The Case for Acoustic Registers

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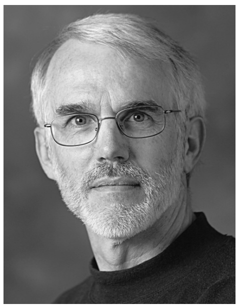

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An extensive and thorough two-part series on vocal registers recently appeared in the *Journal of Singing* that suggested a growing acknowledgment of the role of acoustics in vocal registration.[1] While the role of laryngeal biomechanics across the range of the voice will remain an important subject of ongoing research, this present article will suggest an even more prominent role for acoustic registration, both for our understanding of the mechanisms of registration as well as for effective heuristic pedagogic strategies in addressing them.

DEFINITIONS

Traditionally, voice pedagogues have explained the phenomena of registration primarily through their biomechanical characteristics. The most cited historic definition for vocal registers has been that of Manuel García II (1805–1906).

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

Notice in this description that there are two, essential defining factors: first, *homogeneity* (by which is meant, the continuity of timbral percept of a range segment); and second, *mechanical principle* (by which is meant, the physical cause underneath that timbral percept). To change vocal registers, there must therefore be a perceivable change of timbre *and* an observable (measurable) change of its causal mechanism.

For most of the history of voice pedagogy and earlier voice science, with few exceptions, the mechanisms of change were thought to be solely laryngeal, that is, changes of voice source. Voice researcher Harry Hollien, expanding on García, writes,

> A voice register is a series or range of consecutive phonated frequencies of nearly identical voice quality; they are totally *laryngeal* events and there is little or no overlap in fundamental frequency between adjacent registers.[3]

While, as reported in the above cited Herbst articles, more recent pedagogues and voice scientists are including resonation in the discussion of vocal registers, there remains a general preoccupation with laryngeal biomechanics in both theory and practice as the dominant mechanism responsible for timbral change and register demarcation. This article seeks to reevaluate this position.

PERCEPTION OF TIMBRE

It merits underscoring that having homogeneity of timbre as an essential, defining element of vocal register necessarily introduces perception (psychoacoustics) into the equation. Timbre is essentially how the brain perceives the combination of the relative intensities, tone color contributions, and auditory roughness (perceived "buzziness") of the spectral (frequency) components of a complex sound, and how that composite blend changes over time.[4] Crucial questions that have been largely overlooked in previous discussions of register are: (a) how is vocal timbre constructed; and (b) how can timbre then be altered sufficiently to signal a change of vocal register?

A more recent definition of register acknowledges a greater potential role for acoustic registration and clarifies possible mechanisms for timbral changes (i.e., sudden changes of harmonic content). In 2021, Ingo Titze noted that "a register is a plateau of vocal timbre (voice quality) as pitch, loudness, or vowel is changed," and that "registration involves the whole instrument, the entire airway, not only the larynx." Titze elaborates further the two possible mechanisms of registral change. First, a sudden change in harmonic content can occur from a sudden change in vocal fold medial surface contact. This is equivalent to an abrupt shift from modal to falsetto register as occurs in an upward yodel or vocal "flip," and results in a sharp steepening of the spectral slope. Alternatively, a sudden change in harmonic content can occur due to vocal tract resonances *enhancing or de-enhancing specific harmonics*, that is, from acoustic register transitions.[5]

LARYNGEAL REGISTER BINARITY

"In the wild," voices typically present with a rather binary vibrational modality: a bulkier vibration that involves the cover, body, and muscle layers of the vocal folds (thyroarytenoid involvement—i.e., a chest, modal, or mode 1 registration), and a longer, thinner mode that involves vibration only of the edge of the cover (the cricothyroid or "stretched" vocal ligament—i.e., head, falsetto, or mode 2 registration). Traversing the range then often triggers an audible toggle or "flip" from mode 1 (M1) to mode 2 (M2), resulting in a sudden shift in voice source contribution from a shallow spectral slope to a steep spectral slope, a clear demarcation of laryngeal vocal registers.

I maintain that in a voice well trained in flow phonation and smooth range negotiation—which has eliminated the sudden, binary shift of spectral slope—desirable vocal register shifts will remain. However, this will be due almost entirely to the second causal mechanism identified by Titze: acoustic registers. This view constitutes something of a conceptual paradigm shift in voice pedagogic thinking, which has previously focused predominantly on laryngeal mechanisms.

VOICE SOURCE CONTRIBUTION TO TIMBRE

Let us examine what the voice source can and (perhaps more important) *cannot* contribute to timbre. I will limit this evaluation for the moment to voices that are trained to produce a "clean" source signal, composed essentially of harmonic spectral content with minimal to no reinforced aperiodic (noise) content in the radiated sound. Further, assume a range that is being trained to generate a flow phonation throughout the range. Characteristics of such an instrument would include a balance of transglottal pressure difference, airflow, and glottal resistance for each pitch and situation, as well as a relatively stable vocal tract length for a balanced *chiaroscuro* timbre. This is in fact the goal of historical Western classical training, which is predicated on maximizing efficiencies to facilitate the sustainable production of a variety of skills—e.g., sostenuto, velocity, dynamic flexibility, power—with some degree of timbral unity (*chiaroscuro* balance) at a wide variety of intensity levels and pitches without artificial amplification. Styles using amplification will have access to a wider range of additional sounds, equally valid in human artistic expression, efficiently performable, but many of which cannot be sustainably (healthily) produced at high intensity levels without amplification.

SPECTRAL SLOPE

With these qualifications in place, the voice source contributes only two things: fundamental frequency (and its perceptual equivalent, pitch) and spectral slope. The latter, also called spectral tilt or "roll-off," is the rate at which higher harmonics decline in intensity above the fundamental frequency of the sung pitch (Figure 1). Steepening of the spectral slope will be heard as a

a)
b)

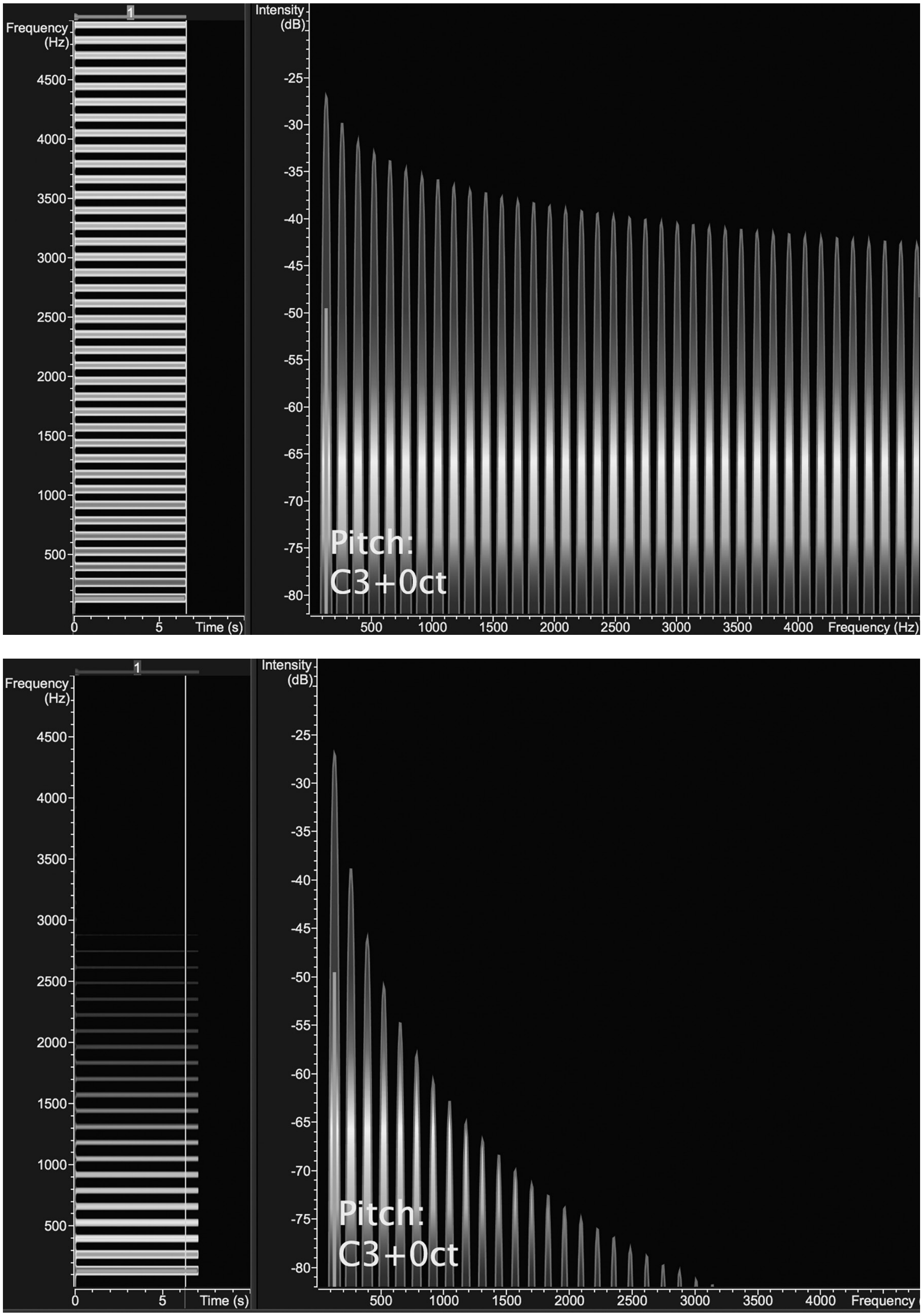

Figure 1. Spectral slope examples: –3dBs/octave: a "shallow" slope with many strong higher harmonics and a brassier timbre, more characteristic of mode 1 (or chest voice); and –12dBs/octave: a "steep" spectral slope with fewer, weaker higher harmonics and a warmer, flutier timbre, more characteristic of mode 2 (or head voice).

warming, rounding, and smoothing of timbre from a decrease in the brighter "over-vowel" content, "singer's formant" contribution, and a reduction in auditory roughness (or buzziness).

With the above suggested smoothness of range successfully trained, the spectral slope of the source will smoothly and gradually steepen with ascending pitch, from low chest (modal) register with its brassier, shallow spectral slope and stronger high harmonic content, to a smoother, high (falsetto) register with a steep spectral slope and much weaker and fewer high harmonics.[6] At no step between consecutive pitches will an audible, binary shift in spectral slope occur; simply put, there will be no voice "break" or yodel. And yet, there still will be discernable vocal register transitions. However, they will *not* be due to voice source changes (spectral slope binarity), but rather to the ever changing relationships between voice source components (harmonics) and vocal tract resonances. In other words, these transitions will be due to changes of acoustic register.

RESONANCE EFFECTS

Let us take a moment to review what "sudden changes in harmonic content" require. As Titze reported, there are two possibilities: either a sudden, large change in spectral slope (as in a yodel from modal to falsetto—i.e., chest to head—something we deliberately train to remove); or, from sudden changes in which *a different set* of harmonics is being featured in the radiated sound—something the voice source *cannot* do, but something that automatically happens between rising voice source harmonics as they interact with and move through the sound transfer characteristics of the vocal tract, that is, the vocal tract resonances. If the vocal tract shape and resonances for a particular vowel are kept the same while the sung pitch is raised, rising harmonics will necessarily and inevitably move through stable vocal tract resonances. The passing of harmonics through the first resonance causes shifts in spectral content that are both audible and feelable, constituting perceivable changes of vocal register as this author has elsewhere described.[7]

The timbral transitions of acoustic registration constitute a thrilling, desirable part of the classical expressive aesthetic, and may also play a role in other genres. Within historical pedagogy, these events have been variously referenced with terms descriptive of somatosense (i.e., how it feels), such as turning over, turning, tipping, or covering. They occur at locations that are completely predictable per voice type and vowel, since they occur relative to first formant locations, which vary per vowel and voice type. Knowing, anticipating, allowing, and/or even "encouraging" these transitions facilitates smooth, dynamic laryngeal registration across range. In contrast, avoiding or preventing them altogether inhibits smooth laryngeal registration across range.

ACOUSTIC REGISTER TRANSITION LOCATIONS

A simple chart of approximate first formant locations—and pitches at harmonic intervals below them—predicts where acoustic transitions can be expected per vowel if the vocal tract shape is maintained. In general, for most vowels, timbre closes and complementary vowel tone color increases when rising through these locations.[8] In fact, there are *both* laryngeal and acoustic registers. The contribution of the larynx is the *sine qua non* of voice. Its role and skill in efficient, smooth negotiation of range are crucial to singing technique. However, the more successful the smoothing process of laryngeal registration is, the less will it be contributing to timbral transitions strong enough to be perceived as changes of register. And yet, there *will* remain colorful, interesting, often exciting changes of timbre perceivable as changes of vocal registers. They will be due to the skillful traversing of hearable, feelable, and desirable acoustic register transitions: open timbre (with various levels or degrees of openness), close timbre, and whoop timbre—respectively identified in historic Italian pedagogy as *voce aperta*, *voce chiusa*, and *voce piena di testa*.

NECESSARY MIGRATIONS

Strategies for negotiating a functionally efficient range require *knowing* the what, where, and why of the necessary migrations of somatosense and timbre across range, *honoring* them, and *having intentional strategies* that anticipate, allow, and even encourage them. If the necessary migrations of timbre and somatosense are *not* honored across the range, laryngeal registration will not make appropriate adjustments, inviting instead spikes in pressure and/or glottal resistance. This further

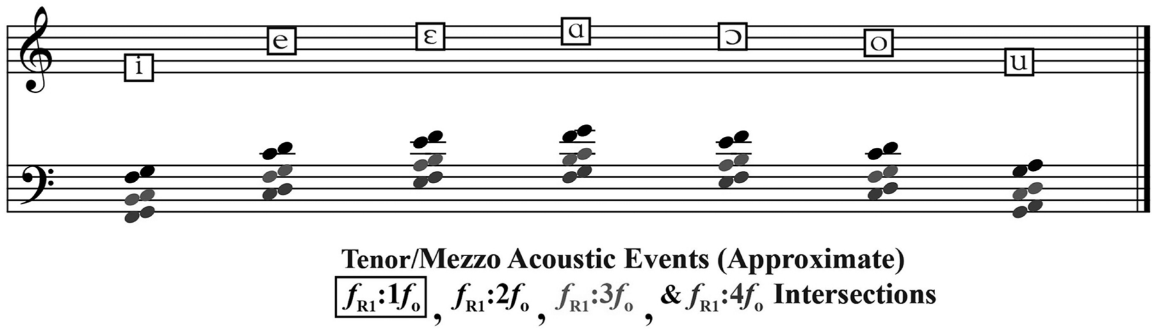

Figure 2. **Levels of acoustic registration events per vowel. Approximate formant locations per cardinal vowel are in boxes on the treble clef. A source harmonic will interact with the first resonance of the indicated vowel on pitches sung at harmonic intervals at or below the formant boxes, causing perceivable timbral transitions: *whoop timbre* for sung pitches at and above the formant boxes; *close timbre* for sung pitches between the formant boxes and the pitches an octave lower; and various levels of *open timbre* for sung pitches more than an octave below the formant boxes, the more harmonics below the first resonance, the more open the timbre.***

*Kenneth Bozeman, *Kinesthetic Voice Pedagogy 2: Motivating Acoustic Efficiency* (Gahanna, OH: Inside View Press: 2021), 77. Versions of this chart for various voice types are freely downloadable at http://www.kenbozeman.com/levels-of-acoustic-registration.php.

destabilizes laryngeal function at various range locations via acoustic interference, resulting in voice "breaks" that seem entirely laryngeal.

AUDITORY ROUGHNESS

Auditory roughness is associated with perception of laryngeal register: buzzier is associated with chestier and smoother with headier (regardless of the actual laryngeal register being employed). Attending to and intending a smooth migration of auditory roughness (buzziness or "sizzle") across range is an effective pedagogic strategy for indirectly coordinating dynamic laryngeal registration. Auditory roughness migrates from buzzy and exposed in open timbre (*voce aperta* and lower range), through a more refined, internalized sizzle in middle voice (close timbre, *voce chiusa*, or mix), and into a smooth, pure sound in high whoop timbre.[9]

NONTREBLE UPPER *PASSAGGIO* VERSUS TREBLE LOWER *PASSAGGIO*

Why does the register transition of the typical operatic nontreble (bass, baritone, or tenor) upper *passaggio* differ noticeably from that of the typical operatic treble (alto, mezzo, soprano, countertenor) lower *passaggio* across the same range (approaching and entering the lower half of the treble clef)? Is that not clearly a laryngeal register demarcation between M1 and M2? This is a legitimate question.

We now know from electroglottograph (EGG) studies that nontreble operatic voices typically stay in mode 1 all the way up, shifting only to an acoustically aided, easier *voce chiusa* (close timbre) version of M1. In contrast, treble operatic voices typically transition to a strengthened version of M2 by (or into) the bottom of the treble clef and higher. This difference in laryngeal register approach does contribute to a difference in spectral slope sufficient to affect timbre. The fact that it overlaps with the transition from open timbre (*voce aperta*) to close timbre (*voce chiusa*) for the open vowels—/ɛ/, /a/, /ɑ/, and /ɔ/—and close timbre to whoop timbre for the closest vowels—/i/ and /u/—in effect causes a "doubling up" of timbral change between laryngeal and acoustic register change for treble voices, augmenting the degree of auditory roughness migration. This creates a kind of "double whammy."

The migration of auditory roughness (from buzzy to smooth) is therefore stronger in the treble voice transition in the $E\flat_4$ to G_4 range. Since nontreble voices do not change to mode 2 (head voice), their timbral transition in this range is due only to changes of acoustic mechanism—not of laryngeal mechanism. Treble voices do change laryngeal register but can be trained to traverse this range similarly to nontreble voices, delaying that transition to mode 2 to several pitches higher even within classical chiaroscuro timbre, and certainly in the brassier timbres of many CCM genres.

CONCLUSIONS

In the paragraphs above, we established several axioms that are useful when considering registral phenomena. First, timbre is composed of the relative percentages of the tone colors of the harmonic set of the sung pitch plus the degree of auditory roughness from higher, closely clustered and resonated spectral content. Second, the harmonic set (and each attendant tone color) changes with every pitch change. Third, the harmonics of a changing pitch inevitably move through relatively stable resonances of a given vowel shape, contributing first more, then less of their tone color to the timbral recipe.

Given these conditions, *vowel and timbral migration is inevitable*: no two pitches can have precisely the same timbre. Every step of the scale necessarily migrates to some degree, often subtly, sometimes more strongly. If flow phonation with a relatively stable tube length is established across range, the spectral slope changes contributed by the voice source will not be sufficiently abrupt to signal a change of voice register. Migrations in which harmonics pass through the first vocal tract resonance, however, *do* manifest shifts in harmonic content strong enough to be perceived as changes of vocal register, especially at the transitions from open to close timbre and close timbre to whoop timbre, but often even at the mini closures within open timbre where the third or fourth harmonics cross the first resonance.

In sum, as laryngeal register smoothing technique improves, laryngeal (voice source) contribution to perceivable register change will diminish, but acoustic register transitions will persist and be even more predominantly featured as part of an expressively modulated range. Acoustic registers are real.

NOTES

1. Christian Herbst, "Registers—The Snake Pit of Voice Pedagogy, Part 1: Proprioception, Perception, and Laryngeal Mechanisms," *Journal of Singing* 77, no. 2 (November/December 2020): 175–190. Christian Herbst, "Registers—The Snake Pit of Voice Pedagogy, Part 2: Mixed Voice, Vocal Tract Influences, Individual Teaching Systems," *Journal of Singing* 77, no. 3 (January/February 2021): 345–358.
2. Manuel García II, *A Complete Treatise on the Art of Singing,* collated, edited, and translated by Donald V. Paschke (New York: Da Capo Press, 1975).
3. Harry Hollien, "On Vocal Registers," *Journal of Phonetics* 2, no. 2 (March 1974): 125. Italics inserted by the author for emphasis.
4. Ian Howell, "Parsing the Spectral Envelope: Toward a General Theory of Vocal Tone Color" (DMA thesis, New England Conservatory of Music, 2016).
5. Ingo Titze, "A Scientific Basis for Combining Registers," Mix Singers Association International Science Seminar: Voice–Body–Expression (Gliwice, Poland; November 19–21, 2021). Italics inserted by the author for emphasis.
6. Even in voices in which laryngeal register binarity is not completely eliminated, any remaining spectral slope binarity will only happen once across the primary range, at the mode 1 to mode 2 transition, usually at or near the bottom of the treble clef, not at the several locations across range where other register changes can be heard.
7. Kenneth W. Bozeman, "A Case for Voice Science in the Vocal Studio," *Journal of Singing* 63, no. 3 (January/February 2007): 265–270. Kenneth W. Bozeman, *Practical Vocal Acoustics, Pedagogic Applications for Teachers and Singers* (Hillsdale, NY: Pendragon Press: 2013).
8. Kenneth W. Bozeman, *Kinesthetic Voice Pedagogy 2: Motivating Acoustic Efficiency* (Gahanna, OH: Inside View Press: 2021), 49.
9. Howell.

Kenneth Bozeman, BM, MM, Professor Emeritus of Music, taught at Lawrence University for 42 years, where he chaired the voice department and from which he received two awards for excellence in teaching. He holds performance degrees from Baylor University and the University of Arizona and subsequently studied at the State Conservatory of Music in Munich. He was awarded the Van Lawrence Fellowship by the Voice Foundation in 1994 for his interest in voice science and pedagogy, is the chair of the editorial board of the NATS *Journal of Singing*, and was inducted into the prestigious American Academy of Teachers of Singing in 2019. His former students have sung with Houston, Boston Lyric, Opera Colorado, Washington, Wolf Trap, Seattle, Chicago Lyric, Deutsche Oper Berlin, Dresden, New York City Opera, San Francisco, the Metropolitan, and Santa Fe Opera.

Mr. Bozeman was an active performer of oratorio, including singing the tenor roles in the *St. Matthew* and *St. John Passions*, the *Christmas Oratorio*, the *B Minor Mass*, the *Magnificat*, and various cantatas of Bach, Handel's *Messiah*, Haydn's *Creation*, Mendelssohn's *Elijah*, and Vaughn

Williams *Hodie*. He has performed with the Milwaukee Symphony, the Wisconsin Chamber Orchestra, the Green Lake Music Festival, the Purgatory Music Festival of Colorado, the Louisville Bach Society, the Historical Keyboard Society of Wisconsin, and on Wisconsin Public Radio's "Live from the Elvehjem."

Mr. Bozeman is a frequent presenter at universities and international voice science conferences, has written several articles on the topic of acoustic voice pedagogy, and has published two books on acoustic pedagogy, *Practical Vocal Acoustics: Pedagogic Applications for Teachers and Singers,* and *Kinesthetic Voice Pedagogy 2: Motivating Acoustic Efficiency.* Mr. Bozeman has been a featured presenter on voice acoustics at numerous national conferences of NATS, was twice selected to be a master teacher for the NATS Intern Program, and has been a featured presenter at NATS Workshops. He continues to be in demand for seminars and master classes on acoustic pedagogy at universities and interdisciplinary conferences and was a keynote speaker for the British Voice Association conference in Leeds, 2021, and the International Congress of Voice Teachers in Vienna, 2022. His activity can be followed at: https://faculty.lawrence.edu/bozemank/.

I would forget so many things:
The moaning wind, and rain,
Uncanny sounds of ghostly hands
At door and window pane.

I would forget the perished leaves
And grass, dismantled trees—
Old loves and hopes, the youth of me
That passed away with these.

But when I see November come,
How shall I then forget;
The other years return with her—
Remembrance and regret.

E. C., "November"