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An Examination of the Mind-Body Coordination of Vocal Technique

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Abstract —

This paper seeks to review the principles of vocal technique as seen from both an artistic and scientific standpoint and ultimately connect these two seemingly incompatible entities. This paper also seeks to review the application of physics to singing; specifically, enhanced coordination between the neural center of the body – the brain – in distinct cortical areas with extremely complex musculature and associated vocal tissues necessary for the production of musical notes. Biophysical modeling can be used to study these intricate processes vis-à-vis the relationship between certain variables such as tract air pressures and the gradients required for song. Such modeling can have clinical and other application in qualifying nature and effect of disease. However, basic understanding of the biophysics of vocalization as opposed to detailed modeling can be sufficient both in the clinical setting and in the musical setting where it is important to better one's vocal technique to maximize song quality. Thus, biophysics has a multifaceted application to singing.

Furthermore, the implication that vocal technique can be thought of not only in musical terms but also scientific terms reveals the importance of biological and neurological processes in the music making process and seeks to debunk the myth that these two thought processes are wholly unrelated. However, through this examination of vocal technique the author seeks to demonstrate the intricate correlation between science and art, specifically the art of singing, and the necessary balance needed to exercise what is known as "good" vocal technique. The author, to further this investigation, seeks to apply her findings in this process to her own singing and exercise of vocal technique to determine its applicability, specifically in a classical music style setting.

I. INTRODUCTION

The art of singing is a complex process that requires the coordination and cooperation of multiple parts of the brain and body. The production of a pleasant tone requires the consideration of the larynx as a sound source and resonators and articulators for the projection and phonation of sound and language. Singing can be viewed as an extension of speech where the sounds produced are dictated by the pitches notated in a musical score which can move up or down and be sustained for varying lengths of duration, and by rhythmic values amalgamated to music notes in the notation system. The subsequent projection and expression of sound in singing is governed by vocal technique that is developed through productive practice habits unique to each musician. Thus, in order to fully explain the music making process with regards to singing, a thorough examination of speech and its associated processes is required to provide the framework for a functional model that can further be applied to singing.

Speech is an act with hemispheric specialization – it is chiefly the function of the left hemisphere of the brain to control speech. Furthermore, there are several structures termed "speech or language centers" that contain the information needed to speak including the phonological system, or language, which deals with the difference in speech sounds, grammar and syntax schematics that govern speech, intonation and rhythmic patterns and the vocabulary needed to convey a specific message [1]. There are two main speech centers in the brain that control the production of speech and the subsequent understanding of speech, known as Broca's Area and Wernicke's Area, respectively. Two additional structures in the brain that assist with speech are the Angular Gyrus and the connection between Broca's Area and Wernicke's Area. Broca's Area is located in the bottom of the left frontal lobe and controls the ability to speak. Damage to Broca's Area results in the inability to speak, termed *expressive aphasia* [2]. Wernicke's Area is located in the left temporal lobe proximal to the auditory cortex and controls the ability to understand the meaning of speech. Damage to this area of the brain results in the inability to understand speech when spoken to, a condition termed *receptive aphasia*.

The connection between Broca's Area and Wernicke's Area allows an individual to both speak and understand speech when spoken to and the Angular Gyrus, located above and behind Wernicke's Area, provides the connection between the two language centers and the visual cortex. Damage to the connection between Broca's Area and Wernicke's Area still allows an individual to speak and subsequently understand speech when spoken to, but renders them unable to repeat what has been said to him or her. This condition is termed *conduction aphasia*. Damage to the Angular Gyrus prevents the individual from being able to read, termed *alexia*, or write, termed *agraphia* [2].

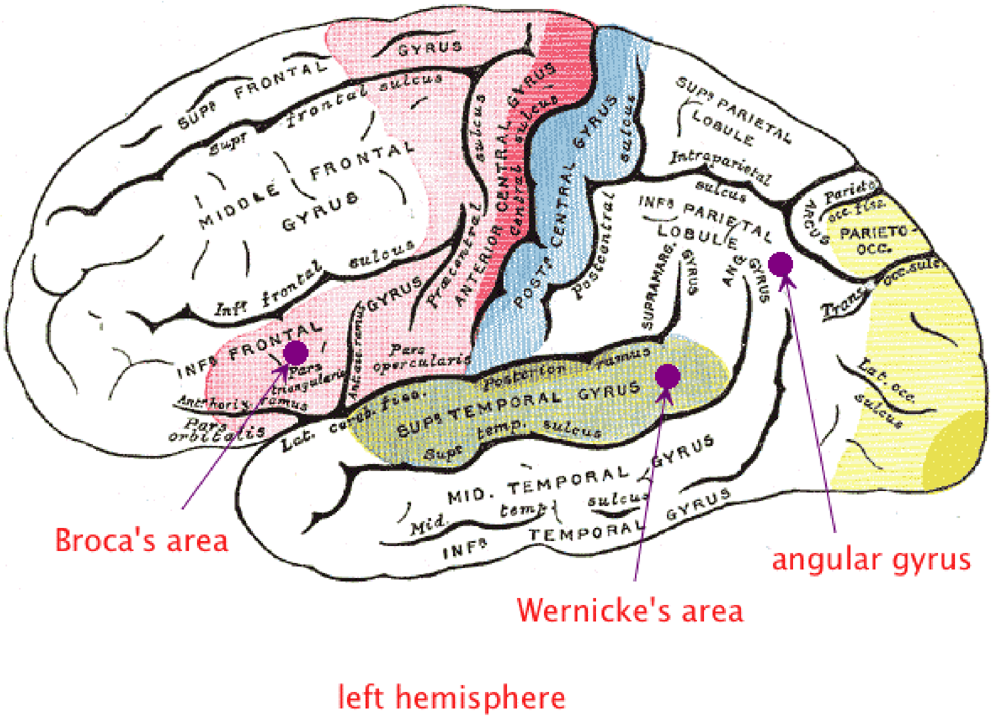


Figure 1: Location of Broca's Area, Wernicke's Area, and Angular Gyrus in the left hemisphere of the brain [2].

Sound is produced during speech via a coupled system consisting of a vibrating source of sound, the larynx, with a resonance system, the vocal tract. Sound produced during singing is executed in the same fashion with an extended resonance system that is not confined to only the vocal tract, but also includes the chest cavity, the oral cavity, the nasal cavity, and the sinus cavity. These additional resonance cavities or chambers function as amplifiers of the original sound produced by the larynx in the vocal tract. The energy supplied during both speech and singing comes from the lungs and respiratory muscles in the chest and abdomen – the abdominal, internal intercostals and lower pelvic muscles for inhalation; and the external intercostals, scalene and sternocleidomastoid muscles for exhalation. Proper utilization of all five resonance cavities enhances the overall production of sound, ultimately giving it multifaceted dimensions of existence and registration in the aural cavities of the head and skull.

II. Basic Singing Mechanics

When an individual is at rest, the span of time for an intake of breath, or the inspiratory phase, equals the expulsion of the same breath, the expiratory phase. Speech and singing, however, require a different pattern of breathing that favors a shorter length of time for inhalation and a longer expiration, sometimes as long as 10 to 15 seconds [1].

The larynx is the sound source for speech and singing. In the process of producing sound, a steady flow of air from the lungs enters the trachea where the edges of the vocal folds are held together to create a pressure gradient. The pressure begins to build up under the vocal folds until it reaches a level where the pressure is sufficient enough to overcome the resistance of the vocal cords causing them to open up automatically.

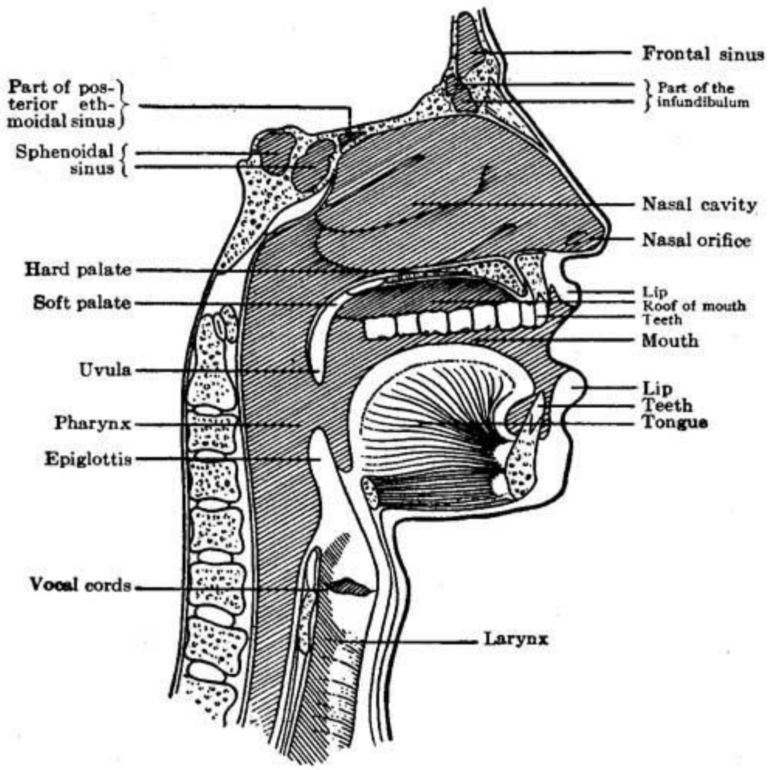


Figure 2: Diagram of the organs of speech and singing including upper resonators [3].

The elastic nature of the vocal folds causes the folds to return to their initial closed position as quickly as possible to once again obstruct the flow of air. The cycle repeats as the pressure builds once again under the vocal folds, provided the presence of a steady airflow, causing the vocal folds to open and close. Bernoulli's effect is also responsible for the rapid closing of the vocal folds, where the increase in airflow when the vocal folds open causes a drop in pressure. The pressure drop creates a suction effect that pulls the vocal folds back into the closed position [4].

Biomechanical modeling allows expression and qualification of the pressure distribution below the glottis, assuming Bernoulli's air flow:

$$P_s = P(x,t) + \frac{\varrho}{2}\left(\frac{U}{h(x,t)l}\right)^2 = P_0 + \frac{\varrho}{2}\left(\frac{U}{h_{\min}l}\right)^2$$

In this model, P_S is the subglottal pressure, P_0 is supraglottal pressure, l is the length of the glottis, ρ is air density, h is air flow channel height described as a piecewise linear function for a four-mass model of the vocal tract, with $h_{\min}$ being the narrowest part of the glottis $\min(h_{1,}\ h_{2,}\ h_3)$, and U is glottal volume flow velocity [5]. This and other biophysical models allow better understanding of the vocal tract, which, in addition to other applications, can have clinical value in qualifying different vocal injuries based on their location, type, and sub-effects on the models' individual variables including pressure.

The alternation between the opening and closing of the vocal folds is the basis for sound as successive puffs of air are expelled into the space above the larynx, which can be controlled by the individual [1].

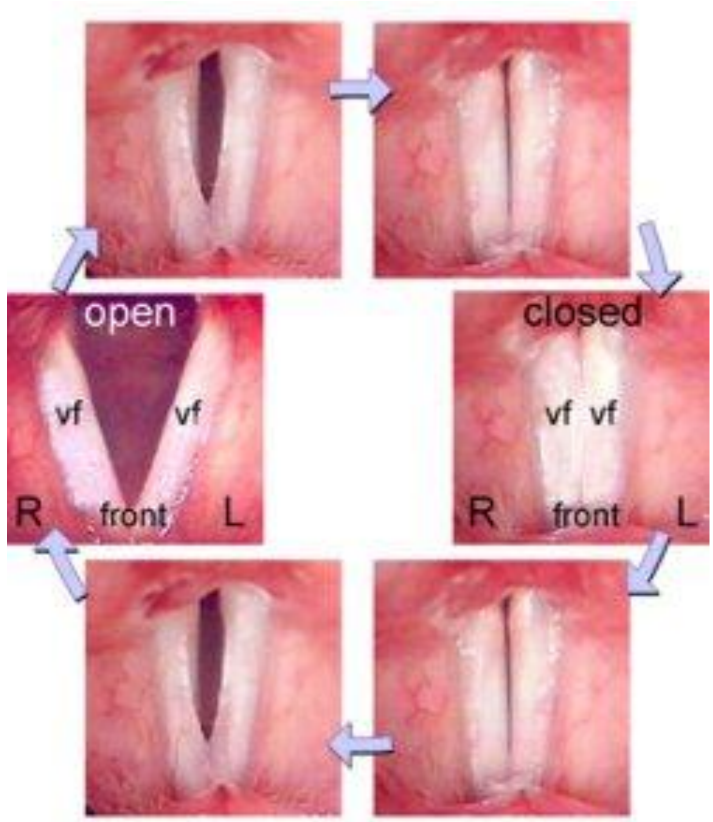
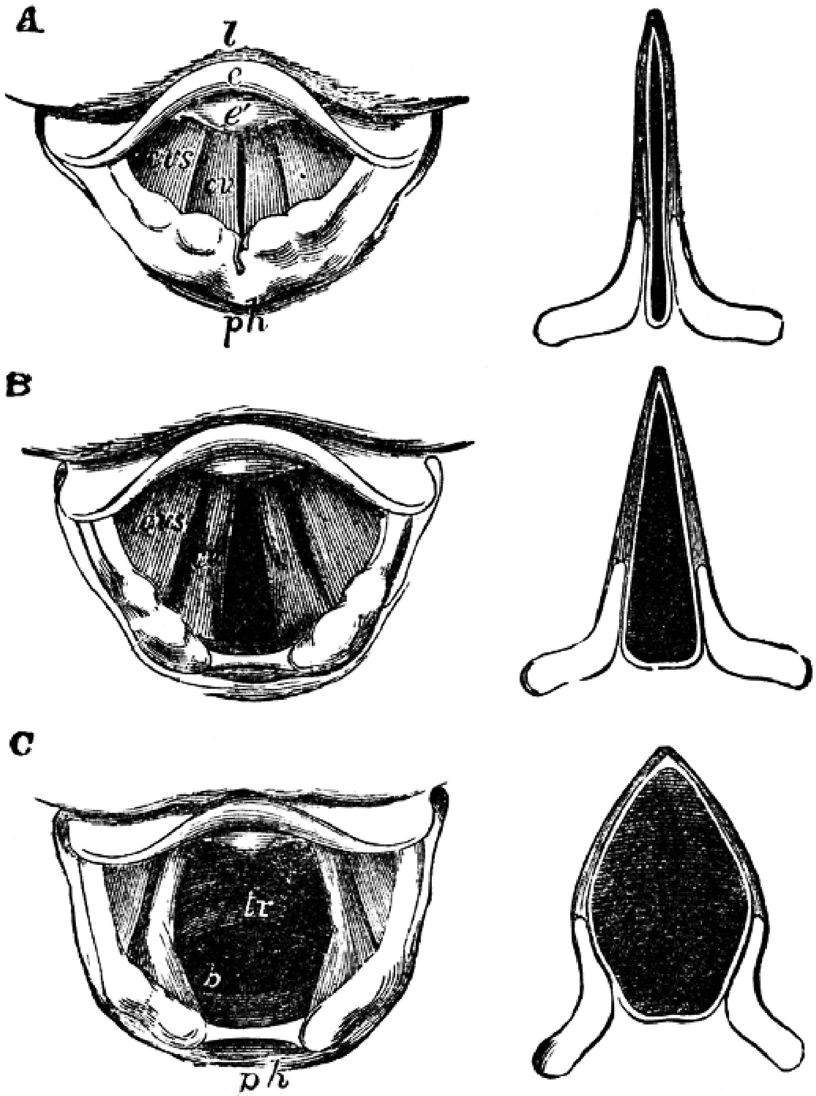


Figure 3: The Vocal Folds (vf) opening and closing [6].

The length of the vocal folds can be modified by two muscle groups in the throat known as the thyro-artenoid muscles, which constitute the actual body of the vocal folds, and the crico-thyroid muscles, which "change the angle between the thyroid and cricoid cartilages and hence both length[en] and stretch the vocal cords"[1].

III. Range and Mental Imagery to Supplement Technique

The change in length of the vocal folds determines the vibrational frequency of the vocal folds to produce a range of frequencies associated with various pitches – the longer the vocal folds, the lower the frequency; and the shorter the vocal folds, the higher the frequency produced. A singer's range is determined in this manner – with the lowest sing-able pitch associated with the longest length of his or her vocal folds vibrating at a very slow frequency and the highest sing-able pitch associated with the shortest length of his or her vocal folds vibrating at a very high frequency. The very size of the larynx itself also plays a role in the establishment of a singer's range with the larynxes of the lower voices, basses and alto, being larger than those of the high voices, tenors and sopranos [3]. Without the vibration of the vocal folds, singing and speech would both be impossible. It should be noted that Fourier series can model these vibrational oscillations in addition to the downstream auditory product.



<u>Figure 4</u>: "The larynx as seen by means of the laryngoscope in different conditions of the glottis. Labels: A, while singing a high note; b, in quiet breathing; C, during a deep inspiration; l, base of tongue; e, upper free edge of epiglottis; e', cushion of the epiglottis; ph, part of anterior wall of pharynx; cv, the true vocal cords; cvs, the false vocal cords; tr, the trachea with its rings; b, the two bronchi at their commencement [11]."

Proper vocal technique stresses the importance of keeping the larynx in the lowest, most relaxed position possible to prevent strain or other injury. This relaxation of the larynx comes not only from relaxation of the larynx but also from relaxation of the surrounding muscles extending primarily from the tongue to the neck and shoulders. Allowing the vocal folds to remain free from conscious tensing will allow them to naturally produce the necessary tension to generate the desired pitch. Conscious tensing of the vocal folds will result in a note that sounds strained and/or pinched that will cause a painful sensation in the throat. Continuous use of the vocal folds in this manner may potentially result in irreparable damage to the vocal folds. Therefore, proper technique is essential in maintaining good vocal health.

Singers do not have physical control of their instrument, the larynx, as instrumentalists do with a clarinet or piano for example. Thus, imagery and specific vocal exercises are used as a medium to teach proper relaxation of the muscles in the head, neck and shoulders and to subsequently produce a more "free" sound. One such example can be seen in an exercise for head alignment and neck releasing used by the voice teacher and vocal coach Betty Jeanne Chipman:

> "Focus on this thought: your head is lightly balanced, like a large balloon on top of the spinal column. Let your head slowly tip backward until it passes the center of balance and then let it drop back as far as it will go. Let your lower jaw drop open to facilitate a feeling of completely 'letting go.' Bring your head slowly forward until it again passes the center of balance and then let it drop forward as far as it will go. Let the head float back up to a position where the head (still like a large balloon) feels perfectly balanced on top of the spine. The crown of your head should be the high point. Keep the feeling of lightness while speaking [ɑ] in a downward sigh. Repeat six times, alternating between [ɑ] and [o] [7]."

This exercise, combined with many others specific to different types of relaxation, provides a framework for the implementation of proper technique related to vowel placement and projection of sound.

Sound is projected via an increased intensity in the air flow underneath the vocal folds. This increased intensity in air flow pushes the vocal folds open wider and keeps them open for longer to produce a more sustained, intense sound. The additional energy required to produce a more intense air flow comes from the use of the respiratory and abdominal muscles, specifically the diaphragm. By lowering the diaphragm and abdominal muscles, the lungs are able to increase the amount of air taken in for what is known as "a low breath" because the lungs are now able to expand not only outward, but also downward. This lower breath provides the necessary tension to push the vocal folds open wider and longer. Here again, improper tensing of the vocal folds will result in a pinched, strained sound, and projection will be limited despite a singer taking a lower breath. Relaxing the larynx will allow the tension to be moved from the larynx to the abdominal muscles resulting in a strong core that is able to support the sound created.

IV. Phonemes and Pronunciation

The tongue and lips act as the articulators of sound to produce vowels and consonants recognizable to a specific language, which for the purposes of this paper will be the English language. The tongue and lips work together to alter the shape of the oral cavity to produce distinct sounds that can be strung together to form words, which can be further organized into coherent sentences able to convey a specific message. This process is completed in the aforementioned areas of the brain: Broca's Area, Wernicke's Area, the connection between Broca's Area and Wernicke's Area, and the Angular Gyrus.

The English language has a fixed set of vowel and consonant sounds derived from the English alphabet system [8]. It is possible to sing incomprehensible gibberish, but the threshold for singing adequately is partially defined by this linguistic caveat. Execution of the specific English phonemes listed below in Table 1 can be governed by the mechanisms of vocal technique, termed vowel placement.

English Phonemes, Spellings, Example Words, and Meaningful Names

Phoneme	Spelling(s) and Example Words	Meaningful Names
/A/	a (table), a_e (bake), ai (train), ay (say)	Long A; Fonzie's greeting
/a/	a (flat)	Crying baby; baby lamb; home alone
/b/	b (ball)	Beating heart; drum
/k/	c (cake), k (key), ck (back)	Nutcracker; golf shot; camera
/d/	d (door)	Knocking; dribbling ball
/E/	e (me), ee (feet), ea (leap), y (baby)	Long E; shriek
/e/	e (pet), ea (head)	Rocking chair; creaky door; hard of hearing
/f/	f (fix), ph (phone)	Angry cat; clothes brush; electric fan; soda fizz
/g/	g (gas)	Croaking frog, gulping soda
/h/	h (hot)	Out of breath; warm breath; tired dog
/I/	i (I), i_e (bite), igh (light), y (sky)	Long I
/i/	i (sit)	Crying puppy; icky sticky; baby pig
/j/	j (jet), dge (edge), g[e, i, y] (gem)	Scrub brush; wood rasp; jump rope
/l/	l (lamp)	Flying saucer; mixer
/m/	m (my)	Mmm mmm good; delicious sound
/n/	n (no), kn (knock)	Mosquito; motorboat
/O/	o (okay), o_e (bone), oa (soap), ow (low)	Long O; Oh, I see
/o/	o (hot)	Say ah; doctor sound; cool drink; yawn
/p/	p (pie)	Popcorn; water drip; stone skip; soap bubbles
/kw/	qu (quick)	Coffee pot; typewriter

/r/	r (road), wr (wrong), er (her), ir (sir), ur (fur)	Chain saw; angry lion; robot; growling dog
/s/	s (say), c[e, i, y] (cent)	Flat tire; hair spray; sizzling bacon
/t/	t (time)	Ticking clock; timer; automatic sprinkler
/U/	u (future), u_e (use), ew (few)	Long U
/u/	u (thumb), a (about), e (loaded), o (wagon)	I dunno; mother bear; punch in the stomach; foghorn
/v/	v (voice)	Electric shaver; airplane; vacuum
/w/	w (wash)	Lariat; fly rod; washing machine
/ks/ or /gz/	x (box, exam)	Soda can; grease gun
/y/	y (yes)	Sticky mess
/z/	z (zoo), s (nose)	Buzzing bee; arc welder; zipper
/OO/	oo (boot), u (truth), u_e (rude), ew (chew)	Ghost; howling wolf; owl
/oo/	oo (book), u (put)	Lifting weights; chin-up bar
/oi/	oi (soil), oy (toy)	Seal; squeaky gate; spring
/ou/	ou (out), ow (cow)	It hurts; inoculation; sting
/aw/	aw (saw), au (caught), a[l] (tall)	Poor thing; crow
/ar/	ar (car)	Spinning tire; grinding gears; gargle
/sh/	sh (ship), ti (nation), ci (special)	Be quiet; watering the lawn
/hw/	wh (white)	Blow out the candle
/ch/	ch (chest), tch (catch)	Old train; antique car; chipmunk
/th/ or /th/	th (thick, this)	Peeling tape; angry goose; wet shoes
/ng/	ng (sing), n (think)	Gong; string bass
/zh/	s (measure)	Sawing wood; sander

Table 1: List of some selected English phonemes with examples (Murray, 2000).

V. Vocal Pedagogy

The classical style of singing is characterized by tall, open vowels equated with the creation of space in the oral cavity. Space is created by dropping the jaw and tongue, and raising the soft palate. The newly created space allows for resonance within the oral cavity to amplify the sound created in the vocal tract by the larynx. Opening the back of the throat by raising the soft palate serves a secondary function, which is to unblock the passageway leading to the nasal and sinus cavities. The opening of these additional cavities allows the sound to be funneled upward to resonate in yet two additional chambers to further amplify the sound before it is projected outward from the oral cavity.

The tongue and lips also play an integral role in articulating both vowels and consonants in the singing process. Both muscles help shape the vowels and consonants as they are to be delivered by the singer in a piece of music. Much precision is required to correctly utilize the tongue and lips. If either muscle is too tense or too relaxed, the resulting sound produced will not be as luminous or as full as it could possibly be. The placement of the tongue within an individual's mouth also affects the clarity of the sound that is produced.

Furthermore, spatial orientation or alignment of an individual's body affects the sound produced. Correct posture is vital to efficient projection of sound. The proper posture is one where the body is held fully erect, but in a relaxed manner. There must be a feeling of balance in the relationship between the muscular and skeletal system in the body, where the skeletal system is working to hold the body erect while the muscles remain un-tensed, free to move the body as needed [7].

In addition to correct posture, a strong core is necessary to provide the support required to control intensity of sound and overall projection of sound. Without a strong core, the resulting sound is heard as weak, feeble, and lacking in intensity. This type of sound will not carry, or project well in even the most "live" recital or concert halls. A strong core assists in creating dynamics – the loudness or softness of a section in a piece of music. When a singer has complete control of these core muscles, he or she is able to control the overall artistry of a piece. Dynamics add an extra dimension to a piece of music, and the ability to control this aspect of the music separates a "good" singer from a "great singer. Thus, a singer who is lacking in a strong core will not be able to effectively convey dynamics in the piece he or she is performing, which will subsequently diminish the overall message he or she is aiming to convey through the music.

Finally, without proper breath control, singing would not occur at all despite a strong core, and correct posture. Robert C. White said it best, when he stated:

> "In the Beginning there was Breath, and Singing was with Breath, and Singing was Breath, and Singing *was* Breath. And all singing was made by the Breath, and without Breath was not any Singing made that was made [12]."

Breathing is at the heart of singing, and without proper breath management, singing is not possible. Breath management comes from awareness of how an individual breathes – whether he or she is taking a "low" breath as described earlier in this paper or a shallow breath where the breathing is limited to the expansion of the lungs and nothing more. Developing a "kinesthetic" awareness of how one breathes is the first step to improving overall vocal technique.

VI. Personal Application

(The reader should note that for the purposes of this portion of the paper the author will refer to herself in the first person.)

In my endeavor to better understand the mind-body coordination of vocal technique, I resolved to apply the information I gathered over the course of this investigation to my own personal approach to singing and the overall music making process. I began by reassessing how I approached vocal technique as a whole, breaking down its constituents and then reconstructing it with this research in mind. I found that this newfound application of vocal technique gave me the ability to have a richer, more fulfilling singing experience.

Understanding the anatomy of the body, which is concrete in nature, has allowed the understanding of music and singing, which are more abstract concepts, to become easier to execute. I began to see that singing was a total body experience, and as a result, I began treating my approach to singing differently from the onset. Dr. Brad Diamond, Assistant Professor of Voice at the University of South Florida School of Music, echoed what I had discovered through my research when he shared this thought with me in a recent correspondence in regards to the question, "How do you teach a student to prepare their body for singing, and what do you tell them to do?":

> "First of all, the body must be physically "warmed up." That means getting some basic physical exercise in before singing. Nothing too strenuous, just enough to get the blood pumping. Then some area-specific stretching exercises are appropriate. Neck and shoulders are particularly tight on most singers, so that should be an area of focus. During technique work, each singer should concentrate on Tongue and Jaw tension EVERY SINGLE DAY. These are huge problem areas for most singers and they really have no idea. This can be done both during and aside from singing exercises. I.E. Just grab the jaw and wiggle it; or stick the tongue out into a position well outside the mouth. Or, you can do the same things while doing a simple vocal exercise [9]."

With this insight in mind, I strove to make sure that I was warmed up whenever I entered my lessons in the weeks leading up to my recital by walking around outside, doing lip and tongue trills and breathing exercises in the practice room before I entered my lesson. I found that in warming up prior to my lesson, my lessons generally went much better than if I did not execute these additional measures. Warming up my body before my lessons helped relax any tension I might have accrued throughout the day and also put me in the right mindset for my lesson. I went into my lessons ready to work, and it showed in the end result.

I also became much more conscious of my body's spatial orientation before, during, and after singing, not only in my lessons, but also during my practice sessions and in everyday situations. I found that I carried a lot of tension in my neck and shoulders, which affected the way I sang. In an effort to combat this tension, I made a conscious effort to be aware of my posture and where my shoulders were located in relation to the rest of my body whenever possible. In the "Music, Medicine, and Myth" seminar class I participated in during the Spring 2011 semester, the instructor, Professor Sang-Hie Lee, Associate Professor in Music Medicine and Research, gave me several simple stretching exercises to help relieve tension in the neck and shoulders, which I was able to easily incorporate into my daily vocal warm-ups. One exercise involved stretching my neck to one side, holding the stretch for 30 counts, releasing the stretch and repeating it on the other side [10]. I found the more I stretched, the less my overall tension became.

Finally, I felt that my personal performing abilities were greatly improved through my newfound approach to vocal technique. In past performances, I found myself personally to be unsatisfied with my overall performance. I was often nervous before entering the stage, which subsequently affected my posture. I found that I held my frame in a rigid manner, which prevented me from taking in a low enough breath to support the sound that I wished to create, and the resulting tone suffered. In implementing my new ideas of spatial awareness during my most recent performance – my senior recital – I was able to control my body's overall rigidity because I had gained a conscious awareness of my body's spatial orientation. Furthermore, I was able to control the tension in my neck and shoulders to a greater degree than before, enabling me to produce a fuller, richer sound overall. In an effort to show the reader how I implemented all these ideas, I uploaded my senior recital performance onto "Youtube" for public viewing. The link to the recital may be found below for your viewing pleasure:

http://www.youtube.com/watch?v=c_cHaYMf6wk*

* It should be noted that this performance was shared with another individual from the author's voice studio and the total program length is fifty-six minutes and forty-three seconds long.

VII. Conclusion

Like many processes involving the human body, there are many relationships between the beautifully complex end result and the fundamental biophysical interactions at the tissue and organ level. Singing is possibly the best example of this marvel. The end result is considered art that can manifest itself in so many rich ways – from opera's vibrancy, to hip hop's beat, to death metal's screams – and may not be *prima facie* conceived to be in any way linked to simple biophysics that can be modeled with mathematical equations limited to a few variables that can be counted on one's hand. But the fundamental processes – the interplay between brain processes and the intricate workings of the vocal tract elements – are truly governed by these biophysics.

With this connection in mind, it is clear that vocal tract models can be constructed to better understand the intricacies of the organs involved with human song. More variables can be added, and the models' complexity can be increased for even better approximation of the workings of the human body. One day, such modeling can be used in the clinical setting for relative quantification of the various parameters involved with singing from patient to patient, and analyses of differences from a "healthy" vocal tract can be used for diagnoses and subsequent treatment of vocal abnormalities.

The author also foresees application in robotics and other related fields as they gradually merge into everyday human life, since vocalization is an important asset in daily functioning and societal relevance; that is, such models can be used to help construct robots that talk like humans.

However, at this time, these intricate models are primarily academic in nature. What is more important than these biomechanical analyses and finite element modeling is a basic understanding of the biophysics that are applied in the generation of these speech and song. Knowing that a glottis-mediated pressure gradient is required in the vocal tract for singing and that there are organic shape changes in the generation of different notes, can be sufficient understanding to know what one is doing wrong or right when singing. That is, mental appreciation of the intricate vocal apparatus governed by fundamentally simple biophysics is good for a singer to have.

The mind-body connection, then, is more than just one of the Broca's Area, Wernicke's Area, the Angular Gyrus, and the downstream vocal apparatus. Rather, the connection is one that can apply not only to singing but also all of the human body and its functions – students of biophysics ought to use their minds to at least implicitly connect with the processes of their body, which are all governed to some degree by fundamental biophysics. This connection does not have to be explicit with mathematical models and such. With this knowledge and reverence of vocal processes applied to singing, one can certainly better his or her vocal technique.

This idea was best stated by Dr. Diamond when he made the following statement:

> "I believe any legitimate teacher of singing has an ethical responsibility to familiarize themselves with the hard scientific facts of vocal pedagogy. Even if they don't use them to teach students directly, they must know what is going on in there. Gone are the days when teachers can claim "I'm not really a believer in the science of vocal pedagogy, I just teach on intuition and guts..." That is simply unacceptable in the modern world. There exist countless sources of good literature on vocal pedagogy that are well written and easy to grasp. We (as teachers) simply need to open them up and read them. If confronted with something that contradicts years of our presumed understanding, we

> must be courageous enough to accept facts for facts and alter our teaching technique in response to them.
>
> Likewise, student vocalists should all develop at least a basic working knowledge of the science of vocal pedagogy. Again, even if they don't necessarily incorporate science or pedagogy into their singing. Many great singers don't... but they have the information at their disposal. The idea of being a "natural" singer that doesn't believe in pedagogy is again, just a cop out. Good singers that have no framework in technique or pedagogy will eventually fail as a result. In contrast, modest voices that base their singing on good technical and pedagogical habits, will improve in the long run and can even surpass the "natural" or "intuitive" singer as time goes on [9]."

Therefore, the author believes that any "good" understanding and application of vocal technique must stem from knowledge of the inner workings of the body and each part's relationship to the other as she learned in her own application of the ideas written in this investigation. Through this review she hopes to have increased the reader's general awareness of the intricate nature of vocal technique and the necessity of understanding one's own body in the implementation thereof in future encounters with singing and the music making process.

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