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Acoustic Interpretation of Resonant Voice

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Summary: Resonant voice, often described in terms of vibratory sensations in the face, is investigated acoustically by calculating vocal tract inertance. It appears that the ease of production and vibrancy of resonant voice depends more on lowering phonation threshold pressure than on tissue or air resonance in or around the face. Phonation threshold pressure is lowered by increasing air column inertance in the laryngeal vestibule. The fact that the sensations are felt in the face is an indication of effective conversion of aerodynamic energy to acoustic energy, rather than sound resonation in the sinuses or the nasal airways.
Key Words: Resonance—Nasality—Placement—Focus—Voice quality.

INTRODUCTION

Resonant voice is defined as a voice production that is both easy to produce and vibrant in the facial tissues. The perceptions of "ease" and "vibrancy" belong primarily to the person producing the sound, but listeners can have similar perceptions. Clinicians consider resonant voice a target vocal production in terms of vocal health, primarily because it is neither taxing nor restricted to low intensity.[1] Furthermore, as a voice quality, resonant voice is regarded as neither pressed nor breathy.[2,3] Pressed voice is rich in harmonic content (like the sound of brass instruments), but appears to be effortful in production and possibly unhealthy (if prolonged) because of excessive mechanical stress imposed on laryngeal tissues. Breathy voice, and its nonaspirate cousin "hooty" or "fluty" voice, are not deemed unhealthy, but lack carrying power because of their poor harmonic content. An output-cost ratio, computed as the ratio between sound power radiated from the mouth to power dissipated in vocal fold tissues, favors a production that is neither hyperadducted or hypoadducted.[4] Resonant voice seems to contain the ideal mix of laryngeal adduction (somewhere between breathy and pressed) and ample reinforcement of vocal fold vibration by the vocal tract.

But the acoustic nature of resonant voice is poorly understood, mainly because sensory perception of resonant voice involves head vibrations.[5] These vibrations, although critical for acquiring and reliably habituating resonant voice, may give confounding clues about where and how acoustic resonance actually occurs. Emphasis is placed on feeling the vibrations in the facial tissues (soft and hard) and, quite understandingly, the belief is that these facial tissues resonate. But if resonance is defined (in the typical way) as the reinforcement of natural modes of vibration with frequencies for which little excitation is needed to produce a large response, only a wall vibration resonator of about 150 Hz has so far been

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identified.[6] Such a resonator is likely to be an energy absorber because acoustic radiation from tissue surfaces is very poor and viscous dissipation within tissues is high. We will show that a more likely resonance is a reinforcement of vocal fold vibration by an inertive vocal tract (IVT), which feeds energy back to the source of sound (the glottal flow), thereby strengthening its harmonic content. This is a nonlinear interaction and cannot be explained by the traditional linear source–filter theory.[6] The key observation by Rothenberg,[7] that skewing of the glottal flow pulse is caused by vocal tract inertance, forms the basis of two decades of exploration into this topic.

Confounding sensations

Voice production is an energy conversion process. Aerodynamic energy is converted into acoustic energy when the vocal folds oscillate; this oscillation modulates the glottal airstream, thereby producing sound in the vocal tract. Because the sound *propagates* along the entire airway system (lungs to sinuses in the head), the acoustic energy is carried *away* from the source. Thus, when the energy conversion process at the glottis is efficient, the vibrations are distributed all over the head, neck, and thorax, but when the energy conversion process is poor, the vibrations are likely to remain more local. Vibrational energy is then dissipated in the vocal fold tissues.

Vocalists producing resonant voice claim that vibrations are experienced in and around the eyes, nose, and mouth. Maxillary bony structures (the hard palate, upper teeth, and cheek bones) pick up vibrations from the acoustic standing waves in the oral cavity.[8] Because these bony structures surround the nasal cavity, the vocalist may associate these vibrations with nasal resonance, even when the velar port is closed.

With regard to voice qualities that are associated with nasality, it is important to distinguish between nasal murmur (a "honky" quality) and twang (a bright and sometimes ringing quality). Nasal murmur is the result of acoustic energy propagated into (and through) the nose. This energy is radiated from the mouth and the nostrils and has primarily low-frequency content (200–300 Hz). It is the sound of the nasal consonants /*m*/, /*n*/, and /ɳ/. Twang, on the other hand, is related to vocal "ring," an acoustic resonation in the laryngeal vestibule, also called the larynx tube.[9] Our preference is to call it the *epilarynx tube*, suggesting that the epiglottis forms the anterior wall of the short tube that is above the vocal folds. Its resonance is primarily of high-frequency content (2500–3500 Hz) and the sound is radiated mainly from the mouth. A twang quality emerges from the ring quality when the pharynx is narrowed, and this twang can be nasalized when velar coupling is added, but nasalization is secondary to both ring and twang. It is quite unfortunate that ring and twang have been so strongly associated with nasality, because this association has led to much of the confusion about "placement" and "focus" of resonant voice.

A simple exploration with one's own voice clarifies the issue. Nearly everyone can produce a nasalized vowel and discover that it is grossly affected in sound quality by pinching one's nose; in other words, the nasal murmur is altered by changing the reflection and radiation of sound at the nostrils. But interestingly, most of us can also produce a twang, and many singers can produce a ring, with the velar port closed (with no change in voice quality when the nose is pinched), clearly suggesting that ring and twang are produced somewhere other than the nose and radiated from the mouth.

Similar disclaimers apply to sound enhancement purported to be associated with the maxillary, ethmoid, and sphenoid sinuses. These sinuses do resonate,[10] but because there are no effective sound radiation surfaces or orifices for these cavities, the airborne sound is changed minimally by these resonations. There are spectral peaks and troughs that add to the formant structure of the airways, but the sound quality as perceived by the listener is not changed much.

The inertive vocal tract

Inertance is an acoustic property of an air mass (usually a column of air in a tube) being accelerated or decelerated by pressure. It is defined as

$$I = \frac{\rho L}{A}, \qquad (1)$$

where ρ is the density of the air column, L is its length (along the direction of acceleration or deceleration), and A is its cross sectional area (perpendicular to the acceleration or deceleration). Figure 1A shows an air column in motion, driven by a pressure *P* at the left. The arrows show local air particle movement, which is oscillatory in acoustics. For this reason, a brief moment later, all movement is to the left.

Inertance is the acoustic equivalent of mass in Newton's second law of motion,

$$F = m\frac{dv}{dt}, \quad (2)$$

where *F* is force, *m* is mass, and *v* is air particle velocity, which is assumed to be spatially uniform in a short air column. If the force is replaced by *PA* (pressure times cross-sectional area in a tube), the mass is replaced by ρLA (density times length times area), and the particle velocity is replaced by *u/A* (volume flow per unit area), then Newton's law for the air column becomes

$$PA = (\rho LA)\frac{d}{dt}\left(\frac{u}{A}\right). \quad (3)$$

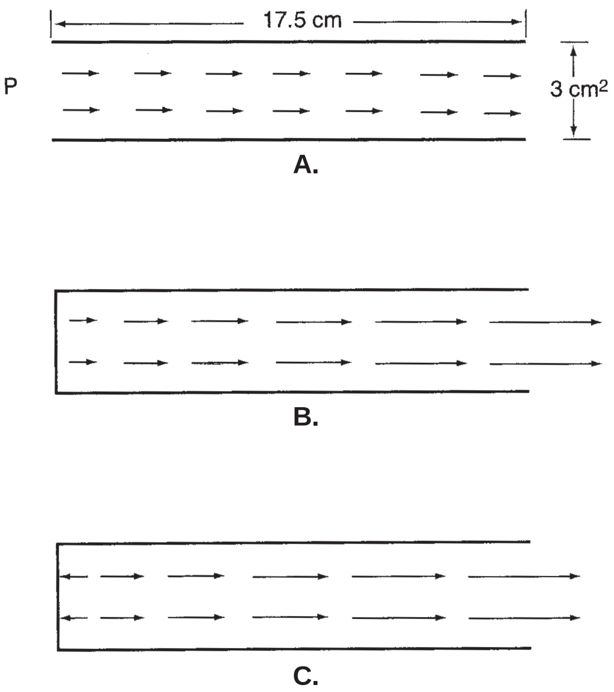

FIGURE 1. Air columns in motion. **A.** Open-open tube with uniform particle velocity; **B.** closed-open tube with nonuniform particle velocity, but unidirectional as in the case $F_0 < F_1$; and **C.** closed-open tube with nonuniform and bidirectional particle velocity, as in the case $F_0 > F_1$.

For a constant cross-sectional area this reduces to

$$P = \frac{\rho L}{A}\frac{du}{dt} = I\frac{du}{dt}, \quad (4)$$

which shows the analogy between mass and inertance explicitly by comparing Equations 2 and 4.

The units of measurement of inertance are kg/m^4 (or g/cm^4). For example, in Figure 1A, an air column of 17.5 cm in length and 3.0 cm^2 in cross-sectional area has an inertance of 0.00665 g/cm^4 if the air density is 0.00114 g/cm^3 and all air particles in the column move uniformly.

In vocal fold vibrations, the air column above the glottis is accelerated and decelerated by the supraglottal pressure. This back and forth motion is, of course, the oscillation that forms a sound wave in the vocal tract. But air particle movement is, in general, not uniform because air compression and rarefaction takes place in the tube. Moreover, multiple reflections create standing waves, with alternately high and low regions of particle velocity and pressure. Only for frequencies below the first formant do all of the air particles in the entire vocal tract move in the same direction (yet not at the same speed) at any moment in time (Figure 1B). Although there is an increase of particle velocity from glottis to the lips, we can nevertheless think of the vocal tract air column as moving like a single unit, a lumped air mass. But the acoustic length of the tube is greater than the physical length because of this velocity gradient.

For frequencies above the first formant, the air particles do not all move in the same direction (Figure 1C). At the glottal end, there is a sudden phase reversal of the particle velocity, which makes the lumped-inertance concept invalid. We shall demonstrate, however, that speakers and singers who use resonant voice are likely to make every attempt to shape the vocal tract so that it remains inertive at nearly all fundamental frequencies.

The inertive vocal tract (IVT) assists the vocal folds in vibration because the supraglottal pressure driving the air column is in phase with the velocity of the vocal folds. As seen from Equation 4, when the rate of change of airflow, *du/dt*, is positive during glottal opening (flow is increasing), the supraglottal pressure is positive. This raises the pressure throughout the glottis and helps drive the vocal folds apart. Conversely, when the glottis is closing and the rate of change of flow, *du/dt,* is negative (flow is decreasing), the supraglottal pressure is negative. This lowers the pressure throughout the glottis and helps pull the vocal folds together. Thus, the IVT provides the push-pull mechanism that is often attributed to the Bernoulli effect (and wrongfully so). It can also be thought of as a feedback mechanism between the pressures in the vocal tract and the vocal fold movement that created them.

In previous work,[11] we have shown that the phonation threshold pressure is lowered by an IVT. A simple relation was found for a one-mass model of the vocal folds coupled to an acoustic inertance I,

$$P_{th} = \frac{1}{2} k_t \rho \left(\frac{B}{2 L_f I} \right)^2 , \qquad (5)$$

where k_t is a transglottal pressure coefficient (about 1.1), B is the viscous damping coefficient of the vocal fold tissue, and L_f is the vocal fold length. This relation shows that as vocal tract inertance I increases, the phonation threshold pressure decreases, making it easier for vocal fold vibration to be initiated and sustained. We claim that this is an important component of resonant voice, together with the selection of the proper glottal width, which can also lower the phonation threshold pressure.[3]

The compliant vocal tract

A compliant vocal tract is one in which the volume of the air column near the glottis is changing dynamically. Figure 1C is such a case. Near the glottal end, air particles move in opposite directions, resulting in a local expansion of air density. (Because the flow is oscillatory, a half-cycle later there will be a compression at the same place.) This volume change delays the buildup of pressure above the glottis. The supraglottal pressure increases slowly by integrating the flow from the glottis into the compliant air space. This pressure is written as

$$P = \frac{1}{C} \int u dt , \qquad (6)$$

where C is the acoustic compliance of the air column and u is the glottal flow. A compliant vocal tract is unfavorable to vocal fold vibration because the supraglottal pressure variation is not in phase with vocal fold movement. The pressure is always smaller during glottal opening than during glottal closing, simply because less of the flow has been integrated during opening than during closing. This steadily rising pressure over the open phase of the glottal cycle produces only a steadily increasing push, but no pull, on the vocal folds. For this reason, there is often a shift to falsetto register, with the vocal folds spreading apart and experiencing smaller amplitudes of vibration, when the vocal tract becomes compliant. Such is the case when the fundamental frequency F_0 exceeds the first formant frequency F_1, unless something is done by the vocalist to maintain an inertive vocal tract by special adjustments (to be discussed later). The acoustic compliance C in Equation 6 can be written as

$$C = \frac{L A}{\rho c^2} , \qquad (7)$$

where L, A, and ρ are the effective length, cross-sectional area, and density of the air column, respectively, and c is the speed of sound in air. But the effective length L is not the physical length of the vocal tract because the air compressions and expansions are not uniform throughout the vocal tract. A distributed (wave) approach to density, pressure, and particle velocity variation along the tube is needed to calculate effective values of compliance. Nevertheless it is interesting to note that compliance generally increases with the cross-sectional area of the tract, whereas inertance decreases (compare Equations 1 and 7). Also, greater air density decreases compliance but increases inertance. Effective length, on the other hand, increases both inertance and compliance. We will now give some quantitative data on vocal tract inertance, based on acoustic wave propagation principles.

Calculations of vocal tract inertance

Based on Equation 1, vocal tract inertance is increased by narrowing and lengthening the vocal tract. But both of these actions are articulatory gestures that affect the phonetic aspect of voiced sounds. So, how can a vocalist make use of vocal tract inertance (for resonant voice) without altering the perceived vowel or consonant? The answer lies in the use of the laryngeal vestibule (the epilarynx tube). This tube, approximately 2–3 cm at the glottal end of the vocal tract (Figure 2), can be narrowed without compromising articulation by the tongue, velum, jaw, and lips.

Vocal tract open at mouth

Figure 3 shows vocal tract inertance as a function of frequency for a 17.5 cm long vocal tract fully open at the mouth. The tract has a 3.0 cm^2 cross section in the pharynx and mouth. Solid lines are for a completely uniform cross section and dotted lines are for a narrowed epilarynx tube 3.0 cm in length and a cross section of 0.3 cm^2 (see inserted diagram). The calculations were based on wave propagation phenomena according to Titze and Story[12] and Story, Laukkanen, and Titze.[13] The input impedance at the glottis was computed and the imaginary part (the inertive reactance, as it is called in acoustics) was divided by the angular frequency $\omega = 2\pi f$, where f is the frequency.

Several observations are noteworthy in Figure 3. First, the inertance is not constant with frequency, as Equation 1 would suggest, because the air particle movement is not uniform along the length of the vocal tract. Rather, a variable inertance pattern exists that is highly frequency dependent. Consider first the solid lines for the wide epilarynx tube. At low frequencies (near the origin), the value of the inertance is 0.00665 g/cm^4, the value computed earlier from Equation 1. The inertance then rises to a value about three times as high, just before 500 Hz, the first formant frequency. (The formant frequency is, by defi-

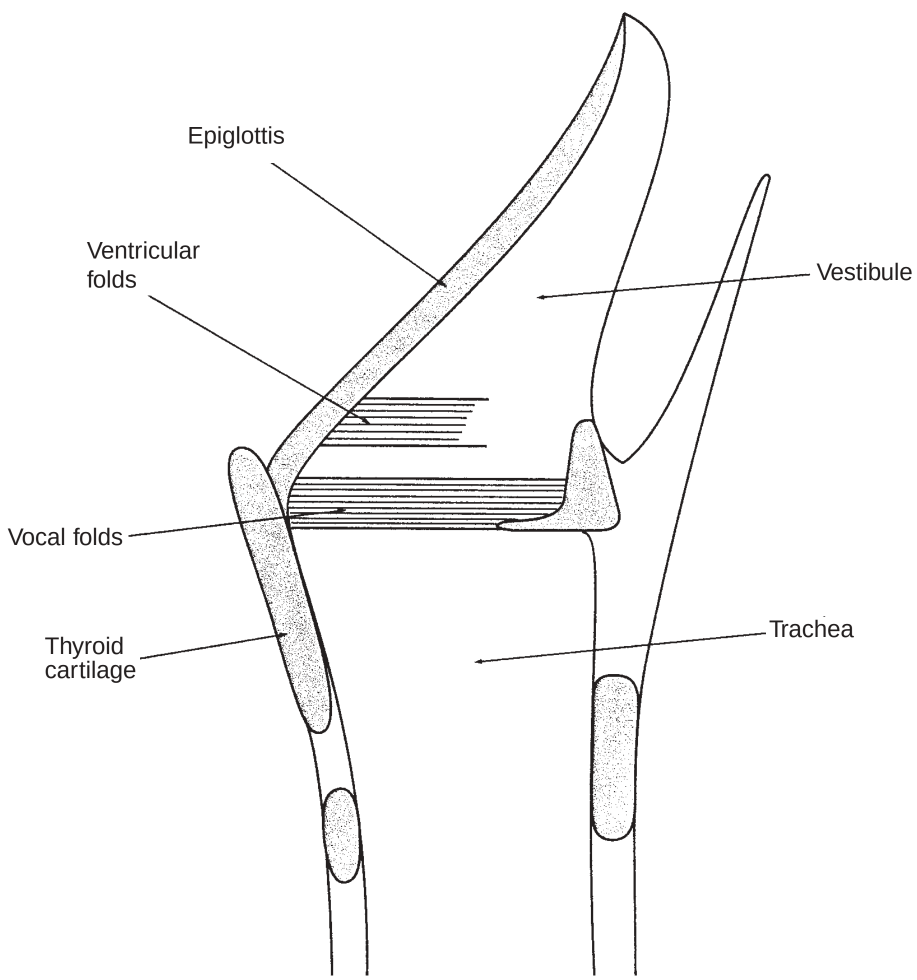

FIGURE 2. Anatomical description of the laryngeal vestibule, or epilarynx tube.

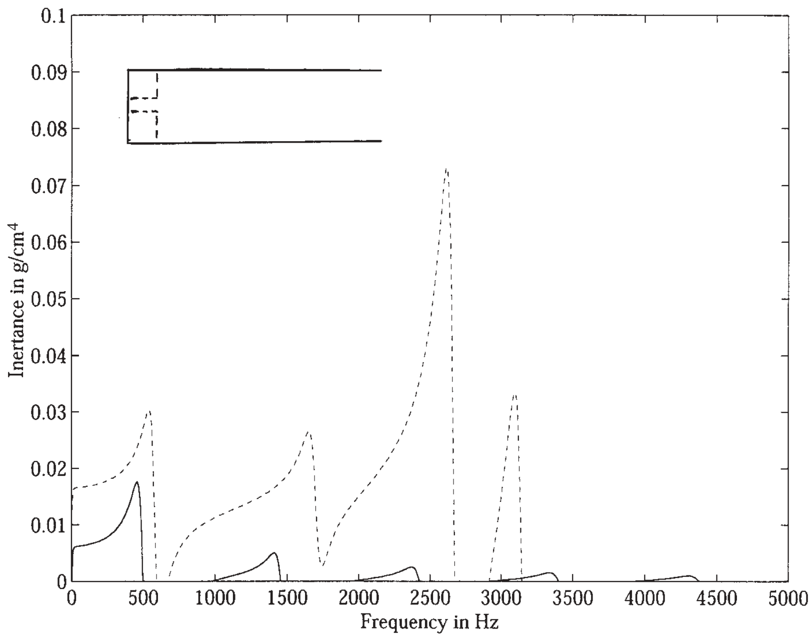

FIGURE 3. Inertance of a 17.5 cm long closed-open vocal tract, without a narrowed vestibule (*solid lines*) and with a narrowed vestibule (*dashed lines*).

nition, the frequency where the inertance goes to zero.) At the point of maximum inertance, the particle velocity distribution is nearly as shown in Figure 1B. The greater particle velocity at the mouth end (due to a quarter standing wave) has acoustically lengthened the tract to raise the inertance. From 500 to 1000 Hz, the vocal tract is compliant, having no net inertance at the glottis. (Compliance is not explicitly shown in the graphs.) This 500–1000 Hz region is a difficult region for maintaining self-sustained vocal fold oscillation, for reasons stated earlier.

At 1000 Hz, the uniform vocal tract becomes inertive again, but the peak inertance prior to 1500 Hz (the second formant frequency) is considerably smaller than the peak inertance near 500 Hz. For yet higher frequencies, the pattern is repetitive, showing alternating inertive and compliant vocal tracts, with the peak inertance decreasing with every repetition.

The pattern changes dramatically when the epilarynx tube is narrowed, as shown by the dotted lines. Overall, the inertance is much larger for this case. If the epilarynx tube alone were the entire vocal tract (like the mouthpiece of a trumpet), its inertance would be 0.0114 g/cm^4 according to Equation 1, about twice the value of the 17.5 cm long uniform vocal tract. This is simply because the cross-sectional area is so small. The two tubes connected serially produce a fluctuating pattern of inertance that reaches 0.03 g/cm^4 at about 550 Hz and nearly the same value at 1700 Hz. Just above 2500 Hz, the inertance reaches 0.075 g/cm^4. More importantly, however, the vocal tract is compliant only over a small frequency region (from 600 Hz to less than 700 Hz). The vocal folds can get reinforcement in their self-sustained oscillation in nearly the entire phonation range, with the exception of this small 100 Hz region. Another observation is that the first two formant frequencies are raised slightly, because the wide section of the tract is reduced in length by the epilarynx tube. Finally, the extremely high value of inertance prior to the third formant results from the third (and fourth) formants being near the quarter-wave resonance frequency of the epilarynx tube in isolation,

$$F_e = \frac{c}{4\,L} = \frac{35{,}000 \text{ cm/s}}{(4)\,(3 \text{ cm})} = 2917 \text{ Hz}\,. \qquad (8)$$

This resonance has been termed the singer's formant.[9] In previous work,[12] it was shown that the quarter-wave resonance frequency of the epilarynx tube "attracts" the formants to the right and left of it, creating a formant cluster described by Sundberg.[9]

This formant cluster can involve F_3, F_4, and F_5, depending on where F_e is located in the spectrum. The smaller the area of the epilarynx tube, the tighter the cluster becomes and the more it will asymptote to the single resonance frequency F_e.

The importance of the above findings is that resonant voice, if indeed produced by a narrowed epilarynx tube, is a nonlinear (feedback) phenomenon, whereby the vocal folds are assisted in their oscillation by increased vocal tract inertance. A by-product is vocal "ring," a clustering of higher formant frequencies to raise the spectral content in the 3000 Hz region. But ring and resonant voice are not necessarily the same thing. A voice can be resonant without the singer's formant.

Vocal tract nearly closed at mouth

Exercises to establish and improve resonant voice usually include occluded or semioccluded vocal tracts, such as those in bilabial fricatives, lip trills, and nasal consonants. It is hypothesized that the primary benefit of these exercises is to get the "feel" of resonant voice, i.e., to get maximum sensory information about what is happening in the laryngeal vestibule in terms of energy conversion. Because acoustic pressures are maximum near occlusions, sensations should be felt in regions where the vocal tract area is small. Thus, for the bilabial fricative or a nasal consonant, one would expect strong vibrations to be sensed near the lips, nostrils, teeth, and the frontal part of the hard palate. But it is not clear (without calculation) whether the inertance can be kept high with these occluded vocal tracts. This was the purpose of the next set of calculations.

Figure 4 shows the inertance curves when the mouth is essentially closed (lip area = 0.01 cm^2, lip length = 0.5 cm). Qualitatively, the curves look similar to those for the open tract, but there are important quantitative differences. First, the formant frequencies have all moved downward. For the uniform tube (solid lines), F_1 is at 200 Hz, F_2 at 1060 Hz, F_3 at 2080 Hz, and F_4 at 3100 Hz. For a hard-walled tube, F_1 would move all the way to zero frequency, but there is an asymptotic limit of about 150 Hz when the walls are yielding.[13] The rest of the formants are close to 1000, 2000, and 3000 Hz, the theoretical values for a closed-closed uniform tube. Note that, again, without a narrow epilarynx tube the vocal tract alternates between inertive and compliant regions (equal in frequency ranges) and the peak inertances decrease with higher frequency.

When the epilarynx tube is narrowed (dashed

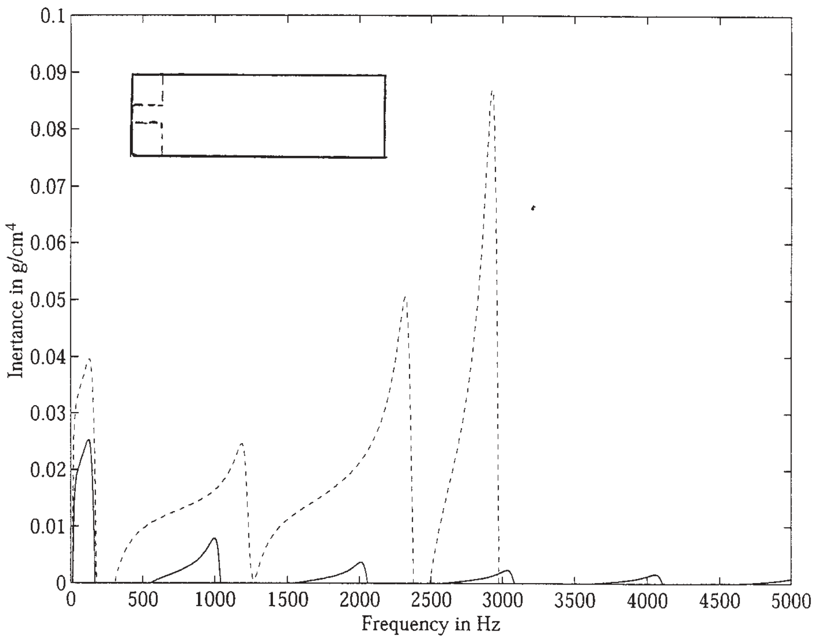

FIGURE 4. Inertance of a 17.5 cm long closed-closed vocal tract, without a narrowed vestibule (*solid lines*) and with a narrowed vestibule (*dashed lines*).

lines), the compliant regions shrink, as with the open mouth tube. In particular, the first compliant region occurs between 200 and 300 Hz. Thereafter, the vocal tract is inertive all the way to 2400 Hz. Of major interest is the 300–1000 Hz region, where singers (except perhaps basses) produce most of their "money notes." Here, a broad inertive vocal tract region is experienced between F_1 and F_2. Thus, singers can use occluded mouth shapes to train vocal tract–vocal fold interactions at high pitches and experience the sensations of efficient energy conversion. Note also that the lowering of all formants with lip occlusion has now brought F_4 in close proximity to F_e (rather than F_3 in the open mouth case). Thus, the singer's formant is preserved with oral occlusion, but radiation of 3000 Hz energy is quite limited because the skin radiates poorly at high frequencies. Internally, however, the vocalist may sense these high frequencies and feel that the production is resonant.

The widened and narrowed pharynx

Estill et al[14] have made the observation that operatic tone quality differs from speech quality (and even more so, twang quality) in that vocal ring (also known as *squillo* in Italian opera lingo) can exist in the presence of a dark, warm background quality if the pharynx is kept wide. In other words, ring is not synonymous with "brightness" or "whiteness." Figure 5 shows support for this observation. When the pharyngeal portion of the vocal tract (a section 7 cm long above the epilarynx tube) is narrowed from 3 to 1 cm^2 (solid lines), the first formant frequency is raised, as in the migration from /ə/ to /əe/ in vowel space. This migration is in the direction of twang (which should *not* be called nasal twang) because of the brightness of the perceived vowel. Story, Titze, and Hoffman[15] investigated this quality with computer simulation and found that it resembled the natural twang produced by several speakers, both male and female. Note also that the constricted pharynx configuration has an even higher overall inertance because the average tube is narrower, suggesting that twang is a highly resonant voice production. (The vocal tract shape resembles a trumpet.) In combination with the 0.3 cm^2 epilarynx tube, the "trumpet mouthpiece," the vocal tract in twang is kept inertive all the way to 730 Hz, a condition that may well be employed by female belters to achieve medium to medi-

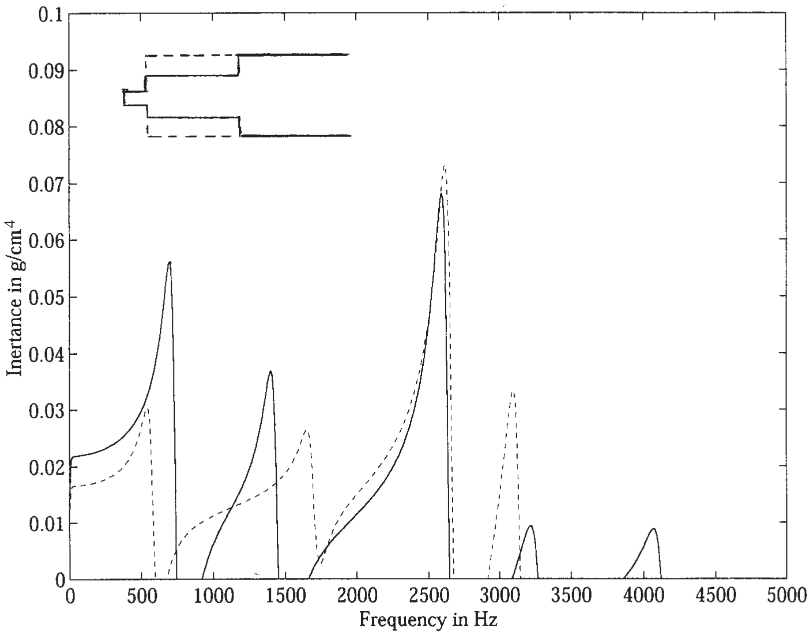

FIGURE 5. Inertance of a 17.5 cm long closed-open vocal tract, with both a narrowed vestibule and a narrowed pharynx (*solid lines*) and with a narrowed vestibule only (*dashed lines*).

um-high frequencies. But from 700 to 900 Hz, a compliant vocal tract is experienced, preventing assistance in vocal fold oscillation in the critical opera-soprano region of G_5 to B_5.

For an occluded vocal tract, the combination of a narrow pharynx and a narrow epilarynx tube has debatable value. As Figure 6 shows, the overall inertance is higher (as in the open mouth case), but the compliant region ranges from 200 to above 300 Hz. This is an important region for the female speaking voice and the male singing voice. It would be profitable, therefore, to practice humming, lip trills, and bilabial fricatives with as much pharyngeal expansion as possible, thinking away from twang and toward a darker quality.

Another point should be made about twang. Because the area expansion from the epilarynx tube to the pharynx is less abrupt, vocal ring is a little less likely to occur simultaneously with twang. The quarter-wave resonance of the epilarynx tube requires an abrupt expansion into the pharynx. Otherwise, the singer's formant will be a broad cluster of F_3, F_4, and F_5.[16] The beginnings of this slight broadening are seen in Figures 4 and 5. Note that the peak inertance prior to F_3 in Figure 5, and prior to F_4 in Figure 6, is a little less for the narrow pharynx (solid line) than the wide pharynx (dotted lines).

SUMMARY AND CONCLUSION

What is clinically known as resonant voice may indeed be based on a physical resonance, but the resonance is likely to be a reinforcement between vocal fold vibration and supraglottal acoustic pressure, a nonlinear (feedback) phenomenon, rather than a facial resonance that "filters" the sound and boosts certain frequencies. The phenomenon is well known in the acoustics of brass and woodwind instruments, in which the resonator (horn or bore) exchanges energy with the sound source (lips or reed), thereby facilitating self-sustained oscillation. But the voice is different from horn and woodwind instruments in that the length of the vocal tract is too short to reinforce many of the harmonics of the source with air column resonances. For this reason, the voice functions best if the vocal tract is kept highly inertive, which means that F_0 should be slightly less than F_1 when the mouth is open (low vowels), or F_0 should be well above F_1

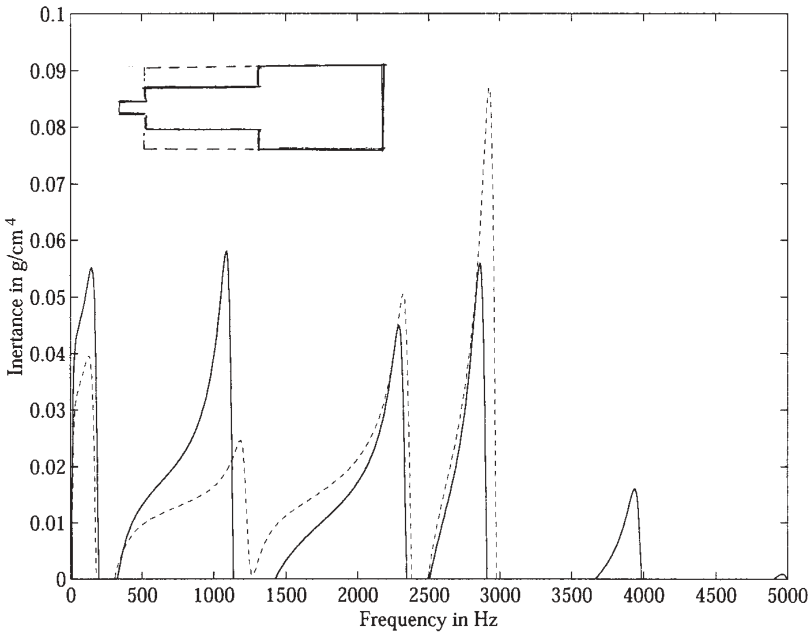

FIGURE 6. Inertance of a 17.5 cm long closed-closed vocal tract, with both a narrowed vestibule and a narrowed pharynx (*solid lines*) and with a narrowed vestibule only (*dashed lines*).

and closer to F_2 when the mouth is nearly closed (humming, bilabial fricatives, lip trills). In both cases, a narrow epilarynx tube helps to maintain the vocal tract highly inertive (rather than compliant), which is the key to resonant voice.

In no way should resonant voice be confused with nasality, even though nasal sounds are often used to train resonant voice. Nasal consonants, for example, are like lip trills and bilabial fricatives (for vocal training) in that they lower the first formant and allow the vocalist to achieve an inertive vocal tract for all fundamental frequencies above 300 Hz. The nasals and lip occlusions also help the vocalist achieve a sensation of efficiency in converting aerodynamic energy to acoustic energy, since regions of high acoustic pressure are formed near the lips and nostrils with these vocal tract configurations.

Much confusion exists about vocal twang. This is not inherently a nasal quality, although it can be (and in some dialects is) nasalized. Twang is a quality produced by a narrow pharynx (in addition to a narrow vestibule), which raises F_1 and brightens the vowel. Based on our calculations, it produces the greatest amount of vocal tract inertance, and would therefore be a desirable target for resonant voice. Unfortunately, many listeners don't like twang because it lacks warmth and depth. Thus, some compromise needs to be made in therapy.

An important clinical issue pertains to the conflict of accepting (and even encouraging) the use of a narrow epilarynx tube for healthy voice production. Vocal hyperfunction is sometimes expressed as a squeezing together of the tissues above the vocal folds, in particular the ventricular folds and, in some cases, the aryepiglottic folds. This could be an attempt by the vocalist to produce a more resonant (and stronger) sound. But for the epilarynx tube to become narrow, the ventricular folds should *not* be approximated. On the contrary, they should be retracted laterally and flattened out (vertically) to create a wall. How this is done is still somewhat of a mystery. One possibility is lowering the larynx, which may stretch the false folds vertically. Another may be moving the tongue forward, which could also stretch the false folds vertically. In either case, the epilarynx tube should be narrowed in an anterior-posterior direction, not in a medial-lateral direction.

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