A Copernican Shift: Reframing How We Think About Breath in Singing

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> Your brain doesn't care what accessory muscles you are using to breathe . . . The system is agnostic.[1]
>
> — Dr. Jack Feldman, Neuroscientist and Distinguished Professor of Neurobiology, UCLA

The next three installments of the "Minding the Gap" column will focus on the activator, vibrator, and resonator. This order of vocal production elucidates the physical mechanism temporally. Singers tend to view the process beginning with their breath, traveling through the vocal folds, and finally transforming into resonance in the vocal tract. Although singing is not a tripartite system, but rather a wonder of symbiotic interactions, breath mechanics often comes first in many singing protocols. In surveying the long history of voice pedagogy texts— from the early treatises of Garcia,[2] to the insight of Vennard,[3] to the later advancements by Miller[4] and Sundberg[5]— invariably, the concept of breath management and physiology precedes elements of vocal fold or articulator mechanics. Ideas regarding audiation, intention, interpretation, or affect tend to be listed in the final chapters, like icing on a cake that is already baked.

The neuroscience perspective on breathing will detail how air is recruited, balanced, and maintained by the brain during phonation (and beyond). However, it will challenge the aforementioned order of these processes and reframe our ideas about how we optimize breathing for singing. When we vocalize, breath has two essential roles: first, it is a constant player in regulating our automatic nervous system; second, it is an integral component to the complex motor system of vocalization. It is the interplay of these two elements that must be considered in singing. A happy side effect is that this information also addresses issues like performance anxiety and focus, for breath is integral to the endless loop of homeostasis demanded by the central nervous system.[6]

Breath is essential to life. We breathe over 25,000 times per day through a mechanism carefully selected through evolution.[7] Oxygen is the fuel that feeds every cell in our bodies, and its efficient transport is necessary for survival. The conundrum in singing is that "we already know how to breathe." So why is it so challenging? Why has it become a pillar of pedagogy? Neuroscience is a relatively new field compared to vocal physiology. Ideas have not fully infiltrated voice science, let alone manifested in practical applications teachers can use. However, when we pay more attention to what the brain cares about when it comes to breath, rather than the act of breathing itself, we gain greater insight to address the challenges and create solutions to overcome them.

Consider this printer metaphor: We can observe the loading of the paper, the roller spooling it through the mechanism, the ink cartridges engaging, the layering of text, and the precise number of pages exiting onto the paper tray. If observed externally, one would assume the first order of action is the loading of the paper. However, we are missing the unseen: the document software, words typed on a computer keyboard, the size and layout chosen, and the command to print. In fact, those inputs are the most critical; they dictate the precision of the mechanism itself. Without it, there is no paper loading into the printer, nor output of text on pages. The state of the printer is equally important; if it is low on ink, we may get incorrect colors as a result. The motor signal also may be modified; we edit a document before it is printed, optimize alignment, change font, or delete ideas without even seeing a physical page processed through the mechanism. It is important to note that any external maneuvering of the print cartridges by hand will not generate the intricacies of a typed sentence; they are too bulky and inaccurate. The complex micro signals are what enables the larger, clumsier mechanism to accomplish such a detailed task.

Much of what we do as singers is similar. The downstream mechanics are coordinated by the unseen actions of our brains, edited and reviewed before a vocalization even is uttered. The decisions aren't made by a few large muscles triggering the process, but rather the micro coordination of over 100 muscles in the brain signaling to act in concert, generating the wondrous outcome of sound. The internal state is also important. We are not as skilled when we are nervous, tired, or frustrated, much like a printer low on ink. However, voice pedagogy has focused primarily on refining the downstream physical processes witnessed as we vocalize. Observations have become the actions, and internal states left out of the equation.

Singing is a predictive behavior. The complex mechanism is orchestrated by the brain's calculations and predictions operating behind the scenes. As the first installment of this series on vocal learning described, the brain "decides" what motor elements to coordinate for a specific sound well before the sound is executed.[8] The silent and usually unconscious auditory step ("hearing in one's head") primes the motor system, and many vocal muscles are activated through this process without any actual sound.[9] This all happens in the absence of actual breath. In fact, immediately prior to the onset of vocalization, once all the motor variables have been calculated for the task, the depth of inhalation is adjusted to the anticipated length of the vocalization, not the other way around.[10] In fact, evolutionary evidence across all species reveals unique neural circuitry when respiration is coupled with vocalization: for example in vocal learning songbirds, specific respiratory center neurons (analogous to ours) are not active during regular breathing but only active during vocalization. The coupling of neuronal circuitry makes sense since inspiratory timing is essential for both bird song and human vocalizations.[11] There are many elements the brain must consider when it calculates breath (Figure 1). This includes the internal state. Dysregulation of critical elements will override the cortical signal for vocalization, just like a pesky error message on a printer when there's not enough paper or there is no more ink.[12] Nothing will come out.

Does this mean all that effort worrying about muscles of respiration in singing is for naught? Should we not think about mechanics and focus only on vocalization? It's not that simple. Historically, such strategies have proven successful. The art of pedagogy is different than science and many successful approaches are without explanation. The hallmark of a complex field like singing is that there are many paths to a successful end; however, when we put those ideas into context, we come to question some of the ideas. We will see that such approaches should be addressed at a later step in the equation, or serve simply as touchstones in a broader scheme of kinesthetic awareness and observation, not a major focus for preemptive action. The accessory muscles of respiration are far too distal and large to achieve the nuance necessary for intricate vocalization. Like the print cartridge metaphor, manually moving large muscles cannot execute the same level of control as the system coordinated as a whole. When we explore the neuroscience of the vibrator in the next issue, those nuances will become even more apparent.

Regarding real-world breath mechanics in singing, a 2012 study revealed measurable variability in specific respiratory accessory muscle functions between profes-

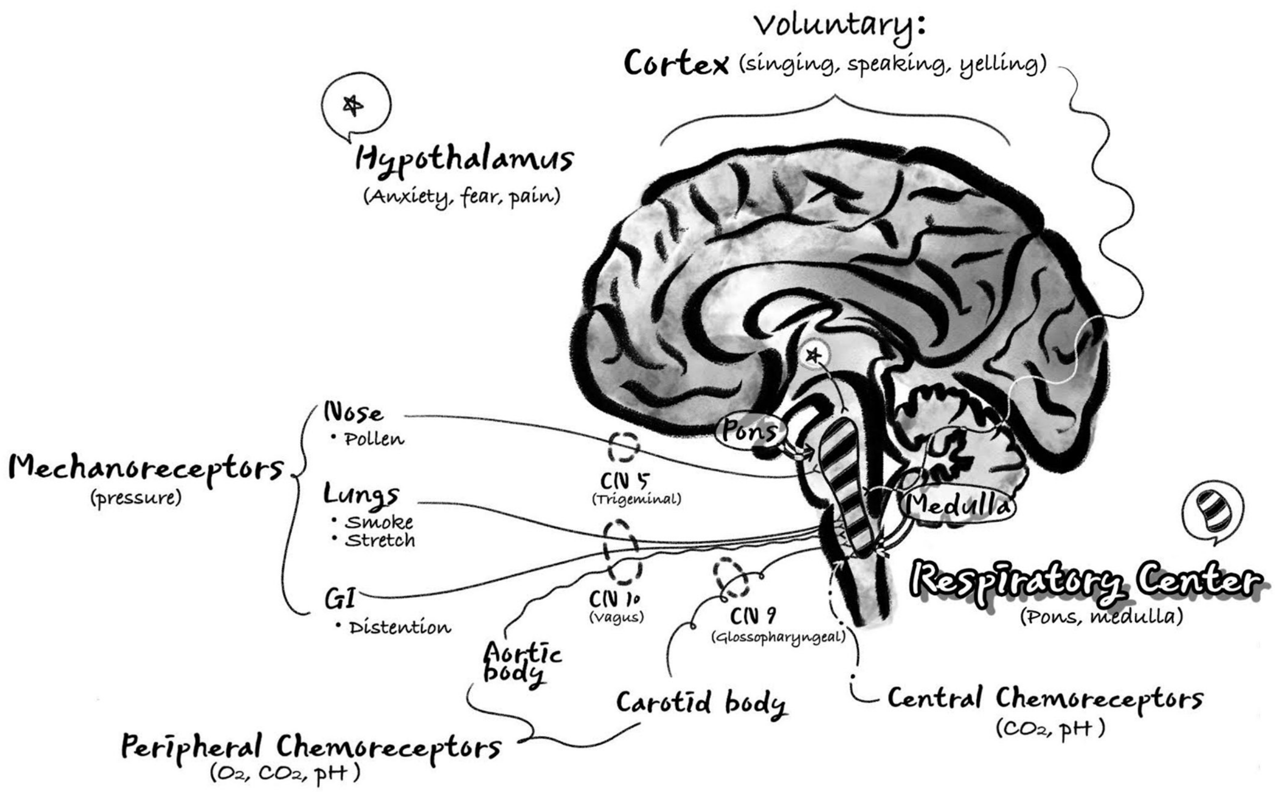

Figure 1. Human respiratory center in the brain (pons and medulla) indicating the various inputs. (Image created by Kang Kang and designed by Heidi Moss Erickson.)

sional classical singers, pointing to no singular strategy of engagement.[13] Scott McCoy had similar observations in his 2005 work on gender-based differences.[14] It would be interesting to compare how these singers were taught versus how they actually executed their breathing tasks. Johan Sundberg in his 1987 book *The Science of the Singing Voice* noted that "different persons seem habitually to use different muscular strategies" and "the choice of muscles used in order to generate the pressure should not affect phonation." Sundberg astutely pointed out that the attention given to respiratory musculature in voice pedagogy could be due to the simple fact that breath is the only aspect of the mechanism that can be "observed by the naked eye," giving credence to the idea of "what gets measured gets managed."[15] Could the only reason the field pays such close attention to the physical mechanics of breath be for the simple reason that it can be directly observed? That we consciously sense it comes first? That it feels more secure when we can physically see and experience something? Alas, we cannot see inside the brain nor the larynx. But knowing the ideas about how the brain signals the inner workings of the instrument, we can better design language and pedagogic strategies to target the unseen and trust how the system is wired.

The differences in breath mechanics observed between singers complements the neuroscience: the individual, the autonomic state, the predictive vocal requirements, and the temporal laws of physics dictate accessory muscle recruitments, not vice versa. The internal state is driven by respiration. Oxygen is the fuel that feeds every cell, and its efficient transport is necessary for survival. Figure 2 displays the simple gas exchange process achieved by respiration: When we inhale, oxygen is transported from the lungs to our red blood cells for distribution. At the exchange point, carbon dioxide (the metabolic waste product) is off-loaded onto the red blood cells and transported back to the lungs to be exhaled. Regardless of whether we are in a state of involuntary passive respiration (at rest), involuntary active respiration (during exercise), or voluntary respiration (like in speech or singing), this is the only process our brain cares about. After calculating all the inputs, it strives for homeostasis and will adjust accordingly to gain balance (Figure 1). Priority is given to gas exchange. No other signal, not even singing, can override this process. The signals for vocalization will always be made under the backdrop of an internal state.

What is often misunderstood is that when we feel the need to breathe, it is not about oxygen. Oxygen levels in the blood are kept at a stable 95%-100% saturation for good reason: cells die without it. Falling below 90% is critically dangerous, as many have observed during COVID-19 (in fact, pulse oximeters had a huge increase in sales in 2020).[16] The real player in our respiratory decision making is carbon dioxide.

Figure 3 shows how carbon dioxide combines with water in the blood to form carbonic acid. It is precisely this feature that allows the brain to detect when the body needs to breathe. When carbon dioxide accumulates, carbonic acid lowers the pH in the blood, and in response chemoreceptors notify the respiratory center (in the Medulla, Figure 1). This cues the respiratory center to send impulses to the external intercostal muscles and the diaphragm, which increases both the breathing rate and the volume of the lungs during inhalation. Individuals with disorders such as COPD are compromised in their inability to offload carbon dioxide and the consequences can be life threatening.[17]

Given its importance, there are several lines of communication via many different nerve pathways for the brain to receive this information (note that the vagus nerve is only one of many; Figure 1). In addition to detecting low pH, the central and peripheral chemoreceptors also detect high pH (alkalosis) caused by hyperventilation. The response by the brain is to decrease the ventilation rate to increase carbon dioxide levels. It is important to note that this response can also be caused by mechanoreceptors sensing stretching of lung tissue (Figure 1). We can trigger this response by overusing accessory muscles of respiration to hyperinflate the lungs. Bulky muscles are not designed to control respiration in the nuanced way required for vocalization, as opposed to medical or rehabilitative strategies where exercising accessory muscles is extremely useful[18] or extreme breath practices like Yogic "Breath of Fire," which necessitate external efforts.[19] This stretching will have the undesired effect of inhibiting respiration and restricting the ease of breathing, making singing harder. Therefore, overbreathing can be worse than not breathing enough.

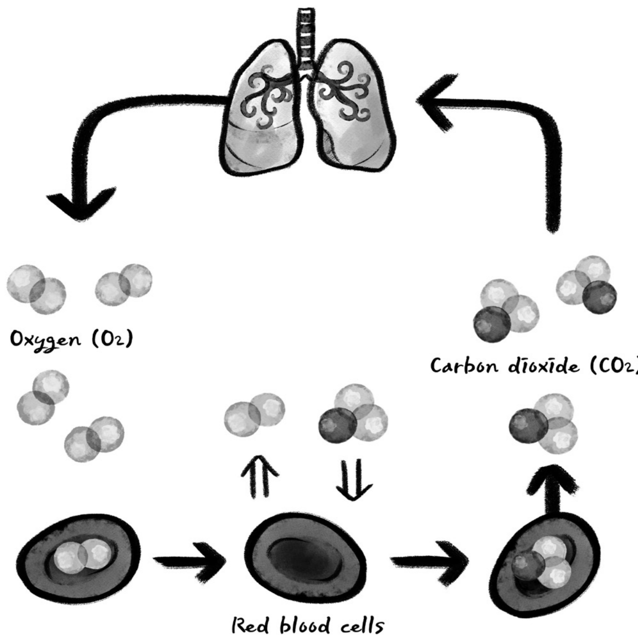

Figure 2. **Cellular respiration showing the transfer of oxygen and carbon dioxide to and from red blood cells via the lungs. (Image created by Kang Kang and designed by Heidi Moss Erickson.)**

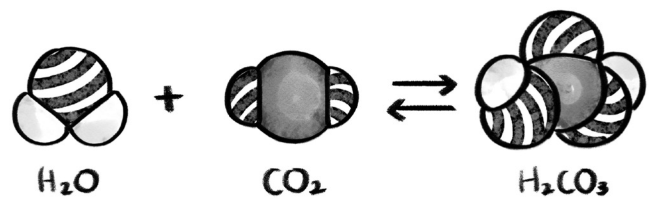

Figure 3. **Water and carbon dioxide combining to form carbonic acid. This reaction occurs in the blood when carbon dioxide accumulates, causing the blood to become acidic. (Image created by Kang Kang and designed by Heidi Moss Erickson.)**

The benefit of singing is that it is based on the necessary exhale. However, there can be musical phrases where one is forced to breathe before the lungs have emptied. In this state, CO_2 remains along with the newly inhaled air (so-called "stacking" the breath). This will lead to acid accumulation in the blood, triggering elevated heart rate, hyperventilation, and the need to breathe more. A short exhale after a phrase before the next inhale or extending phrases with fewer breaths (we don't have to breathe at every rest) are workable solutions to this problem. Carbon dioxide tolerance is also something that can be trained.[20] High level athletes have employed breath holding techniques such as the Wim Hof method for this exact purpose. The ability to withstand higher levels of carbonic acid in the blood can improve athletic performance.[21] Similarly, this kind of training could prove useful to singers as well.

Given the necessity of oxygen and carbon dioxide exchange, there are other ways we can make the process more efficient. First is posture and muscular freedom. This is where kinesthetic and proprioceptive awareness of all muscles, including accessory muscles of respiration, is necessary. Barbara Doscher wisely said, "Rigidity is the enemy of breathing, and indeed of any muscular endeavor."[22] To breathe freely, we need to sense energy without effort and a dynamic flow. Restrictions in our respiratory process, whether due to alignment, misplaced muscular contractions, or stiffness can be inhibitory. This also means overengaging certain muscles prior to phonation or beyond what the brain has signaled for the vocalization. Optimization is key. A Yogi once stated, "Do not force the breath, instead, ask what is obstructing the breath."[23] This is also a good mantra for singing.

A second strategy to optimize efficiency is called the "respiratory sigh" or "physiological sigh" (Tables 1 and 2).[24] Humans sigh about once every five minutes without any conscious awareness. This serves to inflate the terminal alveoli in the lungs (Figure 4), which increases the surface area for optimal gas exchange. Without this action, the balloon-like structures can collapse on themselves and have a dramatic impact on respiration. There are serious conditions that arise in both infants (SIDS) and adults (ARDS) which are due to problems with alveoli collapse.[25] We can assist this process at a conscious level, and for singers, it can be a wonderful preparatory gesture to increase efficiency of respiration and extend phrase length. Two consecutive inhales through the nose to maximize inflation followed by slow extended exhales will accomplish this task in just a few iterations.[26] Nasal breathing has been shown to be far superior physiologically to mouth breathing which is why it is suggested so often in these protocols.[27] It may be challenging to always breathe through the nose when singing, but knowing the benefits can increase the frequency, particularly during long pauses. Interestingly, humming has been shown to also increase beneficial nitric oxide levels in the nose, so as a vocal exercise it has an advantage over other SOVT methods.[28]

Another important feature of respiration is its inextricable coupling with heart rate (Figure 5). Every time we inhale, our heart rate goes up; conversely, when we exhale our heart rate goes down. This Respiratory Sinus Arrhythmia (RSA) is due to simple pressure differentials. During inhalation, the diaphragm contracts and moves downward, creating negative pressure in the thoracic cavity. This increases the amount of blood entering the right side of the heart. If more blood is entering the heart, more blood needs to be pumped out, and the logical solution is to increase the heart rate. As the diaphragm relaxes during exhalation, the pressure in the thoracic cavity becomes increasingly more positive, less blood enters the heart, and the heart rate decreases accordingly.

Like many elements in our biology, heart rate and breath are looped bidirectionally; one influences the other. Additionally, psychological states are influenced by our autonomic states, and vice versa. Figure 1 shows the input from areas in the hypothalamus and cerebrum that feed into the respiratory center. Thus, breath and heart rate are powerful forces for our well-being. Why is it more challenging to sing when we are nervous? If our heart rate is elevated, our respiration will become rapid and more shallow, which is not helpful. Additionally, if a singer is hyperfocused on inhalation efforts and tends to breathe through the mouth quickly, the heart rate will automatically increase more rapidly. These types of actions run the risk of increasing a singer's stress levels. Anxiety is a common phenotype from elevated heart rate interoception and it would adversely interfere with the vocal motor calculation.[29]

One can design simple strategies that bio-hack the nervous system based on the knowledge of RSA (Tables 1 and 2). As an example, to calm the heart rate, breathing through the nose slowly[30] and then doubling the length of the exhale will impact the rate quite quickly.[31] Once a calmer state is achieved, there are other breathing strategies that can optimize the sense of focus and energy. Boxed breathing utilizes a 4–4-4–4 strategy of inhale-hold-exhale-hold, which is also useful to prime the brain and body for singing.[32] Of course, slow nasal breathing is not a luxury one can always afford in real-time performance, but one can use these strategies in reductive

TABLE 1. **Neuroscience-Based Respiration Strategies for Singing: homeostasis + predictive.***

Prepping the body:

- Stand tall or sit on a yoga ball and scan the body for any sources of rigidity. Be an observer. Wiggle or twist to release. Sense dynamic ease.
- Do several forward bends, hanging the head and neck completely.
  - — In this inverted position, take several slow breaths through the nose, exhaling through the mouth and observe the expansion and freedom in all directions.
- Slowly roll up one vertebra at a time, sensing the energy without effort to achieve your dynamic posture (Alexander technique is helpful for this).
- Swing the arms up above over your head for more release and energy. Bonus if done with joy and enthusiasm.
- Perform a final body scan while breathing slowly through the nose for a count of 4 and exhaling through the mouth for a count of 8.

Establishing homeostasis:

- Perform three sets of respiratory sighs: inhale fully twice through the nose in succession and exhale slowly until the lungs are completely empty. Imagine in your mind that you are inflating tiny balloons inside of you that are light, bouncy, and full of energy.
- Scan the body and mind: do you feel ready to sing? Energetic but calm and focused? How does your heart rate feel?
  - — Based on your assessment, choose to:
    - move on to the singing exercise
    - calm heart rate with a few more slow breaths through the nose and exhaling through the mouth in a 1:2 ratio (e.g. 4:8).
    - find focused energy with 3 consecutive sets of boxed breathing: inhale 4-hold 4-exhale 4-hold 4.
- To work on carbon dioxide tolerance, practice extended breath holds after an exhale, or explore Wim Hof or Tummo methods. It is best to do these separately from any singing practice and with caution.

Establishing predictive motor elements to optimize breath:

- Choose a short excerpt from your repertoire that you know well, a vocal exercise, or an extracted excerpt to use as an exercise.
- Audiate one phrase several times. Pay particular attention to the first word or note. This can even be just the vowel alone. It jumpstarts the whole process.
    - Sing the first note aloud a few times to play with ideas and set the physical system into motion (repeated onsets).
- Each time you wish to sing, no matter how big or small, make sure the system is calibrated: a full exhale to offload CO_2, a good inhale through the nose, and a body scan to observe the sense of energy without effort nor rigidity. Use movement if you need to. Poise and patience are key.
- Once the phrase is audiated, add an intention or affect: it can be an emotion or character. At this stage, it doesn't necessarily have to align with the text. Just something which inspires vocalization.
  - — Gesture can help calibrate phrase length: i.e. drawing a big circle with the arms.
  - — Include reductionist strategies to target specific motor elements: i.e., singing a phrase on successive, detached [bo] can fret each note and give it a sense of air equilibrium; or singing legato on [i] or [u] can unify the line in the context of continuous airflow.
  - — Playing with different ideas is helpful for the brain to get a sense of different motor choices. Move around the room. Pretend to be a cat. Dare to be reductionist! Dare to get creative!
- To counter declination rates, directionalize the phrase by hearing the last few notes in your head when you start singing, or even audiate a crescendo to the end of the phrase.
- Have fun!

**Individuals vary so use your best judgement and instinct.*
Include time off and rest in practice: rest is where learning is consolidated (stay tuned).

TABLE 2. Neuroscience-Based Respiration Video Resources.

Physiological sighs (to assist in cellular respiration via expansion of alveoli; also good for relieving stress):

- Dr. Andrew Huberman, Stanford University neuroscientist:
  — https://youtu.be/nWpYHfLtCFY
  — https://youtu.be/rBdhqBGqiMc

Exhale extension variations (to slow heart rate, induce calm, quell anxiety, and de-stress):

- Dr. Andrew Weil demonstrates the 4-7-8 breath strategy: https://youtu.be/p8fjYPC-k2k
- From the "Take a Deep Breath" Youtube Channel, a simple 4-8 strategy: https://youtu.be/8vkYJf8DOsc
- From the "Calm" Youtube Channel: a strategy involving holds in addition to a slightly elongated exhales: https://youtu.be/aNXKjGFUlMs

Boxed (or square) breathing (for calm, focused attention; ready for action):

- From the "Take a Deep Breath" Youtube Channel: https://youtu.be/FJJazKtH_9I
- University of Alabama using a visual representation to demonstrate: https://youtu.be/bF_1ZiFta-E

Wim Hof and Tummo* (to develop carbon dioxide tolerance):

- Wim Hof himself with a tutorial for beginners: https://youtu.be/0BNejY1e9ik
- Tummo breathing with Tim van der vliet: https://youtu.be/KMN_buD22MI
  — For a short description on Tummo: https://youtu.be

*These methods have numerous other effects, including dizziness and generating high body temperatures. Exercise with caution!

practice to give the brain the sense of optimization. They can also be used prior to a performance to quiet the nervous system. Anxiety is of course complex phenotype, but by understanding the biology of RSA these strategies can be a useful tool for singers and teachers.

Respiratory effectiveness strategies can be applied in many spaces: before a phrase, in the middle of a phrase, between songs, before a performance, after a performance, and throughout life. For singing, we need to train the brain to experience optimal respiratory states for all vocal contexts so the brain can focus on a motor signal directly related to the output. A challenging phrase can be worked on in isolation under optimal conditions to imprint a positive memory of success. The pathway becomes solidified with repeated practice and becomes an anxiety-free motor experience in context. We can transform something difficult and make it feel easy, which is an immensely powerful tool. The less effective but all too common alternative is to practice a phrase as is, the same way over and over, without proper homeostasis. This approach reinforces respiratory imbalance and creates a reproducible worry about breath for a particular phrase and compromises the motor calculation. Thus, every time a singer encounters it, there will be associated anxiety, rapid heart rate, and shallow breathing. It is much better to imprint all singing within the context of respiratory homeostasis.

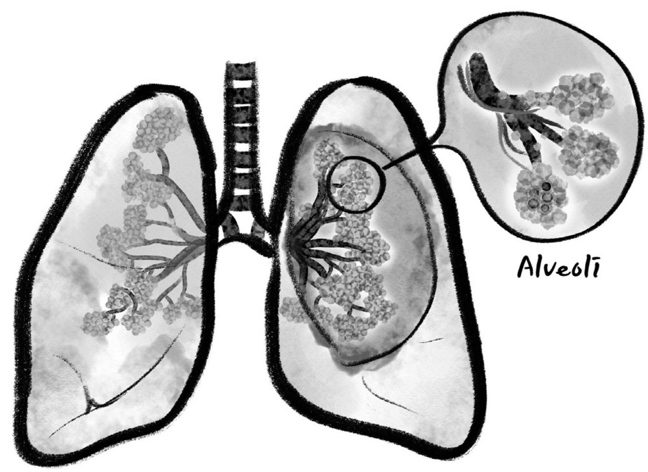

Figure 4. Human lungs with terminal alveoli enlarged. These balloon-like structures are critical for gas exchange. To maintain their structure and increase efficiency, respiratory sighs serve to inflate and expand the surface membrane which increases oxygenation. (Image created by Kang Kang and designed by Heidi Moss Erickson.)

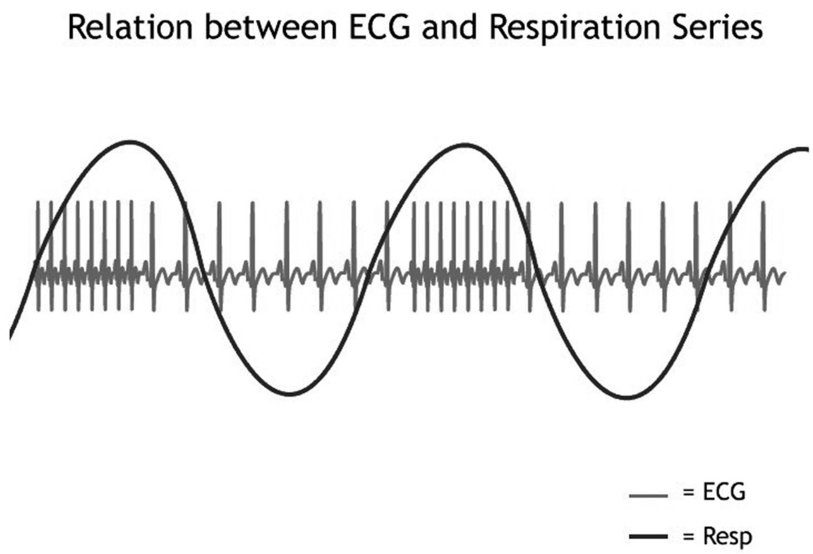

Figure 5. Model of Respiratory Sinus Arrhythmia = RSA. (Image created by Heidi Moss Erickson based on the literature.)

A sample protocol for practicing a challenging phrase begins with a few respiratory sighs, clear audiation of the phrase, a full exhale, followed by a slow, full inhale through the nose (Table 1). Poise is key. Many singers, when they don't like something or want to change an approach, stop, and restart before fully resetting. Teachers encourage this as well with their own enthusiastic cues. However, jumping right back in without recalibrating breath homeostasis results in breath stacking and CO_2 accumulation. Ensuring a student is fully exhaled with inflated alveoli, a good, calm inhale through the nose, and clear audiation with intention before any subsequent attempt is key. The last step is critical to recruit the proper amount of air. The phrase can then be woven in temporally in context, shortening the space each time until it is seamlessly integrated. Anecdotally, this has proven a successful strategy in the studio resolving breath problems without ever mentioning muscles of respiration.[33] If accessory muscle action is observed, it simply means the brain recruited them for the necessary vocalization without conscious activation. This is how the system is wired to operate. For teachers who prefer the mechanistic elements of respiration, this is a good moment for kinesthetic observation: pointing out *appoggio* or other muscle cues, if desired. With this kind of reductionist practice, singers naturally shift to breathing in context with fewer challenges.

These ideas also hold true to counter the natural declination rate. As we sing through a phrase, the pressure in the lungs decreases as it empties, impacting both our kinesthetic sense of airflow and the activation at the glottal source. The brain knows this process well, since it is a natural consequence of the system. Declination rates and pressure at the vocal folds will be addressed in more detail in the next installment on the vibrator, but understanding respiratory homeostasis is critical for addressing this aspect as well.

All singing is based on a motor calculation generated in the brain before the onset of vocalization. Breath is recruited based on that information; therefore, one cannot overemphasize the importance of vocal intention. Context is essential for the correct recruitment of breath. With a complex system and so many possibilities for practice strategies, we must carefully design targeted exercises with applicable concepts that ensure successful execution. When all other variables of respiratory homeostasis are optimized (or at least addressed), the brain can attend to the granular ideas necessary to achieve its vocal goal. Future installments will address these specific calculations more directly, but for breathing, intention of phrase is critical. Conceiving of the whole phrase, hearing it in one's head ahead of time, having an affective intention, even employing a physical movement (like drawing a big circle with an arm timed to the musical gesture), are all wonderful cues. This allows the brain to signal the amount of air necessary and how it should be managed to get through a phrase. Reductionist motor learning in the initial stages also assists in the brain's mapping of the goal and varied emotional and character intentions influence the brain's choice of air energy. This is true for both exercises and repertoire; all vocalizations should involve affect. Play and variation are friends to the brain, allowing it to draw from many sources to calculate the ideal vocal motor output in each moment.

The title "A Copernican Shift: Reframing How We Think About Breath In Singing" is meant to challenge the traditionally held view of breath mechanics as the first order of operation in singing. Breath has two key features singers and teachers need to consider: the autonomic state and the vocal motor calculation, where breath is recruited last. The idea of interpretation, intention, audiation, and affect, generally reserved as a blip in the last chapters in voice pedagogy texts, are essential first ingredients to establish the predictive motor coordination necessary for singing. The neuroscience perspective also reframes the idea that the most crucial element in the respiratory equation is carbon dioxide homeostasis, not the downstream muscular action of accessory muscles. As Dr. Jack Feldman stated, "the system is agnostic." If we choose to practice and perform under the umbrella of autonomic and respiratory homeostasis along with an interpretive intention, singing will become easier and more joyful. This is what we desire for ourselves and our students.

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My sorrow, when she's here with me,
Thinks these dark days of autumn rain
Are beautiful as days can be;
She loves the bare, the withered tree;
She walks the sodden pasture lane.

. . . . .

The desolate, deserted trees,
The faded earth, the heavy sky,
The beauties she so truly sees,
She thinks I have no eye for these,
And vexes me for reason why.

Not yesterday I learned to know
The love of bare November days
Before the coming of the snow,
But it were vain to tell her so,
And they are better for her praise.

Robert Frost, from "My November Guest"