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Don't Throw the Baby Out with the Bathwater: The Muscular Basis for Register Adjustment

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Registration in singing has long been considered to have its basis in adjustments of the intrinsic laryngeal musculature, but most pedagogues also agree that there is an acoustic or resonance component to the production or perception of vocal registers. Shifts in thinking about register adjustment may have led some pedagogues to concentrate on resonance adjustments to produce a particular quality, sometimes without adequate attention to balanced muscle use. This article provides some context for pedagogic consideration of pitch/register adjustment and examples of what can happen if muscular balance is not optimized in singing training for all genres.

Register adjustment has been a thorny issue among singing teachers for decades, if not centuries. It is likely that most *Journal of Singing* readers have been aware of the shifts in register terminology since the 1950s. The increasing inclusion of the "belt" style of singing into traditional voice programs seems to have created new register terminology: some singers, for example, refer to their "high belt-mix" in the same way that they refer to their "head voice" and "chest voice."

The underlying bases for register adjustment have come under additional scrutiny over the past several decades. While register adjustment was long considered to be based on muscular activity within the larynx, it is now widely accepted that there is also a resonance component to both the production and perception of register changes. Descriptions of this phenomenon seem to have varied over time.

Throughout the clinical experience of this author over the past thirty years—and over forty-five years in the singing studio—there have also been trends and shifts in thinking about registers in general. Some of these trends have helped to promote more balanced and sustainable singing for singers of all genres, while others have had unintended and unfortunate consequences.

This article will describe some singing problems related to registration that are frequently encountered in the course of clinical work and private teaching. Particular attention will be paid to a lack of a balanced use of the laryngeal musculature for pitch adjustment. In many cases, the singers and their teachers (or voice therapists) seem to have concentrated on resonance (acoustic) aspects of the voice to the exclusion of achieving optimal muscle use, often with frustrating results.

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To set the stage for this discussion, the author will provide a brief and simplified review of the history of consideration of registers. This is far from exhaustive, and many key players are left out. The focus is on the shifts in thinking about pitch regulation and register adjustment.

DEFINITION OF REGISTER

Discussion of registers in writings about Western classical singing date back centuries. Chest voice and head voice were described as early as the thirteenth century, and Manuel García (*fils*) also described mix and falsetto in various ways throughout his writings from 1841 to 1894.[1] Garcia provided this oft-quoted definition of register:

> By the word register we mean a series of consecutive and homogeneous tones going from low to high, produced by the development of the same mechanical principle, and whose nature differs essentially from another series of tones, equally consecutive and homogeneous, produced by another mechanical principle.[2]

In 1987, voice scientist Johan Sundberg stated, "unfortunately there is no generally accepted clear definition of the term *register,*" but did suggest that register can be described as "a phonation frequency range in which all tones are perceived as being produced in a similar way and which possess a similar voice timbre."[3] While he quoted Hollien (from the speech-science world) as asserting that "there will be little overlap in fundamental frequency," Sundberg himself stated that "the various registers overlap, so that a person may phonate at a given phonation frequency in different registers."[4] Some variation on these general definitions has continued to be accepted to this day but not without considerable debate regarding the exact nature of registers. Henrich provided a historical review of the study and description of registers, including debate over the inclusion of a resonance or acoustic component in the definition of vocal register. She reported that by the late 1970s, experts across the voice disciplines were divided as to whether registration is solely a laryngeal event.[5] It is beyond the scope of this article to provide a comprehensive review of all the well-known vocal pedagogues and their stance on the matter, although it does seem that many pedagogues defined register as having both laryngeal and vocal tract aspects. For example, in 1998 voice pedagogue Clifton Ware stated that a register must have both a "phonation component" and "a resonation component—consisting of acoustic couplings of both subglottal and supraglottal system to the larynx—that produces the harmonic spectrum, which not only determines which vowel is heard, but also the timbre of the voice."[6] In 2009, voice researcher Bernard Roubeau and colleagues suggested differentiating between "laryngeal vibratory mechanisms" and "registers," as "each one has its own specific definition."[7] It does not appear that this specific differentiation has come into popular usage, but definitions of registers do still seem to vary in regard to the inclusion of the acoustic component.

THE MUSCULAR BASIS FOR PITCH AND REGISTER

Perhaps because vocal registers are related to pitch production, and many early scientific studies focused on the nature of pitch control, registration was described according to muscular activity that led to modes of vibration of the vocal folds. This was congruent with García's assertion that a register is determined by a mechanical principle.

Starting in the 1950s and continuing well into the 1990s, EMG (electromyographic) studies showed activity of the thyroarytenoid muscle (TA) and cricothyroid muscle (CT) for pitch adjustments. Though it is beyond the scope of the present article to describe all the research accomplished over several decades, it can be safely said that in general, lowering of pitch is mostly accomplished by the TA and raising of pitch, in contrast, by the CT. Therefore the TA has been associated with "chest voice" and the CT with "head voice." Although different studies showed variability in specific results, and muscular activity is far more complex than these two simple generalizations, it has been possible for pedagogues to base their understanding of registers on these basic laryngeal mechanics.

One of the important culminations of all the EMG research was the "muscle activation plot" (MAP) produced by voice scientist Ingo Titze and others at the National Center for Voice and Speech. Variations of it were published in Titze's book, *Principles of Voice Production* as well as in multiple journal articles.[8] Figure

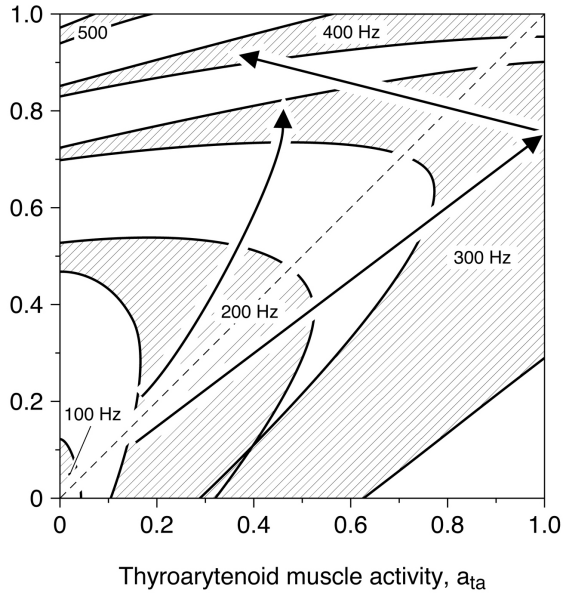

Figure 1. Muscle Activation Plot showing degree of TA and CT activity at various pitches. Constant frequency bands are shown, and the arrows depict ways of increasing pitch. The lower arrow, with greater degree of TA contraction, results in an abrupt register shift.

1 shows one of the variations of the MAP; it is likely that many readers of this journal recognize this multifaceted representation of muscle activity.[9] Basically, all the variations of the MAP show that there are many combinations of subglottic pressure and TA/CT contraction that can result in any given fundamental frequency (f_0) of the vibrating vocal folds. Further scrutiny reveals that some combinations are more efficient than others. The MAP in figure 1 shows gradual and sudden registration events, showing that certain configurations of TA and CT activity will be perceived as a given register.

This more complex description of muscular activity may have helped further the understanding of the laryngeal mechanics at work in register adjustment. It seems to this author that the muscular basis for pitch and register control was more prevalent in pedagogy in the latter part of the twentieth and early part of the twenty-first centuries. As recently as 2022, voice pedagogue Kenneth Bozeman has suggested that this is still the case when he wrote that "there has been a general preoccupation with laryngeal biomechanics in both theory and practice as the dominant mechanism for timbral change and register demarcation."[10]

REGISTER TERMINOLOGY

Register terminology has been a hotly debated issue for decades. While many of us grew up with the traditional chest/head/mixed/falsetto terminology, in the 1970s, voice scientist Harry Hollien and others in the speech and voice science world used the terms "modal" and "loft" (and also included the term "pulse" as a non-singing register). These terms are still in common use among speech-language pathologists. Modal register refers to the register that is typically used in speech (chest), while loft is generally equivalent to head voice or falsetto.[11]

In the early 2000s, the "TA-dominant" and "CT-dominant" terminology became popular replacements for "chest" and "head."[12] At the same time, there was growing use of the term "mode" or "mechanism."[13] In this terminology, the modes refer to modes of vibration of the vocal folds (thick versus thin, with different contact quotient), and the system also includes mode 0 (pulse/fry) and mode 3 (whistle). Although this system of description is based on research using EMG, EGG (electroglottography), and other measurement tools which lends credibility to the use of these terms in scientific circles, voice pedagogue Matthew Hoch and voice scientist Mary Sandage noted that the terms have not been accepted into general use by singing teachers in their studios.[14] For many, it seems, these descriptions do not have the obvious kinesthetic reference that make "chest" and "head" a natural choice for singers.

For this article, I will use the terms "chest voice" and "head voice," as opposed to TA-dominant or mode 1, and CT-dominant or mode 2.[15] These are recognizable terms, and they do describe recognizable sensations, although it goes without saying that kinesthetic sensations of register, indeed all aspects of singing, are highly individual and far from universal. Bozeman also suggests that the terms "chest voice" and "head voice" lend themselves better to "indicate the degrees of a quality."[16] In other words, it's easier to say "chestier and headier" than "One-ier and Two-ier" or "TA-ier and CT-ier."

How, then, should one refer to "belt?" Returning to Sundberg's description of a register—"a phonation frequency range in which all tones are perceived as being produced in a similar way and which possess a similar voice timbre"—it does seem that belt could fit the defi-

nition of a register. However, currently, there seems to be a wide variety of opinions as to what constitutes the manner of production and the timbre of belt. One need only talk to a number of different singers or teachers of singing to realize that descriptions of belt vary as much as any other aspect of singing. In his 2014 definition, Hoch stated the term belt "can refer to a style, a register, and a technique."[17]

On the basis of their 2012 research, speech-language pathologist Kochis-Jennings and colleagues described "chestmix" and "headmix" as distinct registers, not only with different laryngeal configurations and different acoustic characteristics, but also used by singers with different histories of training.[18] On the other hand, we can argue that there are many different timbres and laryngeal configurations for any given singer singing in head or chest registers, whether in Western classical or any other genre. Further, there may be considerable disagreement about whether any production is perceptually in one register or the other. Luckily, there is no need to make a finite decision about this matter in this article. Perhaps in another twenty years there will be a different, or more complete lexicon regarding registration. For now, it seems fair to consider the multifactorial phenomenon of belt as a register, just as we consider the multifactorial phenomena of chest and head to be registers. The more important consideration, and the central argument in this article, is that there is a muscular underpinning that is crucial to successful and sustainable production of all registers.

THE ACOUSTIC BASIS FOR REGISTERS

Register terminology has continued to evolve in response to advances in the understanding of the underlying laryngeal mechanism. Advances in the use of spectrography coupled with EGG made the resulting acoustic manifestations of register change more apparent. The late Donald Miller pioneered the application of these advances to singing voice pedagogy through his development of the computer software voice analyzer "VoceVista."[19] Miller showed how singers used acoustic strategies to accomplish their singing goals, mostly with classical singers. Bozeman also wrote extensively on using acoustic events for pedagogic purposes, especially when training young tenors, baritone and basses, showing formant-tracking (or formant-tuning) strategies that caused the voice to "turn over."[20] These strategies could ostensibly be used without any changes to the muscular adjustments within the larynx. While there is research evidence both for and against this assertion, by 2010 there was increasingly better recognition of the acoustic events that result in the perception of register change, or especially the difference in registration for different genres of singing (especially belt versus classical in treble voices).[21] Research by Titze and associates showed "mouth tracings" for classical and belt singers and introduced the use of the terms "megaphone" and "inverted megaphone" to describe how singers shaped their mouths in these styles.[22] This research showed that the resulting adjustments within the vocal tract (and therefore *resonance* adjustments) resulted in distinctly different timbres. To the extent that we accept the belt quality as a distinct register, this also supported the notion of a resonance, or acoustic, basis for register adjustment.

While the source–tract interaction was well-known in the voice science world long before 2011, it may have taken the right combination of time, technology, and literature aimed at teachers of singing for the concepts to become more accepted in studios.[23] It is beyond the scope of this article to provide a more thorough review of the research and resulting approach to voice pedagogy. The crucial concept is that adjusting the vocal tract can shift the location of its formants to differentially reinforce harmonics of the fundamental frequency to provide the desired timbre, or registration. Moreover, characteristics of the vocal tract can exert an influence on the vibration of the vocal folds, affecting voice output. This is referred to as "source–tract interaction."

THE DILEMMA: TEAM ACOUSTICS VERSUS TEAM MUSCLES

Voice scientists and pedagogues alike currently accept the muscular basis for pitch adjustment, and the notion of register as a psychoacoustic phenomenon that must be based on physiological function (muscle configuration for pitch). That is, for any pitch, there is an event that occurs both at the level of the glottis and within the vocal tract (a source-tract interaction), that results in the perception of a given register.

In 2011, Ingo Titze was in Minneapolis for a two-day seminar, and I remember him remarking that he was starting to think that registration is more of a resonance phenomenon than a muscular one.[24] Even then I remember thinking "I understand the importance of the resonance adjustments, but if you've been in the studio with high school girls who just want to work on their belt voice, you know you need to work on the muscular underpinnings." This is where the baby/bathwater caution comes in.

It is likely that most voice pedagogues and voice therapists agree that muscles need to shift their relative dominance for pitch adjustment as well as coordinate with resonance features of the vocal tract for register adjustment. However, based on the reports of singers who present to the clinic, it may be easier to work on *adjusting* the vocal tract than considering the laryngeal contributions to the vocal production. Singing teachers may concentrate on all sorts of alterations of the jaw, mouth, lips, or vowel shape, in order to optimize voice quality on any pitch. Moreover, when working with a patient with a voice disorder, speech-language pathologists may rely almost exclusively on "resonant voice therapy," using exercises to concentrate on the forward resonance sensation of vocal production. (This may be especially true for SLPs who do not have training as singers.) In the opinion of this author, if it is all about "team acoustics" and no longer about "team muscles," singers may end up with problems, and then have difficulty solving those problems.

In fact, in my decades of experience, there does seem to have been a shift in pedagogic tendencies. With the recognition of the resonance features of register production, particularly in belt voice, I have seen increasing numbers of young singers, usually women, in collegiate programs working on their belt voice; they accept it as a "TA-dominant" production and then they concentrate on the forward resonance (acoustic) aspect of it. They are concentrating on that "megaphone" production and ignoring any work on muscular underpinnings. Probably many do this successfully. The ones who get into vocal trouble may need to be seen clinically, or at least for a change in their voice teacher.

Further, this author has decades of experience working with singers who were trained in an earlier era of consideration of registers, when classical singers were to "stay in head voice" and maintain correct "placement" or "focus." Even though there was very little mention of the acoustics of the singing voice in that earlier pedagogy, there was also often little awareness of real anatomical (muscular) aspects of phonation. Singers who were trained in an era when chest voice was considered dangerous can also get into vocal trouble, for some of the same basic reasons as the current belt singers do—that is, an imbalance in muscle activity that eventually precludes balanced pitch or register adjustments.

THREE DIFFERENT MANIFESTATIONS OF MUSCULAR IMBALANCE

Below are descriptions and audio/video examples of three different voice problems that this author has seen commonly in the clinic, that seem to be the results of the singers failing to establish or maintain optimal laryngeal muscular balance for pitch regulation.[25] Based on discussions during the course of therapy with these singers, it seems that the pedagogic approach was not only resonance-centric, but also stressed the use of "breath support" past the point where it was helpful.[26]

Manifestation 1

This occurs especially in middle-aged or older women who were classically trained in an era and environment in which chest voice was considered improper or even dangerous, and they were taught to carry their head voice down as far as possible. Now those lower pitches (generally E_4 and below) are very troubled. If they do not shift into chest voice (a TA dominant production), when singing lower pitches, they do not get adequate glottic closure or entrainment of the vocal folds, so their lower pitches are weak, unstable, or diplophonic.[27] It is important to note that these singers do not have vocal fold "bowing," and their speaking voices may even be "chesty." But their singing is not chesty enough. Singing lessons or speech therapy may have focused on more "support" (because they were not achieving adequate glottic closure), or more forward resonance, but the problem persists because nothing is being done to activate the TA. And these singers may be resistant to "chest voice" just as many belt singers are resistant to "head voice." This phenomenon can also occur in an active young soprano who concentrates almost exclusively on singing in a tessitura located within the "stratosphere"

to the extent that middle and lower pitches become weak, even when they are singing in head voice. Listen to Audio Sample 1 and notice the irregularity of vibration as she attempts lower pitches in head voice. (**Audio Sample 1** is an example of Manifestation #1 in a singer in her sixties.)

Manifestation 2

The singer in this manifestation is also usually a classically trained singer, who has worked on the covered "inverted megaphone" quality with lots of breath support. They may have "heady" quality, but may actually have inadequate recruitment of the CT. They may end up with problems producing upper pitches, pitch inaccuracy throughout the vocal range, fatigue, and inability to sustain stable phonation. They sound good, until it no longer works. (**Audio Sample 2** is an example of Manifestation #2 in a traditional college-aged singer.)

In Audio Samples 3 and 4, note the loss of entrainment at onset in the descending glides, as well as on the fifths. Also note the effort in phonation, such that he is often under pitch. (**Audio Sample 3** and (**Audio Sample 4** are examples of Manifestation #2 in a singer in his fifties.)

In Video Sample 1, notice that she does not match pitch initially, and loses pitch as she sustains phonation. Also notice the increasing anterior-posterior constriction of the supraglottic larynx as she ascends in pitch, likely thwarting the elongation of the vocal folds (**Video Sample 1** is an example of a singer in her fifties.).

For manifestation numbers 1 and 2, it is possible that there is inadequate recruitment of both the TA and CT. The muscles may be "stuck" in a configuration that works for a small part of the pitch range, as the singers try to maintain consistency of quality throughout the pitch range, throughout the registers, and across all vowels. There is inadequate flexibility for the muscles to change their relative dominance throughout the pitch range. Again, concentration on breath support may lead to a very weighty, or tense, production. Again, it can sound good at first, until it no longer works.

Manifestation 3

This manifestation describes another common one in which singers working on a bright, brassy, twangy "high belt mix" seem to carry too much TA dominance into their upper pitches. Not only do they believe that their belt voice should be TA-dominant, if not even exclusively chest voice, but they are also afraid of sounding too heady, or too "legit." It seems they may also think that using any head voice, or CT involvement, is "cheating," or "the easy way out." Their timbre sounds bright and narrow (constricted) and not excessively chesty.[28] But eventually the mechanism cannot work because of apparent inadequate contraction of the CT. Laryngeal examinations will often show a phenomenon similar to video sample 1, in which there is inadequate elongation of the vocal folds with pitch increase, and possibly anterior–posterior constriction that would inhibit elongation. If there is inadequate elongation of the vocal folds for a higher pitch (i.e., an inadequate shift from TA to CT recruitment), the vocal folds need to vibrate at higher frequency due to increased air pressure, rather than increased longitudinal tension. There is lack of flexibility in the transitions between TA to CT dominance. These singers end up with vocal fatigue, pitch problems, and difficulty with transitions throughout the pitch range. Their belt quality sounds good until it stops working for them.

An important caveat is necessary here: laryngeal EMG has not been performed on any of the singers in these samples. In some cases, a laryngeal exam shows poor elongation of the vocal folds, suggesting lack of contraction of the CT. In other cases, a glottic gap during lower pitch phonation suggests lack of adequate medial compression from the TA; or supraglottic constriction in an anterior–posterior dimension may lead to an apparent thwarting of CT contraction. It is also possible to palpate the larynx and note whether there is closure of the cricothyroid space during an attempt at pitch increase. Still, these muscular behaviors have not been proven (and perhaps cannot be). Rather, they can be inferred by the seasoned clinician, who has seen many hundreds of normal and disordered laryngeal examinations, and has palpated the laryngeal areas of hundreds of patients. Finally, and most important, these singers have improved after practicing exercises that are designed to improve recruitment of either the CT or the TA, or better flexibility in alternating the degree of contraction between the two muscles. This seems to suggest that the assumption of inadequate recruitment was correct.

The issue with all of these manifestations of muscle-based voice problems may not be as much with the background or etiology of the problems, as with the approach to solving the problem. Regardless of how the singer got to this place, once they can no longer produce their voice successfully using their current technique, all the resonance- or support-based exercises in the world will not help if muscular balance and flexibility are not restored.

SOLUTIONS

Experimenting with optimal vocal tract configuration and vowel shape has been at the heart of what singing teachers do for centuries, whether or not we knew we were "formant tuning." However, in this author's experience, most pedagogues who have tried to convince singing teachers to understand the actual science of "formant tuning" will also say that correct muscular balance must be achieved in order for acoustic adjustments to be successful.

The solutions for all the above manifestations seem straightforward: facilitate recruitment of the muscle that is currently inadequately recruited. In the case of manifestation 2, it will be important to facilitate both CT and TA contraction, and work on flexibility of the intrinsic laryngeal musculature. It turns out that this is important for all three manifestations. Singers must be able to recruit their CT and TA at will, and learn the subtle (or not-so-subtle) trade-offs between the two in order to get exactly the balance of muscular activity they want for any given pitch.[29] We know that certain kinds of singing will favor dominance of one muscle or the other. This does not mean voice training should exclude, or nearly exclude, one muscle. Rather, training needs to ensure that both muscles can be active. Remember, the singers in manifestations 1 and 2 had advanced training in the use of head voice, but there was not enough attention to the increased activity of the CT as pitch ascended. This requires more careful attention to technical work that allows the teacher and singer to both hear and feel the subtle differences. The singers in those audio and video samples (and countless others who have been seen in the clinic by this author) benefited from careful attention to both muscles, and how to shift their relative dominance easily.

None of this is to say that the acoustics of the vocal tract are not extremely important considerations in training for optimal voice production in any genre, including speech. This author has repeatedly told singers (and teachers) that "you can't fight physics, so you may as well work with it instead of against it." Voice scientist Christian Herbst articulates this sentiment more eloquently:

> However, the described physiologic and biomechanical underpinnings of singing voice production constitute an unavoidable physical reality, regardless of singing style and aesthetic context. For this reason, it is certainly beneficial for pedagogues to understand these concepts. The respective knowledge may be particularly useful when facing a singer's fundamental technical difficulties, helping to diagnose the issue at hand, and deriving adequate exercises and instructions (rather than relying on imitation learning and uninformed trial and error strategies).[30]

TEAM INTERACTION, HOLISTIC, AND SCIENCE-INFORMED

On further consideration, it seems possible that the problem of muscular imbalance has not actually been due to a shift in consideration of registers from a muscular to an acoustic phenomenon. This is evidenced by the fact that some of the registration problems started with "old school" teaching that relied on, but did not recognize, the acoustic basis for register adjustment. In fact, much of the old school teaching was based on the premise that the more you knew about the mechanics of singing, the more mechanistically (and less artistically) you would sing. (This myth has been soundly dispelled, but the effects of it may still remain.) Rather, some pedagogic approaches of both yesteryear and today may have relied on an overly simplified approach to the concept of muscular adjustment. Just as "old school" teachers were wrong about head voice being the only safe way to sing, "new school" teachers and their students may be wrong in believing that recruitment of the CT is "cheating" and will ruin their belt quality. It's important to assert to students and teachers alike that chest voice does not necessarily mean belting; conversely, head voice does not need to sound like opera.

Perhaps we do not need to think about "registers" per se. This author believes it is time we think about the complex nature of the laryngeal control of pitch—as

well as the adaptations at the supraglottic level for each particular timbre—and realize that we need to train an entire interactive (source–tract) mechanism. This phenomenon cannot be simplified, and it is dangerous to "dumb it down."

This leads to a number of pedagogic considerations. First, and most obviously, it is important to keep in mind the muscular basis for pitch regulation, and to ensure that the intrinsic laryngeal muscles are being trained in a balanced and comprehensive manner. This means exploring the entire pitch range and associated registers, knowing that this can be done safely and effectively. Especially with young singers, teachers should spend time with students ensuring that they can sing high pitches softly and easily, indicating that the CT is able to function without excessive antagonistic resistance from the TA. It is also important that singers with treble voices not spend all their time trying to sing higher and higher. A well-balanced speaking voice and singing in chest voice is healthy for the highest coloratura soprano. Olympic athletes cross-train; vocal athletes can also cross-train without harm.

Second, it behooves teachers to spend time in singing lessons listening to the voice without the confounding effects of the resonance system. It is too easy and tempting to listen to the final product, the particular vowel and timbre that is produced, and if it needs improving, to try to change it by readjusting the resonance system. I have students and patients spend time vocalizing on a soft and easily flowing "ng" (/ŋ/); through this exercise we can hear subtle changes that (ostensibly) are occurring at the level of the glottis, as most of the resonance system is unavailable for adjustments. (You can flare your nostrils or move your jaw and tongue all you want—it won't affect the quality.)[31] Just as this author has suggested—along with many esteemed pedagogic colleagues—that breath support is not the great panacea for all vocal problems, it should also be evident that exclusively concentrating on forward focus, straw phonation exercises, or other resonant voice exercises are not the great panacea for all technical inadequacies.[32] A young woman struggling with her belt voice may not just need "more megaphone," and she should be guided away from the myth that training her CT will ruin her belt.

This brings us to the third pedagogic consideration, alluded to earlier. Not only do singing teachers need to have an appreciation of the concept of source–tract interaction, they also need to truly know how it works in order to help their students achieve their best, most efficient, and most sustainable vocal production. It is not enough to try various alterations of the final product until it sounds acceptable. All components of the vocal mechanism need to be trained carefully and in isolation (to the extent possible). The training should start with the earliest lessons, and continue well into the professional career. Again, Herbst says it more eloquently:

> It should be evident that a voice pedagogue always should consider the final "product" of teaching, that is, the sound of the singer's voice, and how it is perceived within the chosen aesthetic context. In classical singing, for instance, abrupt timbral and pitch changes expose inexpertly executed register transitions (see remarks about blending the registers in Part 2 of this article), while such phenomena might actually be crucial features in other singing styles, such as CCM (contemporary commercial music) or some forms of world music. For these reasons, a teacher's assessment of the singing voice should always have a perceptual component. However, a purely perceptual approach in voice pedagogy—neglecting the physiology and physics of voice production—does have a clear limitation: It treats the voice as a "black box," targeting only the system's output and disregarding its inner workings. Such a *modus operandi* reduces the pedagogue's available didactic strategies to only imitation learning through trial and error, likely introducing a certain degree of inefficiency when student and teacher are not of the same voice type or *Fach*, or in the presence of a fundamental functional voice production issue on the part of the student. In particular, if the physiological reasons and principles of physics (i.e., the inner workings of the "black box") for any (un)wanted vocal phenomenon are unknown, it may be difficult to find the most appropriate teaching strategies.[33]

The clinical experience of this author suggests that many patients have developed significant vocal problems because it appeared that their training did not include a comprehensive approach to using laryngeal musculature in a balanced manner. Often, too much emphasis was put on resonance characteristics of the voice, that is, the acoustics of the vocal tract. But this also suggests that the pedagogic approach did not use the available knowledge of how the interactive system works, to the great detriment of the student. This only strengthens the

call to use a "science-informed" pedagogic approach.[34] This will not in any way interfere with artistry, but it may save students from a great deal of grief.

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20. Kenneth W. Bozeman, "The Role of the First Formant in Training the Male Singing Voice," *Journal of Singing* 66, no. 3 (January/February 2010): 291–97; Bozeman, *Practical Vocal Acoustics*: 77–78. The bibliographies of these publications point to additional resources on this topic.
21. Ingo R. Titze, "An Appreciation of the Bozeman and Miller Descriptions of Formant-Harmonic Relations in Singing," *Journal of Singing* 68, no. 5 (May/June 2012): 543–44; Christian T. Herbst, "Registers—The Snake Pit of Voice Pedagogy, Part 1," 175; Christian T. Herbst, "Registers—The Snake Pit of Voice Pedagogy, Part 2: Mixed Voice, Vocal Tract Influences, Individual Teaching Systems," *Journal of Singing* 77, no. 3 (January/February 2021): 345–58.
22. Titze, Albert S. Worley, and Brad H. Story, "Source–Vocal Tract Interaction in Female Operatic Singing and Theater Belting," *Journal of Singing* 67, no. 5 (May/June 2011): 561–72.
23. Herbst, "Registers—The Snake Pit of Voice Pedagogy, Part 2."
24. Permission to report this recollection provided in personal communication with Ingo Titze on September 11, 2023.
25. The singers who provided these audio and video samples gave their express consent for their use in this article, all stating they hoped that making their previous voice problems available for listening might help others.
26. Deirdre Michael, "Dispelling Vocal Myths, Part 1: 'Sing from Your Diaphragm!," *Journal of Singing* 66, no. 5 (May/June 2010) 547–51.
27. Entrainment refers to the process by which the vocal folds are drawn into self-sustained oscillation, as they become pushed apart and then pulled back together in the airstream; diplophonia refers to the perception of two pitches occurring at once. This is due to lack of entrainment of the vocal folds resulting in asymmetric or irregular vibration of the vocal folds, such that there are two different fundamental frequencies.
28. "Narrow" resonance should not be confused with nasality. Often that "twangy" quality is considered to be nasal, when actually there is no nasal resonance. It is excessively forward sounding, which leads to the use of the term "nasal" in popular parlance. This quality can be described as "narrow" because of the pharyngeal constriction that leads to that

particular timbre. It is helpful to teach singers the difference between nasal resonance and sensation of vibrations around the nasal (cheekbone) area.

29. Bozeman, *Practical Vocal Acoustics*, 93; Herbst, "Registers—The Snake Pit of Voice Pedagogy, Part 1," 183–84. It is likely that one can look in almost any book on vocal pedagogy and find an assertion that the muscles for pitch regulation must be trained to coordinate with one another in order to find an optimal balance for each note, especially for the Western classical aesthetic of a seamless transition between the registers. Further, there is ample research showing that singers who are accomplished in producing specific kinds of voice qualities are proficient in achieving their desired combination of CT and TA activity. A complete review of this literature is beyond the scope of this article.
30. Herbst, "Registers—The Snake Pit of Voice Pedagogy, Part 2," 354.
31. To be clear, the sound emanating from the nasal port during the nasal continuant is not only the source; the effects of the filter are included in the radiated spectrum, which has its distinct spectral characteristics. The point is that when there is minimal adjustment to the vocal tract that can be made, and the volume is quite low, the singer and teacher can have better awareness of changes that are happening at the level of the glottis. Improved learning is possible. In the author's clinical and studio practice with singers who are really struggling, they are urged to use the "ng" /ŋ/ so as to avoid trying to make the voice sound acceptable. I tell them, "You don't get to sing a vowel for a month." This allows the muscles to be trained in isolation, to the extent that is possible.
32. Michael, "Dispelling Vocal Myths, Part 1," 550.
33. Herbst, "Registers—The Snake Pit of Voice Pedagogy, Part 1," 179.
34. Lynn Helding, Chapter 15 "Science-Informed Vocal Pedagogy: Motor Learning, Deliberate Practice and the Challenge of Cognitive Dissonance," in *The Routledge Companion to Interdisciplinary Studies in Singing, Volume II: Education*, ed. Helda R. Gudmundsdottir, Carol Beynon, Karen Ludke, and Annabel J. Cohen (Philadelphia: Routledge, 2020), 182–93.

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