indicate that the vowel should be sung with protruded lips. The singer is to write the correct substitution into his or her music.

Sopranos

D5	E♭	E	F	**F#**	**G**	**A♭**	A	B♭	B	C6
(ʌ)	(ʌ)	(ʌ)	(ʌ)	**ʊ**	**ʊ**	**ʊ**	(ʌ)	(ʌ)	(ʌ)	ʌ
ɛ	ɛ	ɛ	ɛ	**e**	**e**	**e**	ɛ	ɛ	ɛ	e
8	9	10	11	**5**	**6**	**7**	8	9	10	11

Table 4. Soprano vowel substitutions as proposed by Emmons and Chase.[93]

[92] Berton Coffin, *Overtones of Bel Canto: Phonetic Basis of Artistic Singing* (Metuchen, NJ: The Scarecrow Press, 1980), 91.

Emmons and Chase state that although most voice instructors teach vowel modification through "indirect or nonspecific approaches" such as mental imagery, the authors' vowel chart is a "direct, specific and fact-based approach," and therefore likely to a be more efficient method. They write to the choral director that since vowel adjustment is essential to achieve consistent resonance, "You do [your singers] a favor when you encourage them to search for that modification, or, better, teach them what the modification should be."[94] The proper substitute vowel, according to the authors, is one whose formants match the fundamental being sung or one of its overtones.

Barbara Doscher also advocated tuning the vowel formants to match the fundamental or one of its overtones. She noted that the first formants of almost all vowels lie in the range from D4 to F5, and stated that for all frequencies above D4, whether sung by men or women, "the singer must learn how to alter his/her vocal tract to match the appropriate vowel formant frequency with the fundamental being sung."[95] Unlike Appelman, Coffin, Emmons, and Chase, she stopped short of proposing specific vowels for each pitch, noting instead the general methods for adjusting formants described at the beginning of this chapter.

Doscher proposed that if the first formant is not matched to the fundamental or one of its overtones, "a weakening and distuning of vocal cord vibration will result."[96] Conversely, she wrote, tuning the first formant to one of the harmonics being sung can

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[93] Shirlee Emmons and Constance Chase, *Prescriptions for Choral Excellence: Tone, Text, Dynamic Leadership* (New York: Oxford University Press, 2006), 129.

[94] *Ibid*., 124-125.

[95] Doscher, 124.

[96] *Ibid*., 125.

strengthen the vocal fold vibrations. She cites a 1982 article by Titze, in which he notes that studies have shown that acoustic pressures in the vocal tract affect glottal airflow, and thus vocal fold function:

> Different vowels, for example, create different degrees of loading on the vocal folds. We have all experienced this, but it has now been demonstrated scientifically that not only can vowel modification optimize the resonance for a given source, but the source itself can be strengthened by tuning for optimal loading conditions.[97]

Later studies by Titze have demonstrated, however, that rather than reinforcing vocal fold vibration, tuning the first formant *exactly* to a harmonic results in instability of vibration. "Optimal loading conditions" must be achieved in some other way. This is one of several problems with the vowel substitution approach to formant tuning.

Problems with vowel substitution

In 1999, Titze reported further on how the acoustics of the vocal tract affect the function of the vocal folds: recent research had shown that an inert air column above the vocal folds reduces the amount of lung pressure required to set the folds in vibration.[98] An inert air column above the vocal folds will have a delayed response to the opening and closing of the glottis. This creates positive pressure above the vocal folds during opening, helping to drive them outward, and creates negative pressure when the vocal folds are closing, helping to pull them together.[99] The advantage to the stronger opening

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[97] Ingo Titze, "Some Thoughts on Source-System Interdependence," *The NATS Journal* 38, no. 5 (May/June 1982): 28.

[98] Ingo Titze, "The Use of Low First Formant Vowels and Nasals to Train the Lighter Mechanism," *Journal of Singing* 55, no. 4 (March/April 1999): 41.

and closing of the glottis is an increase in the amplitude of all the overtones and thus the richness of the sound.[100]

Titze notes that when a vowel formant is placed at exactly the same frequency as a harmonic of the voice source, the inertance of the air in the vocal tract changes rapidly.[101] As a result, the vibration of the vocal folds can be destabilized, and the amplitude of all the harmonics along with it. This can result in a sudden change of timbre or loudness. Using a substitute vowel with a formant that is an exact harmonic match thus may disturb uniform vocal quality rather than create it.

Despite this problem, Titze points out that the main principle behind Coffin's vowel chart, and other such vowel migration prescriptions, is still valid: "There are good vowels and bad vowels for a given pitch," and the singer must find a way to make optimum use of vocal tract resonance for any fundamental frequency. New additions to the source-filter theory actually make the formant tuning process easier, though, because an exact match is not required; rather, the goal is to adjust a formant frequency so that it is higher than a harmonic, but still nearby. As Titze notes, "fortunately, there is more than one formant" for each vowel, so a certain amount of freedom in selecting a vowel modification is afforded.[102]

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[99] Titze, *Principles of Voice Production*, 101. For further detail, see Ronald C. Scherer, "Laryngeal Function During Phonation," in *Voice Science,* ed. Robert Thayer Sataloff (San Diego: Plural Publishing, 2005): 178.

[100] McCoy, 48.

[101] Titze, "Resurrection from the Coffin," *Journal of Singing*, 64 no. 2 (November/December 2007): 200.

[102] Titze, "Resurrection from the Coffin," 199.

The vowel substitution charts focus on adjusting the first formant only, which is also a problem in light of Titze's suggestion that either vowel formant can be used for formant tuning. Researcher and pedagogue Paul Oncley gives an example of the necessity of moving the second formant on occasion:

> A tenor singing a high A♭ at 417 Hz on the vowel Ah will attempt to so modify the mouth position that the first formant, F1, will rise from its natural position at around 700 Hz to the vicinity of 834 Hz to reinforce the second harmonic. If he continues to B♭ however, at 465 Hz, he will probably not be able to push the formant up to 930 Hz [the second harmonic of that pitch]. Instead he changes his [mouth] position slightly so the second formant drops down from its usual position at about 1100 Hz to 930.[103]

Sundberg points out that a soprano may also adjust the second formant of vowels as fundamental frequency rises, placing the second formant just above the second harmonic: F2 of "front" vowels such as [i] and [e] will be lowered, while F2 of "back" vowels such as [u] and [a] will be raised.[104] Contrary to the goal of the vowel migration charts, vowel modification thus sometimes should affect more than just the first formant.

Another problem with a vowel substitution method such as Appelman's is that it proposes the same substitutions for men and women in their own respective octaves. Considering that vowel modification needs are F_0-dependent, this does not seem logical. Appelman suggests that women should open all vowels between B4 and E5, and men should open all vowels between B3 and E4. Yet the passage between B3 and E4 is exactly the area in which men must *close* their vowels in order to prevent a brash sound.

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[103] Oncley, 40.

[104] Johan Sundberg, "Vocal Tract Resonance," in *Professional Voice: The Science and Art of Clinical Care*, ed. Robert T. Sataloff (New York: Raven Press, Ltd., 1991), 60.

The vowel substitution techniques as presented on paper also fail to take into account the needs of individual voices and the demands of the particular piece of music. Achieving maximum resonance on every note of a fast-moving passage may not be possible or desirable. A perfect acoustical match between the substitute vowel and the fundamental or overtones being sung cannot be guaranteed for every singer, since it is unlikely that any two singers will produce the substitute vowel exactly the same way, with exactly the same formants. Furthermore, singers with voices that are naturally bright, with strong upper harmonics, may not wish to energize those overtones further by moving a formant near them. Singers with dark voices may find that the lip protrusion recommended by some authors causes a too-heavily covered sound. John Nix notes,

> The amount of modification needed varies with the size of the voice, the 'weight' of the voice, the duration of the note being considered, the dynamic level, and how the note in question is approached. Sensitive singers report that the amount of modification they need may vary daily and also during the day, depending on how much they have warmed up.[105]

It is almost certainly true that some of the pedagogues who subscribe to vowel substitution practices do not intend for them to be applied blindly (or rather, without hearing) to every voice. Experienced teachers can determine by listening whether vowel alteration is needed, and can find by experimentation the right kind and degree of modification required. The flexibility inherent in this approach also allows the singer to discover the unique characteristics of his or her own voice, and so to use it to its fullest resonant potential.

[105] Nix, 173.

Vowel modification for unified timbre

The vowel modification techniques described so far have primarily focused on achieving maximum resonance of the singing voice; that is, the greatest possible increase in volume. Being able to create maximum resonance gives the singer a broad dynamic range, which increases expressive potential. More importantly for the present discussion, the ability to maintain the same loudness for all pitches, regardless of their frequency or vowel, is an important part of creating the impression of a "one-register," seamless voice.

A well-blended voice is one which is also able to maintain a unified timbre when changing from vowel to vowel. Richard Miller speaks of this as "resonance balancing."[106] Vowels formed with a high, forward tongue, such as [i], [ɪ], and [e], have high second formants. These second formants can amplify upper harmonics in the sung sound, creating a bright sound. Vowels formed with the high point of the tongue farther back in the mouth, such as [u], [ʊ], and [o], have lower second formants and thus do not cause the same high harmonic amplification. In changing from a back vowel to a front vowel, as in the phrase "You see," a sudden change in the brightness of the tone can be heard, and often a corresponding impression of a louder sound.

Vowel modification can aid in "resonance balancing" when a unified timbre or volume is desired, by bringing the second formants of these vowels closer together. If the forward vowel sounds too bright in comparison to the back vowel, rounding the lips when singing the forward vowel will lower the second formant. If the forward vowel is of suitable timbre, but the back vowel sounds too dark by comparison, making the lips

[106] Richard Miller, *Solutions for Singers: Tool for Performers and Teachers* (New York: Oxford University Press, 2004), 78.

less round while singing the dark vowel can raise its formants. In this way the vowel stays intelligible but matches the timbre of other vowels more consistently.

Vowel modification is a powerful means for creating the impression of a unified voice regardless of the demands of pitch, intensity, or vowel. It can also strengthen the vibrations of the vocal folds and assist in maintaining voice quality at *passaggio* transitions. As such, it is an important tool for every singer.

V. Choral Voice Teaching

Assessing the ensemble

In the solo voice studio, the teacher can assess the skills of each student individually and craft a teaching plan structured to address that student's technical deficiencies. Such a teaching plan might include vocalises, recommended recordings for listening, and particular repertoire assigned to capitalize on a student's strengths or encourage him or her to develop new techniques. In a choral setting, the conductor cannot produce a teaching plan that will be tailor-made for any one student. Instead, the choral conductor can assess the basic skill level of the ensemble as a whole, understanding that there will be singers who are more advanced and perhaps singers who are less skilled, and then choose vocalises and plan repertoire accordingly.

The choral conductor has several tools at his or her disposal to form an assessment of the general skill level of the ensemble. Before the ensemble has even met for the first time, auditions can be helpful in allowing a conductor to get to know the individual voices in the ensemble. Auditions for vocal assessment can take the form of a solo piece chosen by the singer, vocalizations led by the conductor, or a combination of both. If similar problems appear in a number of voices, the conductor can plan to address them through vocalises, rehearsal techniques, and repertoire.

The conductor may discover that most of the men in the ensemble have difficulty managing the first *passaggio*, for example, and may search for repertoire that does not require constant crossing of the break, while developing vocalises to teach them registration-adjustment techniques for the future. Or, the conductor may learn that many singers in the ensemble have a bright sound and can plan to use vocalises to teach vowel modification for a warmer sound. Once the ensemble is formed and rehearsals begin, the conductor can use group vocalises to determine whether his or her initial impressions are borne out in the collective sound of the ensemble.

Diagnosing problems in registration and acoustical tuning

There are several tools all teachers of singing, including choral conductors, can use to determine whether singers are experiencing difficulties in their technique. Most obvious is the teacher's hearing. What does the singer or the ensemble sound like? How is intonation? Tone color? Does the sound seem easy or forced? The teacher should not neglect to use his or her eyes, as well. Difficulties of vocal production can be seen as undue tension in the jaw, lips, or elsewhere in the body. Finally, the teacher may experience sympathetic responses while listening, such as tension in his or her own throat that may mirror similar tension in the singer.

Difficulty in managing muscle coordination and formant tuning may present several different symptoms. An audible break, when phonation stops completely as muscle activity is rearranged within the larynx, is only one sign. Faulty intonation, a sudden change in loudness, or a change in timbre can also indicate that singers are experiencing these difficulties.

Faulty intonation can be a symptom of a lack of coordination of thyroarytenoid and cricothyroid activity as pitch changes. Intonation problems are often heard at or above the *passaggio* when fundamental frequency is increasing, particularly when the thyroarytenoid muscle is very active. Titze has shown that thyroarytenoid contraction can be used to increase fundamental frequency, as long as the cricothyroid muscles are not at their maximum contraction.[107] Under these circumstances, however, once the TA muscle reaches its maximum contraction, no further increase in F_0 is possible. If the singer has been relying on TA contraction to increase fundamental frequency (that is, has been singing in "heavy mechanism" or "chest voice"), the pitch will become flat, since the TA muscle cannot contract further. (A small rise in pitch can be produced at this point if additional breath pressure is applied, or if maximum TA stress is maintained and CT muscles are engaged more strongly, but this can create a pressed sound and will eventually result in a "break," when the TA muscle can no longer maintain maximum contraction and releases abruptly.)[108]

A related pitch problem can occur as fundamental frequency decreases. As singers cross over the *passaggio* from above, they may release the cricothyroid muscle too quickly and increase thyroarytenoid activity too much, resulting in the same problem of maximum TA stress. In this case, the flat pitch will typically be below the *passaggio*. Singing under the pitch at or near *passaggio* points (either above or below the *passaggio*) can thus be an indication that the balance between the activity of the TA and CT muscles has not been gradually adjusted. The conductor can then choose vocalises to assist the singers in learning this important technique.

A sudden change in loudness can be another sign of difficulty in either muscular adjustment or formant tuning. Especially at *passaggio* points, a change from a fairly loud sound to a very soft one can indicate an abrupt shift from thyroarytenoid-dominated production to cricothyroid-dominated production ("chest voice" to "head voice" for

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[107] Titze, *Principles of Voice Production*, 230.

[108] *Ibid.*, 299.

women, or "chest voice" to *falsetto* for men). A change from a soft sound to a loud one can indicate the reverse. Sounds may be perceived as louder because they have greater energy in the higher overtones. Strong upper harmonics are a characteristic of thyroarytenoid-dominated production, because of the relatively large mass of the folds, firm glottal closure, and longer closed quotient which occur with this mechanism. In contrast, the sound created in cricothyroid-dominated production has relatively little strength in the upper harmonics, because of the thinner vocal folds and rapid, often incomplete glottal closure. The change in mode of vibration creates a change in loudness. Learning to gradually adjust the relative activity of the two muscles can solve this problem.

Difficulty with formant tuning can also cause inconsistency of loudness. Over-amplification of high overtones by one or both of the vowel formants can cause the sound to become much brighter, which the listener may perceive as loudness. This can happen quite suddenly, depending on the frequency being sung and the vowel being used. If the formants are lowered so much that the higher harmonics in the sound are not resonated, the sound can become dark or covered, which will sound softer to the listener. Furthermore, an unmodified vowel will sound different depending on where in the singer's range it is sung, because of the changing interaction of source harmonics and formant frequencies. If the formant frequencies are above but within approximately 100 Hz of a harmonic, the vocal tract will provide resonance for the vibrations from the vocal folds, resulting in a stronger sound. However, if the fundamental frequency and its overtones are above the first formant, or too far from either vowel formant, the radiated sound will be weaker. Vowel modification can aid in producing a more uniform degree of amplification by the vocal tract throughout the voice range.

A change in the radiated spectrum of the voice creates a change not just of perceived loudness but also timbre (voice quality or "color"), because the relative strengths of the harmonics create the unique qualities of the voice (see, for example, the discussion of the spectra of the clarinet and cello in chapter 3). Therefore a change in timbre may indicate a problem with either formant tuning or relative activity of the TA and CT muscles.

In a group setting it is possible that some singers are experiencing muscle adjustment problems, others vowel modification difficulties, and some both. Therefore the conductor may use combinations of vocalises to address both problems. The conductor should not be intimidated by the complexity of possible problems; voice teaching of any sort almost always involves a great deal of trial and error and often uses the "cold, warm, warmer, hot" method of helping singers find their optimum singing habits.[109] Armed with an understanding of the physiology and acoustics of the voice as they relate to the "one-register" ideal, as well as his or her own hearing, sight, and sympathetic responses, the conductor is well-prepared to diagnose and help solve a variety of registration problems.

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[109] Titze, *Principles of Voice Production*, 83-84.

VI. Vocalises

Vocal exercises are an important tool in developing reliable technique. Unlike music from the vocal repertoire, which may present multiple difficulties simultaneously, vocalises can be designed to "divide and conquer," focusing on a single area of difficulty. For example, a vocal exercise can be constructed to allow a singer to develop confidence in managing the *passaggio* on an advantageous vowel before introducing other, more difficult vowels. Or, a vocalise can help a singer develop agility without having to simultaneously cope with text changes. A graduated series of vocalises can be designed which will help singers build their technique from the most basic to the most advanced skills. Exercises can also be constructed to address specific areas of difficulty found in the repertoire the singer is preparing. The techniques gained from vocal exercises can then be transferred into the repertoire.

A number of vocalises designed to teach the singer to manage muscular and acoustical adjustments are detailed below. Each exercise is written in musical notation, followed by an explanation of the general principles of the exercise, suggested phonemes (vowel and consonant sounds), pitch levels and transpositions which are beneficial for the particular exercise, special notes for men's or women's voices, and imagery and language the conductor may use to help the singers achieve the goals of the exercise.

General notes about the exercises

These exercises presuppose healthy habits of breathing for singing. If the singers do not understand breath management, vocal fold vibration can be unstable, the sound breathy or pressed, and the sound spectrum unbalanced (that is, the upper harmonics may be extremely weak or too powerful). Addressing registration and vowel modification can only partially resolve these deficiencies. Simultaneous work on breath management, registration, and vowel modification is possible, but the conductor should understand that improvement of breathing technique is the foundation for the rest of the work. Many excellent resources are available which describe fundamentals of breath management and will aid the conductor in teaching this concept.[110]

If singers experience significant difficulty accessing "head voice," a slightly softer dynamic level can be helpful in reducing the engagement of the thyroarytenoid muscle. Researcher Godfrey Arnold explains, "A soft tone at the upper border of a register is sung with the mechanism of the next higher register," while louder singing engages the lower register, or heavy mechanism, more strongly.[111] Singing the exercises at an easier dynamic level at first, and gradually adding intensity as the refined muscle adjustment becomes habitual, is a useful practice.

Transposition of the exercises requires that the conductor monitor the choir very closely for signs of tension. Even with proper breath management, if muscle adjustment is not yet refined, tension can appear as the voice ascends to *passaggio* points or range extremes. It can also occur when singers do not employ adequate vowel modification. When singers begin to experience tension, the conductor may ask them to try the exercise again, using imagery and explanation to help the singers achieve the goal of the exercise. If this is unsuccessful, the conductor should move on to another vocalise but remember

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[110] See Barbara Conable, *The Structures and Movement of Breathing: A Primer for Choirs and Choruses* (Chicago: GIA Publications, 2000); McCoy; Emmons and Chase.

[111] Godfrey Arnold, "Research Potentials in Voice Registers," in Large, 150.

the pitch at which the tension appeared. The next time the exercise is attempted, the conductor's goal should be to help the singers produce as well as possible the pitches *below* the tension point. When these pitches are secure, the pitches above will be easier to manage. In this way, over time, the range of successfully produced pitches will grow, perhaps one half step at a time.

If some portion of the choir seems to have significant difficulty at a particular pitch level but others do not (for example, altos but not sopranos, or men but not women), it can be helpful to have that section sing the same exercise along with the rest of the choir, but a third or more lower (or higher, as the case may be). In this way, the singers who are most challenged by a particular vocalise can work at a more comfortable pitch range, while the rest of the choir develops the same technique higher (or lower) in their voices. No singer is left behind; the focus is on helping each singer develop the required techniques at a pace which will allow for success.

Singers should be encouraged to experiment with degrees of vowel modification as the exercises move through the voice range. Many of them will experience increased ease of production when they happen upon the right amount of adjustment. Choir directors are often taught that in order to achieve perfect choral blend, all singers must be singing the same "pure" vowel. This concept does not withstand scrutiny, however, in light of the resonance frequencies of the vocal tract for each vowel. If the vowel [i] does not exist above C#4 or D#4, when its first formant is surpassed, it cannot be effective to ask sopranos on high pitches to sing the same [i] as basses at the bottom of their range. The shaping of the vowel must vary as fundamental frequency varies. Even within a group of people singing the exact same F_0, different degrees of vowel modification will be required, since every singer has a slightly different vocal tract. Singing vowels which are not resonant creates vocal difficulty, as the singer applies breath pressure or muscular tension to account for the loss in volume. The conductor should listen for a comfortable, resonant sound rather than watch for uniformity of physical presentation.

When the conductor has discovered a vocalise which is effective in solving a vocal problem in the ensemble, he or she should not hesitate to use the same exercise, or a variation on it, for a number of rehearsals in a row. Repeating the same vocalises over the course of many rehearsals allows each singer to fully grasp the concepts presented, and also provides the conductor with a valuable tool when problems appear in the repertoire the choir is singing. For example, if a passage in the repertoire is challenging to the tenors because they are not properly modifying the vowel, the conductor may be able to give them a verbal reminder of the vowel modification they used successfully in the vocalise. The conductor may even choose to stop rehearsing the repertoire for a moment (perhaps no more than a minute) and return to the vocalise which has been successful in helping the tenors with vowel modification. The vocalise should be started near the pitch of the problem spot and transposed until it includes the pitches of the problem area. When the problem has been separated from the repertoire, and the singers have been reminded of the solution they have already learned through a vocalise, the conductor should return immediately to the problem spot in the repertoire so that singers can transfer the technique.

Vocalises to teach adjustment of the laryngeal muscles

One of the causes of register breaks discussed in chapter 2 is a sudden change in mode of vocal production, from thyroarytenoid-dominated to cricothyroid-dominated production. In order to avoid the sudden shift, the singer must learn to engage the cricothyroid muscles at a lower point in the range, well before the shift point is reached, while simultaneously lessening the activity of the thyroarytenoids. Since these muscles are below the level of conscious control, mental imagery is helpful, as is directing the singer to pay attention to sensations elsewhere in the body.

A very simple exercise is shown below.

Exercise 1.

Principles of this exercise: Many voice teachers speak of "bringing the head voice down," a concept that is reflected in this vocalise. The exercise starts on an upper note, allowing the singers to start in a lighter muscular adjustment, with more involvement of cricothyroid muscle than might be experienced lower in the voice. The exercise then requires singers to descend lower in the voice, where they may intuitively employ additional thyroarytenoid contraction. The challenge in this exercise is to release the thyroarytenoid muscle as the pitch ascends back to the starting note.

Suggested phoneme: This vocalise may be especially effective on the vowels [u] or [i], or light humming on the consonant [n]. Titze suggests that a vowel with a low first formant frequency, such as [u] or [i], as well as the [n] hum, can contribute to vocal tract inertance, which encourages vocal fold vibration, particularly at the upper edges of the vocal folds. This type of vocal fold vibration is precisely the sort found in a lighter registration.[112] The vowel sound may be preceded by a consonant such as one of the nasal consonants [m, n] or a voiced consonant such as [v], [z], or [b]. If a consonant is used, it should be applied only to the first pitch, and the rest of the pitches should be sung *legato* on the vowel.

Pitch level: The vocalise should begin on a medium pitch, so that some feeling of lighter registration is present in the sound, but not so high that some singers experience tension. This pitch will vary depending on the skill level of the ensemble. A3 for men and A4 for women can be a good starting point. This is just below the first *passaggio* for men, so it does not engage the "calling voice" described by Richard Miller, in which increased TA tension and breath pressure are often applied by the untrained singer, with accompanying discomfort.[113] It is above the first *passaggio* for women, so it is not likely that women will engage their "chest voice," or heavy mechanism, at the onset of the sound.

Transpositions: Transposing the exercise down by half steps gives women the opportunity to cross over the first *passaggio* into the lower portion of the voice. This encourages them to learn to gradually introduce increased thyroarytenoid contraction, rather than dropping suddenly into "chest voice," and then to release the TA contraction gradually as pitch ascends again. This helps smooth the transition from chest voice upward to middle voice for the soprano and alto. Downward transposition should be

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[112] Titze, "Use of Low First Formant Vowels," 41.

[113] Miller, *Structure of Singing*, 116.

halted when the starting pitch of the exercise is below the first *passaggio* for the women's voices, around E♭4 to F4.

Transposing the exercise up by half steps requires the men in the ensemble to create an increasingly lighter production as they approach their first *passaggio*. Some members of the ensemble may be able to do this, while others may experience tension at some point as the exercise is transposed upwards. The conductor should monitor the ensemble very carefully and follow the suggestions above if the upward transposition produces considerable difficulty.

Notes for men and women: The beneficial vocal tract inertance described by Titze occurs only when the fundamental frequency being sung is below the first formant of the vowel. For men, this will occur naturally at the proposed pitch levels and vowels, since the first formants of [u] and [i] are around C#4 or D4, and nasal consonants have a "murmur" around 200 to 300 Hz (G3 to roughly D4).[114] For women, if this exercise is sung on [i] or [u], vowel modification is required in order to bring the first formant above the fundamental they are singing. Women should be encouraged to lower the jaw as needed, understanding that every singer will need a slightly different degree of jaw dropping, and that women will employ more jaw dropping than men will. Some women find it difficult to use a nasal consonant such as [n] or [m] as pitch ascends. The [ŋ] sound, as in the word "hung," allows a dropped jaw, which may be helpful. It may be necessary to abandon the hum in favor of a vowel if the women in the choir seem to be experiencing tension.

[114] Titze, "The Use of Low First Formant Vowels," 41.

Imagery/language to try: Singers should be taught about the interrelation of cricothyroid and thyroarytenoid muscle activity. For some singers, who are responsive to mental imagery, this is more detail than they need, and they may quickly forget the explanation. For other singers, who may have difficulty connecting imagery to a physical reality, a brief explanation of the science can be extremely helpful. One simple explanation a conductor might use is this:

> There are two sets of muscles that are involved in pitch changing, one which is more active at the bottom of the voice and one which is used at the top. These are sometimes called "heavy mechanism" and "light mechanism." A break in the voice happens when the transfer of activity from one set of muscles to the other is too abrupt. Most of the time that happens when going up the scale, though an abrupt transition can also happen on the way down. The way to keep that from happening is to introduce the "light mechanism" gradually, lower in the voice, on the way up; and to try to keep some light quality in the voice on the way down.

For some singers, this explanation makes a great deal of sense and can help them interpret the imagery which the conductor uses for the rest of the singers.

The conductor may find that singers are responsive to some of the following ideas:

- As you descend in pitch, your voice may pick up some extra weight. Try not to let it pick up too much, and as you go back up, let go of the weight, so that you return to the same weight you started with. (This image is not very picturesque, but it is simple and, since it relates to the physiological explanation given above, it may work well for highly logical singers.)
- Think of trying to carrying a heavy suitcase up a flight of stairs, and imagine taking something out of the suitcase for each step up, so that the suitcase becomes lighter and lighter.
- Let the tone float gently down to the lower pitches, without forcing. (The idea here is to keep the singers from engaging the thyroarytenoid muscles too strongly or too soon.)

- Think of throwing a tennis ball, a basketball, and a very large beach ball over a net. (Singers might even be encouraged to mime this action, exaggerating the force needed to throw the larger balls.) Imagine how much easier it is to throw the small ball. Think of the three notes in the exercise as the three different sizes of ball. As you go from the lowest pitch to the highest, make sure you aren't still trying to throw a beach ball!
- Keep all three of the pitches "behind your eyes." Don't let the sound fall down into your throat. (This corresponds to the vibrations many singers feel in their faces when singing in "head voice." Singers who do not experience these vibrations may not find this image helpful. Singers who are very logical may be resistant to this imagery, since the pitch is not produced anywhere but the throat. The conductor can explain that the vibrations of the vocal folds can be transferred through the tissues of the body, and often vibrations felt in the face are a sign of light mechanism. Singers should not receive the impression that they must feel vibrations in any specific location, however, since every singer is different.)
- Each pitch is a pearl on a string held vertically. Pitches near the bottom are represented by fairly large pearls, high pitches are small pearls, and for every note in between, the size of the pearl changes gradually. The size of the pearl corresponds to the muscle "weight" of the voice, so that the muscular adjustment of the voice is constantly changing. The singer should seek to make the top "pearl" the same "size" at the end of the exercise as it was at the beginning.

The conductor will no doubt develop his or her own imagery to share with the ensemble, and the singers may come up with their own as well. It can be useful for the singers to share their ideas with each other.

Exercise 2 is related to the three-note exercise above, but includes an additional challenge.

Exercise 2.

Principles of this exercise: This exercise also aids in the development of a lighter mechanism as the voice ascends. It can be added to the choir's repertoire of vocalises once they have mastered the first exercise. The additional challenge in this vocalise is that the second half starts low in the voice and then proceeds higher. Inexperienced singers will often start the bottom note in a heavier mechanism, failing to anticipate the lighter mechanism required by the higher pitch. This exercise can teach them to introduce cricothyroid contraction even when starting on low pitches. The advantage of this exercise is that it begins with a pattern which has already been successful in helping them to find a lighter weight for the low note. The second part of the exercise starts on that same note, which should be sung in the same weight used in the first part of the exercise.

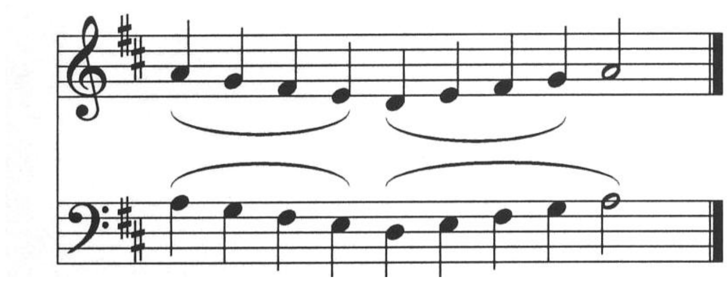
Suggested phonemes: The [i] and [u] vowels and nasal consonants suggested for the previous exercise are useful for this vocalise as well, since they encourage the vocal tract inertance described above. Singers may be ready to try a more open vowel by the time they have mastered the first exercise. [o] and [e] are excellent next steps. If the movement to a more open vowel causes problems, the vowel may benefit from being rounded somewhat. The conductor may need to add exercises designed to help singers explore vowel modification. Some of these exercises are detailed below.

Pitch level and transposition: The suggestions for exercise 1 apply to this vocalise as well.

Notes for women and men: See above.

Imagery/language to try: The above suggestions for explanation and imagery can be used for this exercise as well. The conductor may also remind the singers that the second low pitch should be no "heavier" or "larger" than the first low pitch.

If the singers are proficient at the three-note exercises immediately, or quickly gain skill, the next challenge could be five-note exercises.



Exercise 3.

Exercise 4.

Principles of these exercises: The principles of these exercises are the same as for the three-note exercises, but these vocalises are more challenging because the singer travels farther into the lower reaches of the voice, where the thyroarytenoid must become more engaged. This makes returning to the balanced production of the top note even more difficult. The singers should be encouraged to keep as much "head" vibration or "light mechanism" in the tone as possible, but if the conductor perceives that the sound on the lower pitches is too weak, the singers can be encouraged to introduce more "chest" resonance or "heavy weight." Of course, this will increase still further the challenge of the exercises.

Suggested phonemes: The four vowels proposed above, and the nasal consonants, can be used for these exercises as well. More open vowels can be used, but again, these vowels may require some rounding and closing if the upper pitch is raised above the first *passaggio* for men, or near D5 for women. If the exercise is carried past F5 as the top note for the women, they may wish to sing on [ɑ]. Once the singers have begun to develop the habits of gradual muscle adjustment these exercises are designed to teach, these exercises can be adapted to teach vowel modification, as will be shown below.

Pitch level and transpositions: Like the three-note exercise, the five-note exercise can be begun in middle voice and taken as low and as high as the choir is able to manage successfully. If the exercise is taken very high, basses and altos may wish to drop down an octave, which gives them an opportunity to work on same technique in the bottom octave of the voice.

Notes for women and men: Same as above.

Imagery/language to try: Same as above.

The following exercise is another designed to help singers learn to gradually introduce the action of the cricothyroid muscles.

Exercise 5.

Principles of this exercise: This is another exercise which helps the singer experience a lighter mechanism initially, drops lower in the voice, and then returns to the upper note. This vocalise encourages the light mechanism with its fast-moving inverted mordent, which is difficult to manage if the TA and CT muscles are functioning in strong antagonism. Repeating the mordent then confirms this lighter production. As in the previous exercises, the singer should return to the lighter weight of the upper notes at the end of the exercise.

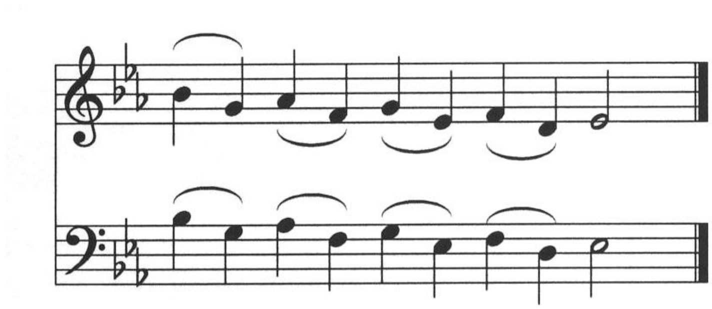
Suggested phonemes: See above for exercises 3 and 4.

Suggested pitch, transpositions: This is an excellent vocalise for upper range extension because of its fast-moving notes. Because the high notes are fleeting, singers may approach them with more confidence (or at least less fear) than they would a sustained high note. This exercise could be begun at A3 or B♭3 for men, and A4 or B♭4 for women, and then transposed upward.

Notes for men and women: No special notes, as long as singers can execute the vowel modifications described in the previous exercise.

Imagery/language to try: The conductor may use certain images and techniques to draw the singers' attention to the freedom of production which is encouraged by the fast-moving notes. Thinking of a laugh or giggle (or even producing one) can help some singers. Other singers may be helped with physical gestures such as shaking the hands lightly at the wrist or flicking imaginary water off the fingertips.

The vocalises presented so far have primarily moved by step. The next exercise introduces a skip down, followed by a step up.



Exercise 6.

Principles of this exercise: For some singers, the downward leap in this vocalise may cause a more dramatic increase in thyroarytenoid contraction than they experience in stepwise exercises. If a singer strongly engages the heavy mechanism, however, the step back up can be quite difficult. In executing the downward leap, singers should try to maintain the sense of light mechanism found in the upper note, so that the step up which follows does not require another dramatic muscular adjustment. This technique helps singers learn how to gradually increase the activity of the thyroarytenoid muscles rather than engaging them strongly at once, thus reducing the likelihood of an audible register break when descending. This is especially important for securing intonation in descending passages in the choral repertoire, especially those which cross a *passaggio*.

Suggested phonemes: This exercise is challenging enough that it may not be desirable to add the complication of vowel modification at first. Therefore the [o] vowel is an excellent choice. It has the advantage of a first formant that is high enough that women will not need to modify it much by jaw dropping, if at all, but not so high that men will need to add much "covering". A glide such as [j] or [w] can be added at the start of each pair of notes for ease of initiation.

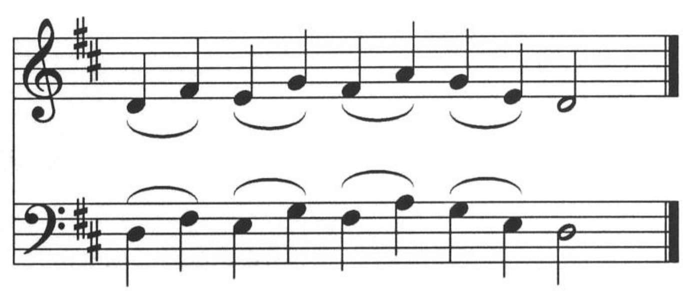
Pitch level: This vocalise is particularly effective in women's voices if it is used in the middle-voice area, approaching and even passing the second *passaggio*. Many women experience intonation difficulties as they descend from above the second *passaggio* down into middle voice, because the thyroarytenoid muscles engage too quickly or the cricothyroid muscles release too soon. Beginning on B♭4 for women and proceeding as high as F5 or G5 can be very useful in ironing out this area.

Transposition: As noted, transposing upward between B♭4 and F5 or G5 is valuable for female voices. Basses will certainly not wish to go as high as F4 or G4, though tenors may. If basses and altos would like to drop down at some point, they might choose to drop a fourth or fifth rather than an octave. This gives them the opportunity to reinforce some of the work they have already done (starting over at B♭ while the sopranos and tenors continue at F, for example), and also serves as excellent ear training for the choir (since tuning the open fourths or fifths is difficult). It can be helpful if the conductor stops and gives the new starting pitch as soon as it seems that some voices would like to drop down, rather than expecting them to find the lower pitch on their own—though this is also excellent ear training.

Notes for men and women: See the above discussion of pitch level and transposition.

Imagery/language to try: The goal of the exercise is to add only a small amount of weight on the downward leap, so that the upward step does not require a great adjustment in muscular activity. Some of the images described for the first vocalise can be useful for this exercise as well. Singers might also imagine how a piece of paper falls when it is dropped from any height: rather than dropping straight down, it seems to drift from side to side and even slightly up and down. This image can counteract the impression of falling while executing the downward leap: it is a gentle sideways dip, rather than a jolting drop. Emphasizing *legato* rather than interposing an "h" between the two notes of each slur is also important: if the two notes are disconnected, it can be more difficult for the singer to be aware of an undesired change in vocal production.

This exercise is a very challenging variation on exercise 6.



Exercise 7.

Principles of this exercise: In this exercise, an upward leap is followed by a step down. The singer must balance the muscle activity on the bottom note so that an upward leap is possible without resistance from the thyroarytenoid muscles. The downward step must not add too much weight, so that the next upward leap can be successful. Each successive upward leap must also lighten the voice further, so that by the high note of the exercise, the cricothyroid muscles have assumed much of the pitch-changing responsibility. Then the singer must manage the downward leap in the second half of the exercise. The singer may experience a great variability in muscle weight in this exercise.

Suggested phonemes: The [i] and [u] vowels may be useful starting points for this exercise, since they encourage the lighter mechanism to take hold. Women will need to modify these vowels slightly by dropping the jaw.

Pitch level and transposition: This vocalise is difficult enough that the conductor may once again observe signs of tension in the choir if the exercise is taken too high. Starting at D3 for men allows them to work on the challenges of the exercise without crossing the first *passaggio* immediately. It can be useful to transpose the exercise down and up within a very short range to work on the basic technique before introducing the additional complication of the male *passaggio*.

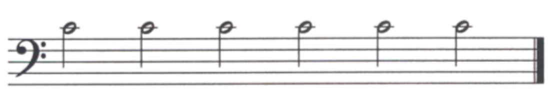
Some women will need to be reminded not to start in their "chest voice," since D4 is below the first *passaggio* for all female voice types. Instead, they should begin the exercise with a sense of lightness, so that the cricothyroid muscles will be engaged even at this low pitch, and so that the crossing of their first *passaggio*, which happens almost immediately, can be as seamless as possible.

Women should be able to continue this exercise up past the second *passaggio* eventually, though the conductor may wish to change to a higher-F1 vowel as they do. Some men may be able to continue ascending along with the women, past the first *passaggio* in the male voice, but others may wish to drop a third or a fifth before continuing. This should be encouraged; if the vocalise is taken so high that muscular tension results, particularly in the form of strong thyroarytenoid contraction, the purpose of the exercise is defeated. As singers gain confidence and coordination at lower pitches, the upper transpositions of the vocalise will become possible.

Notes for men and women: See notes under "Pitch and transposition."

Imagery/language to try: The most challenging part of the exercise is the upward leap. Singers should try to experience less weight (that is, less contraction of the thyroarytenoid muscles) on each successive upward leap, producing a slightly different degree of lift, height, or lightness (or other descriptive word that appeals to the group) for each new high note. The conductor should remind the singers that by making many changes in their vocal production over the course of the vocalise, they create a uniform sound for the listener; conversely, if the singers maintain the same relative level of muscular activity for the entire exercise, a change in timbre from the listener's perspective or even a register break will result. The conductor may model this static approach, so that the singers can witness the undesirable results. Singers may also try the exercise the "wrong" way and observe the additional tension which might result.

A simple exercise can be used to help tenors and basses explore easy production of high notes. A single note near the first *passaggio* is sung two, four, or six times, alternating *falsetto* and a lightweight "full" voice.



Exercise 8.

Principles of this exercise: The purpose of the exercise is to give the singers experience singing an effortless high note, which the *falsetto* provides for many male singers. Achieving the easy onset of the *falsetto* note can give the singers confidence and help them produce a high note in full voice without undue tension. The purpose is not to strengthen the *falsetto* so that it can become the primary mode of phonation in the upper part of the voice. The *falsetto* voice is not strong or colorful enough to be an effective choice in classical solo singing, and its use in the choral setting is limited to two purposes: as a special timbre for dramatic reasons, and as a recourse for male singers who are presently unable to sing in tune or softly enough on a high note in their full voice. There may be many such singers in the bass section and some in the tenor section, depending on how much individual vocal training the members of the choir have had. The goal should be for all singers to learn to access an easy production of high notes without resorting to *falsetto*, in order to provide the greatest possible variety of dynamics and timbres.

Suggested phonemes: The sounds [u], [i], and [n] can be used to assist in creating the vocal tract inertance that encourages light vibrations at the upper edges of the vocal folds, as described for exercise 1.

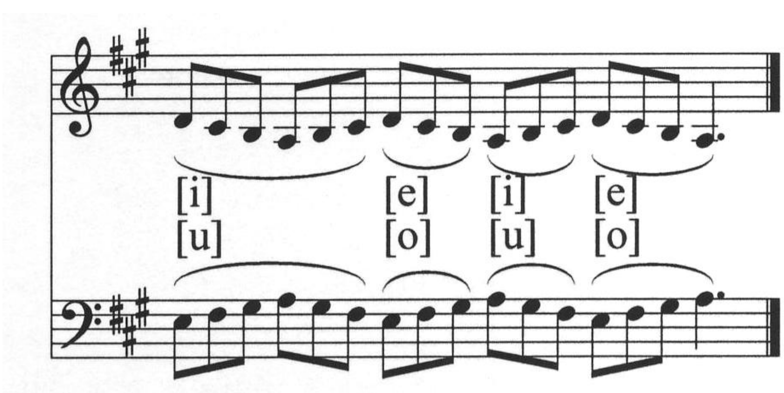
Pitch level: A pitch at or just above the first *passaggio* for basses is a good starting point for this exercise, provided the singers are able to produce a *falsetto* sound at this pitch level. If the singers have difficulty finding a *falsetto* production, descending sighs or sirens from very high in the voice, near C5, can be helpful.

Transposition: The exercise can be transposed upwards as long as the “full voice” sounds can be produced easily. Since the goal of the vocalise is to introduce an easy onset for higher notes, once the initiation of the sound is tense, the exercise is no longer effective. Over time, the singers may be able to proceed higher.

Notes for men and women: Although the term *falsetto* is used by some voice scientists to describe the female "head voice" (or cricothyroid-dominated production), most vocal pedagogues would say that women do not have a *falsetto* as men do, and that the upper register of the female voice should be continuous with middle voice, not a completely separate mode of production.[115] Therefore this exercise is appropriate for male singers only. The conductor may wish to use this exercise only briefly in the warm-up period, so that the women of the ensemble do not sit idle for too long. Alternatively, since this exercise may sound quite strange while the singers are experimenting with it, the conductor may wish to have women hum lightly on the same pitch as the men (in the same octave) so that the men are somewhat "covered up," which may help the men feel less self-conscious.

Vocalises to teach vowel modification for improved resonance

This exercise is designed to teach the lowering of the first formant which is required above the first *passaggio* in the male voice and below the first *passaggio* in the female voice.



Exercise 9.

[115] William Vennard and Minoru Hirano, "The Physiological Basis for Vocal Registers," in Large, 55.

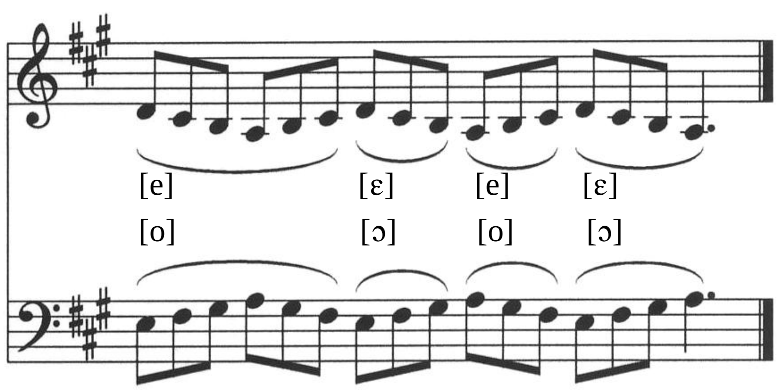
Principles of this exercise: Below their first *passaggio*, male voices typically tune the first formant to an overtone of the fundamental frequency being sung. As they ascend past the first *passaggio*, in order to avoid a brash sound, men must lower the first formant of the vowel so that it is closer to F_0 than to one of the overtones. As women descend low in their voices, they also must lower the first formant of most vowels so that it is closer to the fundamental being sung. That is, women must close the vowel as they go lower, and men must close it as they go higher. In this way they achieve more resonance while maintaining a refined timbre.

The vocalise is designed to use the most closed vowel to "train" the more open vowel. The [i] vowel has a great deal of constriction at the front of the vocal tract because of the high forward tongue; therefore it has a low first formant. Because the tongue is raised less high for a "pure" [e], this vowel has a higher first formant and thus requires modification in the pitch area under consideration.

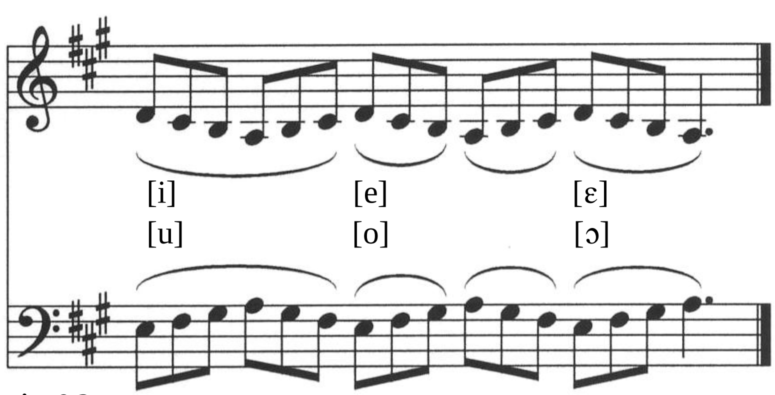
The first six notes of the vocalise use the [i] to establish the tongue position. The second portion begins on the more open vowel, [e], but requires the singer to change to [i] on the lowest pitch, so that the [e] vowel is replaced by a more closed vowel. After the singer has experienced this literal replacement, for the last portion of the vocalise the singer stays on [e] through the final sustained note. The singer should still try to experience a sense of closing which is similar to the sensation of the [i] vowel. This will result in a higher tongue position for the [e] vowel, a vocal tract configuration which is more likely to reinforce the fundamental being sung in this pitch area. Sustaining the final pitch gives the singer time to experience the effects of the more closed [e].

Similarly, [u] has the greatest degree of lip rounding. The vowel [o] has less lip rounding, and therefore a higher first formant. The first formant of the [o] vowel can be lowered by increasing the rounding of the lips. In this vocalise, the [o] should be influenced by the [u] vowel, so that by the final portion of the vocalise, the [o] has a lowered first formant because of increased lip-rounding, while retaining its own distinct quality. (That is, it is more resonant while continuing to sound like an [o], not a [u].)

Suggested phonemes: The suggested vowels above are the easiest to start with, because the closed vowel and its more open partner have fairly similar first formants. More open vowels, such as [ɛ], [ɔ], and [ɑ], will need more modification to lower their comparatively high first formants. Once the singers have mastered the [e] and [o] vowels as above, the vocalise can be adapted to encourage the modification of more open vowels. This is shown in exercises 9.1 and 9.2 below.



Exercise 9.1.



Exercise 9.2.

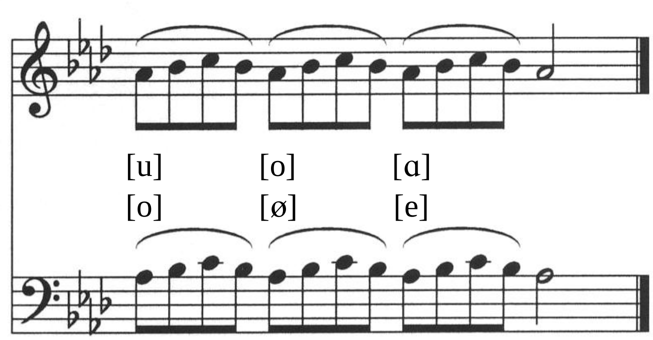
Pitch level and transpositions: This exercise (and its variations) should be used in the portion of the male voice between the first and second *passaggi*. Starting on E3 results in a top note of A3, the first *passaggio* point for a typical choral bass. The exercise can be transposed upward until a top note as high as G4 has been reached (the second *passaggio* for the lyric tenor), though basses, baritones, and lower tenors may wish to drop down a third at some point. The exercise should not be carried up to the point of tension; good habits of coordination of the laryngeal musculature should always be enforced.

For the women's voices to end on A3 as well, their part of this vocalise should begin on D4. This may be too low for some of the higher sopranos in the group, who may wish to start on F#4 instead and sing in parallel thirds with the lower female voices. As soon as they can, these sopranos should join the rest of the ensemble on the lower pitch so that they can reinforce the concept in the lowest part of their voice, where it is most essential.

Imagery/language to try: For singers who experience vibrations in their face and head while singing, it can be helpful to try to create the same vibratory sensations on the more open vowel as on the more closed vowel. Other singers may wish to incorporate physical gestures such as pulling an imaginary ribbon out of the mouth (to keep the attention on the front mouth constriction or lip rounding), making a circle around the lips with a finger while singing the [o] and [ɔ] vowels, or making a tube with the hands and closing it as the pitch descends. Singers may imagine looking through a telescope backwards (this makes the object being viewed look smaller; the singer is trying to make a vowel with a wider opening smaller). Singers who are highly analytical may respond well to a simple request to use more lip rounding in the [o] and [ɔ] in this pitch area, and to raise the tongue a little higher for [e] and [ɛ].

Voice teachers often use the word "focus" or "core" to describe a resonant sound, but these words are not always helpful to a singer who has not experienced a very resonant sound yet. Once the singer has discovered how to produce a resonant vowel, the conductor may say, "That is a focused vowel," or "We could say that vowel has a nice core to it." When those words are defined for the singer by a sensation he or she has already experienced, the conductor can then use the terms as a kind of rehearsal shorthand later.

The next vocalise is designed to help women learn the slight rounding and closing of vowels which is helpful in the approach to their second *passaggio*. Since men also round and close vowels as their second *passaggio* approaches, they may join in an octave lower.



Exercise 10.

Principles of this exercise: At the approach of the second *passaggio*, women should round and close the more open vowels for several reasons: to achieve optimum first formant reinforcement, to lower the second formants to avoid a too-bright sound, and to promote the vocal tract inertance that assists in closing the top edges of the vocal folds, which encourages the engagement of the "light mechanism". An octave lower, men are approaching or crossing their first *passaggio*, where lowering the formants is advantageous for them as well. Like the first vowel modification exercise, this vocalise uses vowels with a great deal of lip-rounding to encourage similar rounding in more open vowels. The mixed vowel [ø], as in the German word "schön", is sometimes described as "[e] tongue with [o] lips," and as such is a logical transition between those two vowels.

Suggested phonemes: The above vowels are excellent places to start with this exercise. As in the first vowel modification exercise, the conductor may add the challenge of more open vowels when the singers have mastered the modifications for [ɑ] and [e].

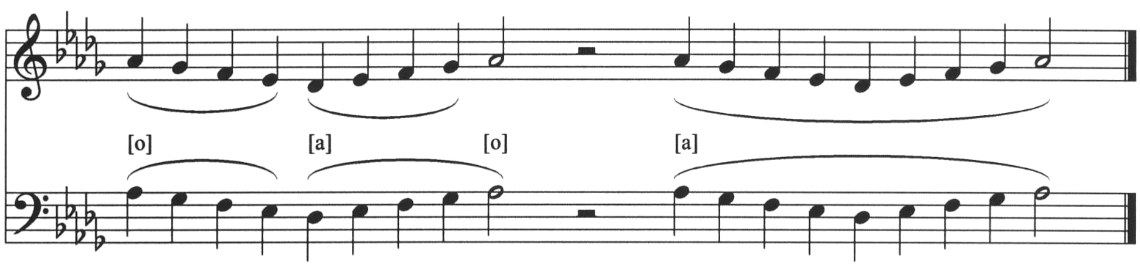
Pitch level and transpositions: The exercise could start at A♭4 for women and A♭3 for men. At this pitch level the vowels would require slight modification. (If basses experience difficulty with the top notes at this pitch level, the exercise can begin at G or F#, which is below their first *passaggio*, and the conductor can remind them to use the muscle-adjustment techniques they have learned from other exercises.)

As the exercise is transposed upward, more modification must be applied. The vocalise can be transposed until the highest note is F5 or F#5 for women, at which point they will probably want to begin to reduce lip rounding but continue dropping the jaw. Tenors should be comfortable continuing to F4 or F#4, but basses and baritones (and low altos) may wish to drop down a third or fourth at some point.

Notes for men and women: Women should be aware that the [u] vowel they will sing in this pitch range will be "taller" (have a more lowered jaw) than the [u] vowel sung by the men. This is because women must raise the first formant of the [u] vowel to bring it above the fundamental frequency they are singing. The goal in using the [u] vowel for this exercise is not to create a tight mouth, but to capitalize on its lip rounding. Women should not try to make a perfect circle of their mouths, but more of an oval.

Imagery/language to try: The images used for the first vowel modification exercise can be useful for this exercise as well, particularly the circling of the lips with the finger while singing. (Women should draw an oval shape, of course.) At the higher pitch level of this exercise, the imaginary ribbon could be pulled up at a diagonal from the mouth rather than straight out, or even from the forehead or top of the head, to encourage a lighter weight along with the focus in the vowel.

Exercise 11 is an adaptation of exercise 3 above.



Exercise 11.

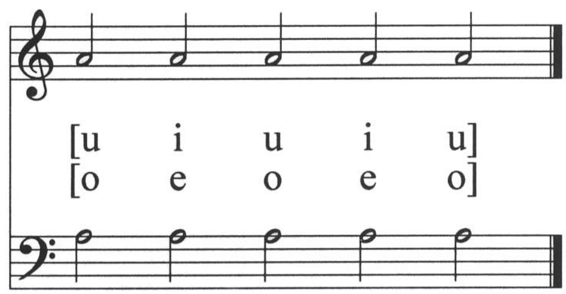
Principles of the exercise: This exercise encourages the rounding of an open vowel as pitch ascends, like exercise 10 above. When the exercise is first introduced, the conductor may wish to omit the second half, so that the singers can first use the influence of the [o] to become proficient at rounding the [a] vowel. Once the desired rounding has been habituated, both parts of the exercise can be performed, or even just the second half. (The first half of the exercise should be reintroduced if the singers need to be reminded of the modification.)

The comments about pitch level, transpositions, and imagery in exercise 10 apply to this exercise as well.

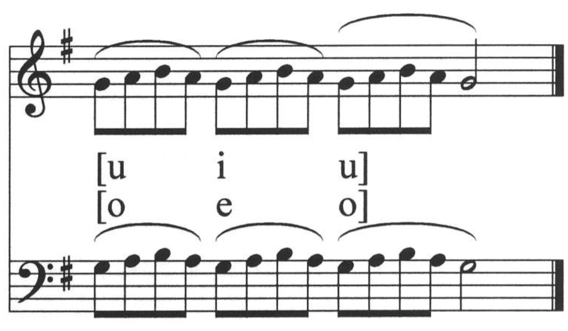
Vocalises to teach vowel modification for resonance balancing

All of the following exercises are designed to balance bright and dark sounds (dominated by higher or lower overtones, respectively, because of their higher or lower second formants). When vowels are of balanced timbre in individual voices, blend within sections and across the entire ensemble is improved.

Exercises 12 and 13 are to be used when the back vowels [u] and [o] are of suitable timbre, but the forward vowels sound too bright.



Exercise 12.



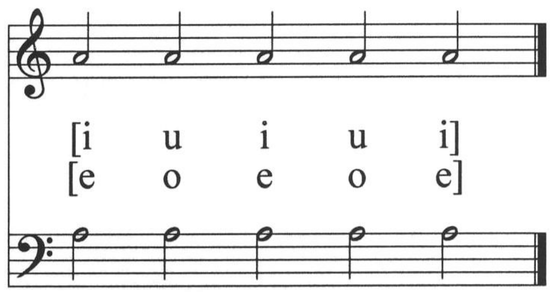
Exercise 13.

Principles of exercises 12 and 13: These two vocalises seek to incorporate the roundness of the [u] and [o] into the bright vowels [i] and [e]. The vowels [u] and [i] have very similar first formants (300 Hz and 270 Hz in male voices, respectively), but their second formants are quite different (870 Hz and 2290 Hz). A similar relationship exists between [o] and [e]. Rounding the lips on [i] and [e] lowers all the formants and reduces the strength of the upper harmonics on that vowel, reducing the brightness of the vowel. In this way the timbre of these vowels more closely matches that of the back vowels with which they are paired in this vocalise.

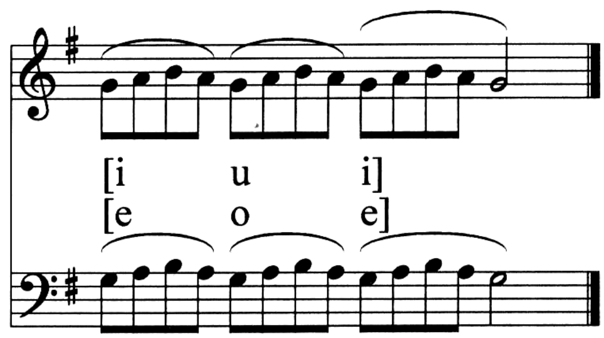
Pitch level, transpositions: These two exercises can be used throughout the vocal range, provided singers are able to modify the back vowels as needed (for example, women will need to drop the jaw as the exercise is transposed higher, and men will need to add more lip-rounding to the [o] above their first *passaggio*).

Imagery/language to try: Singers who are aware of vibrations in their face or head may try to keep the sensations in the same place when they change from the back to the front vowel. Other singers can be encouraged to keep the lip position very similar in changing from the back to the front vowel, avoiding spreading the lips or smiling on the brighter vowel. They will feel the tongue move, but there should be little movement of the lips.

Exercises 14 and 15 are useful when the conductor is satisfied with the sound of the brighter front vowels, but the back vowels sound too dark or “swallowed” by comparison.



Exercise 14.



Exercise 15.

Principles of exercises 14 and 15: The unrounded lips and high, forward tongue constriction of the bright vowels can positively influence the darker vowels, especially if the darker vowels are marked by too much lip constriction or backing of the tongue, which would significantly lower the formants.

Exercises 12 through 15 should make it clear to the conductor that vowel modification for resonance balancing is not a “one-size-fits-all” prescription. Conductors who ask all their choirs to “sing through a fish mouth” (strong lip rounding) or smile when they sing may be exacerbating an unbalanced sound. It is the conductor’s task always to listen to the ensemble first, assess the sound realistically, and then apply the modifications that the group needs most.

Pitch level, transpositions: Like exercises 12 and 13, these vocalises can be performed at any pitch level depending on the needs of the choir. They are particularly useful in the bottom of the voice. As pitch ascends, the [i] and [e] vowels may become overly bright, as their second formants reinforce an upper harmonic too strongly. At that point the conductor may wish to substitute exercises 12 and 13. This helps the choir understand that vowel modification needs may vary over the compass of the entire range.

Imagery/language to try: Singers who are aware of vibrations in their face or head may try to keep the sensations in the same place when they change from the front to the back vowel. Very analytical singers may need to think of not over-rounding the lips or pulling the tongue back too far. Excessive lip rounding and tongue backing may create the impression for the singer of a full, rich sound, but singers should be made to understand that this sound only exists inside their own heads, quite literally. The sound which is radiated to the listener is actually muffled and weaker because the upper harmonics are so attenuated by the vocal tract in this configuration.

The conductor is encouraged to create his or her own vocalises based on the principles set forth in this chapter. Important information to keep in mind (or on one's desk) when doing so includes the following:

- Location of the *passaggi* in all voice types (noting that most choral singers are baritones, lyric tenors, mezzo-sopranos and lyric sopranos, with the occasional lower bass and contralto)
- Vowel formant frequencies for men and women
- Vowel modification needs for men and women at different points in their vocal ranges

By considering each of these factors and their interrelationships, the conductor can create vocalises which will assist the choir in gaining greater ease of vocal production, control of loudness, and evenness of timbre throughout the entire vocal compass: in other words, a “one-register” voice.

VII. The Conductor's Score Preparation

One of the many goals of score study is to help the conductor structure efficient rehearsals. As the conductor studies the printed score, he or she can discover areas of the music which may present particular challenges for the ensemble, and plan rehearsals accordingly. The fourth movement from Johannes Brahms's *Deutsches Requiem*, "Wie lieblich sind deine Wohnungen," will serve as an example of how the conductor can use score study to identify potential register and formant tuning difficulties, so that potential solutions can be in place before the first rehearsal begins.

Challenges of laryngeal adjustment

Musical phrases which cross the *passaggio*, either from below or above, are places where the choir may experience difficulty. One phrase which challenges the sopranos is the very long phrase from measure 142 to measure 153, shown in figure 14.

Figure 14.

This phrase descends from A♭5, above the second *passaggio,* all the way down to D4, below the first *passaggio*. The sopranos must very gradually introduce thyroarytenoid contraction as the pitch descends. If the TA muscle contracts too suddenly, or the cricothyroid muscle releases too soon, intonation problems or changes in volume and timbre can occur. Vocalises which work on muscle coordination in descending passages can be helpful for this challenge. An exercise which would address the specific difficulties of this phrase might begin with an upward leap of a fourth (as if from *sol* to *do*) and then descend a full octave on a major scale. (Making the scale longer than an octave would quickly put it out of range of many singers in the ensemble as the exercise is transposed.) The vocalise could be transposed up to include the highest note of the phrase, and down to incorporate the crossing of the lower *passaggio*.

One challenging section for altos is the section from measures 125 to 134.

Figure 15.

Not only do these two phrases cross the first *passaggio* a number of times (around E4 to G4 for choral altos), they also combine upward and downward leaps in close proximity, in measures 128 to 129 and 132 to 133. Compared to the stepwise passages, the leaps require a larger degree of muscle readjustment, which may be difficult for the singers. Intonation problems and inconsistency of timbre may result.

Exercises 6 and 7 from the previous chapter can help teach the required technique for this passage. If the descending fifths across the bar lines into measures 128 and 129 are particularly troublesome for the altos, the conductor could add exercise 3 or an exercise which uses a *portamento*, or slide, down a fifth. When executing the *portamento*, the singers should be instructed to imagine that all of the nearly infinite number of pitches encompassed by the slide maintain their connection to the top note, or keep some of the light feeling of the upper note. This can help eliminate a sudden change of weight at the bottom of a large leap such as the ones in measures 128 and 129.

A similar leap of a diminished fifth across the first *passaggio* is just one of the challenges in the tenor phrase from measures 115 to 123, shown in figure 16.

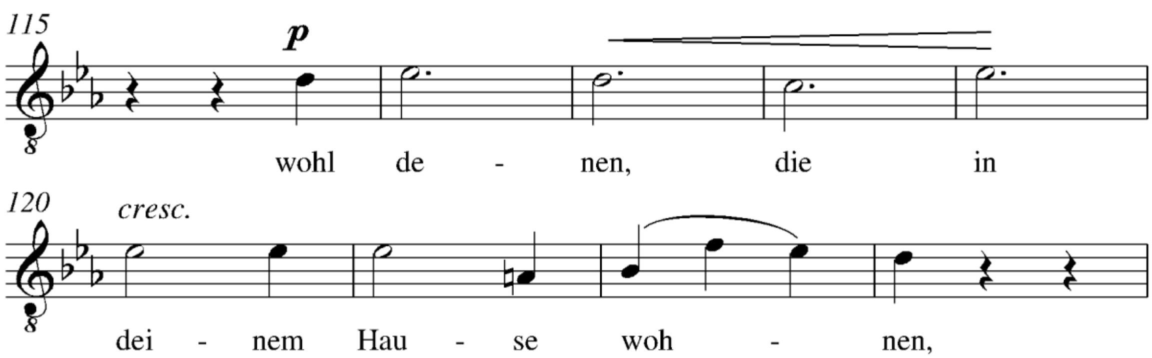


Figure 16.

The leap in measure 121 can be solved in much the same manner as the altos' leap described above. The additional difficulty in this passage is how close it lies to the typical choral tenor's first *passaggio*, around D4. This entire phrase is centered around that pitch: the first four measures contain only the pitches C4, D4, and E♭4, while the latter half of the phrase has an excursion down to A3 and up to F4 before returning to D4. Since the *passaggio* pitch can be sung in either a heavy or light adjustment, the singers must bear in mind that there are higher notes to come which will require the lighter weight. They must sing the first note, then, with less thyroarytenoid contraction so that the upper notes will not sound too light by comparison. The conductor can choose vocalises that address muscle adjustment near the *passaggio*, and can also remind the singers to observe the *piano* dynamic marking, which will encourage a lighter production for the first notes of the phrase.

The basses face challenges of thyroarytenoid and cricothyroid coordination in measures 164 to 173.

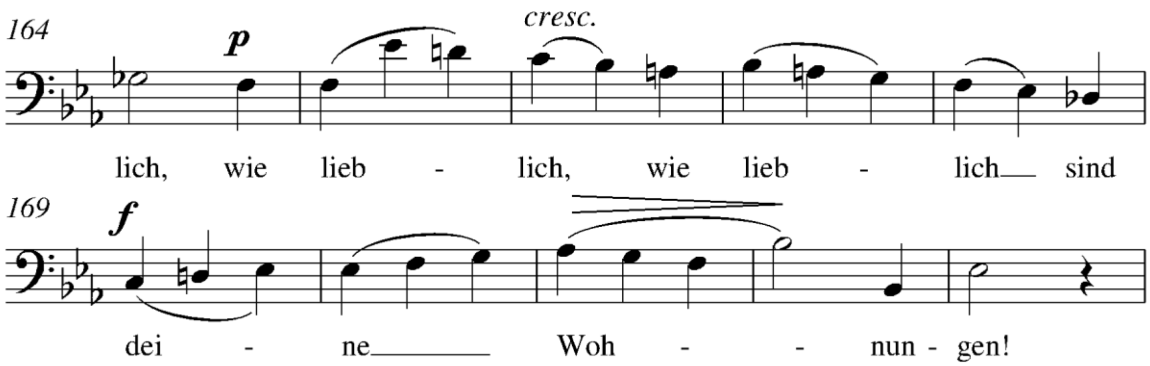


Figure 17.

The wide range of this phrase (an octave plus a fourth) and the high E♭4 (which is very near or above the second *passaggio* for most choral basses) make this phrase very difficult. The *piano* dynamic at the beginning of the phrase will help the basses find a lighter weight for the top note, but some basses may need to switch to falsetto for at least the E♭4. If this is done, they should disguise the return to full voice as much as possible by keeping the full voice very soft at first.

The *crescendo* written on the descending passage from measure 166 to measure 169 may encourage great contraction of the thyroarytenoid muscle. If this occurs, the ascent in measures 169 to 171 will require careful releasing of the TA muscle and introduction of the CT muscle in order to prevent tension and intonation problems. In addition to using vocalises which address this gradual muscle readjustment, the conductor may also have the basses practice the descending phrase with only a small *crescendo* at first, which may reduce the dominance of the thyroarytenoid. The basses may add more sound over the course of several rehearsals as the proper muscle interrelationships become ingrained.

Challenges of vowel modification

The sopranos face many difficult vowel modifications in this movement, because of the great number of [e], [ɛ], and [i] vowels placed on high notes. All of these vowels require increased jaw dropping or lip rounding (or both) as pitch ascends. One example is found in measures 80 to 84, shown in figure 18.

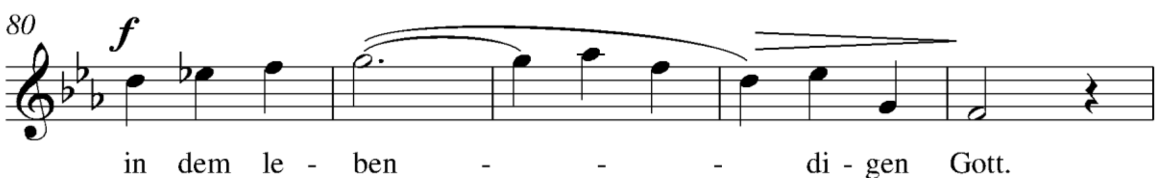


Figure 18.

The first five vowel sounds of this phrase are [ɪ], [e], [e], [ɛ], and [ɪ]. At the beginning of the phrase, the lips may be rounded to lower the second formant, keeping the sound from being over-bright. As the phrase ascends, singers must also lower the jaw to create optimum resonance and ease for the very high pitches. The hardest part of the phrase is yet to come, however, because as the phrase descends from the A♭5, the singers must adjust the vowel modification again, changing from the greatly dropped jaw to the rounded lips that are more advantageous below the pitch F5. For some singers it is helpful to think about "unmodifying" the vowel as pitch descends.

In addition to choosing vocalises which address modification of the forward vowels, the conductor may also wish to have the sopranos sing this phrase without consonants, so they can experience the modified shapes of the vowels without the interruption of closing the mouth to make consonants. When the consonants are added again, they may need to be formed less strongly so that the height of the vowels can be maintained. The conductor should be aware that at this point in the structure of the movement, the drama of a beautifully sung phrase is probably more important than perfect diction from the sopranos.

The primary vowel modification challenge for the altos is the descent into the bottom of the voice, which requires closing of the vowels to lower the formants. One such phrase is found in measures 58 to 62.

Figure 19.

The [ɑ] vowel on E♭4 in measure 58 will need to be closed somewhat, as will the [ɔ] of "Vorhöfen" and the two [ɛ] vowels in "des Herrn." Exercise 9.1 in chapter 6 can be used to teach this technique. (The [o] vowel forms an effective pairing with [ɑ] as well as [ɔ].) If the vowels [o] and [e] are not yet successful at this pitch range, they may need to be "trained" by the [u] and [i] vowels first, as in exercise 9 in chapter 6.

A passage which may present vowel modification challenges to the tenors is measures 142 to 147, which is shown in figure 20.

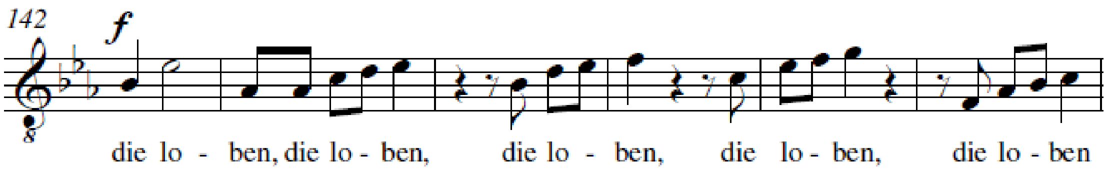


Figure 20.

In this passage, the tenors will enjoy several benefits from vowel modification in the form of lip rounding. First, lowering the formants of both the [o] and [ə] vowels can help prevent a harsh sound in the area above the first passaggio, where most of this passage lies. Modification can also assist in more uniform loudness of the two vowels. The second formant of the vowel [ə] (the second syllable of the word “loben”) is substantially higher than that of the [o] and thus would ordinarily resonate the upper harmonics of the sung tone. Without vowel modification, the unaccented sound [ə] might actually sound louder in comparison with the [o]. Addressing this problem is particularly important in light of the way Brahms has set the text in this section: the unstressed syllable is always in a position where it might be accidentally accented by the singers. The first time it appears, the unaccented second syllable is placed on a downbeat. The other four times, the unaccented syllable is on the highest note in the four-note phrase. Vowel modification thus helps preserve the natural word stresses while maintaining a warm timbre.

To teach the technique on the two vowel sounds in this phrase, the conductor may modify exercises 9 and 10 from chapter 6. Another possibility is to sing both vowels as [o] (that is, sing the non-word “lobon”) to experience the roundness of the [o] on both syllables; then to sing “lobon” again, but elongate the second syllable and slowly migrate toward the [ə] sound, while maintaining some of the quality of the [o]; then to sing the word as written.

One of several vowel modification challenges for the basses can be found in measures 101 to 108, shown in figure 21.

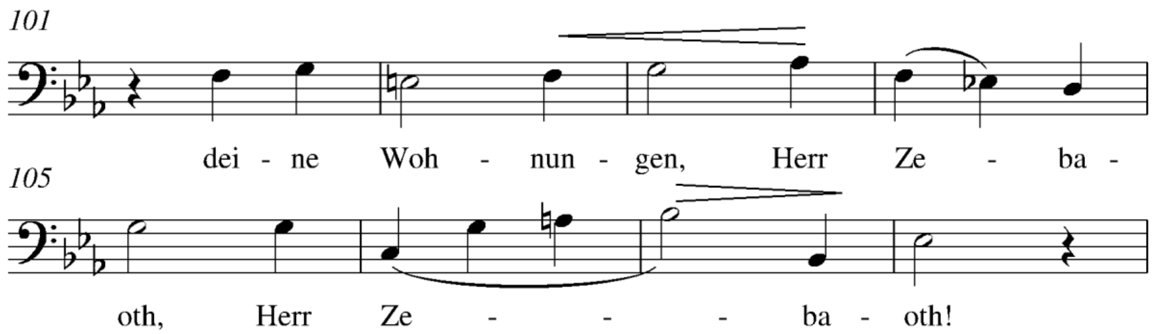


Figure 21.

In this phrase the basses sing “Zebaoth” twice, at different pitch levels, requiring different degrees of modification on the same word. The first time, the melody begins below the first *passaggio* and proceeds downward. No modification is required for this occurrence of the word. The second time the word is sung, the melody ascends almost a full octave, ending above the first *passaggio*. The basses will need to modify the [e] vowel as the pitch ascends. They should round the lips to lower the formants, thus keeping the warm sound of the lower notes in the phrase.

Simultaneous challenges

At times, a musical phrase presents difficulty in both muscle adjustment and vowel modification. One such example is the first eight-measure phrase for sopranos, shown in figure 22.

Figure 22.

This phrase begins on E♭4, in the vicinity of the first *passaggio*, and proceeds all the way up to G5, above the second *passaggio*, before crossing back down to middle voice. With three crossings of the *passaggi*, plus the course of middle-voice pitches in between, the sopranos must be engaged in constant readjustment of the relative activity of the thyroarytenoid and cricothyroid muscles, as well as managing the breath.

The wide range of this phrase indicates that the singers may need to engage in significant vowel modification in addition to muscle adjustment. Many of the vowels in this section are not optimal for the pitches which are written for them. The lowest notes of the phrase are on the vowel [i], so little modification is needed for them. In the middle of the voice, however, around B♭4, the singers may need to close open sounds such as the [aɪ] of "deine" and the schwa, [ə], of both "deine" and "Wohnungen". Lowering the formants of the schwa by lip rounding results in more uniformity of timbre and also reinforces natural word stresses by deemphasizing the unaccented syllables. At the top note of the phrase, G5, the jaw must be dropped considerably for the [e] of "Zebaoth," but at the second "Zebaoth," on D5, the vowel may need more lip rounding than jaw opening.

The conductor may wish to "divide and conquer" the challenges of this phrase by having the sopranos sing it on a single vowel, so that the technique of muscular adjustment can be improved without the added complication of vowel modification. Vocalises which work on regulation of TA and CT muscle activity can teach the basic technique if needed. The conductor may also create vocalises to teach or reinforce modification of the most challenging vowels in the phrase. Ascending vocalises on [e] can prepare the singers for the lowering of the jaw required at G5, while exercises which alternate between the [o] vowel and the [aɪ] diphthong, or between [o] and [ə], can teach the lip rounding required for "deine Wohnungen" at the pitch levels in this phrase.

A challenging combination of crossing the *passaggio*, tuning the formants, and effecting dynamic contrasts can be seen in the alto part from measures 73 to 84, shown in figure 23.

Figure 23.

The phrase begins on D♭4, well below the choral alto's first *passaggio*. The soft dynamic called for on this pitch may help the singer avoid a full "chest" production, but the *crescendo* which follows can encourage dominance of the thyroarytenoid muscle. If that muscle activity is continued at the same rate for the ascending pitches in measures 79 and 80, the choral alto will have significant difficulty at the high note, D5, which is very close to the second *passaggio*. The conductor can assist the altos in learning to surmount this challenge by adding dynamic shading to the usual vocalises used to establish muscle coordination on ascending pitches. The conductor may also ask the altos to save the bulk of the *crescendo* until measure 78 or even later, so that the thyroarytenoid muscle is not engaged so strongly so early.

Vowel modification challenges for the altos include the open sound of [aɪ] on low pitches in the first two words and the [ɔ] vowel of the last word, both of which will need to be closed. The bright vowels on the approach to the second *passaggio* in measure 80 will need to be rounded to balance their timbre and loudness. Exercises 9 and 12 from chapter 6 can be helpful.

Another example of simultaneous challenges is the tenor part from measure 24 to measure 33, shown in figure 24.

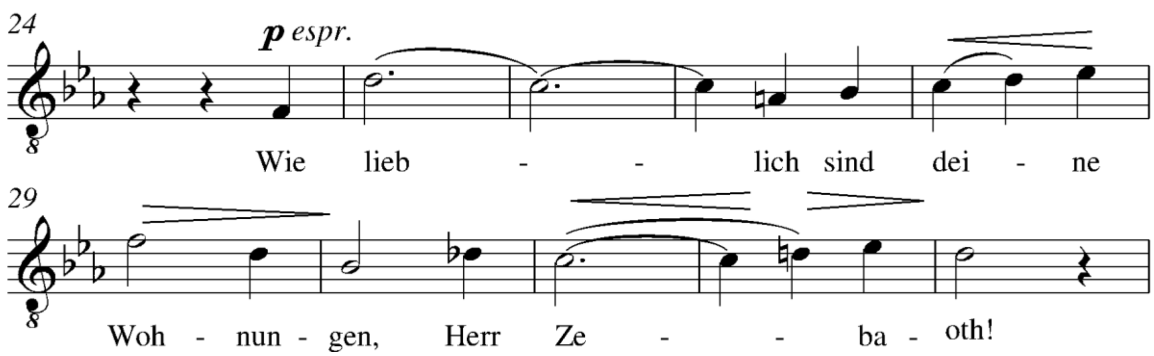


Figure 24.

Like the soprano phrase shown in figure 22, this phrase begins low in the voice and crosses the lyric tenor's first *passaggio*, D4, multiple times. The tenors must be careful to start the phrase with a lighter weight, so that the volume and timbre of the first note will not be dramatically different from the quality of the higher notes in the phrase. The singers must also work to release the TA muscle gradually as the pitch goes up, and engage it again carefully on the descending passages. The dynamic markings make these transitions more difficult: the *crescendo* written on the ascending passages could encourage the singers to carry too much muscle weight upward, and the *decrescendo* in measure 29 could be unsuccessful if the tenors allow the TA muscle to contract too strongly as the pitch descends. Like the altos, the tenors may benefit from introducing dynamic shading to their vocalises.

The tenors must also modify their vowels somewhat for pitches close to and above the first *passaggio*. They must close or round some of the more open vowel sounds of the phrase, such as “deine Wohnungen” and the [e] of “Zebaoth”. (If the conductor decides to use a vocalise to teach the sopranos to drop the jaw on the [e] of that word, as suggested above, he or she should communicate to the singers that the tenors have very different vowel modification needs than the sopranos do at their respective pitch levels. If the tenors drop the jaw on their version of “Zebaoth,” on C4, D4, and E♭4, their sound could become harsh and over-bright.)

The basses have to contend with multiple challenges in measures 49 to 57.

Figure 25.

In this passage the basses must approach or cross the first *passaggio* (roughly B3 for baritones) multiple times, modify the three open vowels in “verlanget” and the [ʊ] of “und” above the passaggio, and manage a very long *crescendo* to *forte*. As in the challenges described above, these difficulties may be addressed using muscle-adjustment and vowel modification vocalises with dynamic shading, and minimizing the *crescendo* until good habits of muscle balancing are established.

The conductor should understand that depending on the skill level of the ensemble and the vocal training of the individual members, some of these potential problem areas may pose no difficulty for the singers at all. The ears, eyes, and sympathetic responses of the conductor will indicate whether additional technical work is needed at any point in the rehearsal of this piece. The goal of this type of score study is to help the conductor analyze in advance what the causes of potential problems might be, so that if the singers do experience difficulty, the conductor has one or more solutions at the ready.

Conclusions

Developing a unified vocal quality throughout the entire range requires management of both physiological and acoustical factors. The ratio of activity of the two pitch-changing muscles, the thyroarytenoid and cricothyroid, requires constant adjustment as fundamental frequency changes. The configuration of the vocal tract changes constantly as well, as different phonemes are formed according to the requirements of the text. The way this resonator filters the vibrations from the voice source strongly influences the timbre and loudness of the sound, and can also enhance or impede vocal fold vibrations. By altering the shape of the vocal tract when needed, the singer can achieve optimal tuning of voice source harmonics and vocal tract resonances, resulting in a more even quality to the voice throughout its full compass.

Singers spend a great deal of time learning and then habituating the coordination of these complex and interrelated factors. The most personalized method of developing these skills is private voice study, but much can be learned in a group setting, such as a choir. In this situation, the choral director becomes the voice teacher of the entire ensemble. Like a solo voice teacher, the conductor uses his or her senses of hearing and sight, as well as sympathetic physical responses, to analyze the general sound that the choir is producing. Potential solutions for any vocal problems grow from proper analysis of the possible causes.

Every ensemble may have slightly different technical deficiencies, and within any ensemble there will always be singers whose skill levels lie outside the average abilities of the group. Even so, the conductor can develop a repertoire of vocalises which will address the main challenges of vocal registration and vowel modification which all singers face. Exercises which train the singers to gradually adjust the relative activity of the thyroarytenoid and cricothyroid muscles help eliminate the abrupt muscle reorganization that causes an audible "break" in the voice. Vocalises which help the singers discover optimal modifications for each vowel at different pitches can aid in uniform dynamic level and timbre, as can exercises which seek to blend bright and dark vowels to a more consistent color. By the use of such vocalises, over time the conductor can help every member of the choir develop a more unified vocal range.

Score study is another valuable tool in the conductor's arsenal, allowing him or her to identify potential problem areas based on knowledge of vocal function. Key data to use in this study are the *passaggio* points in the different voice types, the vowel formant frequencies for men and women, and the vowel modification needs of men and women at different points in their vocal ranges. By considering these physical and acoustical factors while examining the pitches, vowels, and dynamic levels of the repertoire, the conductor can anticipate likely registration and resonance problems. The conductor can then plan methods of addressing the difficulties efficiently if they should arise. The conductor may choose to create vocalises to teach the required techniques before rehearsing the repertoire, or may plan specific "fixes" for a given problem spot, such as a suggested vowel modification or a slight change to a dynamic marking. Preparing these techniques as a part of score study contributes to effective use of rehearsal time.

With a clear understanding of the principles of registration and resonance, and with rehearsal techniques that put this understanding into practice, the conductor is wellequipped to assist the singers in the ensemble to find the ease of vocal production and evenness of timbre which identify the skilled singing voice. The seamless, “one-register” voice prized by Western art music standards is as valuable to the choral singer as to the soloist. A well-functioning voice has great beauty, power, and expressive potential. A choir filled with such voices is a powerful instrument indeed.

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