Vocal resonance: Optimising source-filter interactions in voice training

Zac Bradford[1]

Abstract

The purpose of this article is to assist the voice practitioner in their teaching practice. This article will link information relating to source/filter interactions to practical application. Through the understanding and application of these concepts, one can elicit consistent positive change in students' voices. Furthermore, the practices discussed in this article will provide vocalists with a tangible way of repeating optimal voice production. Readers of this article will likely have different levels of familiarity with this information. I aim to persuade the reader that understanding concepts related to vocal resonance can be advantageous to voice practitioners. I hope to convince any sceptics of its importance to reconsider and explore this topic further. Understanding the scientific terminology and how the elements within resonance connect to each other may be an obstacle for some. The theory regarding vocal resonance is a key element in making voice practitioners more effective in their work. This article will provide a starting point for organising this information in a logical way and provide clear strategies for how this information could be used to enhance the teaching of voice.

Keywords

Voice; Pedagogy; Resonance; Acoustics; Singing; Teaching

Introduction

Voice science is being studied and explored by voice teachers (and other voice practitioners). An increasing number of voice pedagogy courses, being offered through universities and independent organisations suggest this trend will continue (Harris 2016, Courses; Michael, Graduate Voice Pedagogy). Of all topics in voice pedagogy, resonance is often the most challenging to understand. Voice Resonance encompasses concepts such as formant tuning/detuning, semi occluded vocal tract postures, impedance matching, linear and non-linear source filter theory and velopharyngeal opening. I have personally witnessed numerous positive transformations in my

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students as a direct result of applying techniques based on resonance concepts. These topics will be discussed later in this article.

Despite the vast amount of information on this topic available to the voice community, I have observed that there is often a disconnect when it comes to creating clear links between the science and practical application. Howell states: "Admittedly, at least based on how the concept is currently explained, there is a high knowledge threshold required before formant theory becomes truly practical for most singers. A recent informal Facebook poll of my singing and voice teaching friends revealed a wide divergence in both the basic understanding and practical application of formant theory" (Howell, A Spectrogram…). It is my hope that this article will help lessen this disconnect and provide the reader with greater understanding and ability to apply the source/filter concepts.

One approach to training that strives to link voice science and practice is Mindful Voice Production (MVP), created by vocologist Dr Brian Gill (Gill 2015, Mindful Voice Production). MVP is not a method, but rather an approach which utilises "tools" informed by a detailed understanding of the human voice, including resonance and its various topics. Gill says "there are many ways you could approach practical application, but you have to have a-way" (Gill, October 2018 Personal Communication).

This article will begin by providing a brief overview of how the human voice works in light of current voice research. The second part of the article will explore three theoretical concepts relating to vocal resonance, and strategies for utilising them in practical application. The application of the concepts discussed in this article are heavily influenced by Gill and his approach to voice training, MVP.

Why explore vocal resonance?

> *Of all instrument makers the voice builder is in greatest need for exhaustive and exact information about the instrument he makes, for the reason that the voice is of all musical instruments the most complicated in its method of tone production. (Redfield 278-279)*

Having a detailed understanding of how the voice works can be of great benefit to the voice practitioner. I have spoken with many voice teachers who are not familiar with detailed scientific information pertaining to vocal resonance, and vocal production and they are able to achieve positive results with students through intuition, heightened listening skills and time-tested exercises. Understanding source/filter relationships can add to your tool kit, enhance your efficacy as a practitioner, and inform your understanding of why an exercise is, or isn't eliciting efficiency in the voice. Optimising source/filter interactions can result easier vocal production and enhanced sound output for less effort for the student.

Resonance adjustments have the potential to impact the vocal output and input of the voice user (Bozeman 10). The output may consist of vocal dynamics and timbre. Vocal input (the way in which the voice operates) includes stability, ease of production,

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efficiency, flexibility and register transitions. If optimal resonance adjustments are made, vocal function can be enhanced. This enhancement of vocal function may assist in vocal sustainability by minimising vocal fatigue for a given task. Other potential benefits are that as the body is producing sound more efficiently there can be a physical freedom that allows the vocalist to be more expressive in their communication.

It is well established that some professional actors and singers take advantage of resonance strategies (Raphael 83-87). While the science behind resonance is relatively new, the practical effects have been realised in a practical setting for many years. Constantin Stanislavsky (1863-1938) wrote about the positive effects of resonance on the voice, before the scientific community understood non-linear source-filter interactions in the voice. Stanislavsky made specific mention of benefits including balanced timbre, carrying power of the voice, increased range, ease of production, and the ability to vocalise for long periods of time without the voice tiring (Stanislavski 94-101). Teachers of the bel canto tradition, including Mathilde Marchesi (1821-1913), also had discovered this through practical explorations (Doscher 178).

A brief summary of vocal resonance research

Source-filter in voice production

In order to understand source-filter, it is important to first break it down to its components; the source, the origin of voiced sound, and the filter, the cavities which the sound energy passes through as it exits the body (see Figure 1).

Source

The voice source is the pulsing trans-glottal airflow (Miller 122; Sundberg 2018) (Miller 122). In order for voiced sound to be produced, certain conditions must be set up in the vocal apparatus. These conditions involve the positioning of the vocal folds (source) and the sufficient lung pressure. When the vocal folds are adequately adducted (i.e. brought together), an increase in breath pressure (relative to atmospheric pressure) sets the vocal folds into vibration. The vibrating vocal folds create alterations in pressure. Phases of increased pressure (compressions) and decreased pressure (rarefactions) result in sound waves. These pulses of transglottal air flow generated by the vibrating vocal folds will from here on be referred to as the “Source”. Sound waves are then propagated through the vocal tract (Gill, Vocal Tract Tuning).

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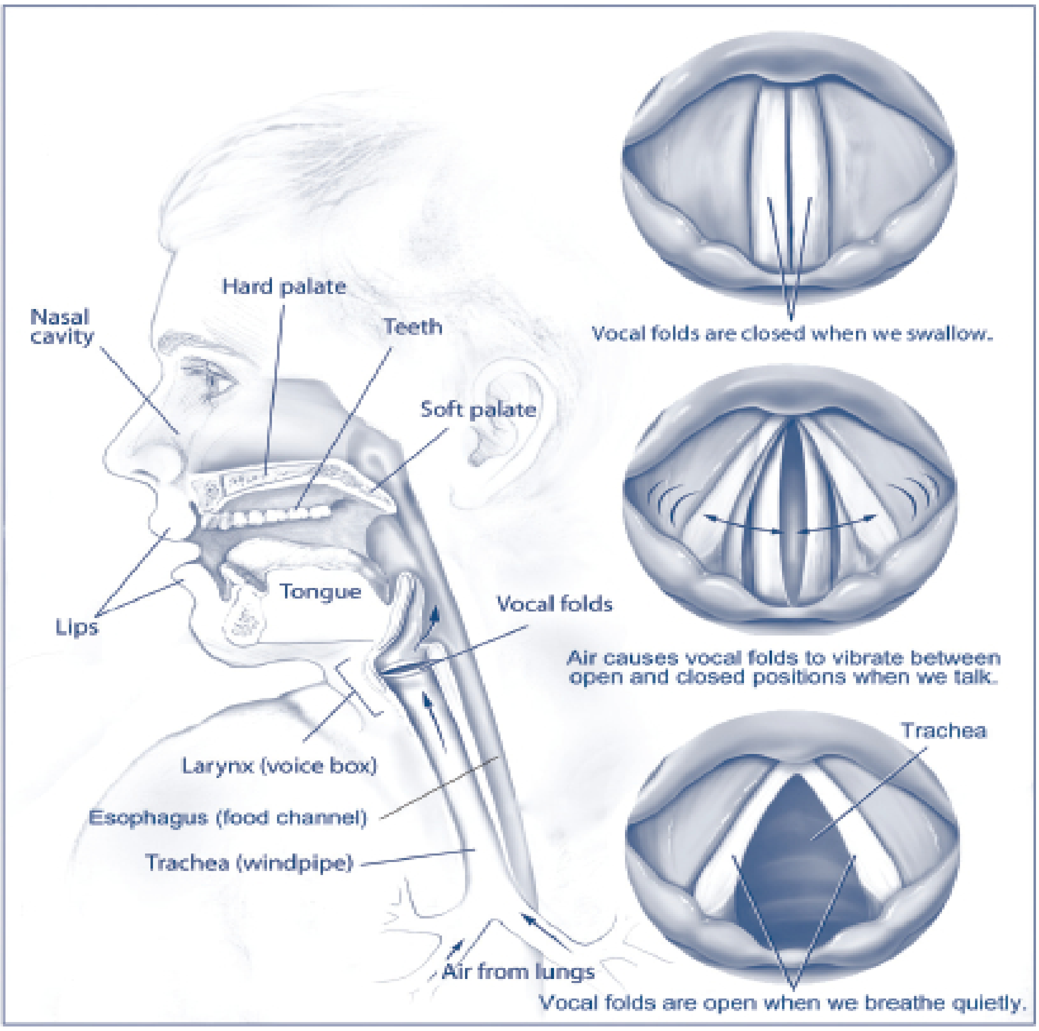

Figure 1. Source, filter and vocal fold vibration. (Source: File: Hoarseness image.jpg, used under Creative Commons Attribution–Share Alike 4.0 International License.)[2]

Filter

The vocal tract is a selective sound filter (Doscher, xviii): selective, in that some information produced at the source is enhanced and other parts of the signal are diminished. The vocal tract is comprised of the pharynx (laryngo, oro and naso), Oral Cavity and Nasal Cavity (McCoy 17) (Gill Vocal Tract Tuning) (see Figure 2). The term "filter" will be used to represent all of the aforementioned components of the vocal tract.

[2] https://en.wikipedia.org/wiki/File:Hoarseness_image.jpg
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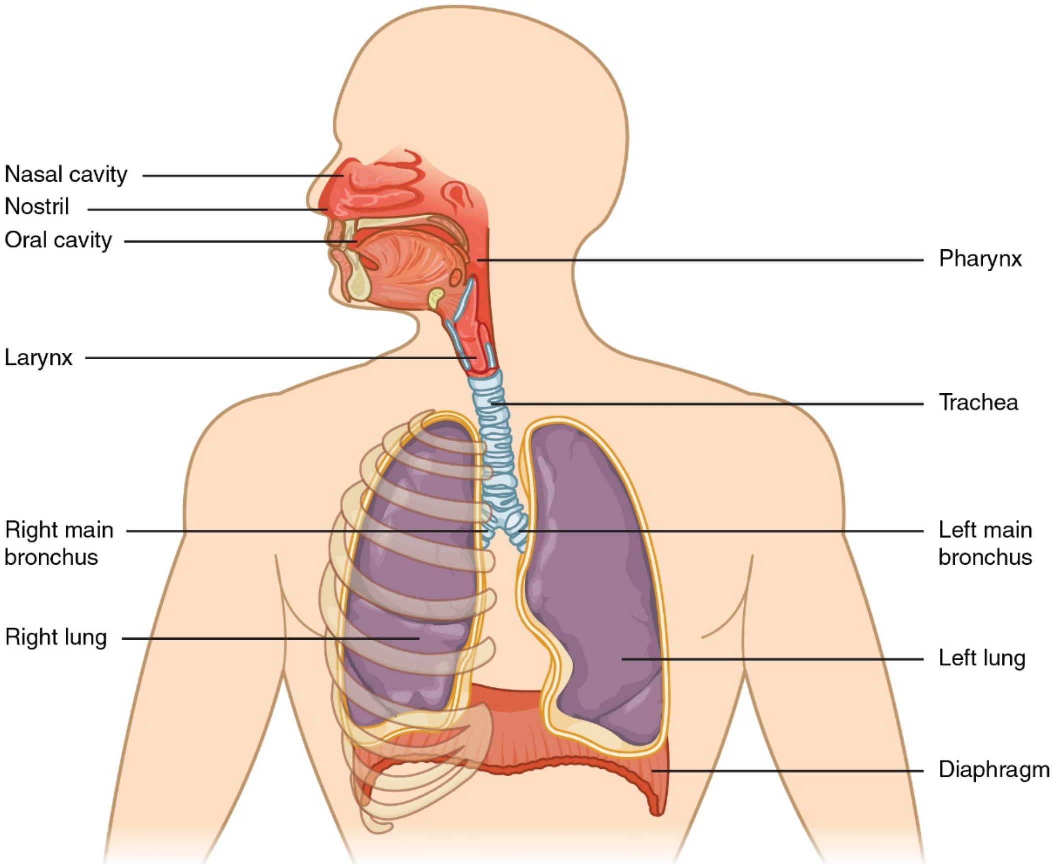

Figure 2. The sound producing system. (Source: File: 2301 Major Respiratory Organs.jpg, used under Creative Commons Attribution 3.0 Unported License.)[3]

Resonance

Before exploring the theoretical underpinnings of the voice source and filter further, it will be helpful to have a definition of what resonance is. Resonance has been defined as "A Condition that exists between the source of energy and the configuration of the medium such that the energy of some frequencies of vibration will be kept alive in the medium while others will quickly die off" (Story 1999, 1).

Using Dr Story's definition as a framework, I will now explore the voice source, the frequencies of vibration produced and the "medium" (aka filter) in which these frequencies travel through. This will provide us with a point of reference in the practical application section of this article.

[3] https://commons.wikimedia.org/wiki/File:2301_Major_Respiratory_Organs.jpg (Creative Commons: https://creativecommons.org/licenses/by/3.0/deed.en)

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Prominent theories of source-filter interaction + analogy

There are two prominent theories of source-filter behaviour in the human voice, the Linear and the Non-Linear source-filter theories. The relationship between a performer, and an audience can be looked at through a linear and non-linear lens (Bozeman 10). In this analogy, the linear relationship is like that of a film actor and a camera (see Figure 3). The performer is the source of energy. This energy is received by the camera, which acts as a filter. The performance is transmitted from the camera to the audience as they view it on a screen. It is important to note that the audience's response does not affect the performer during the filming.

Figure 3. Actor and camera analogy for linear source/filter theory. (Source: Filming Actors at Table, Motion Picture Kitchen Set, Texas-Illinois Co, used under Creative Commons Attribution–Share Alike 4.0 International License.)[4]

In a non-linear relationship, this relationship is like a live show in a theatre. The actor remains the source of energy, and the energy is received by the live audience. The audience may respond or react in a number of ways. The audience reaction, then, has the potential to impact the performer's ongoing performance. If the performer is inexperienced, booing from the audience may derail the performer completely, causing them to forget a line or lose confidence. In an optimal setting, great applause from the audience may give the performer a boost of energy that assists in their ongoing performance. Contrast that with an experienced performer, who on the other hand, may be able to perform at a high level regardless of the audience response (Story 1999, 1) (see Figure 4).

[4] https://www.flickr.com/photos/smu_cul_digitalcollections/14152548523
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Figure 4. Performer and audience interaction, used as an analogy for non-linear relationships in voice production. (Source: No title, used under Creative Commons CCO 1.0 Universal License.)[5]

The voice source and filter can have similar interactions to the performer and audience (see Figure 5). In a linear situation, the information produced at the voice source is filtered by the vocal tract, and received by the listener. In a non-linear relationship, the same occurs, however, the interaction doesn't end there. If the filter is shaped optimally, this has the potential to enhance the vocal fold vibration, via a backward flow of energy from the vocal tract to the vocal folds. If the filter is not shaped well for the given pitch being vocalised, the mismatch of source-filter may interfere with the ease and evenness of vocal fold vibration (Titze Vocology 287).

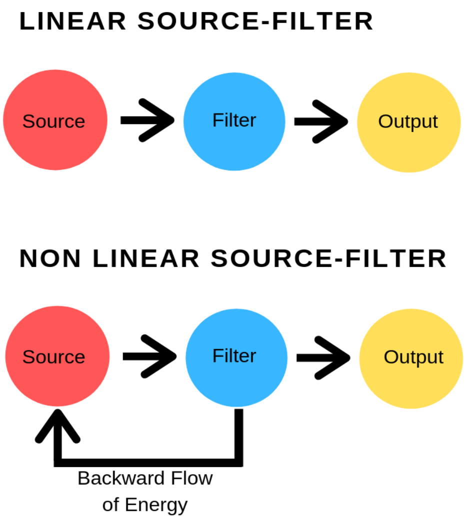

Figure 5. Source/filter theory: Linear and non-linear.

[5] https://pxhere.com/en/photo/950795
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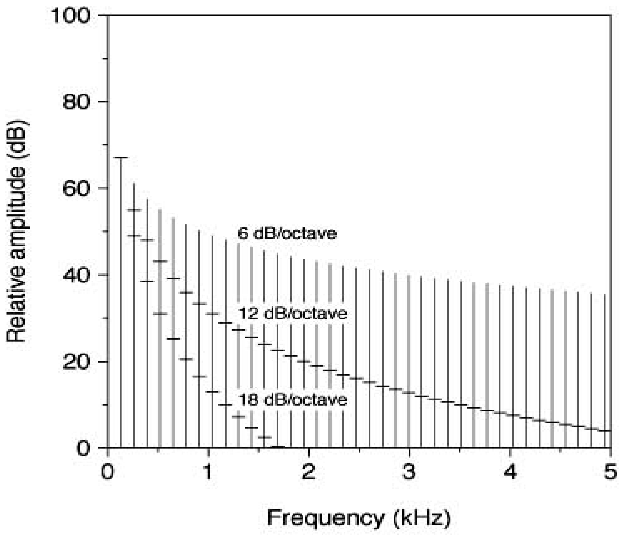

Figure 6. Spectral slope. (Source: Ingo R. Titze, National Center for Voice and Speech, reprinted with permission.)[6]

Source-filter interactions

Taking advantage of optimal vocal tract configurations to enhance vocal fold behaviour in voice training and performance can be beneficial to the vocalist. When the source and filter interact in a positive way, vocal effort can be minimised for a vocal output (Story 2000; Sundberg 2017). Learning what these optimal filter configurations are, and how they can be accessed, will be explored in the practical application section of this article. These strategies may allow vocalists to experience a more efficient way of vocalising (Titze Vocology 286). It can be quite useful for vocalists to learn to bypass these interactions also, when/if needed for a certain timbral aesthetic. However, this is often difficult to achieve initially, and may be wiser to experiment with over a longer period of time during training.

Variations in the sub-systems of the vocal instrument can occur, resulting in endless combinations of interactions, e.g. varying muscular contractions, levels of sub-glottal pressure, lung volume etc. The voice practitioner benefits from considering the interdependency of the systems of the vocal apparatus on the whole instrument. Exploring the endless variables and combinations of the various sub-system interactions are beyond the scope of this article.

Understanding the voice source

The voice source produces a sound wave. This sound wave consists of the fundamental frequency (F0), which is associated with the pitch that listeners perceive, and is synonymous with the first harmonic (H1). Harmonics are all integer multiples of the fundamental frequency (Gill, Vocal Tract Tuning...).

6 http://www.ncvs.org/ncvs/tutorials/voiceprod/tutorial/graphing.html

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Voice scientists use a theoretical construct known as a Source Spectrum to isolate the unfiltered sound created at the voice source from that which is filtered by the vocal tract. This source spectrum is thought to drop off from -6dB in loud vocalising, -12dB per octave in speech, and breathy phonation can be -18dB per octave (McCoy 23; Miller 120-21) (see Figure 6). “Harmonics in the sound produced by the vibrating vocal folds gradually decrease in amplitude relative to the fundamental. This phenomenon is called spectral slope…” (McCoy 23). The amount of contact and closure time of the vocal folds during each vibratory cycle has an influence on the decay rate of harmonics. The longer the closure time the more prominent the higher harmonics (Doscher 126). There is also a link between the source spectrum and the tonal quality the listener perceives in the voice (Sundberg 1987, 76).

This information can be of value to a practitioner. If a student is not needing to produce a brassy sound (rich in higher harmonics), then very little vocal fold closure time will be required. Taking advantage of a well-tuned vocal tract and amplification may be more than sufficient to create the desired aesthetic. Minimising vocal fold closure time, and therefore friction of the vocal fold tissue is also a vocal health and sustainability consideration that can benefit vocalists (Gill, Vocal Tract Tuning…; Titze 2012, 18).

The vocal tract can only filter information produced at the source. For example, if the source does not produce information in the higher frequency range of 2,500 -3,500 Hz, then the filter cannot boost it, because it does not exist. This may happen in breathy vocalisation (refer to Audio Clip 1), which has a strong fundamental frequency and very little information above the first few harmonics (McCoy 23-24).

Audio Clip 1.[7] Breathy phonation (little closure time at the vocal folds results in a steep drop-off of amplitude).

Understanding the filter

As mentioned previously, the filter consists of the pharynx, the oral cavity and nasal cavity. The pharynx can be divided into three sections: the larngo-pharynx, oro-pharynx and the naso-pharynx (see Figure 7).

“The unique feature of the vocal apparatus is that the size and shape of the resonant system is under conscious control of the speaker or singer” (Culver 226). The articulators are under the conscious control of the vocalist. These include the pharynx, tongue, palate, jaw and mouth opening and lips. The configuration of these articulators influences the size and shape of the vocal tract. For example, if the hump of the tongue is depressed, a larger space is created in the oral cavity, and constriction increased in the pharynx. This brings us to the formation of vowels.

[7] To listen to this audio clip (and Audio Clips 2 and 3) please download and save this PDF to your device; Adobe Flash Player may also be required.

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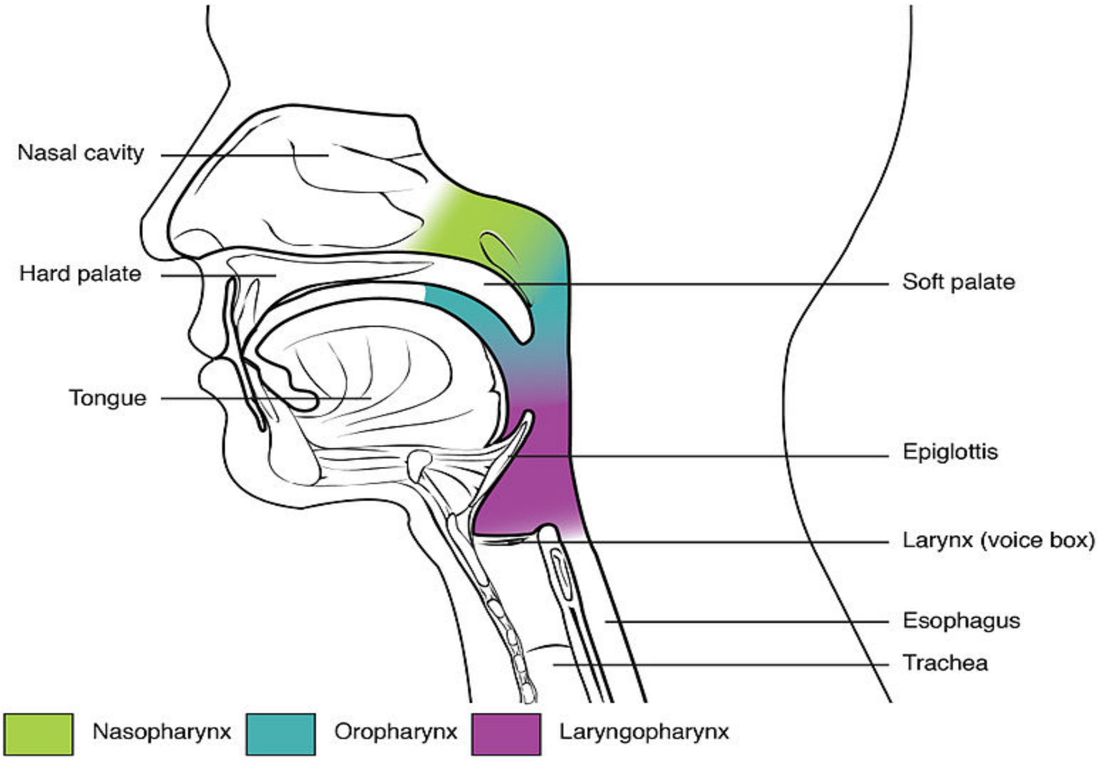

Figure 7. Divisions of the pharynx. (Source: File: 2305 Divisions of the Pharynx.jpg, used under Creative Commons Attribution 3.0 Unported License.)[8]

Formants and vowels

The vocal tract has multiple resonance chambers. If you have read vocal resonance literature, then you are likely to have come across the term formant. "A formant is a variable resonance of the vocal tract" (Miller 113). A formant is variable as you can alter it by adjusting the articulators to form various configurations. The lowest two resonances of the vocal tract are known as vowel formants, often referred to as F1 and F2 (or R1 and R2, R standing for Resonance). F1 is sensitive to changes of space in the pharynx. While F2 is sensitive to changes of space in the oral cavity. It must be said, that F1 is not the pharynx, and F2 is not the oral cavity. This is important, as changes to lip rounding can impact F1, and changes to larynx position can impact F2.

Altering F1 and F2 to be more sensitive to the information produced at the source is often referred to as vowel modification (Miller 29-30). Variations in space, size, opening, texture of the wall can impact the resonance frequency of a Formant. Barbara Doscher says:

> *The larger the cavity, the lower the frequency to which it resonates, the smaller the cavity the higher the frequency … The longer and narrower the neck of the opening, the lower the frequency to which the cavity responds. The wider and flatter the neck, the higher the frequency … The softer the*

[8] https://commons.wikimedia.org/wiki/File:2305_Divisions_of_the_Pharynx.jpg (Creative Commons: https://creativecommons.org/licenses/by/3.0/deed.en)

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> *walls, the more the lower overtones are emphasised. Hard walls encourage higher partials. (Doscher 103-4)*

These acoustical laws will provide insight on how vocalists can produce more output for less effort. I will explore in more detail how these adjustments can be made in the practical application section of this article.

Vowels have certain characteristics that can be visualised using MRI and vowel formant charts. Looking to Figure 8 notice the differing vocal tract shapes for four vowels: /a/, /ɑ/, /i/ and /u/ (refer to Audio clip 2). The /ɑ/ vowel (as in "Father") has a constriction in the pharynx and a large space in the oral cavity. This pharyngeal constriction is linked with a high F1 frequency (see Figure 9). The larger space in the oral cavity is linked with a low F2 frequency. Recall what Doscher said regarding the size of the cavities. Notice how the coordinates for the /ɑ/ are close together at roughly 750Hz (F1) and 1000Hz (F2) (see Figure 9).

The /i/ vowel (as in "tree") has a large space in the pharynx and constriction in the oral cavity, leading us to the conclusion that /i/ will have a low F1 (near 300Hz) and high F2 (2,400Hz). The /u/ vowel has an intermediate pharyngeal constriction, giving it an F1 near 250Hz. While /u/ has a large space in the oral cavity, giving it the lowest F2 of the vowels (600Hz).

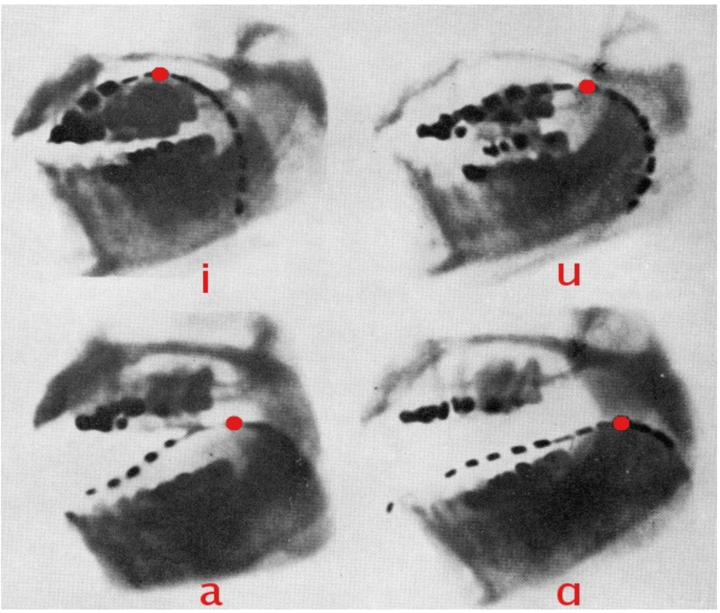

Figure 8. Vocal tract shapes for various vowels. (Source: X-rays of Daniel Jones' [i, u, a, ɑ], used under Creative Commons Attribution 3.0 Unported License.)[9]

[9] https://en.wikipedia.org/wiki/Vowel#/media/File:Cardinal_vowels-Jones_x-ray.jpg (Creative Commons: https://creativecommons.org/licenses/by-sa/3.0/)

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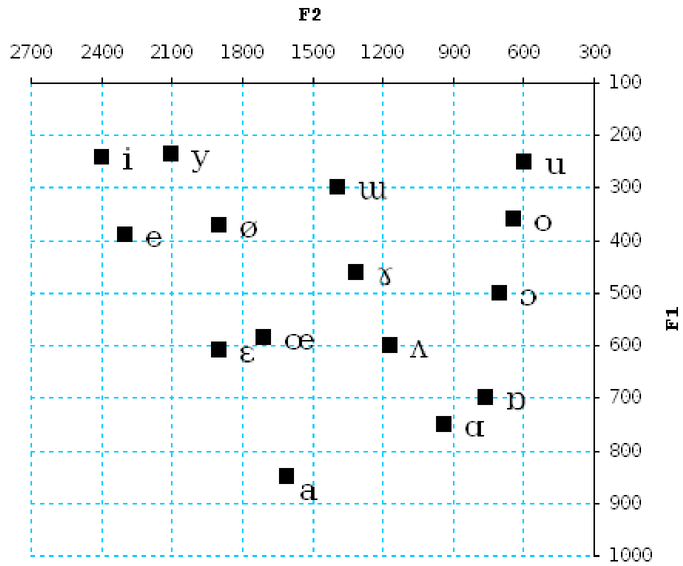

Figure 9. Average vowel formants F1 F2. (Source: File: Average vowel formants F1 F2.png, used under Creative Commons Attribution–Share Alike 4.0 International License.)[10]

An important note: vowels are not defined by an absolute point, but rather, cover a large region. There are a range of options when it comes to shaping a vowel. For example, the /u/ vowel has an F2 that could be as low as 500Hz or as high as 1,110Hz depending on how it is articulated, or who it is articulated by (other vowel charts reflect these variations). The size and shape of the individual's vocal tract are some influencing factors that will impact the formant frequencies of vowels. Shaping vowels so that the resonant frequency of the space (filter) is in close proximity with the frequencies produced by the vocal folds (source) is of benefit to the vocalist. In a practical setting this is valuable information, as it gives you a range of options for shaping a vowel for dramatic, stylistic or functional reasons.

Audio Clip 2. Vowel sequence (/a/ /i/ /u/ vowels vocalised).

Summary of resonance theory

To summarise the theory section, the vibrating fold folds interrupt trans-glottal airflow, which is the source of vocal sound. This source of energy consists of the fundamental frequency (the pitch we perceive) and a series of harmonics, all which are multiples of the F0. This information is selectively filtered by the vocal tract. The shape, size and

[10] https://commons.wikimedia.org/wiki/File:Average_vowel_formants_F1_F2.png (Creative Commons: https://creativecommons.org/licenses/by-sa/4.0/deed.en)

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opening of the vocal tract will determine which harmonics are boosted and which die off. The vowel formants (F1 and F2) determine the vowel.

There are two prominent theories of source-filter interaction, the linear and the non-linear. According to the non-linear source-filter theory, the filter has the potential to influence the way in which the source functions. The remainder of this article will explore practical strategies for taking advantage of these non-linear interactions for optimal ease and efficiency in vocal production.

The how: Practical application, putting it together!

Resonant voice

Before delving into these three concepts, it may be helpful to define resonant voice in clinical terms. “Clinically, resonant voice has been defined as any voice production that is both easy to produce and vibrant in facial tissue” (Titze, 2012, 286). So why is resonant voice so important for vocalists? Firstly, it is a health consideration, the ease of vocal production is linked with minimised friction at the vocal folds. Gill suggests that “The sympathetic vibrations toward the front of the face are indicative of an effective resonator, whereas the ease of production is indicative of an effective use of the vibrator, which is often dependant on the efficiency of the resonators” (Gill, Vocal Tract Tuning…).

These sensations can be useful for the practitioner and student during voice training. Sympathetic vibrations toward the front of the face can aid the vocalist in learning to monitor if the voice production is efficient. When the conversion from Aerodynamic to Acoustic energy is efficient, the sound is carried away from the source, hence, vibrant in facial tissue (Titze 2012, 287).

It is worth mentioning a caveat for all concepts relating to application. If an exercise should work in theory but is causing the student discomfort, e.g. if the student is experience vibrations towards the front of the face during vocalising (which in theory is ideal), but is simultaneously using pressed phonation (straining), then something needs to change. Take into account how much breath the student has inhaled, the age, gender, existing vocal habits and the size/shape of the body of the individual. These variables are just some important things that may influence how you help a vocalist adjust to vocalise more efficiently. For example, working with an unchanged adolescent voice will differ from that of an adult male. Pitch range, formant frequencies and vital lung capacity are just some of the obvious differences that will need to be considered when making adjustments with these two demographics (Titze 2005).

This final section of the article will address three main concepts that take advantage of shaping the vocal tract to enhance the behaviour of the vocal folds. Sound output can also be enhanced (increased volume/clarity), for minimal vocal effort as a result of these source/filter interactions. The three concepts to be explored are Formant Tuning, Semi Occluded Vocal Tract Exercises and Velopharyngeal Opening. All of which will be

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defined, their specific benefits mentioned and practical strategies for their application presented.

Formant tuning: What is it?

The first concept to be explored is Formant Tuning, defined by Bozeman as "The tuning of one or both of the first two formants in order to find a better formant/harmonic match for greater resonance" (106). This involves the vocal tract being shaped in a way that aligns with the pitch being sung/spoken. Both professional actors and singers have been shown to utilise formant tuning (Raphael 83-87). The pitch could be altered so that it better aligns with one of the formants. However, it is often the case in a musical context that the pitches have been decided by the composer of the song. In this situation, it makes more sense to alter the shape of the vocal tract to meet the needs of the sound wave.

As Gill says: "Vowels create spaces. Those spaces have an inherent pitch. The vowels need to be tuned to the voice pitch in order to be acoustically sensitive. Or modified to be acoustically sensitive" (Vocal Tract Tuning…). This concept is often referred to as vowel modification by voice teachers and vocalists. Vowel modification often gets a bad reputation, possibly because the modification is sometimes done to the point where the lyric being vocalised is not intelligible or is too far removed from the intended vowel. I have observed that when modification is done by elite vocalists, it is usually so nuanced that it is probably not noticed by the average listener.

Figure 10 provides an example of a vocal tract configuration where the F1 has a frequency of 300Hz and an F2 of 900Hz. On the right-hand side of the image are the fundamental frequency (bottom), and all of the harmonics produced (above). Notice that all of the harmonics are multiples of the fundamental frequency (i.e. F0 = 300Hz, and 300 x 2 = 600Hz which is H2 etc.).

In this particular example the vocal folds are vibrating at a frequency of 300 Hz (we perceive this as D4). F1 is aligned with H1 (300 Hz), while F2 is aligned with H3 (900Hz). In other words, the frequencies from the vocal folds line up with frequencies of the vocal tract. You could then say that F1 is tuned to H2 (F1/H2) and F2 is tuned to H4 (F2/H4). These particular formant/harmonic interactions have unique aesthetic qualities (timbre, dynamics, etc.) associated with them, as well as a possible influence on the vocal fold vibration. These unique qualities may be used for expressive, stylistic or dramatic purposes.

If you wish to explore this further, there is a range of affordable voice software that can aid in understanding and exploring these concepts. Software includes Voce Vista and Madde Voice Synthesiser, which allow the user to measure acoustic output and experiment with hypothetical formant-harmonic interactions. Voicescienceworks.org also has many wonderful resources on this topic.

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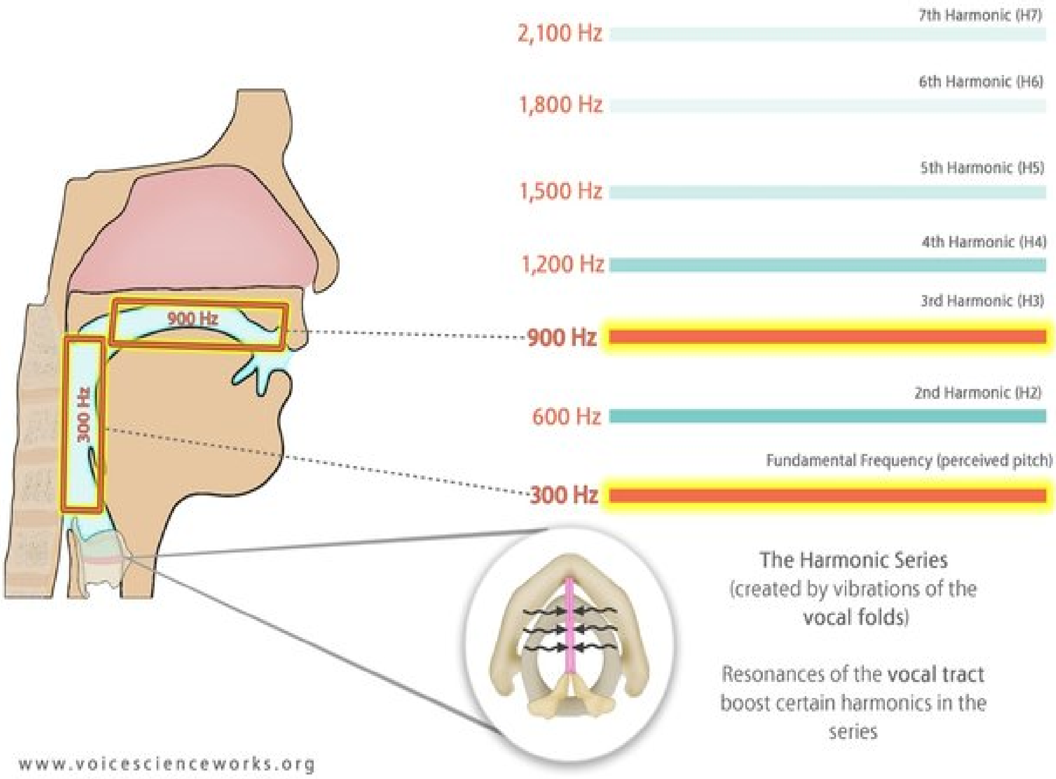

Figure 10. Harmonics from the vocal folds lining up with the formants in the vocal tract. (Source: Laurel Irene & David Harris, Voice Science Works, reprinted with permission.)[11]

Benefits of formant tuning

Vowel modification done well (i.e. formant tuning) can be used to affect positive change in the way in which the vocal folds vibrate. Barbara Doscher says "Simply stated, vowel modification can produce changes in glottal airflow and pressure, which in turn alter the vibratory pattern of the vocal folds" (151). Story agrees, and adds "Phonating at a frequency at or near the first formant may allow for an efficient voice production that could possibly be associated with lower vocal effort" (1999, 1). I have witnessed many times that when the vocal production is more efficient, vocalists are freer to be expressive and communicate more effectively.

In addition to the ease and evenness of the vocal fold vibration, you can also get more bang for your buck with formant tuning. "The most obvious advantage that comes from even an approximate tuning of the first formant is a very large increase in the loudness a singer can achieve for a vocal effort." (Benade 80) It is much wiser to use formant tuning to gain an increase in vocal loudness rather than solely increasing sub-glottic pressure to achieve the same result. Vocalists who use improper amounts of subglottic pressure can experience negative consequences while vocalising (e.g. instability, noise

[11] https://www.voicescienceworks.org/resonance.html

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in the sound, voice cracking, strain etc.). Gill states "Extra subglottic pressure leads to extra friction, which causes a breakdown of the tissue of the vocal folds" (Gill Vocal Tract Tuning; Gill 2014).

How do I tune my formants?

When assisting a vocalist in vowel modification, knowing how filter adjustments will impact formant frequencies (i.e. pitch of the space) is of great use. The following rules have been adapted from Dr Ingo Titze's four rules for modifying vowels:

1. To lower F1 and F2, increase the length of the vocal tract increases (lip rounding and/or lowering of the larynx).
2. To raise F1 and F2, increase lip spreading.
3. Lower F1 and raise F2 by creating a mouth constriction. (close the mouth, front the tongue)
4. Raise F1 and lower F2 by creating a pharyngeal constriction. (lower the jaw, depress the tongue)

(Titze 2005;[12] Gill Vocal Tract Tuning)

Formant tuning strategies

When creating vocal exercises, utilising vowels with formant frequencies in the range you are going to have the student vocalise in may be a wise choice. Let's focus on the F1 (first formant) location of vowels (see Figure 11).

If you were to create an exercise starting at the note F 4 (350Hz), in the passagio for a high voiced male or lower-middle voice for female range, the /u/ vowel (as in "you") may be an ideal choice. The /u/ vowel has a low F1, approximately 250Hz-400Hz. The /u/ vowel may be helpful to the student within a few tones of F 4. If the exercise is taken too much higher, a change may need to be made to the vowel to keep the source-filter interacting optimally.

Continuing with this example, let's say you take the same exercise pattern up to Bb4, where the /o/ vowel is optimal (see Figure 11). You may choose to ask the student to open the vowel slightly, still keeping the lips narrow, but creating a little more space between the front teeth. This opening of the teeth would raise the frequency of F1. If done subtly, it may be enough of a vowel modification to keep the vocalist producing sound in an easy and efficient way, as F1 would stay in alignment with a Fundamental Frequency (F0 or H1). For other students, vowel substitution may be the wiser choice. You may ask the student to substitute to the intermediate vowel /ʊ̈/ (as in "good"), as the exercise ascends from F 4 to Bb 4. This is often enough of a change to help the

[12] www.ncvs.org/ncvs/tutorials/voiceprod/tutorial/rules.html

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student. Some students will need a little more alteration and will benefit from singing /o/.

You as the practitioner can then assess the sound being produced. Is the voice production relatively effortless? Is it clear? Smooth? etc. Your listening ability, coupled with asking the student what it feels like, will give some pretty strong indicators of whether it was a more efficient way of vocalising. When the voice is resonant, students will often describe the experience as feeling forward, or higher up in the face/head. Possibly the most common response when it is "right" is – "that felt so much easier" or "it felt more open".

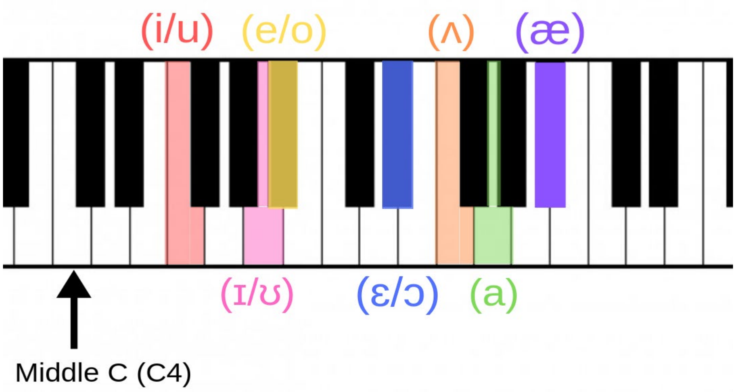

Figure 11. Optimal vowel frequencies.

Pairing vowels

Another useful strategy is to pair a vowel with a F1 approximate to the pitch range the exercise is in, with a vowel that is further away from the pitch to be sung. Let's say a female student finds it challenging to produce an /a/ vowel (as in "father") on an Bb4. A wise choice may be to pair /ɑ/ with /o/ in the exercise. /o/ has an F1 at approximately Bb4. You could then design an exercise starting at Bb4, having the vocalist alternate from /o/ to /a/. The goal would be to have the student try to minimise movement of the articulators as they briskly alternate between the two vowels. What this may do is get the F1 of the /a/ vowel to migrate toward that of the /o/ vowel. In other words, you are helping the student to lower the First Formant (F1) of the /ɑ/ vowel to match the pitch being vocalised. Using a mirror can be helpful for the student to monitor minimising movement of the lips and mouth opening. It is important that the student doesn't lock the articulators into place in order to achieve this, as rigidity may bring about other unwanted tensions. The key is flexibility of the articulators, while minimising their movement.

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While these exercises take advantage of source-filter theory to elicit more efficient vocalising, it is important to note that elite vocalists learn how to take advantage of positive interactions when it suits them and circumvent negative source-filter interactions when they need to (i.e. to produce a certain aesthetic, etc.). I would suggest that this be a long-term goal for all vocalists, and worked on gradually after experiencing optimal source-filter interaction.

Semi Occluded Vocal Tract exercises

The second concept relating to source-filter interaction to be explored is Semi Occluded Vocal Tract exercises (from here on referred to as SOVT). Kenneth Bozeman defines a SOVT as "a vocal tract with an exit sufficiently narrowed to generate flow resistance or acoustic impedance" (Bozeman 112).

Benefits of SOVT exercises

When resistance is created away from the vocal folds, this helps to reduce the pressure that falls across the vocal folds as they vibrate (Gill 2014). SOVT exercises help the vocal folds to stretch and un-press (Titze 2017, 139). Stretching is advantageous as it allows blood to flow to the muscles. It is also a key factor in accessing higher pitches and maintaining vocal flexibility. Un-pressing has to do with bringing the vocal folds apart, also known as abducting. This is very important as it can help minimise the collision force, and friction of the vocal fold tissue as they vibrate. Friction is the enemy of the tissue, excessive friction can lead to injury, so we want to minimise it as much as possible (Gill, Vocal Tract Tuning). It has also been shown that un-pressing assists in the stretching of the vocal folds (Titze 2017, 135-141). Which may suggest that it is beneficial to un-press the middle voice using SOVT exercises, before stretching in the higher range where more stretch is required (Titze 2012, 198).

SOVT exercise strategies

There are many SOVT to choose from, with many variations. SOVT exercises include the lip trill, straw phonation, the raspberry, tongue trill, /u/ vowel (when rounded), hand over mouth, fricatives and many more. Some vocalists find lip trills (two lips vibrating) easier to vocalise on, while others prefer the raspberry (tongue out, and vibrating with lip/s). Understanding Impedance Matching can provide further insight into which SOVT exercises may be more useful in various circumstances. Impedance matching is beyond the scope of this article, so it will not be discussed further.

Optimising a lip trill

We will focus on perhaps the most commonly used SOVT exercise, the lip trill (also referred to as the lip bubble). This SOVT exercise requires air from the lungs to set the lips into vibration. Many students find the lip trill hard to coordinate. Let's explore some approaches to helping your student trill more easily. Learning to do the trill unvoiced is often an easier place to start for most people (where the vocal folds are not

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vibrating). If the student is able to maintain a voiceless trill, then graduating to short, simple musical patterns on a voiced trill may be a logical next step.

Breath energy is one of the most useful elements to consider when enhancing the trill. If the lips are not vibrating easily, ask the student to increase the amount of air they blow. They may need a little or a lot more, and in some cases the thought of less breath will help the student find the balance required to set the lips into steady motion. It can also help to ask the vocalist to do a voiceless trill for a couple of seconds and then add voice in the same uninterrupted trill. For some students the vibration at the lips will diminish or even stop when the voice is added. Asking them to "sneak" the sound in, or to be "gentler" with the voice as it enters the trill will often help them to find a better flow/pressure ratio (Gill 2014).

Another element under the conscious control of the vocalist is the tension of the lips. If the student's lips are tight (i.e. they are unable to move in a trill), asking them to gently stretch the facial tissue on and around the lips (with their hands) prior to trilling, may be sufficient to set the lips up to better receive the air. For others, the position of the lips may be too far apart when the breath flow starts, preventing easy vibration. In this case, asking the student to gently press their lips together and protrude them (prior to trilling), may be enough of an adjustment to encourage easy and even vibration of the lips.

It is likely that some students will have air fill their cheeks as they start to trill, and the lips fail to vibrate easily. Placing their hands on their cheeks can be a starting point for directing the air to the lips and away from the cheeks. You can then encourage them to experiment with various hand positions (relative to the lips), and varying amounts of tension of the facial tissue (influenced by hand position and pressure against the face). Students will likely find a "sweet spot" after exploring various combinations of hand placement and tension of facial tissue. These adjustments may seem like tedious task to undertake, but the positive change they can elicit continues to amaze me. Gill states, "Hypothetically, even and easy vibration at the lips during a lip trill, is indicative of evenness and ease of vibration at the vocal folds" (Gill, October 2018 Personal Communication).

Contexts for the lip trill

Lip trills (and other SOVT exercises) can be combined with other concepts such as formant tuning for further benefit. If the student is in the lower middle voice (male or female) approximately around D3 or D4 on the piano, then vocalising an /i/ vowel just prior to the lip trill may set up a more optimal vocal tract configuration, potentially enhancing the source-filter interaction while trilling. Recall that the /i/ vowel is ideal in the neighbourhood of 300Hz, near to D4, however vocalising an octave lower on D3 could align H2 with F1 (see Figure 11 for /i/ F1 location) (Gill, May 2018 Personal Communication).

Trilling (and other SOVT exercises) can be done on musical patterns, sustained pitches or melodies of songs. It depends on what the student needs. If the student is struggling to flow through a phrase using lyrics, trilling through an entire phrase or song may be a

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wise choice. If they are able to trill in a way that allows them to vocalise with ease through those phrases, then using the lip trill as a lead in to the phrase may be fruitful next step. I will often ask my students to prep the first note of the melody on a lip trill and then continue vocalising with a similar feeling on the lyric. If the trill is free and easy for the singer, but the melody starts to become forced half way through the phrase, I may ask the student to stop and focus on the challenging note/lyric, and apply the trill to the note where there is a tendency to use excessive pressure.

Velopharyngeal opening

The final topic is Velopharyngeal Opening (VPO). When the velum makes complete contact with the pharyngeal wall, the velar port is closed. VPO requires space between the velum and the back wall of the pharynx so that sound energy can pass through the nasopharynx and nasal cavity (Miller 122).

VPO versus nasality

VPO is often referred to as nasal resonance by vocalists and voice practitioners. The potentially negative impact of using the term "Nasal" is that it can imply tonal quality that many vocalists and teachers push back against. Dr Johan Sundberg conducted a perceptual study in 2002, where an expert panel of listening experts rated samples of professional opera singers. 15 of the 17 singers from the study were shown to have used a VPO on three vowels, at varying pitch levels. There was no correlation in this study between a VPO and rated "nasal" tone quality. This deserves a further look from the voice community (Sundberg 2002).

Benefits of VPO

"Narrow" VPO has been shown to result in the most balanced spectrum, when contrasted with "much" or "no" VPO. The "Narrow" condition also resulted in the highest overall sound pressure level (SPL), and the high frequency energy was the greatest in this condition (Lee, Jessica, et al. VP27). The high energy information (2-4KHz) is advantageous, as the human ear canal is sensitive to information in this region (Titze 2001, 41-43). This high-end information also exists above the average noise of an orchestra and background noise (e.g. in a restaurant) (Sundberg 2018, Resonance). VPO can also act as a SOVT exercise. The resistance that builds up at the opening of the velum during a VPO could help to reduce pressure that falls across the vocal folds as they vibrate, allowing easier and more even vibration (Birch et al. 70; Sundberg 2006, 137). Recent research also suggests "that a slight VPO can serve the purpose of optimising the ratio between sound level produced and subglottal pressure" (Gill, Dec 2018 Spectrum Effects). VPO has also been shown to increase stability at register transitions (Sundberg 2017, BSc29). VPO can be used as a way of Formant Tuning, as it lengthens the vocal tract and lowers all formant frequencies (McCoy 154).

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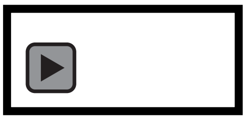
Practical Strategies for using a VPO

Perhaps the easiest way to gain access to VPO is to hum. Humming a simple melodic phrase from of song, may be useful for a student learning to access VPO. You can also ask a student to hum just prior to vocalising, this may encourage a VPO to remain throughout the piece being worked on. This needs to be monitored via the student's sensations and your ears (Stoney, Nasal Resonance Explained).

A strategy that I have adopted, is having the student pinch their nose (with thumb and index finger), with the intention of feeling vibration in the nose as they vocalise (Gill, May 2018 Personal Communication). If there is uncertainty about whether vibration on the nose is linked with VPO, you can have the student pinch and release rapidly while vocalising (refer to Audio Clip 3). If there is a VPO you will hear a rapid interruption of the vocalised sound (Gill 2014).



Audio Clip 3. Rapid pinch (where both nostrils are completely shut off, resulting in a noticeable interruption of the sound being produced).

One of the benefits of the nose pinch is that the vocalist can monitor sensations via kinaesthetic awareness with the finger and thumb. The other major benefit is that the student can vocalise words with the nose pinch. As a student gets used to accessing VPO with the nose pinched, you can have them start vocalising a phrase, and midway through the phrase take the pinch away. If they are able to maintain a similar sensation and the tone continues to be produced with ease, clarity etc. then they are likely maintaining a similar a VPO.

While a student is learning to access VPO consistently, the amount of VPO may need to be exaggerated initially. Learning to fine-tune the amount of VPO will likely impact the balance of "bright" and "dark" tonal qualities. Birch et al. say "...varying VPO shapes suggest that singers may use a VPO to fine-tune vocal timbre" (70). That being said, I would encourage you to initially focus on the functional advantages related to ease of production, then fine-tune aesthetics throughout the course of the training process. In prioritising vocal sustainability over tonal aesthetic while balance is being discovered, the student will not tire nearly as much in the process. Alternately, if the singer aims to produce a "finished product" immediately (focusing on the goal), regardless of the vocal function used, it is possible that excess muscular force could be used to achieve that tonal goal. Ultimately, easy, efficient voice production used to create a balanced timbre for the given vocal task should be high priority in voice training.

Conclusion

There is great benefit for voice practitioners in considering linear and non-linear source/filter interactions in voice production. The benefits for the student can include easier, more efficient vocal production and more sound output for a given vocal effort.

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The practitioner also has the advantage of a factual point of reference when working to correct a vocal issue with a voice student, which often leads to targeting the cause of the issue more promptly.

Familiarity with the harmonic series, and formant frequencies of the vowel formants (particularly F1 locations) is helpful knowledge for the voice practitioner, as it provides a foundational context for vocal resonance. All information relating to vocal resonance should be looked at in the context of the whole vocal apparatus. If an exercise based on a theoretical concept is not working for a student, it is important to consider other subsystems such as the breathing system or the alignment of the individual.

We live in an exciting time, where information about the voice is more accessible than ever through the internet and modern technology. We are constantly receiving new information from scientific research, and are able to experiment with voice software designed for in-home use. While this constant stream of new research may mean that teaching practices need to be updated in the future, the information in this article provides a strong foundation based on what is presently known. Teaching voice is a life-long endeavour for the practitioner. I believe it is a worthwhile endeavour, as this knowledge can be used to enhance the human voice, and more importantly the quality of life for the vocalist and for all who hear them.

References

Ahmed, Azlifa. *"The Sound Producing System."* http://Www.azlifa.com, 18 July 2006, www.azlifa.com/phonetics-phonology-lecture-2-notes/

Aye, Jeremy. *"Optimal Vowel Frequencies."* https://Vocalrepertoireforteachingcv.weebly.com, 1 Sept. 2015, vocalrepertoireforteachingcv.weebly.com/optimal-vowels.html

Barrichelo-Lindström, Viviane, and Mara Behlau. "Resonant Voice in Acting Students: Perceptual and Acoustic Correlates of the Trained Y-Buzz by Lessac." *Journal of Voice*, vol. 23, no. 5, 2009, pp. 603–609. doi:10.1016/j.jvoice.2007.12.001

Benade, Arthur H. *Fundamentals of Musical Acoustics*. Publisher Not Identified, 1990.

Birch, Peer, et al. "Velum Behavior in Professional Classic Operatic Singing." *Journal of Voice*, vol. 16, no. 1, 2002, pp. 61–71. doi:10.1016/s0892-1997(02)00073-5

Bolles, Blaire. "Why a Lowered Larynx Is Good for Human Speech Production." *Replicated Typo*, 24 Oct. 2010, www.replicatedtypo.com/why-a-lowered-larynx-is-good-for-human-speech-production/2697.html

Bozeman, Kenneth W. *Practical vocal acoustics: Pedagogic applications for teachers and singers*, Vol. No. 9, Pendragon Press, 2014.

Bradford, Wade. "Samuel French Inc.: Play Publishing Company." *Https://Www.thoughtco.com*, ThoughtCo., 2 Mar. 2018, www.thoughtco.com/samuel-french-inc-2713631

Culver, Charles A. *Musical Acoustics*. 4th ed., McGraw-Hill, 1956.

Doscher, Barbara M. *The Functional Unity of the Singing Voice*. 2nd ed., Scarecrow Press, 1994.

Gill, Brian. "Personal Communication." Skype , Bloomington - Brisbane , 17 May 2018.

Gill, Brian P. "Acoustics of the Voice." Pedagogy - Researche. 10 Nov. 2014, New York City, NYU Steinhardt, East Building, 239 Greene St, New York, NY 10003, USA.

Gill, Brian P. "Vocal Tract Tuning for Contemporary Singing: How Vocal Tract Shape And Vibratory Mode Affect the Spectrum." Oren Lathrop Brown Professional Development

ISSN 2201-7208 | Published under Creative Commons License (CC BY-NC-ND 3.0)

Program, 27 May 2017, New York City, 79 Madison Ave, www.nyst.org/content/vocal-tract-tuning-contemporary-singing-how-vocal-tract-shape-and-vibratory-mode-affect

Gill, Brian P., et al. "Spectrum Effects of a Velopharyngeal Opening in Singing." *Journal of Voice*, 23 Dec. 2018, doi:10.1016/j.jvoice.2018.11.014.

Gill, Brian. "Mindful Voice Production." *Mindful Voice Production*, 15 June 2015, www.mindfulvoiceproduction.com/

Gill, Brian. "Personal Communication." CBD, Sydney, 8 Oct. 2018.

Hallqvist, Hanna, et al. "Soul and Musical Theater: A Comparison of Two Vocal Styles." *Journal of Voice*, vol. 31, no. 2, 2017, pp. 229–235. doi:10.1016/j.jvoice.2016.05.020

Harris, David, and Laurel Irene. "Harmonics and formants: What happens when they combine?" https://www.voicescienceworks.org, *Voice Science Works*, 19 Mar. 2017, www.voicescienceworks.org/resonance.html

Harris, David. "Courses." *Voice Science Works*, 25 Aug. 2016, www.voicescienceworks.org/courses.html

Howell, Ian. "A Spectrogram Primer for Singers." *NEC Vocal Pedagogy*, vocped.ianhowell.net/a-spectrogram-primer-for-singers/

Ingo, Titze. "Factors Influencing Fundamental Frequency." *Ncvs.org*, 22 June 2005, www.ncvs.org/ncvs/tutorials/voiceprod/tutorial/influence.html

Irene, Laurel, and David Harris. "Harmonics Vs. Formants." *Https://Www.voicescienceworks.org*, Voice Science Works, 24 Feb. 2016, www.voicescienceworks.org/harmonics-vs-formants.html

Lee, Jessica, et al. "Annual Symposium: Care of the Professional Voice." The Voice Foundation, *Spectrum Effect of Different Degrees of Nasalization*, 2015, p. VP27, voicefoundation.org/wp-content/uploads/2014/07/4-2015-Abstracts.pdf

McCoy, Scott Jeffrey. *Your Voice: an inside View*. 2nd ed., Inside View Press, 2012.

Michael, Joseph, et al. "Graduate Voice Pedagogy Programs." Ian Howell, 18 Nov. 2017. Posted to Facebook - "Voice Geek Group page".

Miller, Donald Gray. *Resonance in Singing: Voice Building through Acoustic Feedback*. Inside View Press, 2008.

Radolf, Vojtˇech, et al. "Air Pressure, Vocal Fold Vibration and Acoustic Characteristics of Phonation during Vocal Exercising." *Engineering Mechanics*, vol. 21, no. 1, 2014, pp. 53–59.

Raphael, Bonnie N., and Ronald C. Scherer. "Voice Modifications of Stage Actors: Acoustic Analyses." *Journal of Voice*, vol. 1, no. 1, 1987, pp. 83–87. doi:10.1016/s0892-1997(87)80029-2

Redfield, John. *Music: A Science and an Art*. Tudor Pub. Co., 1935.

Rothman, Howard B, et al. "Spectral Changes Due to Performance Environment in Singers, Nonsingers, and Actors." *Journal of Voice*, vol. 16, no. 3, Sept. 2002, pp. 323–332. doi:10.1016/s0892-1997(02)00104-2

Sawyer, J. "Physiology of Vocal Fold Vibration." *Http://My.ilstu.edu/~Jsawyer/PhonationNIU/phonationsoftchalk15.Html*, 26 Apr. 2017, my.ilstu.edu/

Stanislavskij, Konstantin S., and Elizabeth R. Hapgood. *Building a Character*. Methuen, 1991.

Stanislavsky, Konstantin, and Elizabeth Reynolds Hapgood. *An Actor Prepares*. Bloomsbury, 2014.

Stoney, Justin. *"Nasal Resonance EXPLAINED!" - Quick Singing Tips 18*. *YouTube*, YouTube, 30 Sept. 2018, youtu.be/S8vvmw2cMgg.

Story, Brad H. *A Note on Vibration and Resonance*. *A Note on Vibration and Resonance*, Wilbur James Gould Voice Research Center Denver Center for the Performing Arts, 1999.

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Story, Brad H., et al. "Acoustic Impedance of an Artificially Lengthened and Constricted Vocal Tract." *Journal of Voice*, vol. 14, no. 4, 2000, pp. 455–469. doi:10.1016/s0892-1997(00)80003-x

Sundberg, Johan. "The Acoustics of the Singing Voice." *Scientific American*, vol. 236, no. 3, May 1977, pp. 82–91.

Sundberg, Johan, and Filipa M.B La. "Annual Symposium: Care of the Professional Voice." The Voice Foundation, *Resonance Bandwidth and Vocal Fold Vibration*, 2017, p. BSc29.

Sundberg, Johan, et al. "Annual Symposium: Care of the Professional Voice." Abstract, *Nasal Resonance and Singing*, 2016, p. BSc21.

Sundberg, Johan, et al. "Experimental Findings on the Nasal Tract Resonator in Singing." *Egyptian Journal of Medical Human Genetics*, Elsevier, 28 Feb. 2006, www.sciencedirect.com/science/article/pii/S089219970500158X

Sundberg, Johan. "Function - Course P 20170." Vocology. Know Your Voice, 12 Dec. 2018, Bloomington, Indiana University.

Sundberg, Johan. "Resonance." Vocology - Course P 20170607. Know Your Voice, 15 Dec. 2018, Bloomington, Indiana University.

Sundberg, Johan. *The Science of the Singing Voice*. Northern Illinois University Press, 1987.

Titze, Ingo R. "How Well Does Speech Exercise the Larynx?" *The Journal of Singing*, vol. 69, no. 5, 2013.

Titze, Ingo R. "The Larynx and the Ear- How Well Do They Match." *The Journal of Singing*, vol. 57, no. 5, 2001, pp. 41–43.

Titze, Ingo R. "Rules for Modifying Vowels." *Ncvs.org*, The National Centre for Voice & Speech, 22 June 2005, www.ncvs.org/ncvs/tutorials/voiceprod/tutorial/rules.html

Titze, Ingo R., and Katherine Verdolini Abbott. *Vocology: The Science and Practice of Voice Habilitation*. Compton Publishing Ltd, 2012.

Titze, Ingo R. "Human Speech: A Restricted Use of the Mammalian Larynx." *Journal of Voice*, vol. 31, no. 2, 2017, pp. 135–141. doi:10.1016/j.jvoice.2016.06.003

Titze, Ingo. *"Vowel Formant Chart."* Http://Www.ncvs.org, The National Centre for Voice & Speech, 1 Feb. 2001, www.ncvs.org/ncvs/tutorials/voiceprod/tutorial/filter.html

Unknown. *"Spectrum-100.Png."* http://Home.cc.umanitoba.ca, 20 Apr. 2017, home.cc.umanitoba.ca/~krussll/phonetics/acoustic/img/spectrum-100.png

Verdolini-Marston, Katherine, et al. "Preliminary Study of Two Methods of Treatment for Laryngeal Nodules." *Journal of Voice*, vol. 9, no. 1, 1995, pp. 74–85. doi:10.1016/s0892-1997(05)80225-5

Winslow, Terese. "Pharynx Anatomy." *Https://Visualsonline.cancer.gov*, National Cancer Institute, 21 May 2012, visualsonline.cancer.gov/details.cfm?imageid=9254

Witherspoon, Herbert. *Singing: A Treatise for Teachers and Students*. Da Capo Press, 1980.

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